CLIMATE VARIABILITY AND EXTREME EVENT, HYDROLOGY AND RESERVOIR MANAGEMENT, AGRICULTURE AND WATER IN NORTHERN NIGERIA

FINAL REPORT

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Climate Variability and Extreme Event, Hydrology and Reservoir Management, Agriculture and Water in Northern Nigeria

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EXECUTIVE SUMMARY

The African Network of Centres of Excellence (ACEs) on Water Sciences Phase 2 (designated ACE Water 2) is aimed at fostering sustainable capacity development at scientific, technical and institutional level in the water sector by carrying out high-end scientific research on water sectors in order to provide effective and educational support to governments in partnership with UNESCO and JRC. With this view, the Centre of Excellence (CoE) at National Water Resources Institute (NWRI), Kaduna has carried out a study on the issues bordering on Water-Energy-Food-Ecosystem (WEFE) in the northern Nigeria part of the Niger River Basin (NRB), to review climate variability and extreme event, hydrology and reservoir management, agriculture and water issues. This report is the result of the literature studies carried out in the exploration of five major areas of WEFE in the northern part of Nigeria in the NRB.

The study area covered the Niger River Basin (NRB) in the northern part of Nigeria. The basin has an area of approximately 2.3 million sq km spreading over 10 countries. The Basin has its largest part in Mali, Niger and Nigeria, each covering about 25% of the total basin area with approximately 100 million people earning livelihood mainly on the traditional, low input, rainfed farming, nomadic animal rearing and small scale irrigated agriculture. The Basin is drained by River Niger which covers a distance of approximately 4,200 km, joining its main tributary, the Benue River in south-central Nigeria and flows into the Atlantic Ocean. Nigeria alone contains 28.3 percent (424,500 square kilometers) of the Basin area and more than half of her major rivers are in the Niger River Basin. Almost 60 percent of Nigeria’s population, or about 67.6 million inhabitants, live in the Basin.

Purpose and Objective

i. The main purpose of the studies is to provide a WEFE assessment in Northern Nigeria within the Niger River Basin. The specific objectives are to carry out research on:
ii. Climate database update, climate variability/change and extreme climate events and environmental (i.e. flooding, drought) and social impact analysis, food and water insecurity;
iii. Hydrology and water demand versus availability bi-sector (human supply, agriculture and energy);
iv. Inventory of large reservoir and management rules faced to water demand in agriculture and irrigation expansion, flood control, hydropower production, impact on groundwater recharge, environmental flow, water quality, including specific issues as reservoir sedimentation;
v. Agriculture (crops, spatial patterns, irrigation expansion) and best practices assessment (i.e. irrigation techniques, adaptive cropping patterns, rainwater harvesting techniques)
vi. WEFE interlinks and implications, leading to lesson learned contributing to both NRB hydrological model calibration/validation and assessment of simulation scenarios.

The report is sub-divided into chapters as follows:

Chapter 1: Background of the studies, its purpose and objectives and general description of the Niger River Basin (NRB).

Chapter 2: Tools and methodology adopted for the studies, which focused on the review of existing data, reviews, journals and reports made on issues bordering on WEFE to address climate variability and extreme event, hydrology and reservoir management, agriculture and water on Niger River Basin.

Chapter 3: Findings of the studies, mainly based on review of available literature. The chapter is structured in five parts.

The first part describes the variability in climate and as it impacts on the environment, food and water in the northern Nigeria, within the NRB. Two seasons are significant in Nigeria, wet and dry seasons. The annual rainfall has reduced significantly over 20% of the landscape and the amount of annual rainfall reduced by 50–350 mm in 64% portion of Nigeria. It has been observed that the climate of the region has undergone serious alterations in its underlying characteristics to the extent that a new mean and a new standard deviation were established. The increasing temperature and decreasing rainfall have led to frequent drought and desertification affecting large areas of arable land, thus reducing viable agricultural lands and crops' production. This has prompted massive migration and resettlement of people to areas less threatened by desertification.

The second part describes the hydrology and water demand of the area. The NRB is entirely drained by the Niger River originating from the mountains of Guinea near the border with Sierra Leone. In Nigeria, the Niger River is joined by numerous tributaries, including its most important tributary, the Benue River in Lokoja. The Benue itself rises in Chad and in Cameroon receives water from several tributaries. The Niger River thereafter heads southwards and empties into the Gulf of Guinea through a network of outlets that constitute the maritime Niger delta.

Water is a major contributing factor for increasing both agriculture outputs and sustainability in production systems like power supply. Allocation of available limited water resources for sustainable water use have been issues of increasing concern, leading to higher water demand and consumption. The estimated cumulative water demand of the Local Government Areas (LGAs) of each of the major states (Sokoto, Kebbi, Zamfara and Katsina) of the Basin in Nigeria ranges between 16,846,845 and 97,288,485 litres per day. However, the total water demand for each local government within these considered states is reported to be about 4,010, 897, 289 litres/day.

The third part focuses on the dams/reservoirs available in Nigeria within the Basin, and their main characteristics as summarized in the Annex I. The dams' properties and attributes are highly variable with maximum height of 115m at Shiroro dam and minimum of 9m at Swashi dam. Tiga dam has the longest crest length of 5,790 m while the Kubli dam has shortest length of 110m. The highest reservoir capacity was 15,000MCM at Kainji dam, while Gusau dam has the lowest of 3MCM. The highest reservoir area of 392,000m^{2}was found at Dadinkowa dam, while the smallest of 179m^2 was at Gubi dam. The spillway capacity of 7900MCM was identified as being

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the highest in Kainji dam and the least of 63MCM at Doma dam. Only few of the dams were originally designed for hydropower generation. These include Bakolori dam designed to supply 10.4MW of electricity, the Dadinkowa dam to supply 40MW of electricity and the Kainji dam. Almost all the dams were used for water supply, irrigation, flood control, fishing, and livestock farming. Only few are used fornavigation and tourism.

The fourth part addresses the agricultural production activities within the Basin. The Niger River basin scale and diversity provide a remarkable cross section of the efforts placed by African smallholder farmers to produce the food security requirements for the population. Rainfed agriculture cannot be relied upon in order to meet the food security potential and employment generation target. Consequently, irrigation projects have opened up more hectares of land for cultivation in the Niger basin, especially in the northern part of Nigeria. The most common methods of irrigation employed include surface method - furrow, border/bay, flooding; sprinkler - centre-pivot, travelling gun; and subsurface irrigation methods.

The fifth part describes the WEFE interlinks and implication especially the interaction between reservoir variables and energy generation. The modeling of hydropower reservoir variables for energy generation through the Neural Network approach is documented. Reservoir variables were the same as those employed to model the two hydropower dams of Kainji and Jebba on the Niger River in Nigeria. The yearly rainfall data for Niger State from 1983-2017 was generated using CHRS iRAIN. The yearly rainfall projections for the next 25 years from 2018 were also produced. However, this simulation as in the yearly historical data from 1983 – 2017 showed no significant trend.

The hydrological simulation of the Hadejia-Jama'are basin, located in semi-arid north eastern Nigeria using Soil Water Assessment Tool (SWAT) model indicated that the full implementation of all the planned water resource developments would have severe consequences for the basin's flood plain wetlands and areas further downstream. Reduced river flow would lead to a decline in the area of wet season inundation and will dramatically reduce the productivity of an area which is currently one of the most productive in northern Nigeria. The reduced productivity from the flood plain would not be replaced by yields from the formal irrigation since the water resources of the basin might not be able to support the envisaged extent of these schemes.

In the same vein, Hadejia-Jama’are-Komadugu-Yobe river basin (HJKYRB), one of the major river basins of which the water resources are vital to the sustenance of the livelihood of the growing population in Northern Nigeria. The basin is among those which proper management of the scarce resources due to competing demands is of growing concern. In predicting the Stream flow of Hadejia-Jama’are-Komadugu-Yobe river basin using SWAT model, based on the calibration and validation results, the coefficient of determination (R^2) and Nosch-Sutcliff Efficiency (NSE) obtained suggested that SWAT could be useful as a decision support tool for

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water resources management policies in the basin. The most sensitive of the 17 important model parameters determined during calibration was CN2 which relates to land cover and land use.

The climate extremes as related by the Nigeria Hydrological Services Agency (NIHSA) was considered in the studies. The extremity of climate thus results into either high dryness or flooding. Floods especially have been occurring in most places in Nigeria until it reached its peak in the year 2012, which caused so much devastation and had become a hallmark of/baseline for floods in the country. Hence, the Annual Flood Outlook (AFO) of the NIHSA, established and started publication in 2013 has been creating awareness on flood events and proffering some mitigation measures to flood occurrences. Models such as the Geospatial Streamflow Model (GeoSFM) and the Soil and Water Assessment Tool (SWAT) models were employed to make annual flood prediction. The annual prediction of floods and their extent serves as a useful decision support tools and provides an indication of areas likely to experience flood within Nigeria. Sub-basins of the country in the year 2018 which were vulnerable to flood risks included areas around the Rivers Niger and Benue; and Sokoto-Rima, Komadougou-Yobe axis in the northern part of the country.

The assessment of water quality in part of the Nigeria Northern States in the NRB indicated the presence of high levels of fluoride. Water sources investigated in Zamfara State had lead concentrations within the range of 0.04–0.062 mg/l. The results showed that 83% of sampled drinking water sources have lead levels above the Nigerian Standard Drinking Water Quality (NSDWQ) and WHO recommended guideline value of 0.010 mg/L for drinking water. The result of microbiological analyses in Taraba State signified that the faecal coliforms content for the borehole water supplies ranged between 0 and Too Numerous To Count (TNTC) cfu/100mL. 26% of the samples had values above 0 cfu/100 mL faecal coliforms recommended by NSDWQ and WHO for drinking water. The total coliforms content for borehole water supplies ranged between 0 and TNTC cfu/100mL, with 30% of the samples had values above 10cfu/100mL total coliforms recommended by NSDWQ and WHO for drinking water. Pipe borne water supplies had total coliforms content ranging from 0 – TNTC cfu/100mL, with 64% contains potential pathogenic organisms. The cause of the total coliforms contamination was found to be due to inadequate disinfection, improper connection, leakages, and intake malpractice activities. Those locations that recorded TNTC for the faecal and total coliform had very poor hygiene and sanitation practices coupled with lack of protection to the pumping mechanisms and were sited downhill/down slope of the area.

In conclusion, this research work has been implemented in the framework of the NEPAD ACEWATER 2 project, with the objective to carry out a WEFE nexus assessment in the Niger River Basin in the northern part of Nigeria. The research, addresses climate, hydrology, dams and agriculture issues and analysis of interlinks and implications, focusing on climate change impacts as water demand for domestic, agriculture, hydropower, and industries becomes higher. The effects have caused untold hardship on the people both economically, socially and health

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wise. Since demand control policies, however, it is important that water supply agencies in the basin area establish complete, accurate, and representative information about current water consumption patterns.

Recommendations

To check the diminishing rainfall regime of the area, the study suggests the following, which if implemented, will impact positively on the regional weather and climate, improve the hydrological regime and stabilize the ecosystem. Hopefully, the desiccation of the last 40 years would be reversed, with droughts becoming less frequent:

i. local and regional development policies that recognize the fragile nature of semi-arid environments should be adopted in pursuing livelihoods especially in the area of agriculture;
ii. more effort should be made to discourage deforestation while encouraging soil and water conservation strategies;
iii. governments at both the local, state and national levels should embark upon massive tree planting projects throughout the northern parts of Nigeria;
iv. Water could be transferred from rivers with surplus yield in southern Nigeria to regions of water deficit in northern Nigeria.

CHAPTER 1

1 Introduction

1.1 Background of the Study

In order to address water resources challenges in Africa, the New Partnership for African Development (NEPAD) established Centres of Excellence (CoE) in Water Science and Technology for the development and management of water resources in the continent. The African Networks of CoE on Water Science PHASE II (ACE WATER 2) aims at fostering sustainable capacity development at scientific, technical and institutional level in the water sector. The project supports twenty (20) AU-NEPAD African Network of CoEs in Water Science and Technology organized in three regional networks, in conducting high-end scientific and educational support to governments.

The Niger River Basin (NRB), the second widest hydrological basin in Africa (after Nile), was proposed as the case study area for the West Africa Network of Water Centers of Excellence (WANWATCE), in consideration of both its relevance, spatial extension (more than 2 million km^2) and former/ongoing baseline characterization and modeling activities. The National Water Resources Institute (NWRI), Kaduna and the University of Benin, Benin City are the two Institutions hosting the Centers of Excellence in Nigeria. The CoE at NWRI in part has a mandate to address shortage in skills and training needs in the water sector in the country. The African Head of States noted the shortages of skilled manpower especially at the middle level for which the NEPAD Phase I survey was carried out to determine the requirements in higher education and training for practitioners in the water sectors. Therefore, the African Network of Centres of Excellence (ACEs) on Water Sciences Phase 2 designated ACE Water 2 was aimed at fostering sustainable capacity development at scientific, technical and institutional level in the water sector by carrying out high-end scientific research on water and related sectors in order to provide effective and educational support to governments in partnership with UNESCO and JRC. This report is therefore, the result of the activities carried out in the exploration of five major areas of Water-Energy-Food-Ecosystem (WEFE) in the northern part of Nigeria in the NRB.

1.2 Purpose and Objective

The main purpose of the project was to provide a baseline database and WEFE assessment in Northern Nigeria within the Niger River Basin.

The specific objectives of this research project in the Northern Nigeria part of the Niger River Basin are to:

i. Carry out research on climate database update, climate variability/change and extreme climate events and environmental (i.e. flooding, drought) and social impact analysis, food and water insecurity

ii. Carry out research on the Hydrology and water demand versus availability bisector (human supply, agriculture and energy
iii. Carry out research on inventory of large reservoir and management, rules faced to water demand in agriculture and irrigation expansion, food control, hydropower production, impact on groundwater recharge, environmental flow, water quality, including specific issues as reservoir sedimentation
iv. Carry out research on Agriculture (crops, spatial patterns, irrigation expansion) and best practices assessment (i.e. irrigation techniques adaptive cropping patterns, rainwater harvesting techniques)
v. Analysis of WEFE interlinks and implication, leading to lesson learned to contribution to both NRB hydrological model calibration/validation and assessment of simulation scenarios.

1.3 Characterization of the Study Area

The study area covers the Niger River Basin (NRB) in the northern part of Nigeria. The Niger River Basin is a large catchment area with significant water resources developmental potential. The basin has an elongated total area of approximately 2.3 million sq.km that spread over10 countries. It possesses active drainage area comprising less than 50% of the total basin area and with 4,200 km in length; the NRB has the third longest river in Africa and the world's ninth largest river system. It covers six agro-climatic zones with the largest part of the basin in Mali, Niger and Nigeria, each covering about 25% of the total basin area (Olomoda, 2002; Zwarts et al., 2006).

The NRB hosts approximately 104.5 million people. The main livelihood is traditional, low input, rainfed farming, nomadic animal rearing and small scale irrigated agriculture in parts of Mali, Niger and Nigeria and fishing throughout the riparian countries. Much of the population in the basin suffers from extreme to chronic poverty and remains vulnerable to droughts with ongoing political insecurity which further complicates the development of the basin. A large part of the basin is situated in the semi-arid region of the Sahel, with the most northern section covering parts of the Sahara, receiving almost no rainfall (Ogilvie et al., 2010; Olomoda, 2002; Zwarts et al., 2006).

1.3.1 Geography and Hydrology

The Niger River Basin stretches over great parts of the interior of West Africa. It covers parts of the national territories of nine states: Guinea, Cote d'Ivoire, Mali, Burkina Faso, Republic of Niger, Benin, Chad, Cameroon and Nigeria. The Basin forms an elongated area - resembling roughly a crescent - that covers about 2,000,000 km², of which some 1,500,000 km² form the active part of the basin, the rest is desert with virtually no drainage at present. The Niger River Basin is drained by the Niger River, which covers a distance of around 4,200 km. It is the third-

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longest river on the African continent, spanning from Guinea in the basins westernmost corner over Mali and the Republic of Niger to Benin and western Nigeria.

By far the biggest tributary of the Niger River is the Benue River, which rises from south western Chad, passing through northern Cameroon and eastern Nigeria. It had a confluence with the Niger River in Lokoja, north- central, Nigeria, and flow toward the southern part of the country. When reaching the southern coast of Nigeria, the Niger River flows into the Atlantic Ocean, splitting up into numerous rivers and creeks, forming with its sediments the Niger Delta (Figure 1.1).

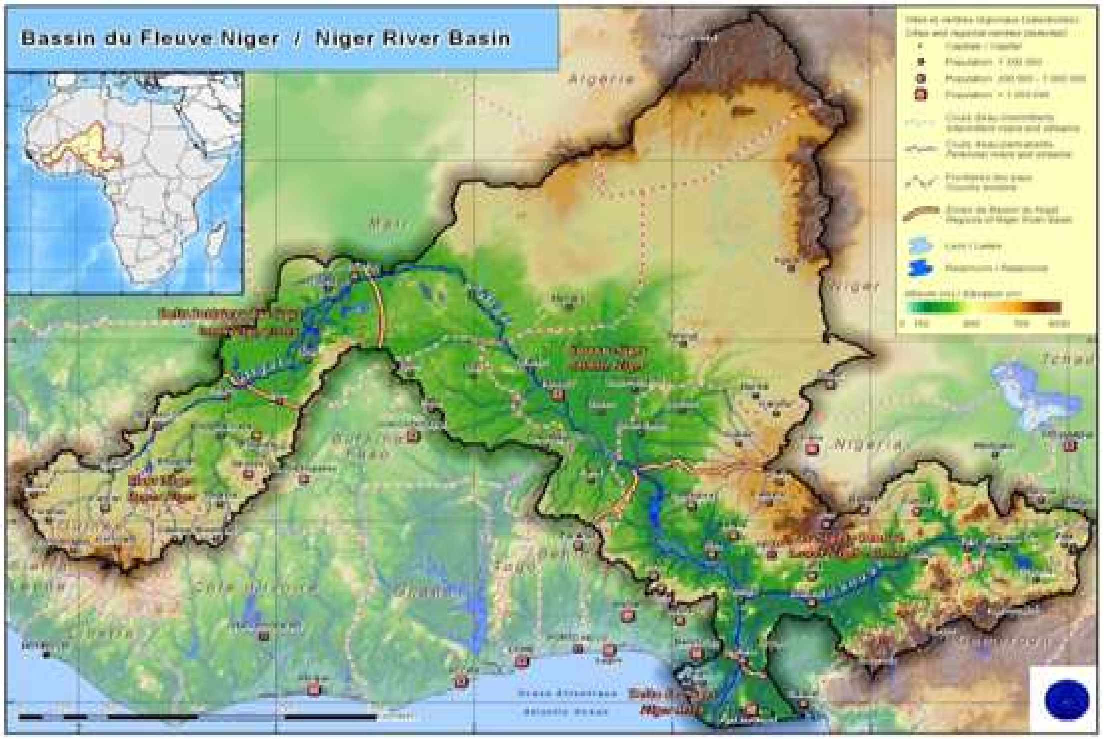


Figure 1.1: Topographic map of the Niger River Basin (Source: ABN (2007))

The northern section of the basin, extending across the Sahara desert into Algeria, is hydrologically inactive. The active basin, which we call hereafter the basin, covers 1,272,000 km^2 (Table 1.1) and nine countries: Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Nigeria and Niger. They are all members of the Niger Basin Authority (NBA).

1.3.2 Demography

Population of the basin was estimated at 94 million in 2005 (CIESIN/CIAT, 2005), of which 71% live in Nigeria. Due to a high fertility rate, populations of most countries in the basin increased by 50% between 1990 and 2005 (Tabutin and Schoumaker, 2004) and the growth rate of the population is currently estimated at 3.0% (Bana and Conde, 2008; Guengant 2009). Demographers estimated that according to the lowest scenario, that the population of the basin will double by 2050, but, if the fertility rates remain constant, the population could increase fourfold by 2050.

Table 1.1: Countries of the Niger Basin

Country	Area km^2	Proportion of basin within country %	Proportion of country within basin %
Benin	44,967	3.5	38.7
Burkina Faso	86,919	6.8	31.5
Cameroon	86,381	6.8	18.4
Côte d'Ivoire	23,550	1.9	7.3
Guinea	98,095	7.7	39.9
Mali	263,168	20.7	20.9
Niger	87,846	6.9	7.4
Nigeria	562,372	44.2	61.5
Chad	19,516	1.5	1.5
Total Active Basin	1,272,814	100	

Source: Marquette (2008).

The increase in population could jeopardize current and future development. Population density in the basin is four to five times greater than the national averages, as people concentrate along the riparian zones of the Niger River as their lifeline. The population is 64% rural. However, this is changing rapidly and by 2025 it is expected that the majority of the settlements may become urban. Urbanization is fuelled by a massive rural exodus, as well as a century-old migration from the inland to coastal areas and is sustained by recent political and climatic crises. The population is young (44% are under 15 years of age) and largely illiterate (with 35% overall literacy rates and only 18% for women).

1.3.3 The Nigerian Stretch of the Middle Niger and Its Left-Bank Tributaries

Nigeria is the final downstream country through which the Niger River flows, and contains 61.5 percent (562,372 square kilometers) of the Basin area. The Niger Basin extends across 20 of the 36 states of Nigeria and comprises two main rivers, the Niger and the Benue, and 20 tributaries. Out of Nigeria's major rivers, more than half are in the Niger River Basin. Their combined length accounts for almost 60 percent of the total length of all important rivers in Nigeria. Almost 60 percent of Nigeria's population, or about 67.6 million inhabitants, live in the Basin. These Nigerians comprise 80 percent of the population of the entire Basin.

CHAPTER 2

2 Tools and Methods

2.1 The Approach

The main approach adopted in carrying out this work focused on review of existing literature, data, reviews, journals and reports made on issues bordering on WEFE in the northern Nigeria particularly part of NRB, which addressed climate variability and extreme event, hydrology and reservoir management, agriculture and water on Niger River Basin.

Experts in related areas contributed to the various thematic areas according to the objectives of the project. Literature, data, extant reports, etc from different organizations and individuals were sourced from libraries and the internet sources. In addition, consultations were made in order to elucidate and derive maximum information based on the knowledge and experiences of these experts.

2.2 Data for the Study

Most of the data employed in this study included rainfall, temperature, solar radiation, harmattan dust and streamflow which were largely drawn from literature. Some of these data were processed using software’s like Microsoft Excel, SWAT and others.

CHAPTER 3

3 Findings of the Research Project

The findings of the research work are addressed based on topic by topic as described in the paragraphs below.

3.1 Climate Variability/Change and Extreme Climate Events, Environmental (Flooding, Drought,) and Social Impacts Analysis, Food and Water Insecurity on Niger River Basin in Northern Nigeria

3.1.1 Climate Change/Variability

IPCC (2007) defines climate change as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period typically decades or longer. The length of time it takes the changes to manifest may matter, and the level of deviation from the normal and its impacts on the ecology are most paramount. According to Idowu, et al. (2011), climate change is also defined as an adverse environmental phenomenon that is causing enormous concern all over the world. It refers to some anomalies in the climate system that is as a result of human activities. These anomalies include increase in the concentration of Green House Gases (GHGs), Hydro-Fluoro Carbons (HFCs) and Chlorofluorocarbons (CFCs) in earth's atmosphere, which will ultimately lead to global warming. Weather patterns affecting the country are driven by the northward and southward movement of the Inter-Tropical Discontinuity (ITD) as well as developments within the pressure systems created by the two distinct wind regimes north and south of the ITD. The climate of Nigeria, in particular, the Sahel zone, is characterized by multi-year persistence of anomalously wet and dry conditions. The terms climatic variability/change denote inherent dynamic nature of climate on various temporal scales, which could be monthly, seasonal, annual, decadal, periodic, quasi-periodic or non-periodic. Climate change is caused by two basic factors, which include natural processes and human activities (anthropogenic). As earth's temperature has risen between 0.4 and 0.8°C in the last over 100 years denotes that Global warming has already begun (Idowu, et al., 2011). One of the visible impacts of climate change and climate variability is extreme weather events that occur from time to time. A climate extreme is "the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable" (Adeoluwa, et al., 2017).There is a growing global concern that anthropogenic activities are a major cause of the variability in the intensity and frequency of weather and climate extremes. However, it can also be argued that climate extremes are just a part of decadal global climate cycle and variability (IPCC, 2014).

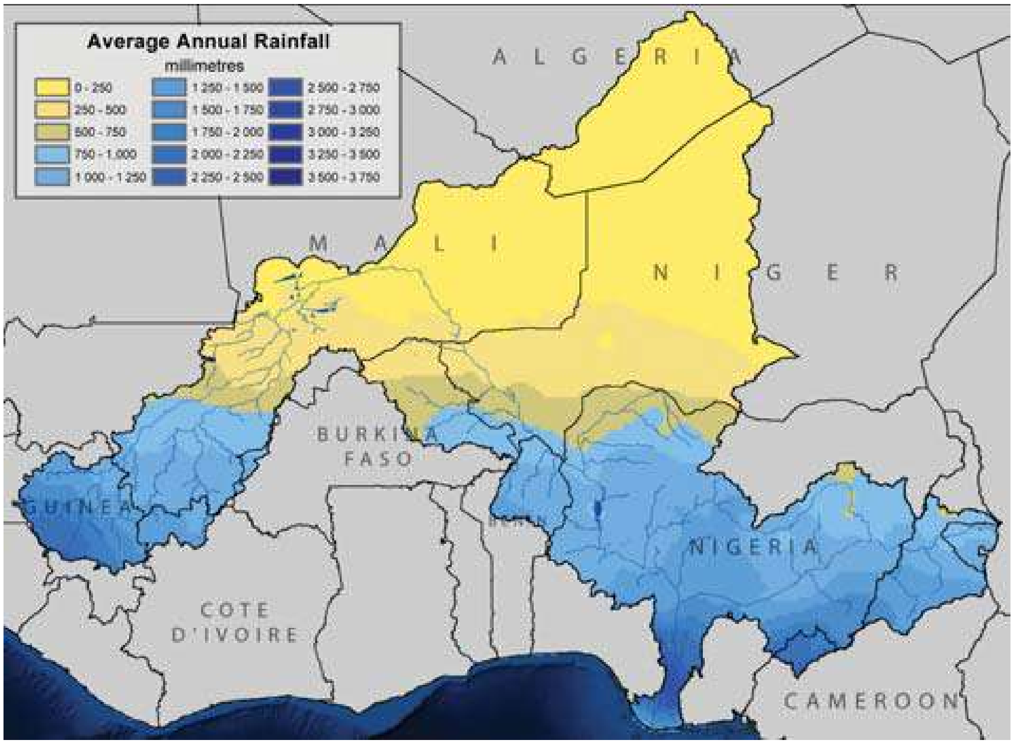
3.1.2 Climate Variability/Change in the Niger Basin

(a) Rainfall in the Niger Basin

The majority of the rain falls during the rainy season that occurs during tropical summer. The Sahelian sub-desert zone by Timbuktu receives about 250 mm/yr, whereas the basin as a whole received roughly 770mm/yr. This difference was a reflection of the patchiness of the rainfall of the basin. There was uneven distribution of precipitation over the basin; the upstream sections in the south can receive over 2000 mm of precipitation during the rainy season (July - October), while the more northern sections only receive 200-500 mm per year (or as little as 0 mm for the Saharan parts) (Zwarts et al., 2006; Liersch et al., 2013; www.fao.org3) (Table 3.1). Besides this, there is also an enormous seasonal and inter annual variation in rainfall as well as river flow (Zwarts et al., 2006; Pedinotti et al., 2012). For example, Analysis of monthly rainfall data for the whole region by Le Barbe and Lebel (1997) shows that the dry period was characterized by a decrease in the number of rainy events, while the mean storm rainfall varied little. Precipitation is very variable spatially and temporarily in the Niger basin. Precipitation amounts from one year to another shows wide variations which often results in floods and droughts at different times. The variation in annual rainfall distribution within the basin is shown in Figure 3.1. The uneven distribution of precipitation was the reason why the relatively small sections of the basin in Guinea and Ivory Coast (together contribute only 5.3% of the total basin area) were responsible for most of the water flowing through the river until the confluence with the Benue River in Nigeria, a major tributary flowing into the River Niger near Lokoja.

Table 3.1: Average Annual Rainfall in the Niger Basin

Country	Total Area of Basin (%)	Average Annual Rainfall in the Basin Area		
		Min.	Max.	Mean
Guinea	4.3	1240	2180	1635
Côte d'Ivoire	1.0	1316	1615	1466
Mali	25.5	45	1500	440
Burkina Faso	3.4	370	1280	655
Algeria	8.5	0	140	20
Benin	2.0	735	1255	1055
Niger	24.8	0	880	280
Chad	0.9	865	1195	975
Cameroon	3.9	830	2365	1330
Nigeria	25.7	535	2845	1185
Niger basin	100.0	0	2845	690



Source: UNEP (n.d)

Figure 3.1: Average annual rainfall distribution of the Niger Basin

Declines in rainfall over the past half century in West Africa, particularly in the Sahel, have been associated mainly with a reduction in the number of significant rainfall events during the rainy season of July through September. For West Africa as a whole during the 1968-1991 period, rainfall declined 20 to 40 percent as compared to rainfall during the 1931-1960 period (Chappell and Agnew, 2004; Dai et al., 2004; Nicholson, 2005). This variability in rainfall has been associated with fluctuations in atmospheric circulation and tropical sea-surface temperature (SST) patterns in the Atlantic, Indian, and Pacific Oceans (Dai et al., 2004). While rainfall variability has continued, since 1991, however annual rainfall in the Sahel has recovered.

(b) Trend Analysis of Rainfall in the Basin

The records of rainfall characteristics at 25 locations were analyzed for the occurrence of abrupt changes and trends using the Pettitt and the Mann-Kendall tests. Variables analyzed included annual total rainfall and number of rain days, the dates of onset, termination and duration of the rainy season as well as monthly rainfall, monthly number of rain days and various categories of rainfall above certain intensities. An abrupt change occurred in the time series of annual rainfall, number of rain days and affected areas north of latitude 11° N. However, the sub-periods prior to and after the change points may be considered to be homogenous. The series of variables related to the duration of the rainy season exhibited no significant trends or jumps. It is concluded that recent changes in rainfall over the Sahel were driven by a reduction in the frequency of rain days of high rainfall intensities during the months of August and September. The fact that the high intensity rainfall does not contribute significantly to crop growth may explain the continuation of agricultural activities in the Sahel despite massive variations in annual rainfall.

Because rain-fed agriculture is the most important mode of employment and food production in West Africa, records of several rainfall variables are used extensively in planning for agricultural and water resources projects. To obtain reliable estimates of the characteristics of rainfall as well as to determine the magnitude of climatic fluctuations, it is necessary that segments of the time series analyzed should be relatively homogeneous. Previous research applied in northern Nigeria was often based on the so called standard climatic normal's or 30-year, non-overlapping periods. Other work analyzed arbitrary periods, sometimes determined solely by the availability of data (Hulme, 1992).

(c) Temperature Pattern in Niger Basin

According to Oyebande and Odununga (2010), the mean maximum and minimum temperatures for the region of the Niger basin show increasing trends. The temperature of the region shows an increase of about 0.2-0.3ºC per decade. Projections for the 21st Century in the Savanna and sahel indicate a general increases in minimum temperature for all the months in this zone. These increases may be as high as over 5ºC for January to less than 3.5ºC for August (IPCC, 2007). With these increases, the nights are still expected to remain cool and pleasant, with temperatures in the range of 20ºC to 28ºC. Projections of the mean maximum temperatures in Savannah zone indicate increases in mean monthly temperatures. These increases will raise mean monthly maximum temperatures to a range from 34ºC to 43ºC. There is hence the possibility of an increase in heat related health problems by 2070 to 2099 time slice (IPCC, 2008).

3.1.3 Climate Variability and Weather Patterns in Northern Nigeria

Nigeria lies between longitudes 2°49' E - 14°37'E and latitudes 4°16'N-13° 52' N and is in the humid tropics. It has a land area of 923, 850 km2. Over 70% of Nigeria's population is engaged in agriculture as their primary occupation and means of livelihood. Small-scale, resource-poor farmers operating in 0.1 to 5 hectares with low-level traditional technologies dominate this large population. The Nigerian agricultural activities relied mainly on rain-fed farming with the farmers engaged in crop production, livestock rearing, fisheries and post-harvest activities (Idowu, et al., 2011).

Nigeria is one of the world's most densely populated countries with a population of 180 million people, half of which are considered to be in abject poverty and is recognized as being vulnerable to climate change. Climate change and global warming if left unchecked will cause adverse effects on livelihoods in Nigeria, such as crop production, livestock production, fisheries, forestry and post-harvest activities, because of the occurrence of the altered rainfall regimes and patterns, floods which devastate farmlands, increase in temperature and humidity which increases pest and disease and other natural disasters, which not only damage Nigerians'

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livelihood but also cause harm to life and property (Idowu, et al., 2011).Available evidences showed that climate change would be global, likewise its impacts, but the biting effects would be felt more by the developing countries, especially those in Africa of which Nigeria is one due to their low level of coping capabilities (Nwafor, 2007; Peter, 2010). Researchers showed that Nigeria is already being overwhelmed with diverse ecological problems, which have been directly linked to the on-going climate change (Ayuba, et al., 2007). There has been erratic pattern of weather elements in Nigeria, which has started impacting on desertification and also impacting negatively on plant species composition in northern Nigeria.

(a) Rainfall Distribution in Northern Nigeria

Nigeria has only two seasons, which are the dry and rainy seasons and are brought about by the influence of the dynamics of two major wind systems known as the trade winds. The winds meet along a slanting surface called Inter-Tropical Discontinuity (ITD) (Odekunle, 2004).Varying degrees of convective activity and precipitation takes place at the southern part of ITD while little or no cloud development or precipitation occur in the northern part of ITD (Ilesanmi, 1972).

The dry season is accompanied by a dust laden air mass from the Sahara Desert, locally known as Harmattan (The Tropical Continental (CT) air mass) while the rainy season is heavily influenced by an air mass originating from the south Atlantic ocean, locally known as the south west wind (The Tropical Maritime (MT)) air mass (Stephen and Tobi, 2014). The influence and intensity of the wet season decreases from the West African coast northwards (Adefolalu, 1986).

The Tropical Continental (CT) air mass does not possess the ability to form rainfall because of low humidity. When it passes the Sahara Desert, it picks up dust instead of water thereby creating little chances for rainfall. This produces difficult effects on the environment and the people; creating poor visibility and produces almost desert conditions during the dominance of the air mass (the harmattan). However, it assists farmers in drying their crops since the low humidity present in the air quickens the drying of crops (Wikipedia, 2018).

Recently, large and extended weather and climate extremes were recorded in different parts of the country, causing significant socio-economic impacts. Observations showed that the savannah and semi-arid areas of Nigeria have suffered from inter-annual to seasonal climatic variability and there had been droughts and desertification processes, particularly in the 1960s and 1980s. In a study in which mean annual and monthly temperature and rainfall data collected over a period of 105 years (1901-2005) were analyzed showed that temperature increased by 1.1°C in the 105 years while rainfall decreased by 81mm. Desert encroachment, coastal inundations, drying up of surface waters and shift in crops cultivated over time were also noticed (Peter, 2010). From various other climate studies carried out at different times in Nigeria (Adefolalu, 1986; Bello, 1998; Ati, et al., 2009), it was concluded that 'annual rainfall has reduced in some past years significantly over 20% of the landscape and the amount of annual rainfall reduced by 50–350 mm in 64% portion of Nigeria' (Stephen and Tobi, 2014). Drought is a condition of extreme but short term climatic variation which results in insufficient rainfall to meet the socio-economic demands of a region in terms of water supply for domestic and industrial uses, agriculture and ecosystem. Based on the opinion of some experts, it was indicated that the people of the Sahel have systematically degraded their lands through forest clearing, overgrazing, and inappropriate land-use practices. Additionally, variations in annual rainfall amounts and decreases in vegetation cover were the evidence of environmental change or the encroachment of the Sahara desert (Imo and Ekpenyong, 2011). Some studies suggested that the build-up in atmospheric dust, exacerbated by anthropogenic factors such as fire-wood exploitation, bush burning and poor farming practices, as well as, frequent sand storms, which cause changes in land surface structure may be responsible for large-scale climatic alterations in the Sahel (Ekpoh, 2007). Furthermore, most of the droughts that occur in this region have been found to be associated with a late start of the rainy season and early cessation of the rains, resulting in drastic reductions of the length of the rainy season (Imo and Ekpenyong, 2011).

Although northern Nigeria has experienced decreasing number of dry conditions in some years past, however there is increasing wetness from the 1990s in recent years as shown in Figures 3.2 and 3.3. The findings is in agreement with that of several other authors (Odekunle, et al., 2008; Abaje et al., 2012; Ifabiyi and Ojoye, 2013; Abaje et al., 2014). The increase in rainfall pattern is one of the factors responsible for the recent occurrences of floods within the northern part of Nigeria. It was indicated that the increasing wetness appears to be accounted for by significant northward shifts in the surface location of the ITD over the country. It was further noted that these variations in rainfall usually showed completely different patterns within the same climatic zones and that stations located relatively close to one another exhibited different patterns of rainfall (Figures 3.3 and 3.4). Analysis of rainfall anomalies and maximum temperature departures in the past years brought out some clues to the spate of recent and wide spread of flooding across the country (Okoloye, et al., 2013). Therefore, the recent incursion of floods, in parts of the country especially northern Nigeria seriously threatened lives and property, important business centers and agricultural farm lands and was an example of the danger that could be posed by weather and climate extremes.

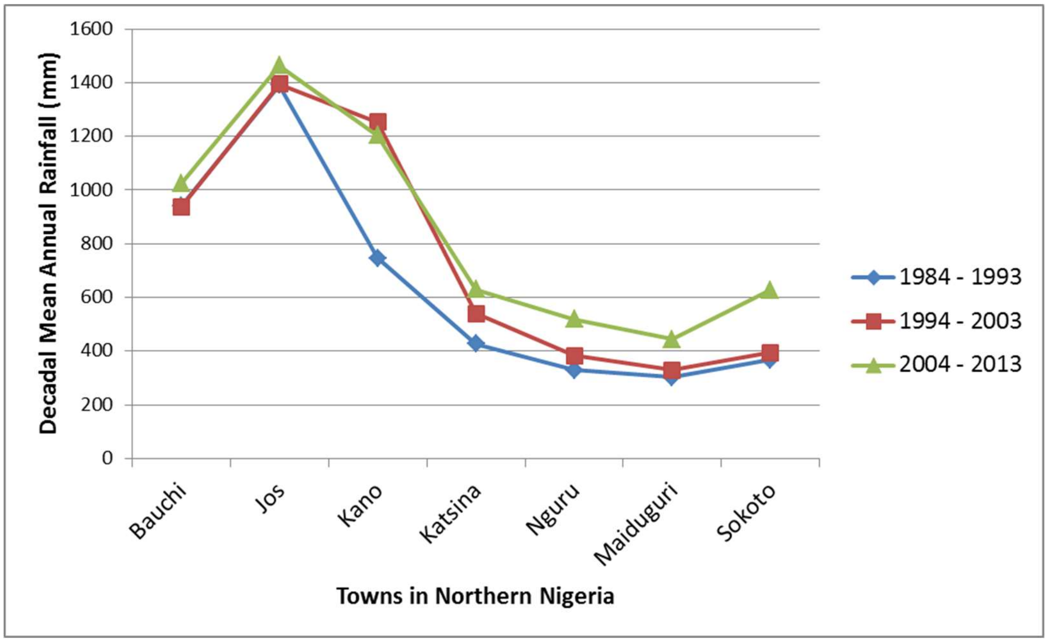
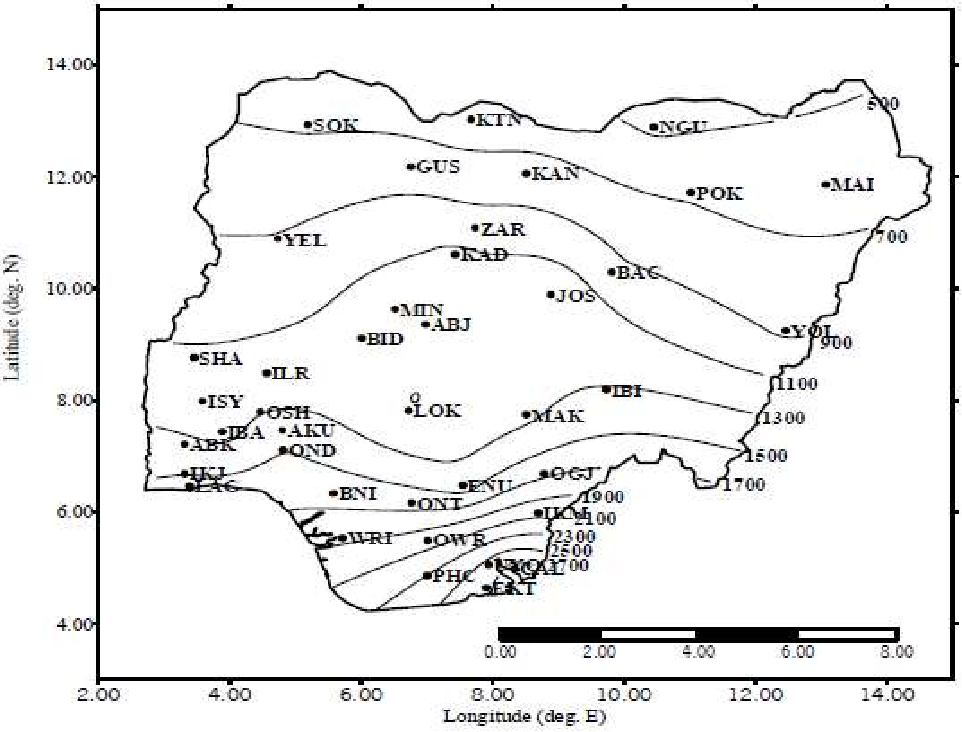


Figure 3.2: Trends of rainfall distribution in some major towns in northern Nigeria



Source: NIMET (2011)

Figure 3.3: Mean annual rainfall distribution (mm) in recent years in Nigeria

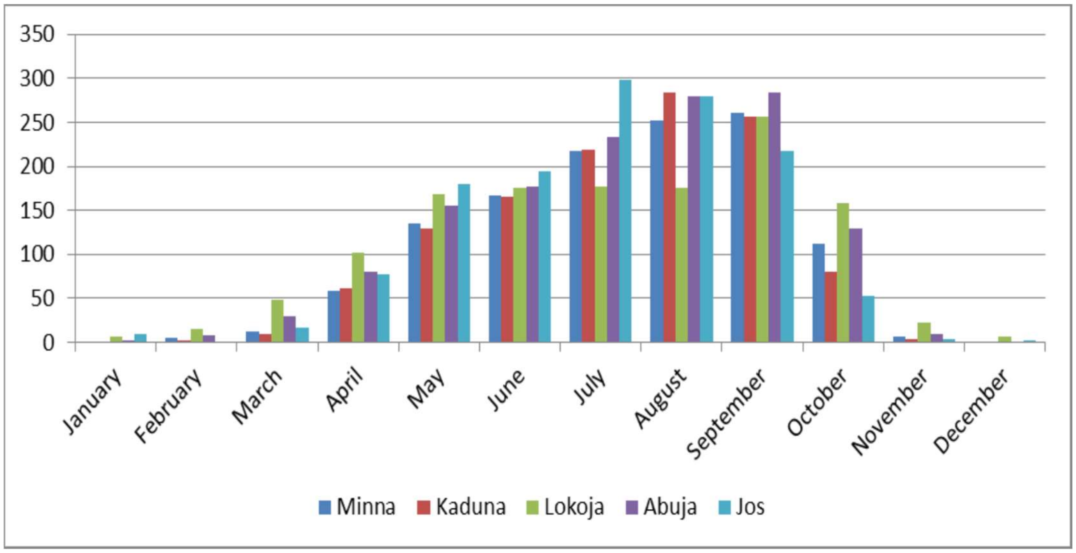


Figure 3.4: Long term rainfall at selected stations around the northern Nigeria in mm

Climatic variation in northern Nigeria is not altogether new because this part of Nigeria contains a significant portion of the Sudan-Sahel ecological zone of West Africa. However, since the early 1970s, climatic anomalies in the form of recurrent droughts, frightening dust storms and rampaging floods have overprinted their rhythms, creating short-duration climatic oscillations as against the normal cycles of larger amplitudes. Thus the past several years have witnessed severe droughts, numerous dust storms and killer floods. Indeed, the climate of the region has become highly unpredictable. The persistence of drought in parts of northern Nigeria during the 1970s, 1980s and 1990s has been attributed to the conditions related to the tropical component of the global general circulation system (Imo and Ekpenyong, 2011).

(b) Temperature Pattern in Northern Nigeria

The temperature trend in Nigeria since 1901 shows increasing pattern (Figure 3.5). The increase was gradual until the late 1960s and this gave way to a sharp rise in air temperatures from the early 1970s, which continued till date. The mean air temperature in Nigeria between 1901 and 2005 was 26.6ºC while the temperature increase for the 105 years was 1.1ºC. This is obviously higher than the global mean temperature increase of 0.74 ^{O}C recorded since 1860 when actual scientific temperature measurement started (IPCC, 2007). Should this trend continue unabated, Nigeria may experience high risk of temperature increase between 2.5ºC and 4.5ºC by the year 2100. Furthermore, the mean of the hot season temperatures in northern Nigeria clearly shows increasing trend as shown in Figure 3.6. In addition, this analysis reveals a high rate of temperature increase in the northern part of the country (1.4°C per decade). The period of sharp temperature rise correspond to the period of drastic rainfall decline as shown in Figure 3.7. For example the hot season in 2012 was warmer than normal in the northern parts of the country with maximum temperature departures ranging between 0.5 and 2.5°C as shown in Figure 3.8.

Maximum temperatures for the same year during the hot season (March and April) in the north showed that temperature ranged between 30.0 – 40.0°C as shown in Figure 3.9.

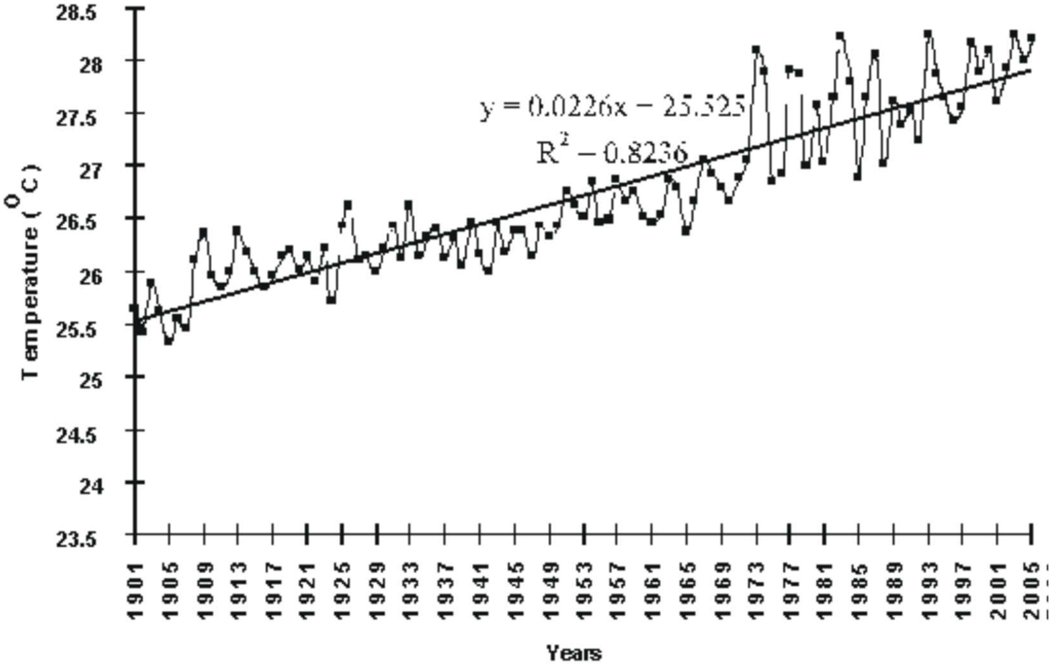
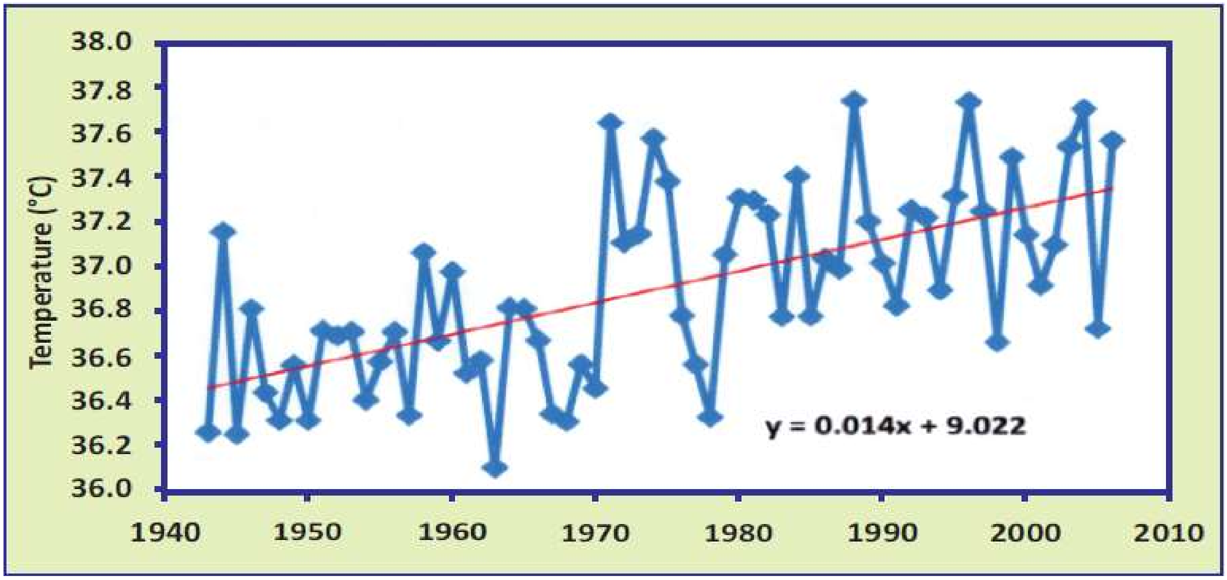


Figure 3.5: **Air temperature distribution in Nigeria between 1901 and 2005**



Source: NIMET (2011)

Figure 3.6: **Trend of hot season temperature in northern Nigeria (1941 - 2010)**

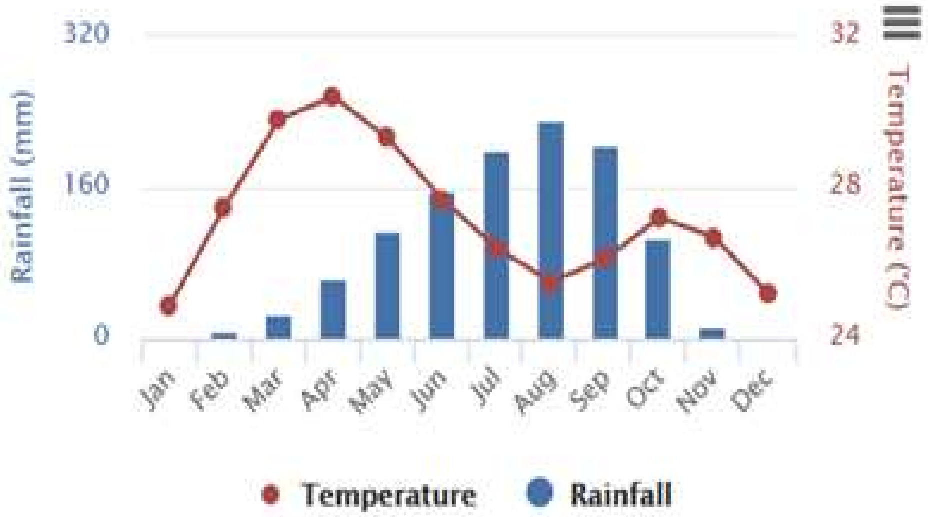
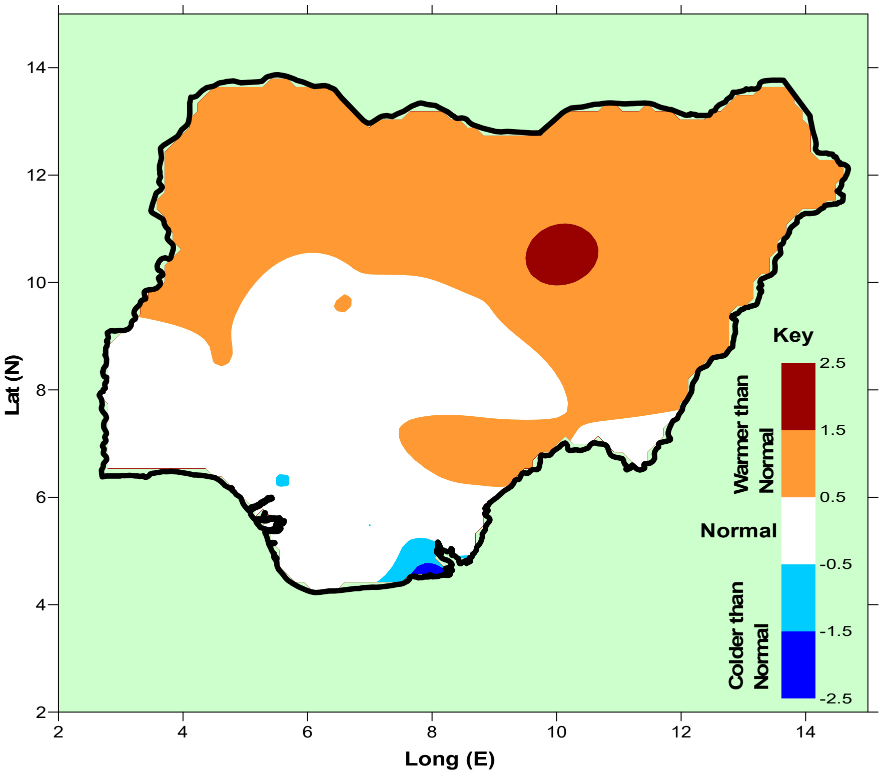
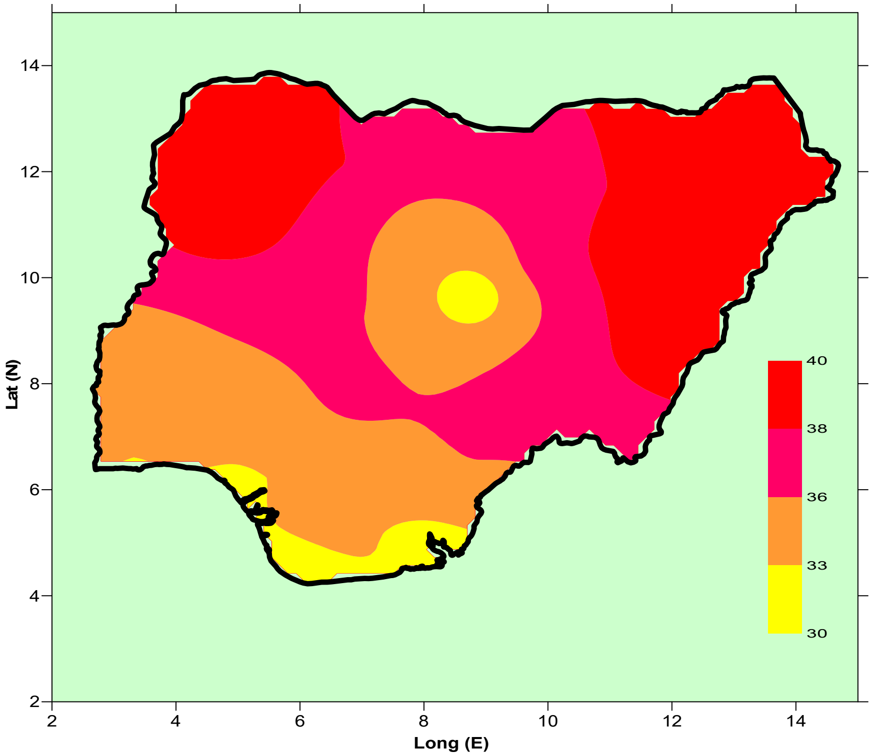


Figure 3.7: Mean monthly temperature and rainfall for Nigeria during 1901-2017



Source; NIMET (2012)

Figure 3.8: Hot season maximum temperature anomaly in Nigeria in 2012

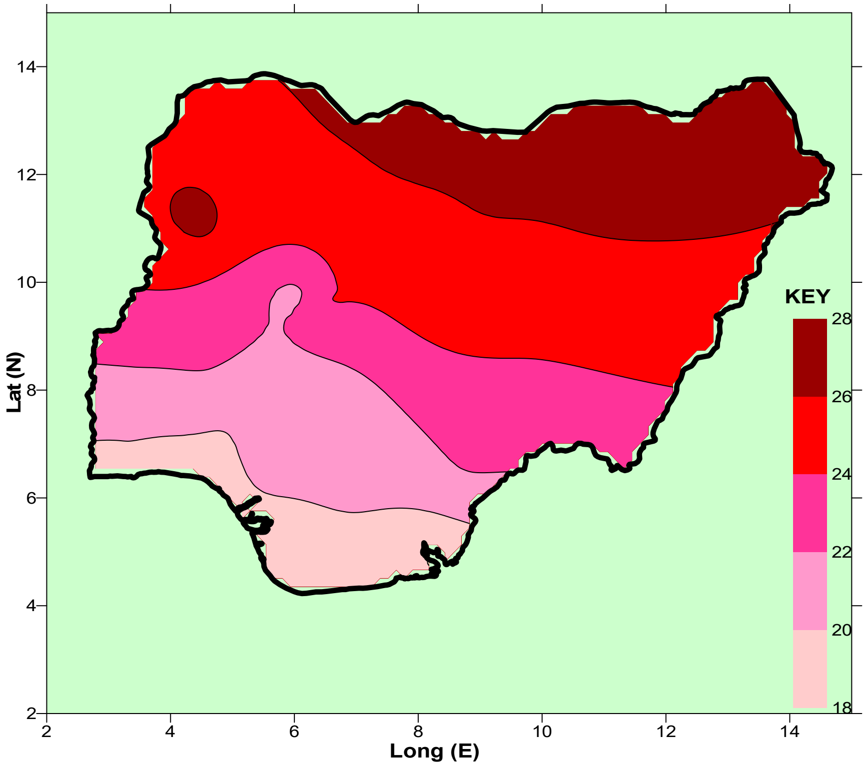


Source: NIMET (2012)

Figure 3.9: Distribution hot season maximum temperature in Nigeria in 2012

(c) Incident of Solar Radiation in Northern Nigeria

The northern parts of Nigeria often received the greatest amount of incident of solar radiation in the country. Comparatively, the amount of incident of solar energy received in the north was generally higher than the energy received mostly in the southern part of the country. This is the trend particularly in recent years in the country. For example the incident of solar radiation received especially in Katsina, Kano, Jigawa, Gombe, Yobe and Borno states was the highest ranging from 26.0 – 28.0 Wm^{-2} day^{-1} during the hot season in the year 2012 in the country (Figure 3.10). The incident of solar radiation for the same year under review was between 24.0 - 26.0$Wm^{-2}day^{-1}$ over Sokoto, Kebbi, Zamfara, Kaduna, Bauchi, Plateau, Taraba and Adamawa states, while states in the central region received 22.0 - 24.0 Wm^{-2} day^{-1} of solar radiation.



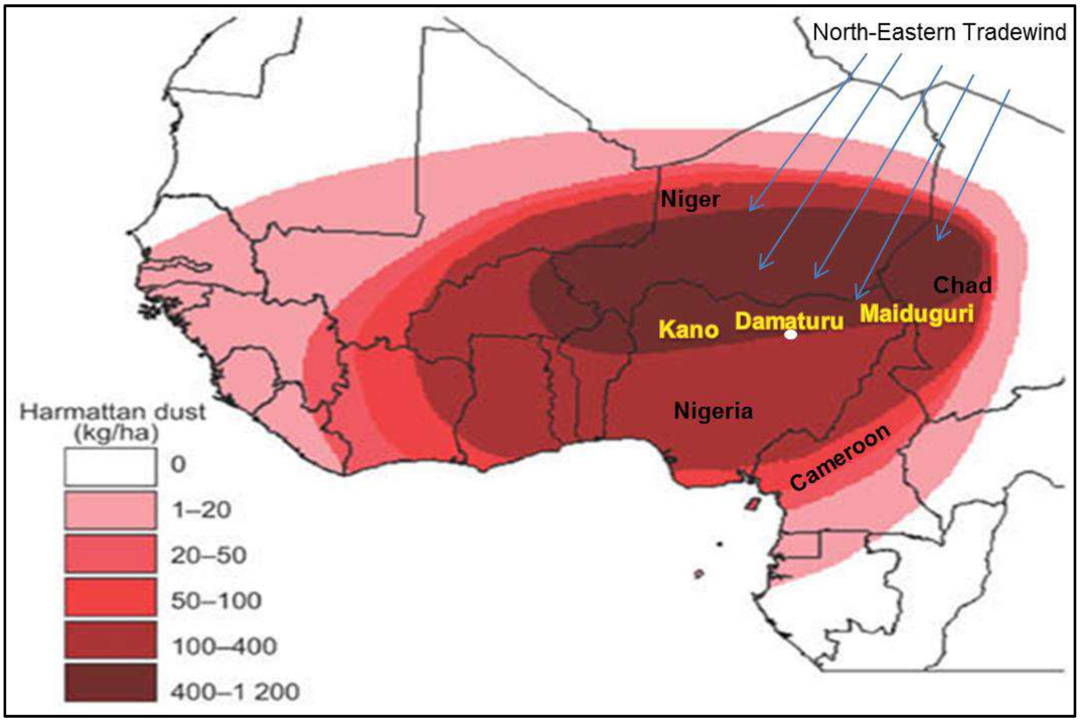
Source: NIMET (2012)

Figure 3.10: Incident of solar radiation in Nigeria in 2012

(d) Occurrence of Harmattan Dust Haze and its effects in Northern Nigeria

Harmattan dust is a common and widespread meteorological phenomenon in the savannah region of Africa. The Harmattan is a dry and dusty wind characterize by fine particle, typically 0.5 µm–10 µm, resulting from storm activities especially in northern Nigeria. It raises large amounts of dust into the atmosphere, which is carried predominant by the north-east trade winds, from the Sahara into the Gulf of Guinea, including Nigeria between November and March (winter) every year (Achudume and Oladipo, 2009). The dust is lifted by convection (air mass passing over hot desert loose soils) to a very high altitude and then transported over long distances. The composition of the Harmattan dust is complex, consisting of various compounds including microbial entities. The frequency of the harmattan dust storms has increased approximately 10-fold during in the last half-century since the 1950s, causing topsoil loss in northern Nigeria (Griffin et al., 2002). The dusts disperse soil and dried sediments with potential to induce health risks such as asthma outbreaks, particularly in elderly and infants populations. For a greater part of the Harmattan period in Nigeria, the atmosphere in northern Nigeria often becomes heavily clouded with the Harmattan dust, causing a variety of domestic inconveniences as a result of the layers of dust that envelopes the environment (Adedokun et al., 1989). During the dust haze event, the high amount of dust in the air can severely limit visibility and block the sun for several days. This causes the cancellation of flights in parts of northern Nigeria (Dajab, 2006). Figure

3.11 shows the intensity of the Harmattan dust as it is blown by the north-east trade winds across the sudano-sahelian region of northern Nigeria having the highest Harmattan dust deposit.



(Adopted online@: blocs.extec.cat)

Figure 3.11: Distribution of harmattan dust in northern Nigeria and parts of West Africa

The northern part of the country has been experiencing an increase in rainfall and rates of heat in recent times (Obioha, 2008; Onyekuru, and Marchant, 2014; Ta et al., 2016). Additionally, climate projections for the country show a significant increase of temperature over all the northern ecological zones (Abiodun et al., 2013) which may have negative impacts on agriculture and food security.

3.1.4 Implications of Climate Change in Northern Nigeria

Studies have shown that among all the climatic elements, rainfall is the most variable element especially in northern Nigeria, both temporally and spatially and such variations can have significant impacts on ecological and economic activity (Kowal and Kanabe, 1972; Ekpoh, 1991, Adefolalu, 1986). Increasing temperature (global warming) and decreasing/increasing precipitation in most parts of the world are the greatest impacts of climate change. These bring about either negative or positive ecological impacts in different parts of the world. The increasing temperature has led to increased land-based ice instability and its melting. The thawing of the Arctic, cool and cold temperate ice, the increasing rainfall in some parts of the world and expansion of the oceans as water warms has started impacting on sea level rise, coastal inundation and erosion.

The climate of northern Nigeria has shown considerable temporal and spatial shifts in its variability and change. Extreme climate and weather events (drought, flood, temperature change etc) have become more regular events in recent years. Notable amongst the observed features are positive rainfall anomaly recorded in most parts of the northern Nigeria. Indeed the Northeast zone recorded positive anomaly for the first time in the last 5 years and the highest anomaly in the last 10 years. The harmattan dust is becoming very pronounced in northern Nigeria. Its severity and the duration was the highest recorded in the last 5 years. Most states in the North also recorded above normal day time temperatures at early part of the year which increased the discomfort level to living organisms. All living things are affected by the climate systems and in particularly by the climate extremes which threatens safety of lives and property and sustainability of ecological and socio-economic activities. The impacts of extreme weather and climate may be gradual but they are destructive to lives and property, negatively impact on the ecological settings and economy. The above normal rainfall resulted in unprecedented flooding which caused loss of lives and properties. Floods have become a perennial challenge with increasing intensity each year, leaving colossal losses and trauma. The low-lying coast of the country experiences perennial inundation due to ocean surges and strong tidal waves. The Intergovernmental Panel on Climate change (IPCC) has shown that the anthropogenic activities have contributed significantly to the variations and changes observed in the world climate system today. However, since climate know no natural, geographical, political or disciplinary boundaries, cooperation amongst relevant institutions become very necessary to put in place a robust and effective mitigation and adaptation measures to the variability and change of the climate systems in northern Nigeria in order to achieve the much desired stabilization.

3.1.5 Water and Food Insecurity Implications of Climate Change

Climate variability/change has started to, and will continue to impact negatively on agriculture and food security especially in tropical and subtropical regions because greenhouse gas emissions would increase the risk of hunger by additional 80 million people by 2080 in Africa and southern Asia **(**Odjugo, 2001a; DFID, 2006; Nwafor, 2006, 2007; DeWeerdt 2007)**.** Agriculture is a sector in Nigeria that is highly dependent on weather due to the rainfed agricultural practice in the country. The late onset of the raining season, prolonged dry spells and excessive rains leading to flooding have led to a shift in crops cultivated in northern Nigeria. For example, as at 1978 the preferred crops cultivated by the farmers were guinea corn followed by groundnut and maize, but due to increasing temperature and erratic nature of rainfall occasioned by climate variability/change, the farmers as a means of adaptation in 2007 shifted to the production of millet followed by maize and beans (Odjugo, 2008).

(a) Crop Production

Climate variability/change affects crop production in a number of ways, for example, uncertainties and variation in the pattern of rainfall, floods and devastated farmlands, cause pest and diseases migrate in response to changes in climate while high temperatures smother crops. For example in 2011, in the extreme northeast, the late onset of the raining season, prolonged dry spells which occurred in the year led to below average millet, sorghum and cowpea production. On the other hand, there was below average harvest in the same 2011 due to excessive rains leading to flooding, destruction of productive assets such as farmlands (see Figure 3.12), fishponds and crops in Kano, Katsina, Taraba, Adamawa, Sokoto, Bauchi and Gombe. Irregular and unpredictable rainfall and sunshine hours continue to take the toll on hitherto low-level harvests of rice, maize, cassava, melon, sorghum and yam with at least 2.5% decline of harvests per annum. Pest and disease incidences which become varied and uncontrollable under extreme weather events continue to cause decline in crop harvests, especially that of cowpea, tomatoes, pepper and groundnuts. Drought and flood extremes feature prominently northwards of the country, affecting crops farming and harvests as well as livestock production, the feed of which are mostly crop-based. For example, due to the likely impact of the flooding on crops production, a forecast of 2012 indicated that out of the major food crops (Yam, Cassava, Maize, Sorghum and Rice) produced in Nigeria, yam was likely to be the most affected crop, followed by rice and cassava (Figure 3.13). An assessment of flood impacts on agriculture across in 2012 in northern Nigeria showed that over 1,600 farm lands were affected by flood in Gombe State and no fewer than 400,000 farmlands were destroyed in Jigawa State by the flood.

Figure 3.12: Typical flooded farm in Nguru, Yobe State in northern Nigeria

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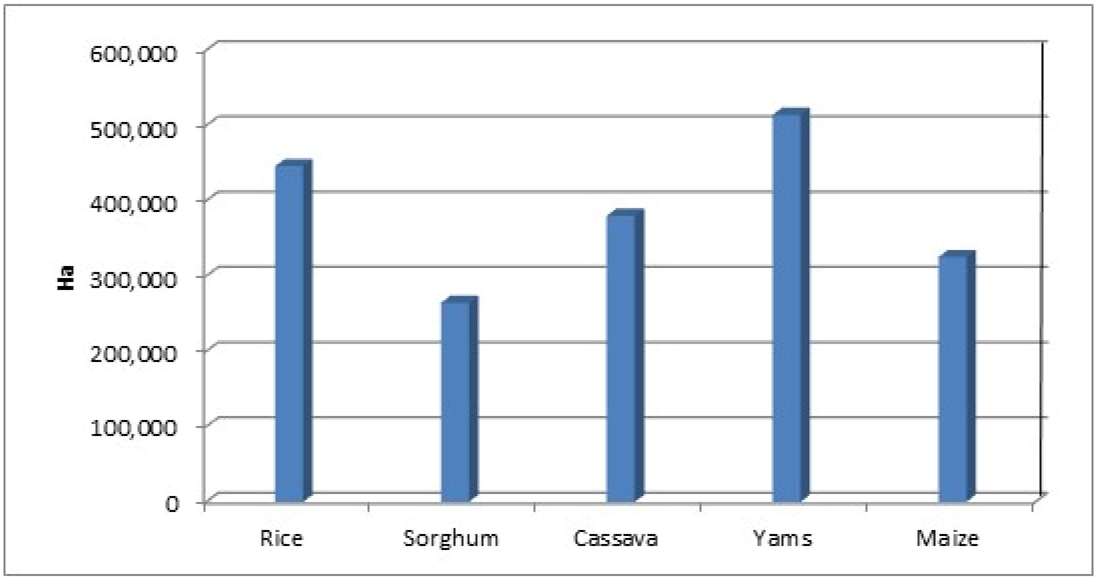
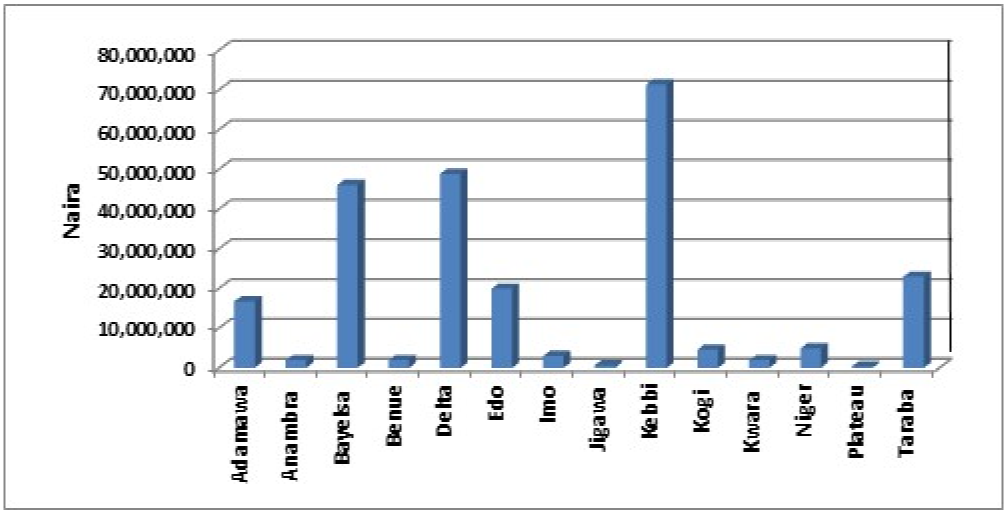


Source: NIMET (2012)

Figure 3.13: Projected estimated crop loss due to flooding in 2012

(b) Livestock Production

Climatic variations between the Northern and Southern parts contribute to the distribution of animals in the country. Generally, the large ruminants, geese, guinea fowls and turkeys are more common in the Northern parts of the country where rainfall and humidity are lower, the dry season is longer, diurnal and seasonal temperature fluctuations are wider. The availability of natural grasses for grazing is very limited and highly dependent on rainfall which is erratic in most parts of the North. Climatic stress reduces feed, water intake, grazing time and hence rate of growth and productivity. For example, estimated losses of fisheries due to the flood impact in some states in Nigeria was put at close to two hundred and thirty million naira (N230,000.00). The states that were most impacted and the respective losses are shown in Fig. 21. Kebbi state which is one of the northern states suffered the highest estimated loss amounting to over seventy one million naira (N71.397m) as shown in Figure 3.14. High temperatures have hindered livestock production, reduced meat and milk outputs, as well as the grazing lands. Animal production as well is affected by increases in disease and pests under the influence of climate change impacts that cut investment profits in livestock production system by more than 20% per annum. Severe livestock mortalities occur under the impact of global pests and diseases such as avian influenza, Swine fever, Swine influenza (flu), etc, all of which jointly reduce livestock production by at least 25% annually.



Source: NIMET (2012)

Figure 3.14: Estimated fisheries loss due to impact of flooding in 2012

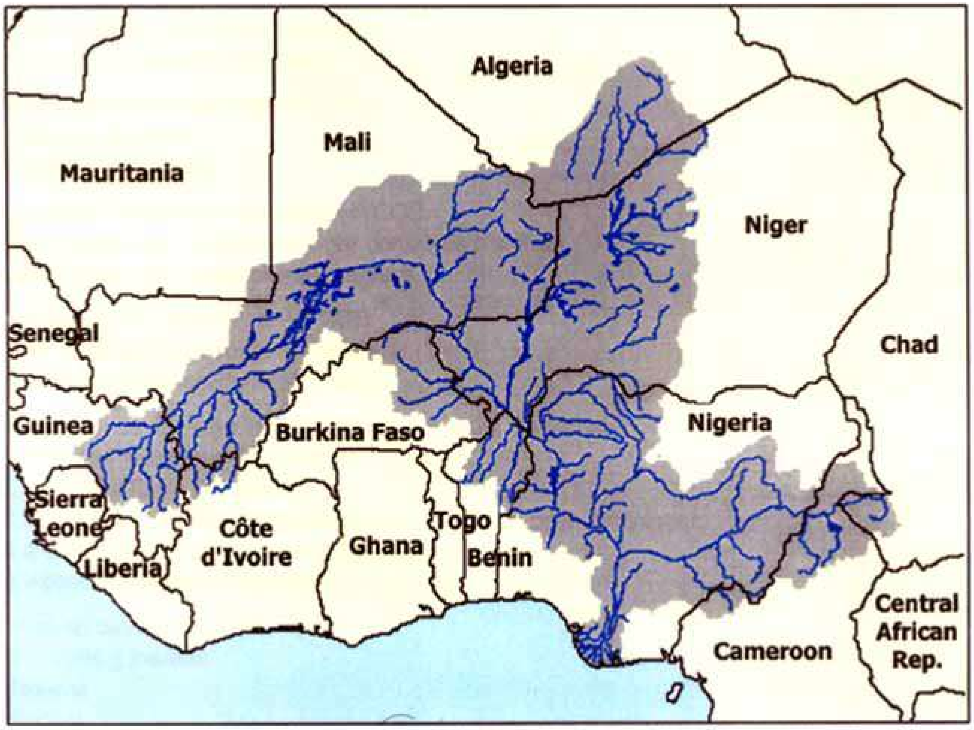
3.2 Hydrology and Water Demand versus Availability Bisector (Human Supply, Agriculture and Energy)

3.2.1 Hydrology of the Niger River Basin

The hydrology of the basin is divided into three main parts as the hydrological processes along the Niger River, the water demand and the trend analysis.

(a) River Systems and Discharges

The Niger basin entirely drained by the longest and largest river in West Africa, the Niger River, having an approximate length of around 4,200 km making it the third-longest river on the African continent after the Nile and the Congo/Zaire Rivers. The river spans from Guinea in the basins westernmost corner over Mali and the Republic of Niger to Benin and Nigeria. Figure 3.15 shows the drainage system of the Niger basin.



Source: Oyebande and Odunuga (2010)

Figure 3.15: Drainage system of the Niger basin in West Africa

The Upper Niger River System

The source of the Niger River is in the mountains of Guinea near the border with Sierra Leone. Together with several tributaries it traverses the interior plateau of Guinea flowing north-east towards the border with Mali. Just after the border, it is joined by another tributary which also originates in Guinea. The total annual flow entering Mali from Guinea is estimated at 40 km^3. The river then proceeds north-east towards the inner delta in Mali, where it is joined at Mopti by an important tributary, the Bani River, which is about 1100 km long and has its sources from Cote d'Ivoire and Burkina Faso.

The Inner Delta in Mali is one of the largest wetlands and multi-use systems in Africa covering an estimated area of about three million hectares with over one million herders, fishermen and farmers. The total area covered by the inner delta, which is a network of tributaries, channels, swamps and lakes, can reach about 30000 km^2 in flood season. The delta area is swampy and the soil is sandy in nature. Consequently, the river 'loses' nearly two-thirds of its potential flow between Segou (at 900 km from its source) and Timbuktu (at 1500 km) due to seepage and evaporation, the latter being aggravated by the fact that the river here touches the southern flanks of the Sahara desert. All the water from the Bani tributary, which flows into the Niger River at Mopti (at 1150 km), does not compensate for the 'losses' in the inner delta, as the total flow further downstream still decreases rather than increases. The average 'loss' is estimated at 31km^3/year, but varies considerably according to the years. For example, it was 46 km^3 during the wet year of 1969 and about 17 km^3 during the dry year of 1973.

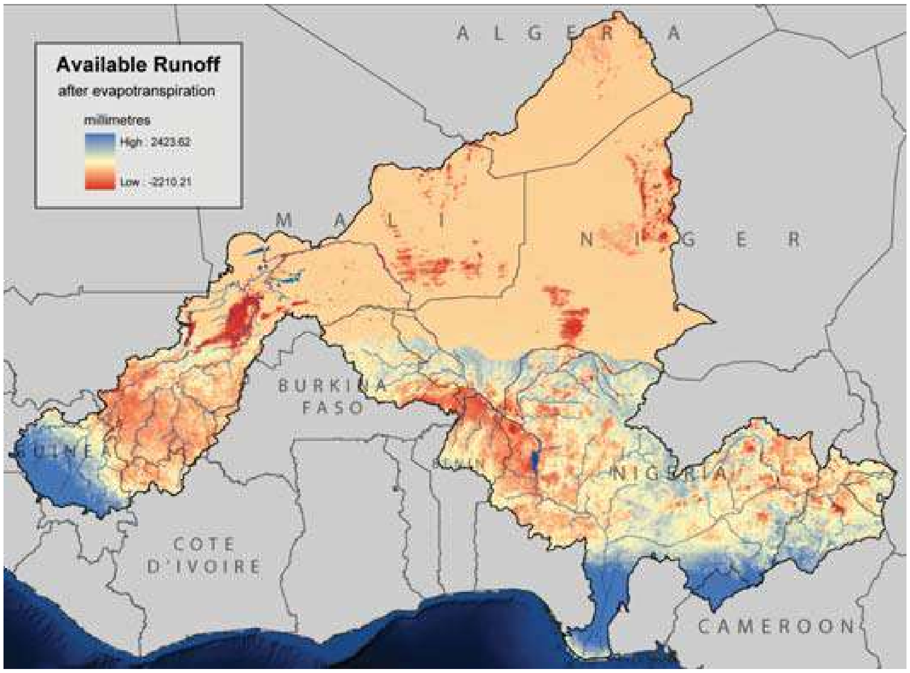
The Lower Niger River System

Leaving the border between Niger and Benin the river enters Nigeria, where it is joined by numerous tributaries. One of the most important tributary of the Niger River is the Benue which merges together at Lokoja in Nigeria. The Benue itself rises from Chad however there are almost no surface water resources in its uppermost part. In Cameroon it receives water from several tributaries. The slope in Cameroon is considerable and the discharge there has significant seasonal variations. From the confluence with the Benue, the Niger heads southwards and empties its contents in the Gulf of Guinea through a network of outlets of its sediments that constitute the maritime Niger Delta. Despite the facts that the river sources in Guinea and Ivory Coast are located in tropical regions, however only an estimated area of about 1.2 to 1.5 million km^2 is considered to be hydrologically active (Olomoda 2002; Ogilvie et al., 2010). The rest part is desert, forming a relatively large section of the basin that is not hydrologically active.

(b) Runoff

There were studies related to historical precipitation with various hydrologic variables, such as runoff and discharge, as indicators of surface water supply. Of these indicators, runoff is the most common. Since the great droughts of the past century in the Sahel, through which six of the 11 transboundary river basins run, several studies have shown that runoff has been decreasing by up to 60 percent alongside decrease in rainfall (Milly, Dunneand Vecchia, 2005; Mahe and Olivry, 1999; Ardoin et al., 2009; Roudier and Mahe, 2010a). Annual river discharge largely varies in conjunction with rainfall variability.

However, this relation proves quite different at the temporal scale, as relative hydrologic variability (rainfall, evapotranspiration, runoff, and river discharge) was much higher in the dry period than in the wet period (Li et al., 2004), indicating a higher level of climate vulnerability in the dry season in the basin. For example, a model of simulated available runoff in the Niger basin after evapotranspiration component has been removed is shown in Figure 3.16. These studies may seem to suggest a consistently direct correlation between decreasing rainfall and declining runoff. However, this relationship was actually quite variable at different spatial and temporal scales (Conway et al., 2008), resulting in economic, environmental, and social burdens in many locations (Sutcliffe and Knott, 1987; Grove, 1996; Laraque et al. 2001; Conway, 2002; Ogutunde et al., 2006; Hamandawana, 2007). From the studies, it has been demonstrated that the significance of spatial scale in the rainfall-runoff-discharge relationship cannot be understated. As Descroix et al., (2009) signal, the most important factor at the local scale is changing land cover, which influences soil hydrodynamic processes. However, at larger scales, a more dominant factor in river discharge is groundwater discharge flow, which can eclipse or even reverse the local impacts of land cover change.



Source: UNEP (n.d)

Figure 3.16: Modeled available runoff in the Niger basin

(c) Flow Characteristics

As the river flow eastwards towards the arid desert, the flow decreases as a result of low rainfall and high evaporation rates. Within the basin, a deficit of 10 to 30% in the rainfall generally leads to a deficit of 30 to 60% in river discharge (UNEP, 2008). The inland delta is an area of infiltration and high evaporation both of which decrease flow in the river, only the combined input from tributaries downstream of the inland delta allows the Niger River to grow to a larger river and reach the Gulf of Guinea.

The amount of water entering Mali from Guinea and Ivory Coast (about 40 km^3/year) exceeds the amount entering Nigeria from Niger (about 36 km^3/year), even though the river has travelled roughly 1,800 km further downstream, theoretically allowing a lot of additional input (Zwarts et al., 2006). This was caused by a relatively low input from precipitation and small tributaries along this stretch of the river, and by the high amounts of evaporation in the Niger Inner Delta (Olomoda, 2002; Zwarts et al., 2006; Mahé et al., 2009; Dadson et al., 2010; Mahe et al., 2011).

The Niger River receives a lot of rainfall from its headwaters in Guinea and Ivory Coast. This remains the case in south-western Mali, before it reaches the Inner Delta. The average input discharge here was approximately 1,490 m^3/s (over the period 1955-1996), which is decreased while it is passing through the delta until there is approximately only 900 m^3/s left as output discharge near the town of Tombouctou (Mahé et al., 2009).

Inflow from the Bani tributary does not compensate this loss of discharge (Zwarts et al., 2006). After the Inner Delta the Niger River does not receive any additional inflow over a long distance,

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with its discharge remaining relatively stable. The lower reaches of the Niger River are located in more humid regions, where it receives input from a number of small tributaries and continues to grow with the contributions. Downstream from the Sokoto on the left bank, which drains a partially semiarid, partially tropical, basin upstream of the Kainji Dam, the average annual flow is significantly increased by other more southern contributors. At Jebba, the Niger had a long-term mean annual flow of 1,600 cubic meters per second, although this had dropped to an average of950 cubic meters per second. After receiving Kaduna River (watershed of about 65,500 square kilometers) with a flow of 600 cubic meters per second (and floods of 3,000 cubic meters per second, on average), the Niger flowed to Baro. Over the period 1914–60, the average flow was 2,500 cubic meters per second, or a flow of 79 cubic kilometres for a 730,000-square-kilometer watershed at Baro. The annual maximum flow reaches 9,000 cubic meters per second and the 10-year flood flow reaches 12,000 cubic meters per second. The lower reaches of the Niger River are located in more humid regions, where it receives input from a number of small tributaries and the Benue River (near the town of Lokoja), which is by far its largest tributary. In fact, the discharge of the Benue exceeds that of the Niger itself. Shortly afterwards, the river reaches its coastal delta and discharges into the Atlantic Ocean. Figure 3.17 shows the average discharge of the Niger River over its entire length, with discharge values obtained for the period 1920-1990. It clearly shows the decrease in discharge that occurs over the Inner Delta, as well as the large contribution of the Benue River to the total discharge of the Niger. This figure is constructed with yearly averaged values and thus does not show seasonal variations. These variations are very important regarding the flooding of the Inner Delta, as this only occurs during the peak flows of the wet season.

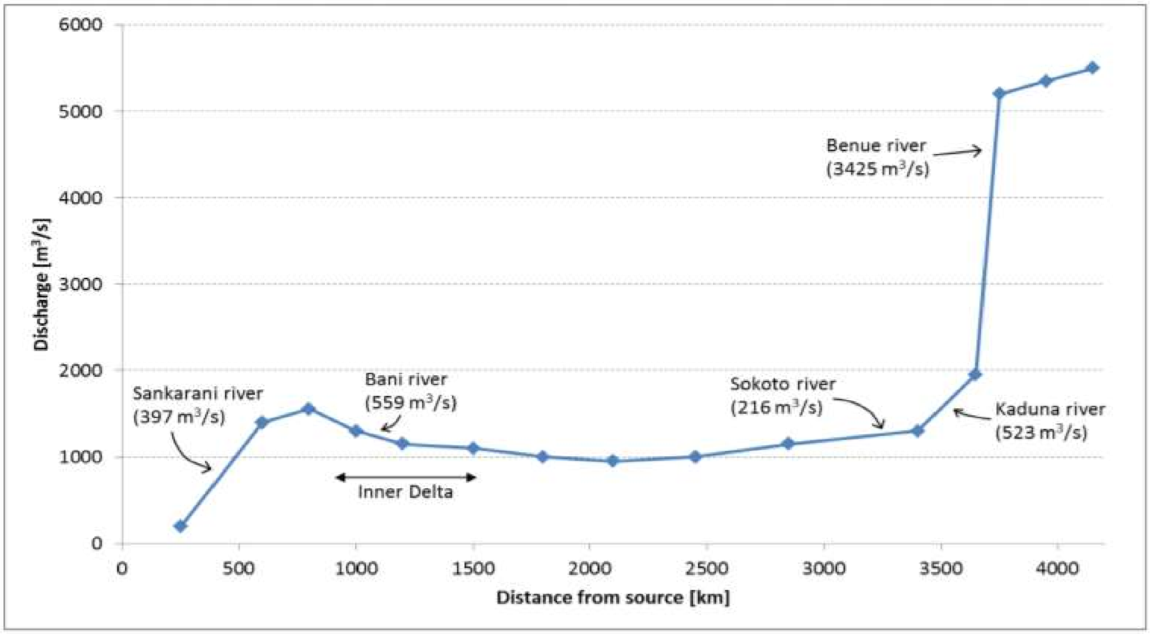

Figure 3.17: Average discharge of the Niger River over its entire length, including the contribution of its main tributaries (adapted from www.fao.org).

Nigeria is the final downstream country through which the Niger River flows, and contains 28.3 percent (424,500 square kilometers) of the Basin area. Of Nigeria's major rivers, more than half are in the Niger River Basin. Almost 60 percent of Nigeria's population, or about 67.6 million inhabitants, live in the Basin. These Nigerians comprise 80 percent of the population of the entire Basin. Within Nigeria; the Niger River continues to grow with the contributions from its rain-fed tributaries.

3.2.2 Water Demand Analysis of Niger River Basin in Northern Nigeria

Water is the most essential element to life on Earth, sometimes scarce resource and fundamental for living. It is also essential for both agriculture in many regions of the world and means to achieve sustainability in production systems. Maximizing net returns with the available resources is of the utmost importance, but doing so is a complex problem, owing to the many factors that affect this process (e.g. climatic variability, irrigation system configuration, production costs, and subsidy policies). Allocation of limited water resources, environmental quality and policies for sustainable water use are issues of increasing concern (Uitto, 2004; Conway et al., 2009). Water makes life possible as without it; life and civilization cannot develop or survive. As man's standard of living increases; so does his need for consumption of water.

Water demand analysis is crucial for water utilities to make a financially sustainable plan in terms of water pricing and infrastructure investments. It includes customer segmentation, influencing factor analysis and demand forecasting. Its technique considers both historical water consumption and influencing factors, e.g., water price, weather, household size, etc. for fully understanding customer behaviors. The outcome of the analysis can also be used for accurate marketing, efficient customer survey and customer behavior monitoring. It has tragic consequences in the Sahel countries, such as desertification. This drought, which is notably characterized by a decrease of rainfall, global surface-water flows and by a change in the rainy season characteristics, contributes to reduce the water availability in the Niger River Basin. This climate shift must be born in mind if one wants to understand the present hydrology and water uses in the basin.

The Niger River basin is the largest basin in West Africa. It covers six agro-climatic zones in nine countries and presents a cross-section of the complex development issues of West African societies. The main livelihood is traditional, low input, rainfed farming, irrigated and fertilized agriculture in parts of Mali, Niger and Nigeria and fishing throughout. The Inner Delta in Mali is one of the largest wetlands and multi-use systems in Africa at three million hectares with over one million herders, fishermen and farmers. Much of the population in the basin suffers from extreme to chronic poverty and remains vulnerable to droughts and ongoing political insecurity further complicates the development of the basin. The Niger River Basin, host to approximately

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104.5 million people, is a large catchment area with significant water resources development potential. The basin has an agricultural potential of about 2.5 million hectares, out of which only 20% has been exploited. With 36 different fish families and about 250 fresh water species, the basin has a fishing potential estimated at 7.5 tons per km of water course per year.

(a) Determination of Water Demand

Going by literature and previous researches, values of per capita water demand have been determined by Adewumi, (2008) who stated that the value of water demand for developing countries (sub Saharan African inclusive) lies within the range of 50 – 120 litres per capita per day. Water demand projection method used by FMWR/JICA, (2014) for the update of Nigeria National Water Resources Master Plan was adopted. With this method, the product of population and per capita water consumption was used in calculating water demand taking into account other factors such as commercial and industrial water use, and water loss. Settlements were categorized based on population and other socio-economic considerations. The basis for the categorizations was presented in Table 3.2. For the purpose of this work, 120 litres per capita per day was used for the calculation of the total daily water demand for the states and LGAs within the basin as it is the standard recognized by WHO (2004). The population figure of 2006, quoted in Ifabiyi et 'al (2012), was used for the analysis. Sokoto, Kebbi, Zamfara and Katsina had a total population of 3,696,999; 3,238,628; 3,259,846 and 5,792,576 respectively. This value was projected on a standard progression of 3.0% yearly population growth.

Table 3.2: Categorization of Settlement and their per Capita Demand Estimation

S/No	Population Size	Settlement Category	Per Capital Consumption (l/d)	Type Of Water Supply Scheme
1.	More than 20,000	Urban	120	Surface water, piped supply, house or yard connection
2.	5,000– 20,000	Semi urban/ Small town	60	Surface or groundwater, small scale piped supply, communal standpipes, house or yard connection
3.	Less than 5,000	Rural	30	Groundwater, 250m radius, 250 – 500 per point

Modified from FMWR/JICA (2014)

Municipal water demand (MWD) of a settlement was calculated (as shown in equation 1) as summation of Average Domestic Water Demand (ADWD), Commercial Water Demand (CWD), Industrial Water Demand (IWD) and Water Loss Factor (WL). The formulae for calculating ADWD, CWD, IWD, and WL are presented in equations 2.0, 3.0, 4.0, and 5.0 respectively. Commercial water demand ratio for Northern Nigeria with exception of Kano was estimated as 1.25% of ADWD, 30% of water loss ratio was applied across board in Nigeria with the exception of rural area, (FMWR/JICA, 2014), (Table 3.3).

MWD is calculated using equation 1.0:

MWD = ADWD + CWD + IWD + WL ……….................. 1.0

ADWD = pop * PCC ……………................................... 2.0

Where pop = Estimated population of the settlement

PCC = per capita water consumption.
CWD = 10% of ADWD = 0.1ADWD………......................... 3.0
IWD = 1.25% of ADWD = 0.0125ADWD …………................. 4.0
WL = (ADWD + CWD + IWD) * 0.3 ………….. .... 5.0

Table 3.3: Estimated population and Water demand of four northern states

State	Population	Water Demand (L/Day)
Sokoto	5,302,484	920,246,098
Kebbi	4,710,396	817,489,226
Zamfara	4,790,388	831,371,837
Katsina	8,307,670	1,441,796,128

The water demand of the LGAs ranges between 16,846,845 – 97,288,485 litres per day with an overall total water demand of 4,010,897,289 litres per day. The population and water demand of the LGAs in the four states (Sokoto, Kebbi, Zamfara and Katsina) are presented in Table 3.4.

Table 3.4: Water demand and population of some states in Northwest Nigeria

State	LGA	Population	Water Demand (L/Day)
Sokoto		**5,302,484**	**920,246,098**
	SabonBirni	297,158	51,571,770
	Gada	356,675	61,900,946
	Tambuwal	323,575	56,156,440
	Gwadabawa	331,637	57,555,601
	Wamakko	256,738	44,556,880
	Illela	215,044	37,320,886
	Kware	192,023	33,325,591
	Bodinga	249,630	43,323,286
	Goronyo	260,769	45,256,460
	Wurno	232,549	40,358,879
	Rabah	213,559	37,063,164
	Silame	149,799	25,997,616
	Binji	149,375	25,924,031
	Dangeshuni	277,001	48,073,523
	Gudu	136,644	23,714,566

	Isa	215,150	37,339,282
	Kebbe	176,321	30,600,509
	Shagari	224,699	38,996,511
	Sokoto North	333,653	57,905,478
	Sokoto South	283,048	49,122,980
	Tangaza	164,333	28,519,992
	Tureta	97,921	16,994,189
	Yabo	19,809	28,648,940
Kebbi		**4,710,396**	**817,489,226**
	Bagudo	344,262	59,746,670
	Birninkebbi	388,501	67,424,348
	ArewaDandi	274,455	47,633,665
	Suru	214,726	37,265,697
	Maiyama	251,327,	43,617,800
	Gwandu	218,545	37,928,484
	Koko/Besse	223,956	38,867,563
	Dandi	211,437	36,694,891
	Ngaski	182,368	31,649,966
	Aleiro	97,072	16,846,845
	Argungu	289,625	50,264,418
	Augie	168,364,	29,219,573
	Bunza	178,655	31,005,575
	Fakai	173,245	30,066,669
	Jega	286,018	49,638,424
	Kalgo	122,852	21,320,964
	Shakaba	132,718	23,033,209
	Shanga	183,854	31,907,861
	Wasagu/danko	383,727	66,595,821
	Yauri	145,449	25,242,674
	Zuru	239,127	41,500,490
Zamfara		**4,790,388**	**831,371,837**
	Gusau	560,579	97,288,485
	Bungudu	377,892	65,583,156
	Zurmi	429,452	74,531,394
	Tsafe	389,988	67,682,417
	TalataMafara	315,087	54,683,348
	Maradun	303,205	52,621,227
	Bakura	273,394	47,447,528
	Bukkuyum	316,042	54,849,089
	Anka	209,846	36,418,773
	BirninMagaji	268,938	46,674,189

	Gummi	302,038	52,418,694
	KauraNamoda	416,933	72,358,722
	Maru	428,285	74,328861
	Shinkafi	198,600	34,467,030
Katsina		**8,307,670**	**1,441,796,128**
	Katsina	455,550	79,060,702
	Malumfashi	261,936	45,458,992
	Daura	322,089	55,898,546
	Kankara	348,399	60,464,646
	Batsari	297,688	51,663,752
	Mai'adua	288,989	50,154,041
	Kafur	299,810	52,032,025
	Bakori	214,089	37,155,146
	Jibia	239,763	41,610,868
	Mani	252,494	43,820,333
	Bindawa	216,211	37,523,419
	Dutsin- ma	243,158	42,200,070
	Ingawa	242,203	42,034,330
	Kaita	261,193	45,330,045
	Danja	179,504	31,152,919
	Batagarawa	270,741	46,987,100
	Musawa	243,476	42,255,259
	Matazu	162,954	28,280,666
	Kurfi	167,091	28,998,643
	Baure	290,580	50,430,159
	Charanchi	196,160	34,043,568
	Dandume	208,148	36,124,085
	Dan musa	162,105	28,133,322
	Dutsi	173,139	30,048,273
	Faskari	278,380	48,312,849
	Funtua	322,407	55,953,734
	Kankia	216,848	37,633,970
	Kusada	140,887	24,450,938
	Mashi	244,961	42,512,981
	Rimi	220,667	38,296,757
	Sabuwa	201,465	34,964,250
	Safana	265,225	43,387,500
	Sandamu	196,160	32,089,395
	Zango	233,425	36,549,630

(b) Geological Setting and Hydrogeology of the Sokoto Basin

In northwestern Nigeria the sediments of the Sokoto Basin were deposited during three main phases of deposition: Continental Mesozoic and Tertiary phases, with an intervening marine Maastrichtian to Paleocene phase (Figures 3.18 - 3.20). Overlying the Precambrian basement unconformably is the Illo and Gundumi Formations, made up of grits and clays, forming part of the "Continental Intercalaire" of West Africa (Kogbe, 1989).These are overlain unconformably by the Maastrichtian Rima group, consisting of mudstones and friable sandstones (Taloka and Wurno Formations); separated by the fossil ferrous shaly Dukamaje Formation. The Paleocene Dange Formation (mainly shales) is separated by the calcareous Kalambaina Formation. The overlying continental Gwandu Formation (Continental Terminal) is of Tertiary age (Jones, 1948; Kogbe, 1989). These sediments dip gently and thicken gradually towards the northwest, with a maximum thickness of over 1,200 m near the frontier of Niger Republic (Wright et al., 1985; Kogbe, 1989).

The principal water-bearing beds in the Sokoto sediments are the surface laterites, sandstones and grits in the Gwandu Formation, limestone beds in the Kalambaina Formation, sandstones in the Wurno and Taloka Formations as well as grits and sandstones in the Gundumi /Illo Formations (Jones, 1948). Groundwater occurs under water table conditions throughout the area. Moreover, the association of inclined impervious beds alternating with water-bearing horizons gives rise to pressure-water conditions in some parts of the Sokoto Basin. Perched bodies of groundwater also exist in the area. In the valley depressions along the watercourses, alluvial aquifers up to 20 m thick can be found consisting of intercalations of gravels, sands silt and clay causing locally confined conditions. The depth to groundwater in the alluvium of Wurno area is about 1-3 m, but reaches several tens of meters under topographic highs. Some of the tubewells provided for irrigation purposes in the study area have been sampled for both physical and chemical parameters. Analyses of pumping tests carried out in the shallow aquifer yielded transmissivities in the range of 200 to 5000 m^2/d and storage coefficients of 10-2 to 10-5 indicating semi-unconfined to confined conditions. Based on these results, the hydraulic conductivity varies between 10-4 to 10-3 m/sec. The yield of tubewells up to 20 m depth is generally 0.2 to 2 L/s. The fluctuation of the water table in the Fadama areas is about 2-3 m throughout the year. The water table is lowest in June and highest in September, during the rainy season.

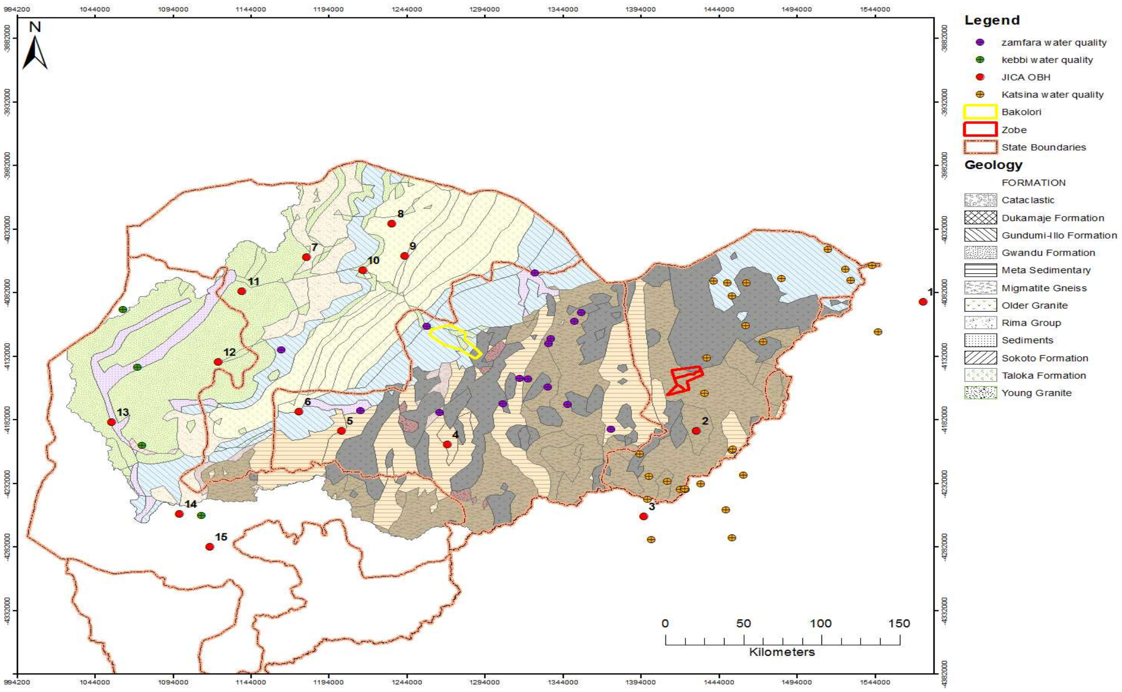

Figure 3.18: General Geological Map of the Sokoto Basin

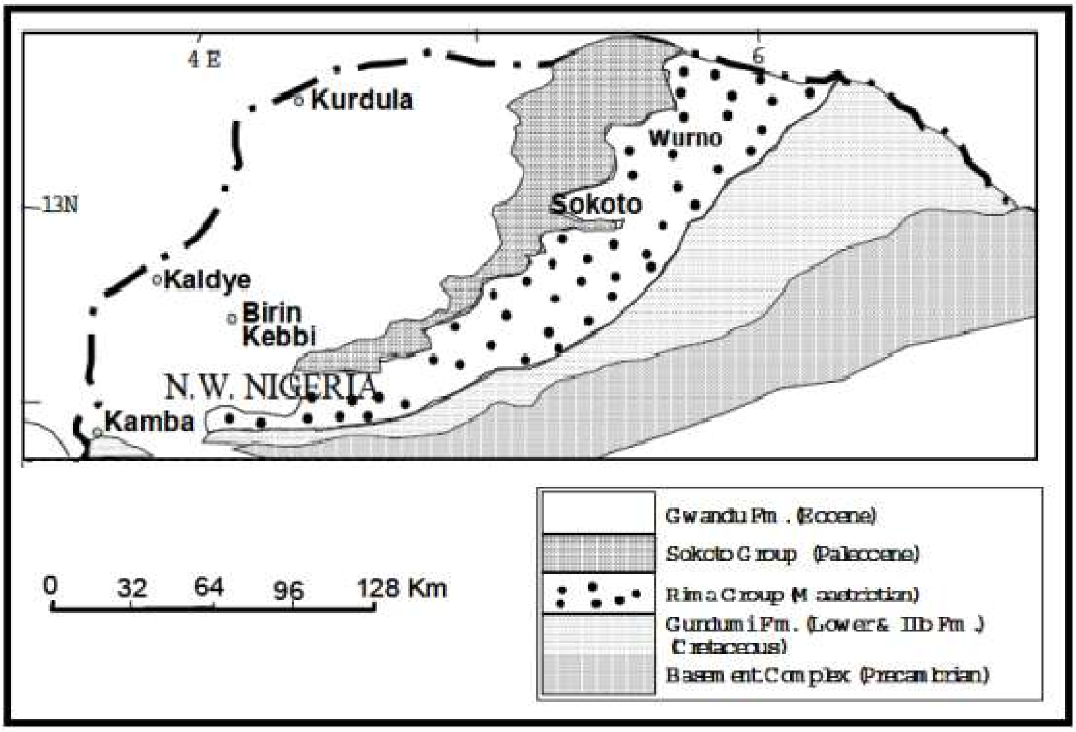

Figure 3.19: Geological map of Nigerian sector of the Iullemmeden Basin (after Adelana et al., 2003; modified from Oteze, 1991)

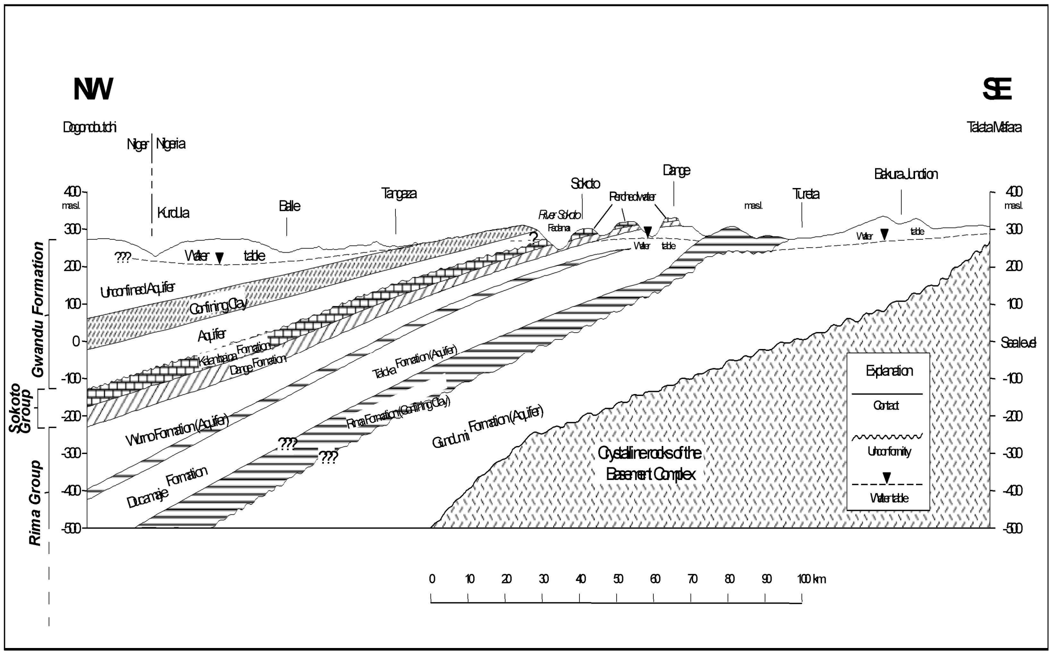

Figure 3.20: Hydrogeological cross-section through Sokoto Basin, North-West Nigeria (modified from Anderson and Ogilbee 1973)

The drainage pattern is somehow radial in nature. Main tributaries rise from the south eastern part of the state and in neighboring Kaduna state. The major rivers are Gagere, Bunsare and Maradi. They flow northward and later unite to form Rima River. On the basement complex, drainage pattern is dendritic. Drainage density is high on metamorphic rocks. On the basement complex, gradients are steeper; on leaving the precambrain they develop wide flood plains. The width of the flood plain bears no relation to the present flow. Their size can be as a result of climatic changes that have taken place in the quaternary era, when the Pleistocene climate was wetter. There is little groundwater recharge in the basement complex as rivers on them cease to flow after rainy season.

Two hydrological regions are discernable; these are head water part of the catchment overlying the basement complex and the lower part of the catchment overlying the sedimentary rocks. The upper part forms the headwaters of river Rima with higher drainage density, steeper gradients, lower infiltration and higher runoff coefficient. On the other hand, the lower part has higher infiltration and lower runoff coefficient due to its sedimentary nature.

3.2 Inventory of Large reservoir and Management, Rules Faced to Water Demand in Agriculture and Irrigation Expansion, Flood Control, Hydropower Production, Impact on Groundwater Recharge, Environmental Flow, Water Quality, including Specific Issues as Reservoir Sedimentation

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3.2.1 Dams/Reservoirs in the Niger Basin

Major dams in the Niger Basin include the Selingue Dam in Mali and Kanji, Jebba and Shiroro Dams in Nigeria. These dams provide large-scale hydropower not only in their countries but also to their neighbors as in the case of Nigeria and Niger. It was estimated that the Niger River has hydropower potential of about 30,000 GWH, of which only 6,185 GWH/year is being exploited, that is 20.6% in total. Other dams under construction or study include the Tossaye Dam in Mali, (under construction) and the proposed Kandadji Dam in Niger and Fomi Dam in northeastern Guinea on the Niandan River. The Selingue Dam and two other dams, the Sotuba and Markala also provide water supply for irrigation in Mali. The construction of Tossaye Dam in Mali will bring about 150 GWh/yr of additional hydropower capacity in the country. In Niger, the Kandadji Dam, which has been under study for three decades will no doubt increase the country's electricity supply and provide water supply for drinking and irrigation especially in the capital city of Niamey. However, the impact of the upstream dams will definitely affect flow downstream of the basin.

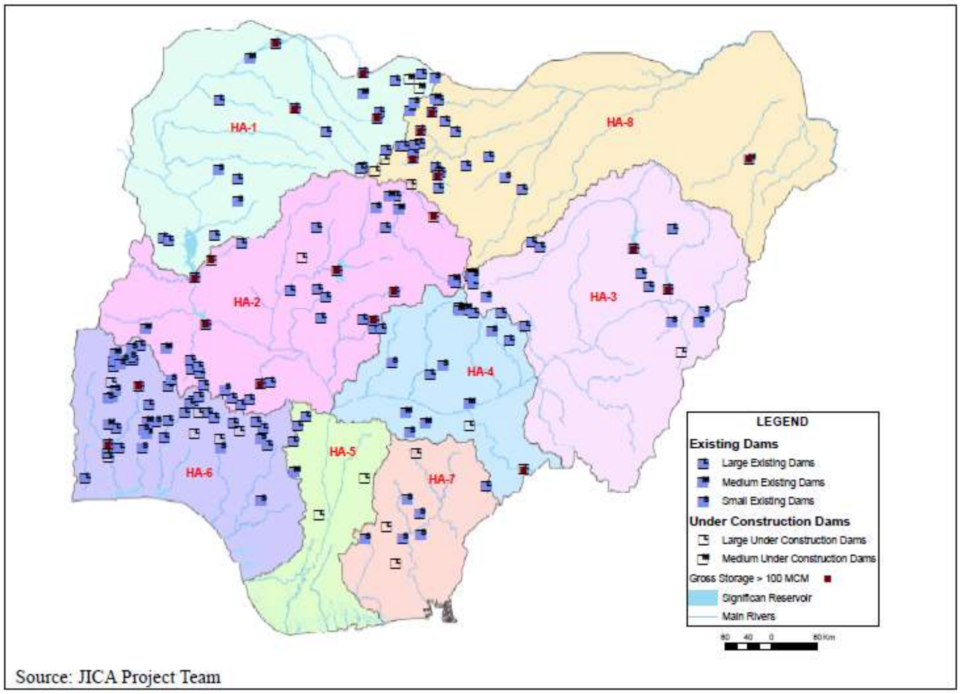
3.2.2 Dams/Reservoirs in Nigeria

The characteristics of the Dams/reservoirs in the Northern Nigeria are presented in Annex I. The research showed that the dams' properties and attributes are highly variable (see Annex 1). The dam height has its maximum value (115m) at Shiroro dam, while the minimum is 9m at Swashi dam. Tiga dam has the longest crest length which is 5,790m with the shortest length being 110m at Kubli dam. The highest reservoir capacity is 15,000MCM and this is found in Kainji dam, while Gusau dam has the lowest of 3MCM. The reservoir area of Dadinkowa dam is 392,000m^2, and this is the highest, while the smallest is found in Gubi dam at 179m^2. The spillway capacity of 7900MCM is the highest and it is found in Kainji dam, while Doma dam has the least capacity of 63MCM. Almost all the dams are used for water supply, irrigation, flood control, fishing, and livestock. While only few are used for hydroelectricity, navigation and tourism. As at 1995, Nigeria has a total of 160 dams across the six geo-political zones of the country (Table 3.5). This was based on an inventory of dams conducted by Japan International Cooperation Agency (JICA).

Table 3.5: Inventory of dams in Nigeria as at 1995

Location	**North West**	**North East**	**Central West**	**Central East**	**South West**	**South East**	**TOTAL**
No. of Dams	20	23	32	35	32	18	160
Acting reservoir capacity(10^6m^3)	13,269	5,951	7,980	2,413	1,053	2	30,668

However, over the years, the number of dams in Nigeria has increased greatly. In a recent survey by the JICA Team, Nigeria has more than 200 dams located across the country as shown in Figure 3.21.



Source: JICA Project Team

Figure 3.21: Location of existing and under construction dams in Nigeria as at 2014

(a) Water Supply

The different dams have varying design capacities for water supply which are meant for specific purposes. For instance, the Goronyo dam was designed to supply 80MCM of water to Sokoto State, Argungu and Birnin Kebbi water schemes in Kebbi state and also to provide water for irrigation and the development of downstream areas of the middle Rima valley and Zauro Polder project in Kebbi state covering 17,000ha. The Dadinkowa dam was designed to provide 76 million litres of portable water to Gombe. Dadinkowa water plant has the capacity of fifty thousand tons, covering of about 100,000m^2. The Doma dam was originally designed to provide 60million litres per day but now producing 12 million litres per day. While Kiri dam was designed to supply 70% water needs in Adamawa to mention but a few.

(b) Possibility of Expansion

As a consequence of emerging challenges, many of the dams have the potential to be expanded in the near future. For example, the Dadinkowa is part of the dams the Federal Government marked for hydropower installation and the Power Ministry has completed studies on that. Also, Studies have shown that the Doma Dam is suitable for the production of hydroelectric power and its generation potential is between 0.61MW and 0.70MW. In 2008, the United States Trade and Development Agency issued a request for proposals on constructing a 35 MW hydroelectric power plant at the Kiri dam. Also at Goronyo dam, the 200km^2 lake formed by the dam is expected to boost the fishing activities.

(c) Agriculture and Irrigation

It was observed that in most of the dams, the design capacity for irrigation are not met, and the intensity of agricultural activities has generally reduced, as a case study, the original goal of the Bakolori project was to supply irrigation water to the estimated population in the project area of about forty to fifty thousand farming families. The Irrigation project was designed for 30,000ha, but only 23,000ha so far being developed and put to use, 8000ha for surface irrigation and 15,000ha for sprinkler. Also as a consequence of reduced intensity of annual flood, recession agriculture on the flood plain has been seriously curtailed; both in respect to under cultivation and the market value of the crop being planted. In Doma dam, 39,000 hectares of land was projected to irrigate land for agriculture, but the present capacity for irrigation is 1,600 hectares covered so far for gravity irrigation, 2000 hectares had been developed for sprinkler irrigation.

(d) Hydroelectric Power Production

Only a few of the dams were originally designed for hydropower. This include the Bakolori dam which was designed to supply 10.4MW of electricity, the Dadinkowa dam designed to supply 40 MW of electricity and the Kainji dam.

(e) Impact on Groundwater Recharge

Generally, the lower river level, lateral groundwater movement toward the river would cause more rapid flood recession that it would have occurred before the river were regulated by dams and reservoirs. This premature draining of groundwater to the river reduces the amount of residual soil moisture available for dry season cropping. For instance, at Sokoto Rima River Basin, in some places where farmers previously cultivated wet season rice, they are now obliged to cultivate sorghum or millet owing to the reduced floodwater and the consequent loss of residual soil moisture. Recharge of the underlying soil structure or aquifer soil layer still takes place, but in a more restricted zone along the river.

(f) Environmental Flow

It was also observed that generally, there is a fall in environmental flow during rainy season and increase in drier season. For instance, in Kiri dam, flood peaks dropped from 1,420 m^3/sec to 1,256 m^3/sec. While flows in drier seasons increased from 5.7m^3/second to 21m^3/second. The river downstream from the dam has narrowed and become less windy, with fewer separate channels.

(g) Water Quality

Due to inadequate treatment of both domestic and industrial wastewaters in most of the riparian cities along the Niger River, the water quality of the River is prone to pollution. In addition to urban pollution sources, agricultural runoff from most of the irrigation schemes, particularly fertilizers has been a great source of pollution to the River water.

(h) Specific Issues on Reservoir Sedimentation

As a consequence of silting and sedimentation occurrence in the dams, there is a general reduction in the volume of water stored in the dam reservoirs and the apparent drying up of the water

3.3 Agriculture (Crops, Spatial Patterns, Irrigation Expansion) and Best Practices Assessment (i.e. Irrigation Techniques Adaptive Cropping Patterns, Rainwater Harvesting Techniques)

The Niger River basin gathers 100 million people over 2.1 million km^2, ten countries and six agro-climatic zones, ranging from Saharan in the north to Equatorial coastal around the Gulf of Guinea. Its scale and diversity provide a remarkable cross section of the efforts placed by African smallholder agriculturists to produce the food security requirements for the population despite limited means and unreliable water resources, through traditional low input rainfed agriculture, livestock and localized fishing (Ogilvie, et.al, 2016). In terms of agriculture, the Niger River plays a crucial role both in the region and the countries its runs through. It meets the needs of riparian populations, notably in various food productions (agricultural, fishing and pastoral). With an agricultural potential of about 2.5 million hectares, only 20% is currently being exploited. The basin also has a fishing potential estimated at 7.5 tons per km of water course and per year. The water plans of the basin have 36 fish families and about 250 fresh water species, including 20 one can find nowhere.

Nigeria is the final downstream country through which the Niger River flows, and contains 28.3 percent (424,500 square kilometers) of the Basin area. The Niger Basin extends across 20 of the 36 states of Nigeria and comprises two main rivers, the Niger and the Benue, and 20 tributaries. Of Nigeria's major rivers, more than half are in the Niger River Basin. Their combined length accounts for almost 60 percent of the total length of all important rivers in Nigeria. Almost 60 percent of Nigeria's population, or about 67.6 million inhabitants, live in the Basin (World Bank, 2005). These Nigerians comprise 80 percent of the population of the entire Basin. Given Nigeria's size and location, its agricultural production, both rainfed and irrigated, is substantial (Table 3.6) (World Bank, 2005).

Agriculture is one of the most important sectors in Nigeria economy. More than 70% of the labour force is concentrated in agricultural sector. Agricultural crops grown in most part of Northern Nigeria are noncash such as Sorghum, Maize, Millet, Cassava, Yams, Cowpea,

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Cocoyam, Beans, Sweet potatoes and Rice. The major Industrial and Cash crops are Cotton, Soya beans and Ginger. Groundnuts and Sesame are considered minor crops and Gunamelon. Vegetables like onions, tomatoes, peppers, cabbages are also grown large quantities.

The soils in the northern region of Nigeria are categorized as reddish brown or brown soils of the semi-arid and arid regions. They are also known as tropical ferruginous soils and are considered to be comparable to Ferric Luvisols. These are sandy soils that are made up of about 85% sand. Their pH values range between 6.0 and 7.0, and their bulk densities are about 1.4 g/cm^3.

Table 3.6: Socio Economic Statistical Characteristics of the Niger River Basin Countries (Adapted from World Bank, 2005)

Parameter	Benin	Burkina Faso	Cameroon	Chad	Code d'vore	Guinea	Mali	Niger	Nigeria
Total area (millions km^2)	0.114	0.274	0.475	1.284	0.322	0.246	1.24	1.27	0.924
Population (millions)	6.75	10.7	14.9	8.3	15.4	7.1	10.6	10.7	114
Population increase (% year)	3.1	2.3	2.3	3.2	2.1	3.1	2.2	3.5	2.7
Urban population (%)	39.9	18	48.1	23.5	45.8	32.1	29.4	20.1	43.1
GDP/person (US$)	933	965	1.573	850	1.653	1.934	753	753	853
Estimated population 2025 (millions)	11.5	21.7	27.8	13.4	29.9	14	22.7	19.2	235
Agricultural production (1,000 tones)									
Rice	36	89	65	100	1.162	750	590	54	3,400
Peanuts	-	205	160	372	144	182	140	-	2783
Corn	662	378	600-850	173	575	89	341	-5	5127
Millet	29	979	71	366	65	10	641	2.391	5956
Sugar cane	-	-	-	280	-	220	303	174	675
Cotton	150	136	75-79	103	130	16	218	-	55
Livestock (head, millions)									
Beef	1.35	4.55	5.90	5.58	1.35	2.37	6.06	2.17	19.8
Sheep	0.63	6.35	3.80	2.43	1.39	0.69	6.0	4.31	20.5
Freshwater fishing (1,000 tons)	44	-	89	6	68	103	108	6	383
Within Niger Basin *Hydrologically active*									
Area (10^3 km^2)^a	37.50	58;5	66.0	15.0	18.0	69.0	454.50	357.0	424.50
(%)	2.50	3.90	4.40	1.0	1.20	4.60	30.30	23.80	28.30
Population	1.95	2.12	4.46	0.08	0.80	1.60	7.80	8.30	67.60
(%)	2.10	2.20	4.70	0.10	0.80	1.70	8.20	8.80	71.40

3.3.1 Irrigation Expansion

Nigerian agriculture is not living up to its potential. In a system mostly dependent on the rainfed cultivation, many Nigerians face ongoing food insecurity and poverty, due in part to chronic under-investment in agriculture. If Nigeria is to attain robust and sustainable growth, it must improve agricultural methods, starting from the ground up. Expanding small-scale irrigation is one necessary step in a larger movement toward more sustainable and equitable agricultural growth in Nigeria. Breaking the annual cycle of uncertainty and stagnation can help secure local food systems and stable economic growth. Irrigation can provide the boost that the Nigerian economy needs to make the leap from rain-fed to grower-led. Nigeria cannot rely on rain fed agriculture if it must meet the food security potential and employment generation target. Irrigation Projects have opened up more hectares of land for cultivation in the Niger Basin.

In the Upper Niger River Basin Development Authority – Minna, some of the irrigation projects are:-

- Jebba - 500 hectares
- Doko - 400 hectares
- Badeggi - 500 hectares
- Wuya - 100 hectares
- GussoroAwutu - 100 hectares
- Tafa - 145 hectares
- ZangonKataf - 150 hectares
- Pambeguwa - 204 hectares
- Mbone - 500 hectares

In the Upper Benue River Basin Development Authority – Yola, over 500,000 hectare has been cultivated. Some of the Irrigation Projects in the area are:-

- Kiri - 12,300 hectares
- Waya - 2,000 hectares
- Jada - 500 hectares
- DadinKowa and Guyuk - 19,000 hectares
- Yola (Lake Geriyo) - 1,200 hectares
- Lower Taraba - 2,000 hectares

In the Lower Benue River Basin Development Authority – Makurdi, some of the notable irrigation projectsin the area are:-

- Katsina-Ala - Expansion from 1,500 hectare – 2,000 hectares
- Naka - Expansion from 50ha – 1000 hectares
- Okete - 1000 hectares
- Doma - 2000 hectares
- Dep - 1000 hectares
- Wuse - Expansion from 300 ha – 3000 hectare
- Shendam - 1000 hectares

- Oforachi - 1000 hectares
- Oguma - 1000 hectares

In the Sokoto Rima River Basin Development Authority (SRRBDA) from Goronyo to Birnin Kebbi:

i. Its inception was 1999
Middle Rima Valley Irrigation Project
The Irrigation Area was 736Ha

ii. Zobe Irrigation Project Dutsin-Ma
The initial Irrigation Area – 8140Ha reduced to 5,000ha
iii. Jibia Irrigation Project – Katsina State
To cover Irrigation Area of 3450Ha.

iv. Bakolori Irrigation Project – Talata Mafara
Area of Irrigation is 11,425Ha.

v. Zauro Polder Project (Irrigation)
Total Irrigable Area 10,000ha
Fully developed Irrigable 80ha.

vi. Talata Mafara Irrigation Project
Total Irrigable Area 23,00ha.

vii. Shagari Irrigation Project
Irrigation land 220ha.

Lower Niger River Basin Development Authority, Ilorin:

i. Oke-Oyi Irrigation Scheme - 500hectares
ii. Oloru Irrigation Scheme - 300hectares
iii. Onire Irrigation Scheme - 2,000ha Expansion 70ha
iv. Abati Irrigation Scheme - 200ha
v. Arin-Ile Irrigation Scheme - 1000ha
vi. Ajase-Ipo Irrigation - 100ha
vii. Okuta Irrigation Scheme - 500ha
viii. Tada-Shonga Irrigation Project - 3200ha Expansion 500ha
ix. Duku-Lade Irrigation Scheme - 1000Ha
x. Kampe (Omi) Irrigation Project - 4100ha

3.3.2 Irrigation Techniques in the Niger Basin in Northern Nigeria

Irrigation is a method of water supply to fields lacking wetness. It increases water content in the root layer of soil in order to increase the fertility of such soil, though it is necessary to consider the fact that some plants prefer dry soil and some need moisture. Before applying an irrigation farming system in Nigeria, it is needful to study the peculiarities of crops to be produced. Irrigation, as well as drainage, constitutes land enhancement techniques. Irrigation improves the supply of plant roots with moisture and nutrients, reduces the temperature of the soil surface and increases its humidity. Water in the fields can be distributed using different methods. Currently in about 19 states of the country, there are about 400,000 irrigation farmers with majority coming from the north. The following are the common irrigation methods used in Nigerian agriculture, especially in northern Nigeria.

(a) Surface Irrigation

This method has three varieties as described below.

(i) Border/bay strip method.

When using bay or border strip method (Figure 3.22), the water moves along parallel thin ridges on the surface that are lined up in long strips and in the process of moving the water is absorbed into the soil

Figure 3.22: Typical border irrigation system

(ii) Furrow Irrigation

When watering fields by furrows (Figure 3.23), running water soaks into the soil through the bottom and sides of furrows in the process of moving. Such method is mainly used for growing maize and vegetables.

Figure 3.23: Typical furrow irrigation system

(iii) Flood irrigation

The flooding method; a small area is surrounded by soil ridges from all the sides; it is filled with a layer of water, which then seeps into the soil. The water comes from lakes and rivers, wells and boreholes.

Surface irrigation is characterized by the following features:

i. Watering is carried out periodically, water reserves are accumulated in the upper soil layers and are consumed in irrigation intervals;
ii. It is possible to reach different depths large fluctuations in soil moisture between water application time;
iii. After watering the soil crust is formed on the entire wetted surface, which reduces aeration, nitrification and increases evaporation from the soil surface;
iv. Crisp crust prevents the appearance of weeds.

(iv) Sprinkler Irrigation

In comparison with surface irrigation, this type of irrigation is more expensive to implement, as the required equipment costs more. Despite this, applying sprinkler irrigation may get better harvest.

(a) Centre-Pivot

Plants are watered with the help of mechanically rotating pivot (Figure 3.24). It functions as a sprayer of water on a large circular field territory. A possible area of water delivery by Centre-Pivot hoses varies from 20 to 40 hectares.

Figure 3.24: Typical sprinkler irrigation system

(b) Traveling Gun

Such kind of a sprinkler moves along crops grown in a line or a row. Traveling gun delivers water on the top of plants. It is applied for watering of various types of fruits and vegetables, apart from tomatoes.

Using sprinkler irrigation gives the following advantages:

i. Irrigation is provided intermittently, the water accumulates in the upper soil layers;
ii. It moistens not only the soil but the plant itself, that activates its physiological processes;
iii. The depth of soil moisture is generally less than in a case of surface irrigation;
iv. One can apply frequent watering and small irrigation norms and thereby create more uniform soil moisture regime.

(v) Subsurface Irrigation

This type of irrigation allows one to:

i. Get the only capillary hydration of the upper layers of soil;
ii. Maintain a certain depth of moisture;
iii. Greatly reduce water evaporation from the soil surface;
iv. Provide a continuous supply of plants with water;
v. Does not restrict the work of agricultural machinery.

3.3.3 Harvesting Rainwater for Agricultural Purposes

Rainwater harvesting is the collection and storage of rainwater for reuse on-site, rather than allowing it to run off. The term "rainwater harvesting is usually taken to mean "the immediate collection of rainwater from surface upon which it has fallen directly (Pacey and Adrian, 1986).

Thus, the capturing and collection of rainwater from the roofs of buildings can easily take place within our cities, towns and rural areas. All that is necessary to capture this water is to channel the flow of rainwater from roof gutters or rooftops to a rainwater storage tank or reservoirs. By so doing water can be collected and used for domestic and agricultural purposes. Rain Water Harvesting (RWH) techniques have been utilized throughout time as some irrigation methods have been used by the people of Ur (present Iraq) around 4500 BC and are at present used in India (Khadin structures). Today rainwater harvesting is being used worldwide for drinking (human and livestock) and agricultural purposes. Previously, the concept of rainwater harvesting has received very little consideration (especially for drinking purposes) in larger donor financed projects, but recently, with the increasing pressure on available water resources, renewed interest has emerged.

(i) Rainwater Harvesting Methods

Rainwater harvesting is one of the most effective methods of water management and water conservation. It involves collection and storage of rain water at surface or in sub-surface aquifers, before it is lost as surface run off. Water collected could be used for domestic needs, livestock, agro forestry and small-scale farming in order to overcome the inadequacy of surface water to meet demands and to checkmate declining ground water levels. It has been noted that because this technique is cost effective, farmers in drier regions of the country can engage in water harvesting for irrigation, moisture conservation and also recharge of existing water sources to ensure availability of water all year round. The techniques for water harvesting are location specific. Farmers could harvest water through percolation tank which is an artificially created water body or through gully plugs where bunds are created across small gullies and streams carrying water to tiny catchments during the rainy season, and also through channeling filtered water from fields to dug wells to store it. Various methods of rainwater harvesting are described in this section. There are basically two methods of water harvesting;

a) Surface run-off harvesting;
   In urban area rainwater flows away as surface runoff. This runoff could be caught and used for recharging aquifers by adopting appropriate methods;
b) Roof top rainwater harvesting.

It is a system of catching rainwater where it falls. In rooftop harvesting, the roof becomes the catchments, and the rainwater is collected from the roof of the house/building. It can either be stored in a tank or diverted to artificial recharge system (Figure 3.25). This method is less expensive and very effective and if implemented properly helps in augmenting the groundwater level of the area. Technical description and materials for rooftop harvesting:

Generally, rainwater harvesting systems have three (3) components, they include:

a. A collection area (the catchment surface roof and other surfaces);
b. A conveyance system (the delivery system to transport the water from the roof to the storage reservoir); and

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c. A storage area (the reservoir to store the rainwater until it is used).

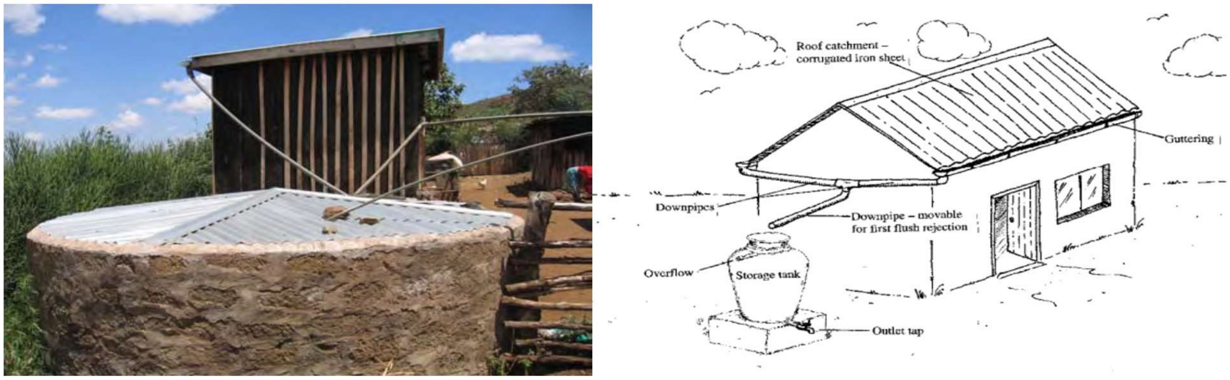


Figure 3.25: Typical domestic rain water harvesting

3.3.4 Other Practices within the Basin

(a) *Surface catchment systems* (Figure 3.26)

i. Harvesting of rainwater from rock outcrops/slopes, concrete surfaces, plastic sheets or treated ground surfaces;
ii. Consist of catchment area, retention and conveyance structures and storage tank/reservoir or even low yielding wells (recharging aquifers with rainwater – categorized as recharging structures);
iii. Water quality acceptable to beneficiaries (taste and appearance);
iv. Safe water for human consumption can be assured with proper O&M and simple disinfections techniques if needed;
v. Useful in arid and semiarid region (rainfall between 200 and 750 mm) – even semi-desert (< 200 mm) depending on area of surface catchment;
vi. Used for domestic and livestock consumption mainly.

Figure 3.26: Rock and other surface catchment systems

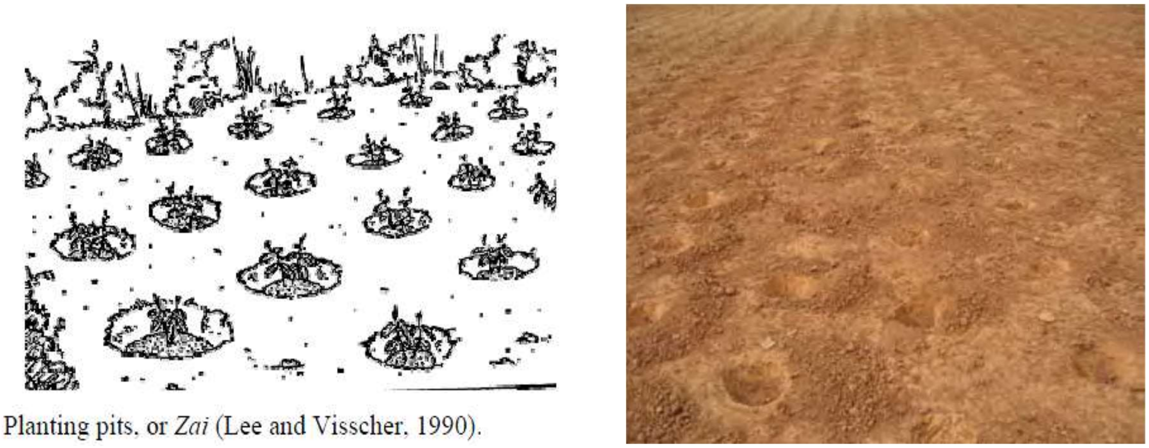
(b) *Small Scale Dams* (Figure 3.27)

i. Harvesting of rainwater/surface run-off within water shed and storage in various types of reservoirs;
ii. Consist of retention structure (earth dams, stone masonry/concrete dams or simple excavated ponds), structures to extracting water (for example hand dug wells, or horizontal intake pipes connected to well shaft);
iii. Water quality acceptable to users and normally consumed without any further treatment;
iv. Safe water for human consumption can be assured with proper water extraction structures and simple disinfections methods if needed;
v. Highly functional in arid and semi-arid region (rainfall between 200 and 750 mm) – even semi-desert (< 200 mm) depending on water availability (scarcity) and available catchment area (suitable landscape);
vi. Used for domestic, livestock and small scale irrigation (e.g. kitchen, gardening);
vii. Overland flow/run-off harvested from short catchment length;
viii. Catchment length between 1-30 metres;
ix. Runoff stored in soil profile;
x. Ratio catchment: cultivated area (CCA) usually 1:1 to 3:1;
xi. Since handling normally only small flows, no provision for overflow;
xii. Plant growth is even;
xiii. Use to replenish soil moisture, increase crop production and soil conservation.

Figure 3.27: Still water used to tend animals. Micro catchment (inclusive of in-situ conservation)

Note: Attached in annex is summary of dams in Nigeria.

The planting pit system is a micro catchment technique. Planting pits are made on land which low permeability to allow for runoff collection (Figure 3.28). Planting pits are holes dug to catch runoff and allow time for infiltration and they are usually fertilized with organic matter in the form of plant debris or compost. They are predominantly used for annual and perennial crops for example sorghum, maize, millet, cowpeas, sweet potatoes, groundnuts and bananas.



Planting pits, or *Zai* (Lee and Visscher, 1990).

Zai
Kadiogo, Burkina Faso

Figure 3.28: The Planting Pit System

The Zai form are dug with approximately 80 cm apart to a depth of 5 to 15 cm, with a diameter of between 15 and 50 cm, but the planting pits also exists in much greater size and with different spacing (Figure 3.29).

Figure 3.29: Stylized representation of Katumani pits

They are also primarily used for re-vegetation of degraded grazing land and cultivating crops like bananas in areas with rainfall as low as 300 mm/year and maize in wetter areas.

External catchment systems

i. Overland flow or runoff harvested from catchments of areas ranging from 0.1 ha to thousands of hectares;
ii. Diverted from farms land, hill side, pasture, or even roads;
iii. Runoff stored in soil profile or even stored in ponds, tanks or groundwater aquifers;
iv. Catchment 30 - 200 metres in length;
v. Ratio catchment: cultivated area (CCA) usually 2:1 to 10:1;
vi. Provision for overflow of excess water;
vii. Uneven plant growth unless land leveled;
viii. Use to replenish soil moisture, increase or ensure crop production.

Main Reasons and Scenarios to Utilize RWH: For agricultural (or soil/water conservation) purposes rainwater harvesting can be applied advantageously under the following scenarios/areas:

i. Rain-fed agriculture produce a low yield (< 1 tons/ha);
ii. High on land water loses (runoff unacceptable high);
iii. Soil erosion predominates (caused by short and intensive downpours) and the sustainability of potential farmland requires soil erosion control (Figure 3.30) and water management;
iv. High risk of meteorological droughts/dry spells;
v. Rainfall inadequate and poorly distributed over the cropping season to produce acceptable crop yields;
vi. Areas with a demand for food security;
vii. In areas, where farmers already use traditional RWH techniques, but need for improvement and expand required;
viii. RWH used for the production of maize, paddy rice and vegetables – crops that can be sold for cash.

Figure 3.30: Soil conservation and erosion control

In all scenarios above, most rainwater harvesting techniques would be applicable. The selection depends on landscape, slope, rain fall and rain pattern, soil type, crop and availability of local material and labour.

3.4 Analysis of WEFE Interlinks and Implications; Leading to lesson learned in the Contribution to both NRB Hydrological Model Calibration/Validation and Assessment of Simulation Scenarios

3.4.1 Modeling of Hydropower Reservoir Variables for Energy Generation: Neural Network Approach

Efficient management of hydropower reservoir can only be realized when there is sufficient understanding of interactions existing between reservoir variables and energy generation. Reservoir inflow, storage, reservoir elevation, turbine release, net generating head, plant use coefficient, tail race level and evaporation losses are the major hydropower reservoir variables affecting the energy generation. In order to model the reservoirs, variables of the two hydropower dams along the River Niger (Kainji and Jebba dams) in Nigeria for energy generation. Total monthly historical data of Kainji and Jebba hydropower reservoirs' variables and energy generated were collected from Power Holding Company of Nigeria respectively for a period of (1970-2011) and (1984-2011) for the network training using multilayer perceptron neural network.

The data sets were partitioned into three sets; training, testing and holdout samples for each of the stations. The training data records were used to train the neural network in order to obtain a model. The testing sample is an independent set of data records used to track errors during training in order to prevent overtraining. The holdout sample is another independent set of data records used to assess the final neural network; the error for the holdout sample gives an estimate of the predictive ability of the model. In this study, multilayer perceptron (MLP) was adopted with sigmoid activation function both at hidden and output layers. A normalized method of rescaling was used for scaling the HP reservoir variables. The neural network was trained with 504 data for Kainji station and 336 data for Jebba station. The data for each of the stations include reservoir inflow(Mm^3), storage (Mm^3), reservoir elevation (m), turbine release (Mm^3), net generating head(m), plant use coefficient, tail race level (m) and evaporation losses (Mm^3) as input layers and energy generation (MWh) as output layer. In the training process, the weights of input layer and hidden layer nodes are adjusted by checking the training and testing stage performances of neural networks. The coefficient of correlation and the mean square error are the performance criteria for the testing stage.

The neural network summary yielded a good forecast for Kainji and Jebba hydropower reservoirs with correlation coefficients of 0.89 and 0.77 respectively. These values of the correlation coefficient showed that the networks are reliable for modeling energy generation as a function of reservoir variables for future energy prediction.

The study area, Kainji and Jebba hydropower reservoirs are located in the lower Niger basin, established majorly for hydroelectric power generation. The flow of river Niger downstream of Jebba dam is governed by the operations of the Kanji and Jebba hydroelectric schemes and runoff from the catchments (Sule et al, 2009). Kainji hydropower reservoir was installed between 1964 and 1968 with a capacity of 760MW and provisions for expansion to 1156 MW while Jebba was installed between 1979 and 1983 and located at about 100Km downstream of Kainji on latitude 90061N and longitude 40501E with a capacity of 540 MW. Features of the two HP reservoirs are as shown in Table 3.7 and location map is shown in Figure 3.31.

Table 3.7: Features of Kainji and Jebba Hydropower Reservoirs

Reservoir Features	Kainji	Jebba
First year of operation	1968	1984
Installed capacity (MW)	760	540
Design power plant factor	0.86	0.70
Number of generators	8	6
Reservoir flood storage capacity (Mm3)	15,000	4,000
Reservoir flood level (m)	143.5	103.55
Maximum operating reservoir elevation (m.a.s.l)	141.83	103.00
Minimum operating reservoir elevation (m.a.s.l)	132.00	99.00

Maximum storage (active storage capacity), (Mm3)	12,000	3,880
Minimum storage (Dead storage capacity), (Mm3)	3000	2,880

Source: Power Holding Company of Nigeria (2012)

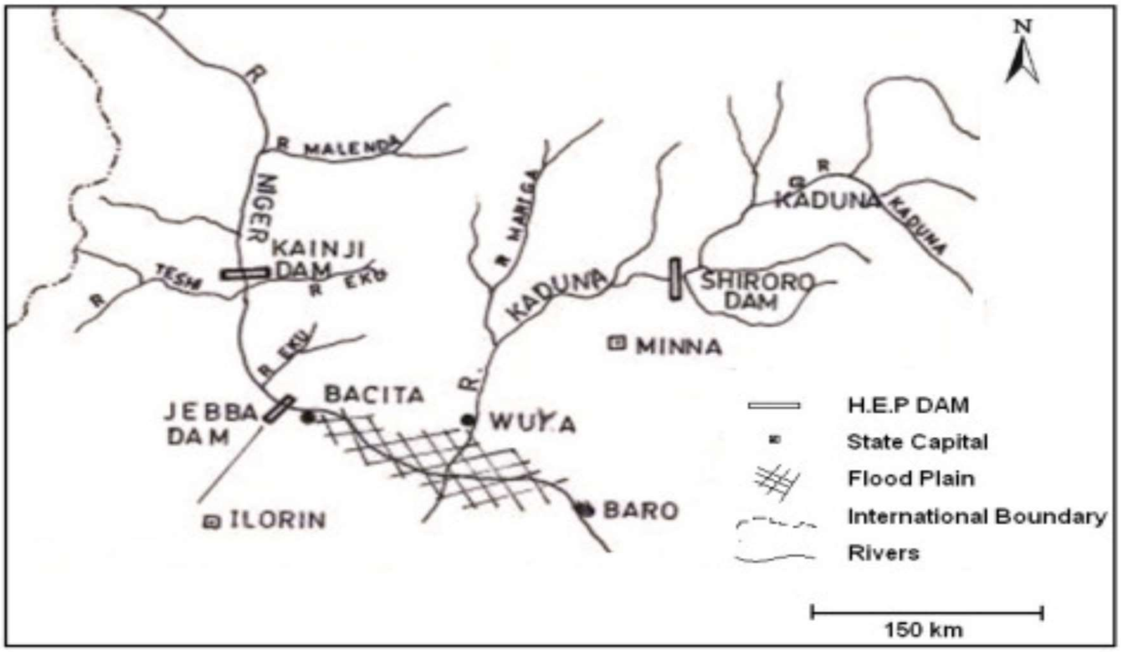


Figure 3.31: Location Map of the Kainji and Jebba Hydropower Reservoirs on Niger River

Total monthly historical data of HP reservoir variables for Kainji and Jebba stations were analyzed. The data include reservoir inflow (Mm3), storage (Mm3), reservoir elevation (m), turbine release (Mm3), net generating head (m), plant use coefficient, tail race level (m), evaporation losses (Mm3) and energy generation (MWh). These data were collected from Power Holding Company of Nigeria (PHCN) for a period forty two years (1970-2011) for Kainji and twenty eight years (1984-2011) for Jebba station. The summary of the statistical analysis is presented in Tables 3.8 and 3.9 for Kainji and Jebba HP reservoirs respectively.

Table 3.8: Summary of Statistical Analysis of the Kainji HP Data (1970 - 2011).

Reservoir Elements	Mean	Median	SD	DV	Minimum	Maximum	Skew
Reservoir Inflow (Mm^3)	2504.35	2408.77	632.93	0.25	1396.93	3653.04	0.44
Reservoir Inflow (Mm^3)	8058.58	8088.18	722.04	0.09	6654.53	9258.92	-0.17
Reservoir Elevation (m)	138.17	138.12	0.67	0.00	136.86	139.34	0.00
Turbine Release (Mm^3)	1881.96	1880.54	419.47	0.22	1131.05	2806.00	0.18
Net Generating Head (m)	38.57	38.48	0.59	0.02	37.63	39.90	0.41
Energy Generation (MWh)	178570.26	158016.25	73090.93	0.41	81553.53	378612.85	1.13
Plant Use Coefficient	0.39	0.35	0.15	0.39	0.17	0.80	1.06

Tail Race Level (m)	100.97	100.37	1.92	0.02	98.02	103.83	0.26
Evaporation Loss (Mm^3)	145.20	146.00	5.30	0.04	138.52	152.10	-0.09

Note: S.D = Standard deviation, C.V = Coefficient of variation

Table 3.9: Summary of Statistical Analysis of the Jebba HP Data (1984 - 2011)

Reservoir Elements	Mean	Median	SD	DV	Minimum	Maximum	Skew
Reservoir Inflow (Mm^3)	2617.90	2474.85	729.23	0.28	1588.86	4154.26	0.51
Reservoir Inflow (Mm^3)	3595.74	3594.00	79.81	0.02	3423.55	3751.58	0.13
Reservoir Elevation (m)	102.01	101.99	0.34	0.00	101.22	102.60	-0.17
Turbine Release (Mm^3)	2182.05	2186.21	297.70	0.14	1566.66	2572.62	-0.37
Net Generating Head (m)	28.15	28.22	0.54	0.02	26.61	29.07	-1.05
Energy Generation (MWh)	175134.17	163525.08	54346.26	0.31	103542.36	282039.95	0.77
Plant Use Coefficient	0.47	0.45	0.15	0.33	0.26	0.72	0.20
Tail Race Level (m)	73.69	73.61	0.40	0.01	73.09	74.54	0.64
Evaporation Loss (Mm^3)							

Note: S.D = Standard deviation, C.V = Coefficient of variation

The historical total monthly data for each of Kainji and Jebba HP reservoirs' variables were statistically analyzed. Statistical parameters such as mean, median, standard deviation, coefficient of variation, minimum, maximum and skewness were computed for each of the variables as shown in Tables 3.8 and 3.9. Application of NN model to Kainji and Jebba HP reservoirs data, reservoir inflow, storage, reservoir elevation, turbine release, net generating head, plant use coefficient, tail race level and evaporation losses were used as input layers and energy generation as output layer for the training of the network. This training involves estimation of main controlling parameters called network weights. A supervised training algorithm otherwise known as feed forward back propagation or MLP algorithm was adopted. Neural network model as applied to Kainji and Jebba HP reservoir variables yielded a network structure containing 8: 7: 1 of input, hidden and output layers network structure. The generated model structure is as shown in Figure 3.32. After training, the neural network models and test performances were checked. The performances of neural network models for prediction of energy generation were demonstrated in Figures 3.33 and 3.34 in the form of scatter plots. The correlation coefficients of 0.89 and 0.77 were obtained for Kainji and Jebba HP reservoirs respectively. This shows that there is linear relationship between the network outputs (estimates) and the corresponding targets (observed data) for the test data set.

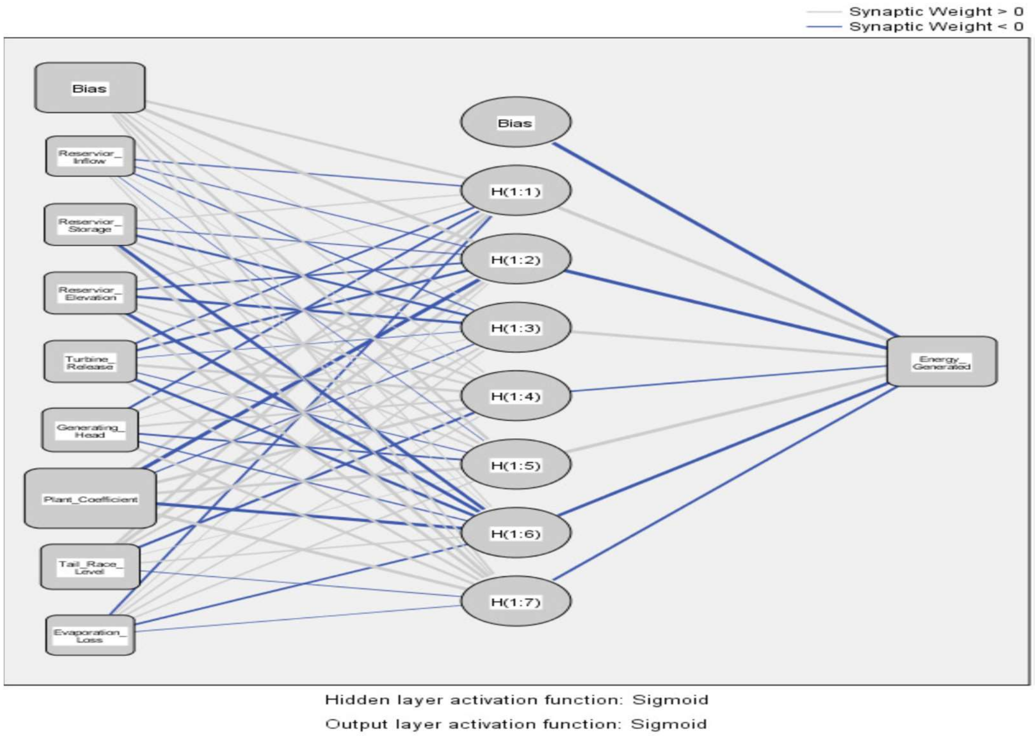


Figure 3.32: Generated Network Structure

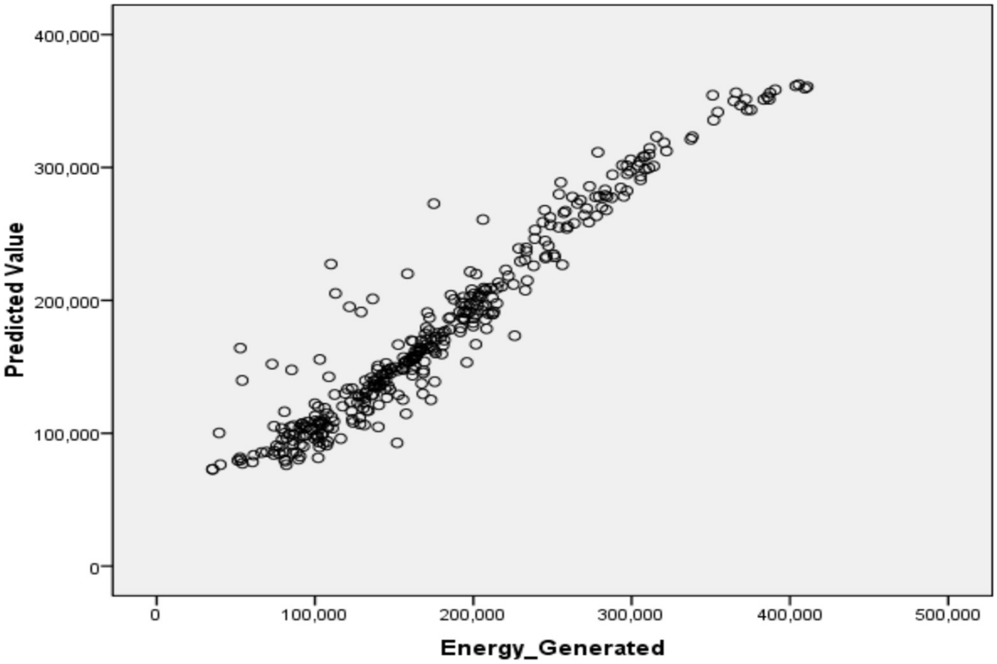


Figure 3.33: Scatter Plot of Predicted and Observed Energy Generated for Kainji HP

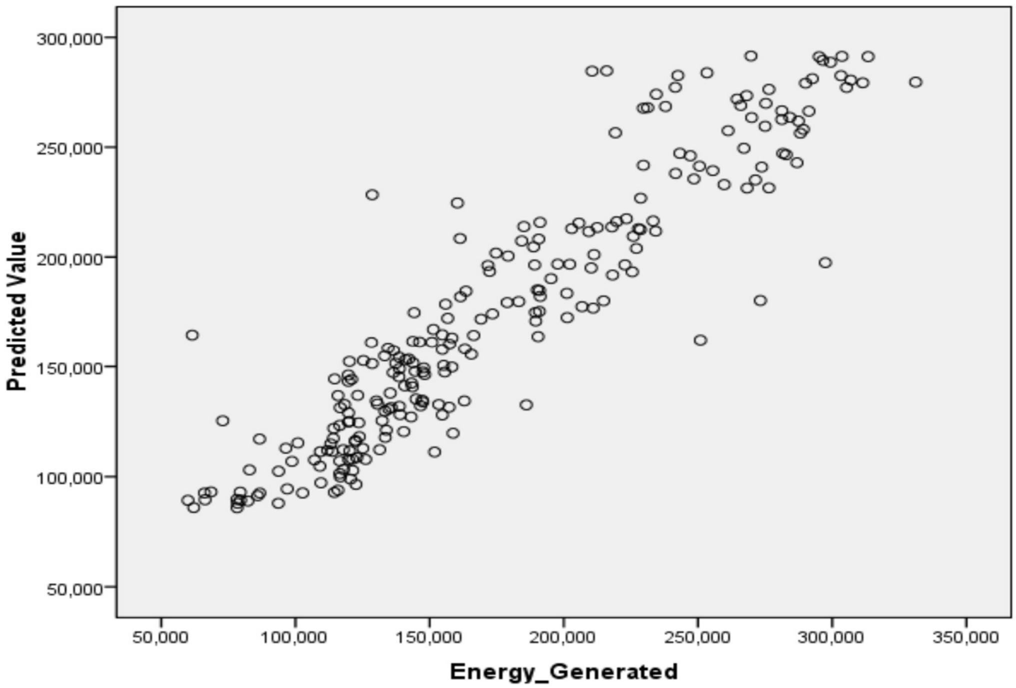


Figure 3.34: Scatter Plot of Predicted and Observed Energy Generated for Jebba HP

Energy generation from HP reservoir rely majorly on the adequate planning and operation of the reservoir which can be achieved through modeling of its variables in relation to energy generation. Kainji and Jebba hydropower reservoir variables were modeled for energy generation using neural network multilayer perceptron with sigmoid function as activator. Neural network model yielded a good forecast for Kainji and Jebba hydropower reservoirs with correlation coefficients of 0.89 and 0.77 respectively. These values showed strong linear relationship between the observed and predicted energy generation and this is an indication that the NN model is reliable for modeling of HP reservoirs for energy generation.

3.4.2 Rainfall trend and the future of Rice production in Niger State, Nigeria.

The United Nations World Water Development Report (WWDR) 2018 shows that Nigeria had no physical water scarcity in 2010, however the projected change in Water scarcity by 2050 shows that some parts of Northern Nigeria can move from “no water scarcity” to “water scarcity”. Regions are considered water scarce when total annual withdrawals for human use are between 20 and 40% of the total available renewable surface water resources, and severely water scarce when withdrawals exceed 40%. Furthermore the scenarios used for this modeling exercise are based on ‘water extended socio–economic pathways’. The-middle-of–the-road scenario assumes world development is progressing along past trends and paradigms, such that social, economic, and technological trends do not shift markedly from historical patterns i.e. business-as-usual (WWAP/UN-Water, 2018).

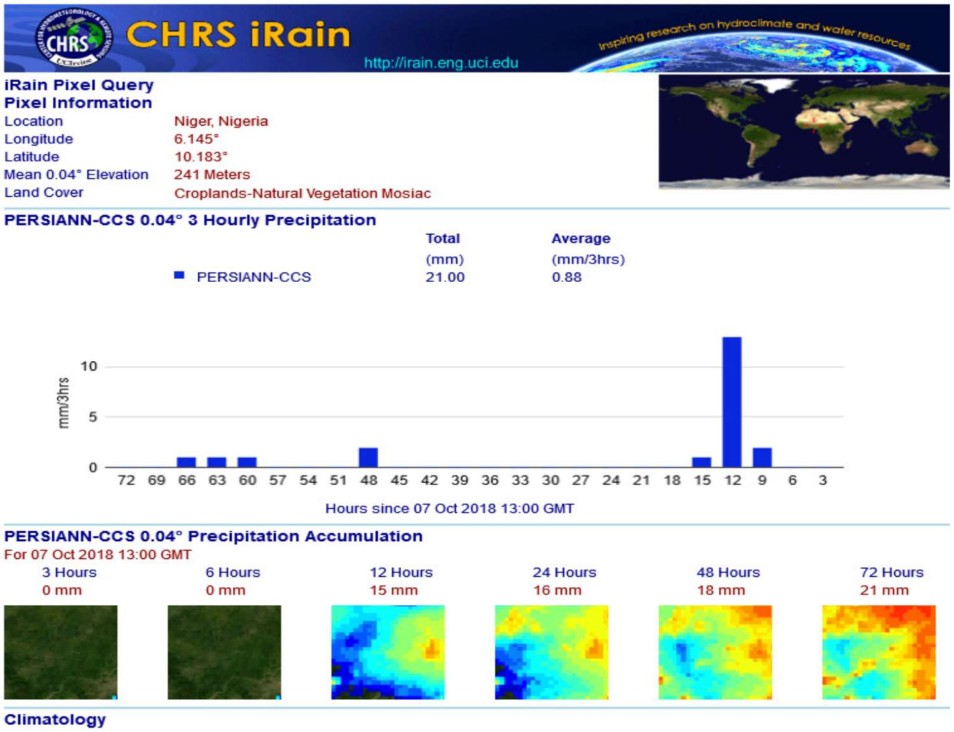
Rainfall is a key variable in the hydrologic cycle. Being able to accurately observe rainfall is extremely important in Water Resources Management planning and mitigating the impact of natural disasters such as drought, floods, flash floods and landslides. The portion of the Niger River basin in Nigeria is sparsely gauged, hence, Remote sensing techniques can be used to estimate rainfall for Niger State. The available rainfall can impact positively the agricultural landscape of Niger state.

Rainfall estimation for the two selected area was done using the PERSSIAN System estimation. The PERSIANN data have been used in a wide variety of studies including hydrologic modeling, drought monitoring, soil moisture analysis, and flood forecasting. PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) is a satellite-based rainfall estimation algorithm. It uses local cloud textures from long wave infrared images of the geostationary environmental satellites to estimate surface rainfall rates based on an artificial neural network algorithm. Model parameters are frequently updated from rainfall estimates provided by low-orbital passive microwave rainfall estimates. The PERSIANN algorithm has been evolving since 2000, and has generated near real-time rainfall estimates continuously for global water and energy studies (Kuo-Lin and Soroosh, 2000).

The first Global Real-time Crowd-sourced Rainfall Observation system called iRain and uses the PERSIANN system. iRain was a joint project between the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine and the Integrated Media System Center of the University of Southern California. CHRS iRain was used to generate real time rainfall data, retrieve historical rainfall data from 1983 t0 2017 and perform yearly rainfall simulation from the present upwards to 100 years (Figure 3.35).

This study primarily focuses on Niger state as an agriculturally endowed state in Nigeria. The contributions of other states in Northern Nigeria are also compared with the output from Niger state for some of the crops. Besides being a big player in Rice production, Niger state has within its borders some Water Resources Infrastructures like dams, Water Treatment plants, Irrigation projects that need to be managed sustainably. Adequate information on the rainfall trend, rising temperature because of climate change has implications for sustainable management of Water Resources Infrastructures. This will ensure the maximizing of the social and economic benefits to the citizenry as well as managing the environment well.

The yearly rainfall data for Niger state from 1983 to 2017 was generated using CHRS iRain. The yearly rainfall projections for the next 25 years from 2018 were also produced using CHRS iRain (Figure 3.36).



iRain Pixel Query
Pixel Information

Location	Niger, Nigeria
Longitude	6.145°
Latitude	10.183°
Mean 0.04° Elevation	241 Meters
Land Cover	Croplands-Natural Vegetation Mosiac

PERSIANN-CCS 0.04° 3 Hourly Precipitation

	Total (mm)	Average (mm/3hrs)
■ PERSIANN-CCS	21.00	0.88

PERSIANN-CCS 0.04° Precipitation Accumulation
For 07 Oct 2018 13:00 GMT

3 Hours	6 Hours	12 Hours	24 Hours	48 Hours	72 Hours
0 mm	0 mm	15 mm	16 mm	18 mm	21 mm

Climatology

Figure 3.35: 3-hourly Precipitation Accumulation for Niger state

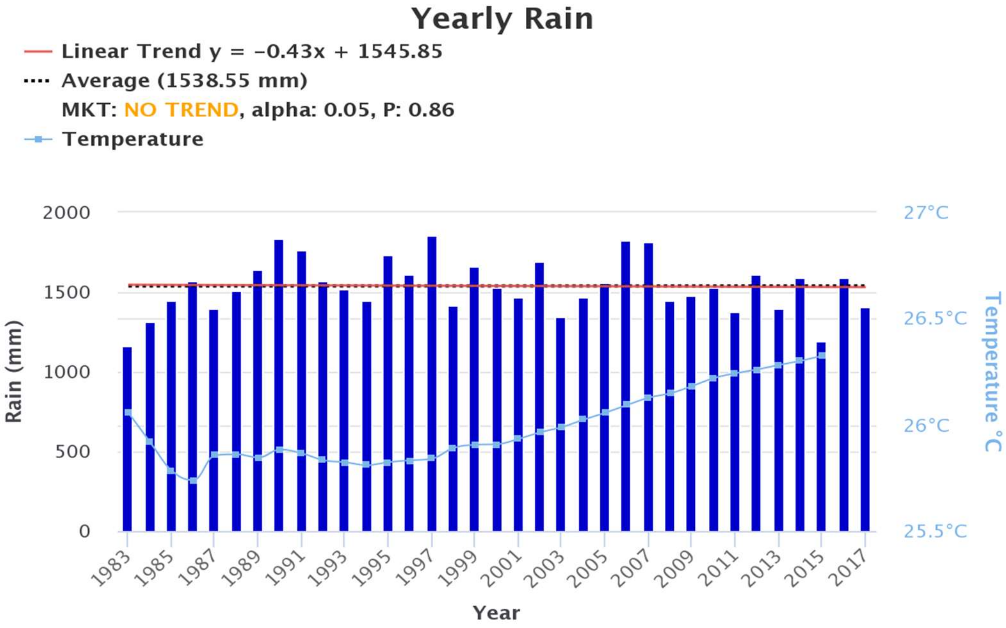


Figure 3.36: Yearly Rain for Niger state (1983 – 2017)

Table 3.10: Yearly Rainfall simulation for Niger State 2018 – 2042 (25 years projection)

Time	RCP2.6 (Low Emissions Scenario) (mm)	RCP4.5 (Stabilization Emissions) (mm)	RCP8.5 (High Emissions) (mm)
2018	1332.75	1275.04	1280.47
2019	1314.79	1314.43	1300.46
2020	1352.45	1271.89	1300.7
2021	1272.7	1260.34	1303.62
2022	1325.6	1244.39	1311.41
2023	*1271.02	1263.91	*1259.6
2024	1331.24	1328.02	1327.21
2025	1295.32	*1253.77	1274.78
2026	1342.59	1264.1	1318.99
2027	1283.37	1273.68	1325.33
2028	1262.56	1302.08	1264.32
2029	1298.47	1307.81	1293.41
2030	1274.15	1342.21	1345.76
2031	1319.32	1310.73	1347.99
2032	1277.88	1281.86	1284.99
2033	1319.63	1268.81	1330.13
2034	1326.55	1265.56	1294.25
2035	1321.74	1315.9	1297.56
2036	1300.05	1273.45	1324.67
2037	1281.76	1329.54	1289.68
2038	1285.51	1275.35	1303.29
2039	1362.35	1268.87	1341.7
2040	1308.41	1301.96	1267.4
2041	1341.25	1316.24	1274.57
2042	1351.07	1276.79	1275.17

The simulation shows that the yearly rainfall was generally lower than the yearly average, i.e. 1538.55mm for the historical yearly rainfall from 1983 to 2017. The difference between the historical yearly average and the least projected yearly rainfall (as asterisked in Table 3.10 from the low emissions, stabilization emissions and high emissions scenarios are 267.53mm, 284.98mm and 278.95mm respectively. The yearly historical figures from 1983 – 2017 showed no significant trend. The simulated yearly rainfall does not show any significant trend.

(a) Rice Production in Niger State

A survey conducted by the National Agricultural Extension and Research Liaison Services (NAERLS) of Ahmadu Bello University, Zaria, in conjunction with Agricultural Development Projects (ADPs) and the Federal Department of Agricultural Extension carried by This Day Newspaper article titled, “Survey Ranks Niger Leading Rice Producing State in 2017”, (Ajimotokan, 2018) reported that “The Agricultural Performance Survey (APS) for 2017 has rated Niger State as the leading producer of paddy rice in the country.

The total land area cultivated by the state for the period was 229,080 hectares with production volume of 541.83mt (Figure 3.37). All the 36 states of the federation, including FCT, were assessed in the survey certified by National Technical Committee on Agricultural Statistics. Kogi State followed with an output of 512,610 MT cultivated on 235,521 hectares. Benue was in third position with a production volume of 486,620mt. Its cultivated area was 227,730 hectares. Kano (418,480 mt), Kebbi (411,490mt), Nasarawa (410,820mt), Kwara (408,250mt) and FCT (408,111mt) were rated 4th, 5th, 6th, 7th and 8th respectively. The ranking also showed that Akwa Ibom with a volume of 19,199 MT was the least rice producing state in 2017, with a little over 10,000 hectares of land cultivated. Other lesser producers are Delta (44,230mt) in 36th position and Abia (50,312 MT) in 35th place. According to the APS, the estimated cropped area for rice was 3.90 million hectares, which represented an increase of about 6.9 percent over the 3.17million hectares cultivated in 2016. The survey said a total output of 8.02 million mt was produced in 2017 as against the 6.99 million mt recorded in 2016, showing a significant increase in output of about 14.7 per cent. It also noted that all states recorded an increase in the production of the crop, with Lagos State having the highest increase of 30.5 per cent. An average yield of 2.4 tonnes per hectares was recorded for the crop in 2017.

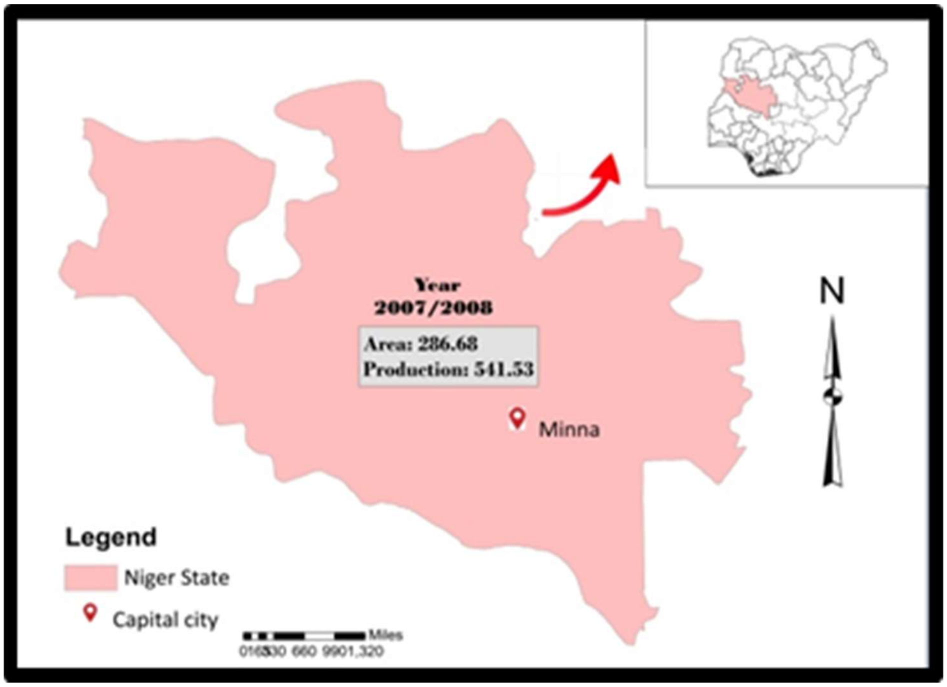
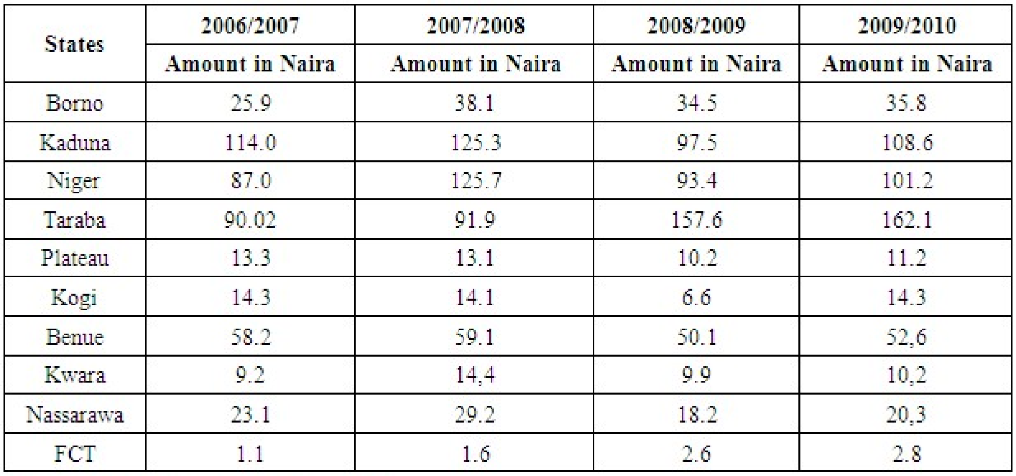


Figure 3.37: Rice planted and production (2007 -2008)

(b) Rice Farm Land Use in Niger State

The monetary costs of rice seeds as a factor in the planting season also increased from the 2006/2007 levels of N87 million to N125.3 million and N93 million to N101.2 million (Table 3.11). This seems commensurate with the amount of money devoted to seedlings in the production of rice in the two other Middle Belt states of Kaduna and Taraba. From the profile, farm gate prices for rice dropped from N25.45-N24.35 but only to rally slightly by N25.60 to N26.39 at an average of N24.94 in the entire period (Table 3.12, Table 3.13).

Table 3.11: Costs of seedlings of Rice (Million Naira) by State 2006-2010

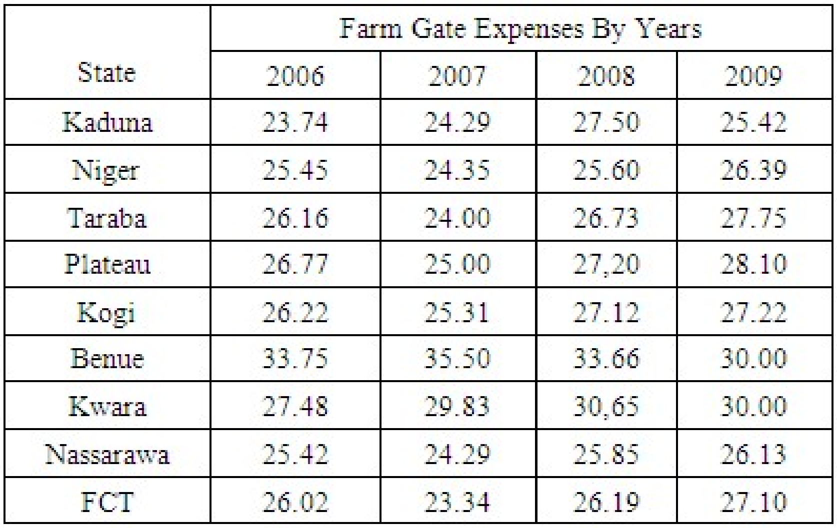


States	2006/2007	2007/2008	2008/2009	2009/2010
	Amount in Naira	Amount in Naira	Amount in Naira	Amount in Naira
Borno	25.9	38.1	34.5	35.8
Kaduna	114.0	125.3	97.5	108.6
Niger	87.0	125.7	93.4	101.2
Taraba	90.02	91.9	157.6	162.1
Plateau	13.3	13.1	10.2	11.2
Kogi	14.3	14.1	6.6	14.3
Benue	58.2	59.1	50.1	52,6
Kwara	9.2	14,4	9.9	10,2
Nassarawa	23.1	29.2	18.2	20,3
FCT	1.1	1.6	2.6	2.8

Source: National Bureau of Statistics, 2010

With the increases in fertilizer treatment of land evident in Niger state, during 2006-2010, among the crops, the average quantity of fertilizer needed for rice farming stayed stable at 1.6 bags between 2008 through 2010. During that period, the total amount of fertilizer required for farmland cultivated with rice not only rose from an opening value of 260,920 to 264,304 tons in 2008 and 2009, by 2010 the overall fertilizer required for areas cultivated with rice dropped slightly to 250,304 tons (Table 3.14).

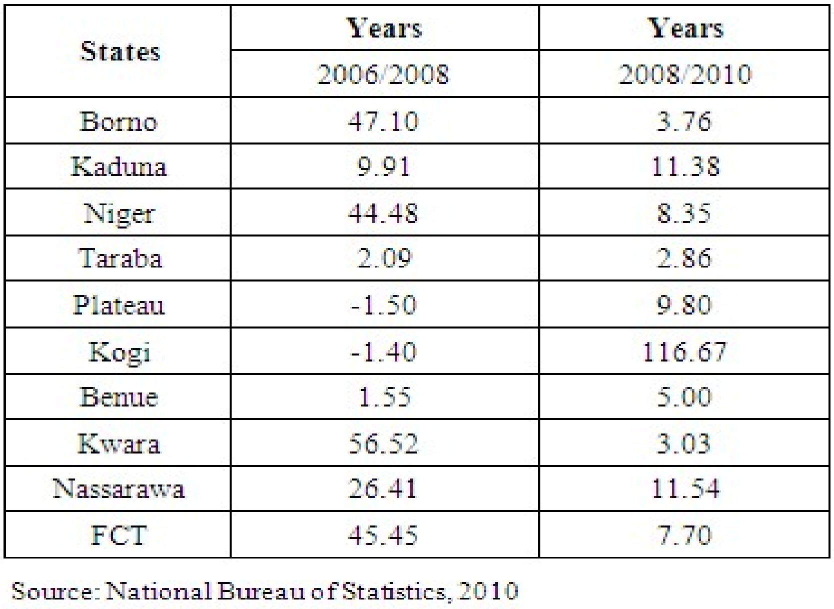
Table 3.12: Farm Gate Price by Crop and State in Naira for Rice, 2006-2009



State	Farm Gate Expenses By Years			
	2006	2007	2008	2009
Kaduna	23.74	24.29	27.50	25.42
Niger	25.45	24.35	25.60	26.39
Taraba	26.16	24.00	26.73	27.75
Plateau	26.77	25.00	27,20	28.10
Kogi	26.22	25.31	27.12	27.22
Benue	33.75	35.50	33.66	30.00
Kwara	27.48	29.83	30,65	30.00
Nassarawa	25.42	24.29	25.85	26.13
FCT	26.02	23.34	26.19	27.10

Source: National Bureau of Statistics, 2010

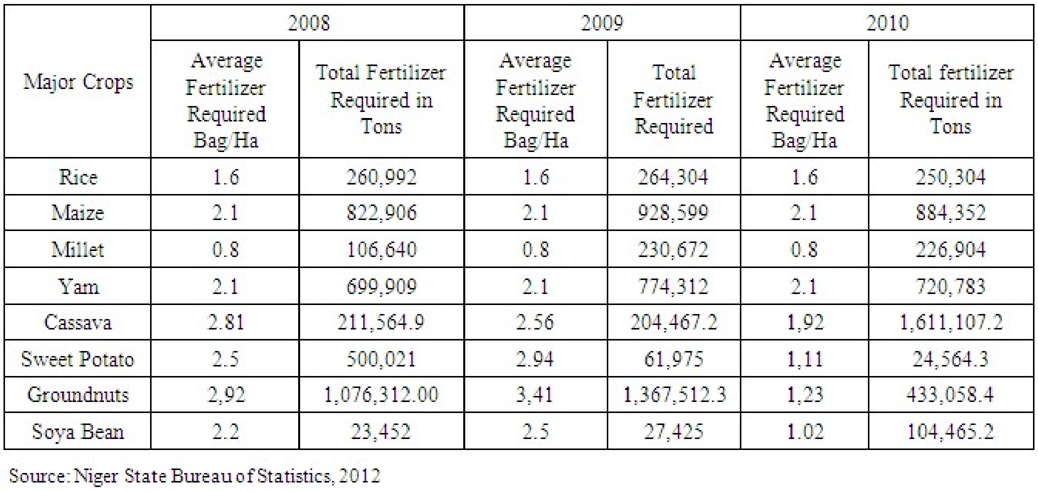
Table 3.13: The Percentages of Change for Costs of Rice Seed 2006-2010



States	Years	Years
	2006/2008	2008/2010
Borno	47.10	3.76
Kaduna	9.91	11.38
Niger	44.48	8.35
Taraba	2.09	2.86
Plateau	-1.50	9.80
Kogi	-1.40	116.67
Benue	1.55	5.00
Kwara	56.52	3.03
Nassarawa	26.41	11.54
FCT	45.45	7.70

Source: National Bureau of Statistics, 2010

Table 3.14: Fertilizer Applications for Different Crops 2008-2010 in Niger State

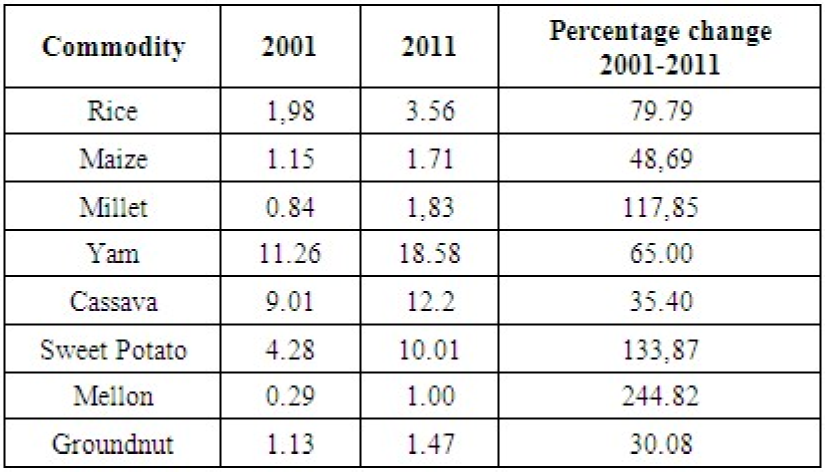


Major Crops	2008		2009		2010	
	Average Fertilizer Required Bag/Ha	Total Fertilizer Required in Tons	Average Fertilizer Required Bag/Ha	Total Fertilizer Required	Average Fertilizer Required Bag/Ha	Total fertilizer Required in Tons
Rice	1.6	260,992	1.6	264,304	1.6	250,304
Maize	2.1	822,906	2.1	928,599	2.1	884,352
Millet	0.8	106,640	0.8	230,672	0.8	226,904
Yam	2.1	699,909	2.1	774,312	2.1	720,783
Cassava	2.81	211,564.9	2.56	204,467.2	1,92	1,611,107.2
Sweet Potato	2.5	500,021	2.94	61,975	1,11	24,564.3
Groundnuts	2,92	1,076,312.00	3,41	1,367,512.3	1,23	433,058.4
Soya Bean	2.2	23,452	2.5	27,425	1.02	104,465.2

Source: Niger State Bureau of Statistics, 2012

To further buttress the great potentials of agricultural productivity in the state, the yield per hectares for rice rose by 1.98 -3.56 at a rate of 79.79% between 2001 through 2011 (Table 3.15). At the same, Niger state is also not an exception when it comes to the falling pace in farm gate prices by crop as manifested in the other Northern states.

Table 3.15: Yield per Hectares for Major Crops Northern states of Nigeria



Commodity	2001	2011	Percentage change 2001-2011
Rice	1,98	3.56	79.79
Maize	1.15	1.71	48,69
Millet	0.84	1,83	117,85
Yam	11.26	18.58	65.00
Cassava	9.01	12.2	35.40
Sweet Potato	4.28	10.01	133,87
Mellon	0.29	1.00	244.82
Groundnut	1.13	1.47	30.08

Source: Niger State Bureau of Statistics, 2012

(c) Rice Productions over the Years: The 1990s

In terms of rice production profile particularly, so far Niger state stands as a major contributor to rice farming in Nigeria. In the preceding years of 1991-1998, the state saw an increase in production probably connected to the policy introduced in 1985, after the military administration banned rice and maize importation into Nigeria. By 1995, the government of Nigeria imposed a 100% tariff on rice; this impacted the overall volume of production in Niger state's output. Such a scenario seemed to have induced rice farmers in the state to produce more to augment the nation's overall rice yield. During that period, the highest level of rice production in Niger state in 1998 which stood at 600,960 tons grew at 11.52% percentage points. This could be associated also with the introduction of better technology and good weather. Furthermore, rice yield fell in the next year to 532,870 tons by 11.3%; this decline in production persisted till 2002 at 315,190 tons. This represents a severe drop in Niger state's rice yield. Following that, the rice yield once again moved up slowly by 407,200 tons, while the slow surge held steady till 2009 at 532,010 tons on a low pace, it still could not crack the 1997 high production levels.

The drop-off in production in the other years did not operate in a vacuum. It might be attributed to a host of factors such as rice importation, the absence of lines of credit to farmers in the state and post-harvest handling as well as human and natural factors of climatic variability and others. The factors shaping rice farm activities and changes in Niger state do not exist in isolation; they consist of recurrent issues and the inability to handle Post Harvest Losses (PHL). The others include a handful of socio-economic, natural and biophysical elements such as pests, diseases, poor line of credits and climate change stressors. Meanwhile, the state had faced fluctuations in the price of rice seedlings and farm gate prices that are sometimes associated with uncertainty from lack of access to efficient storage and the limited capability in the handling of harvested farm produce. The absence of strong private sectors to harness the vast agricultural potentials in the face of low levels of investment and efficient storage facilities for the harvested rice were so crucial that any iota of drought, diseases, or invasion from rodents in those circumstances spells disaster for those involved; this made post-harvest losses quite a common occurrence to the detriment of rice farmers who were unable to store excess farm produce efficiently under extreme weather conditions, and the importance of PHL as a major constraint in the agricultural policy framework of Niger state can no longer be underestimated. The continued occurrence constitutes a serious challenge to food security and the fulfillment of policy objectives. The dwindling success in reducing PHL in the state and the meager technical capacity to address the issues posed indicated that the changes in rice production in the state over the years are partly attributed to PHL.

The challenges from human activities, global climatic variability and natural forces also impeded efficient and sustainable increases in rice output. As a result, climactic stressors like water strain and flooding already are responsible for extensive rice yield losses across the world and the anticipated rise in these elements due to climate change would further accelerate rice production losses in the years ahead. Previous research showed that humidity and minimum temperature were the climatic factors that affected rice production in the area in which 1% increase in humidity resulted in 17% declines in rice production in the state (Merem, 2017).

3.4.3 Hydrological Modeling and the Sustainable Development of the Hadejia-Nguru Wetlands, Nigeria.

Thompson and Hollis (1995) also performed Hydrological modeling and the sustainable development of the Hadejia-Nguru Wetlands in Nigeria. The study noted that the Hadejia-Nguru Wetlands produce agricultural, fishing and fuel wood benefits of up to 1,277 Nairahr-1 (Nl = US$22, October 1994), over five times the productivity of formal irrigation schemes. The wetlands play a vital role in aquifer recharge. The key is the annual wet season flooding of over 2000 km^2 in the 1960s and around 1500 km^2 in the 1970s. A water balance model, utilizing monthly hydrological and meteorological data simulates flood extent and groundwater storage within the wetlands. The model was operated between 1964 and 1987 and were calibrated using observed flood extents ranging from 50 to 3265 km^2. Subsequently elements were added for dams and irrigation schemes. Results indicate that full implementation of all the schemes constructed or planned would cause flooding to be less than 375 km^2 for 60 % of the time and groundwater storage to fall by over 5500 106 m^3.

It is possible to define an operating regime for the basin's hydraulic structures which could provide artificial floods and enable a distribution of water between formal irrigation, small scale irrigators, the wetlands and downstream users. This regime would provide assured flooding, of around 1000 km^2 each year, and a reduced loss of groundwater storage. Such a sustainable development scheme could offset decades of piecemeal development and bring a philosophy which emphasizes water use throughout the basin not just in irrigation in the upper reaches. The Hadejia-Nguru Wetlands are located in semiarid northeastern Nigeria, around and upstream of the confluence of the region's two principal rivers, the Hadejia and the Jama'are (Figure 3.38).

Nguru's mean annual rainfall for the period 1942-1990 was 487 mm. The climate of the region is dominated by the annual migration of the Inter-Tropical Convergence Zone which reaches its most northerly position above Nigeria in July or August and whose influence produces the distinct wet and dry season characteristics of Sub-Saharan West Africa (NEAZDP, 1990). Consequently, the region's rivers exhibit ephemeral flow patterns (Umar, 1985) with periods of no flow in the dry season (October to April) and a marked concentration of runoff in the wet season with almost 80% of the total annual runoff in August and September.

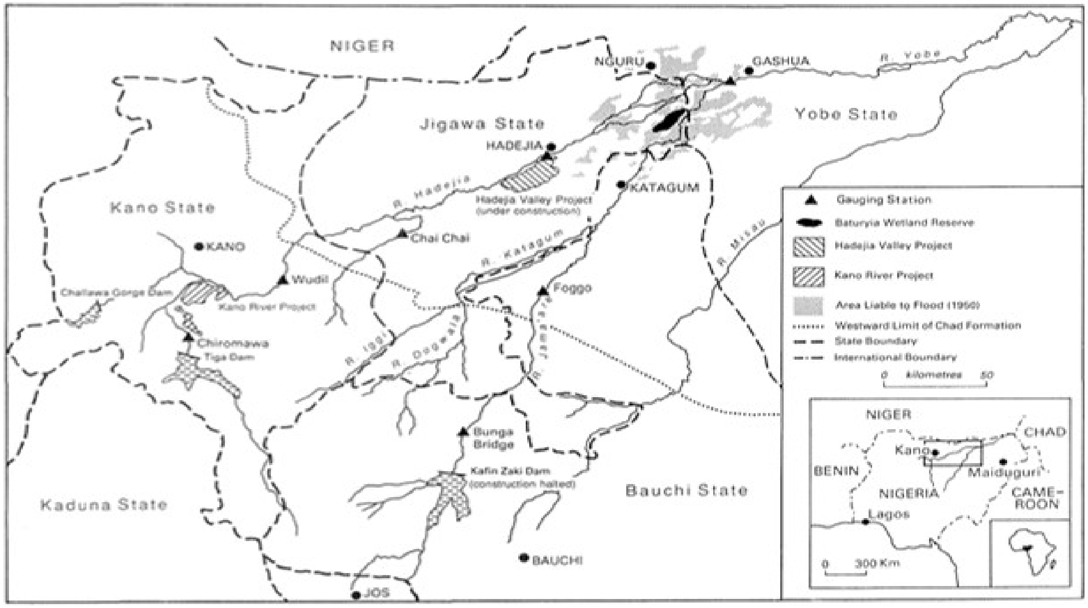


Figure 3.38: TheHadejia-Jama'are Basin

It is during these periods of high river flow that the Fadama (Hausa word for land which is seasonally waterlogged or flooded) of the lower part of the Hadejia-Jama'arebasin flood. It is this flooding which imparts the many valuable functions and values to the wetlands. According to Adams (1994), the Hadejia-Nguru wetlands have for centuries played a vital role in the regional economy, being one of the most productive areas of northeastern Nigeria. They can be likened to the Sokoto flood plain of northwest Nigeria of which Adams (1986) stated "the flood plain and the floodwater ... represent important ecological and economic resources for the development of the region".

Analysis of the wetland economy undertaken by Barbier*et al.* (1991) revealed that the present value of the agricultural, fishing and fuel wood benefits provided by the wetlands is between 849 and 1277 Naira per hectare. Table 3.16 provides a "breakdown" of these benefits and shows that they are substantially greater per hectare than those deriving from the Kano River Irrigation Project, a formal irrigation scheme on the Kano River, a tributary of the Hadejia. Besides the quantifiable agricultural, fishing and fuel wood benefits, the wetlands possess values less readily evaluated on an economic basis: dry season grazing for livestock from the surrounding Sahelian

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pastures; non-timber forest products; groundwater recharge; refuge for human populations during times of drought; and habitat for both Afro-tropical and Palaearctic birds. Arguably the most important of these functions is the recharge of the shallow and deeper aquifers of the Chad Formation which is facilitated by the wet season flooding of the fadama (Schultz, 1976; Diyam, 1987). These aquifers are extensively utilized for domestic and agricultural purposes by large human populations both within the flood plain and beyond. However, the maintenance of the many values possessed by the floodplain wetlands of the Hadejia-Jama'are basin is threatened by the combined influence of drought and the uncoordinated development of the basin's scarce water resources. Grove & Adams (1988) stated that the succession of drought years experienced throughout Sub-Saharan West Africa in the last two decades has led to a marked reduction in the discharge of the region's rivers.

Table 3.16: Present value of benefits from the wetland and Kano River Irrigation Project (after Barbier*et al,* 1991) (NI = US$22, October 1994)

Wetland Value	Present value of Wetland benefits (Naira/ha)[1]	
	Lower Estimate	Higher Estimate
Agriculture	558	838
Fishing	197	300
Fuelwood	91	139
Total	849	1277
Kano River Irrigation Project[2]	153	233

[1] Averaged over die total production area of 730,000 ha (230,000 ha for cropland, 100,000 ha for fishing and 400,000 ha for fuelwood). Based on the 1985/1986 cultivated area of 19,107 ha and allowing for project operating costs which have ranged from 7.7% to 37% of the total value of crop production.

Reduced flow within the Hadejia and Jama'are has diminished the area of wet season inundation within the wetlands (Hollis *et al.,* 1994; Hollis & Thompson, 1994a). In the wet seasons of 1969 and 1974, 2350 km^2 and 2004 km^{2}respectivelyof the flood plains were inundated (Schultz, 1976). More recently, aerial surveys undertaken by the Hadejia-Nguru Wetland Conservation Project have revealed that in the 1991 wet season, flood extent was 962 km^2 (Morgan,1994)

(a) The Model

A water balance model, initially developed by Adams & Hollis (1988), was refined using a monthly hydrological and meteorological data matrix for the period January 1964 to November 1987. The most extensively used sources of data were Diyam (1986) and Umar (1985). Additional data were obtained from Yearbooks and manuscript records of stage and rating curves obtained from the Water Resources, Engineering and Construction Agency (WRECA). The model was programmed using Quattro Pro spreadsheet software and was set up to run as a menu driven system (Thompson, 1993). Following the approach of Schultz (1976) and Sutcliffe and Parks (1987), the model calculates, on a monthly basis, the volume of water entering the

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wetlands via Wudil, Chai Chai, Bunga Bridge and some smaller tributaries but not leaving via Gashua. The water retained within the wetlands is supplemented by local rainfall and runoff in the wet season and depleted by evaporation, soil moisture recharge and infiltration to groundwater. The resulting volume is converted into an area of inundation by means of synthetic volume/area relationship, a methodology also adopted by Sutcliffe and Parks (1987, 1989) in a number of other African wetlands (Figure 3.39). Such a relationship was required due to the absence of any elevation data on the maps of the area.

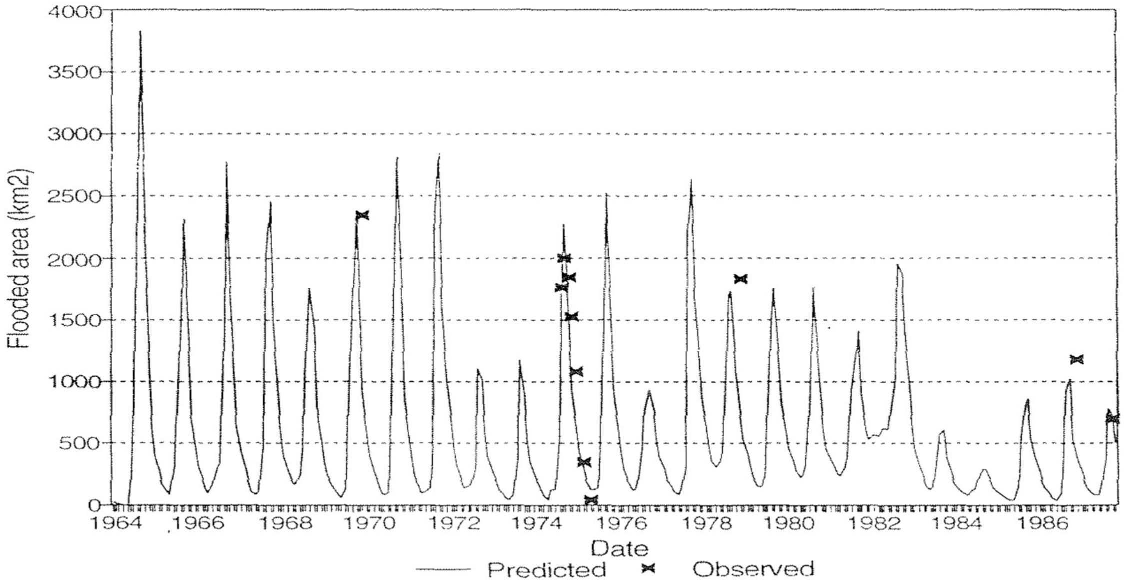

Figure 3.39: Flooding under natural conditions

The hydrological simulation of the Hadejia-Jama'are basin indicates that the full implementation of all the planned water resource developments will have severe consequences for the basin's flood plain wetlands and areas further downstream. Formal irrigation will consume large quantities of water originally destined for these wetlands. Reduced river flow will lead to a decline in the area of wet season inundation and will dramatically reduce the productivity of an area which is currently one of the most productive in northern Nigeria. The reduced productivity from the flood plain will not be replaced by yields from formal irrigation since the water resources of the basin will be unable to support the envisaged extent of these schemes. It is argued that the most appropriate use of the basin's water resources is the sustainable utilization of the flood plain wetlands rather than the expansion of formal irrigation. This will require the operation of existing irrigation schemes and their associated reservoirs in a way that will facilitate the distribution of water between formal irrigation and the water users within the flood plain and downstream.

3.4.4 Prediction of the Streamflow in Hadejia-Jama'are-Komadugu-Yobe river basin, North Eastern Nigeria, using SWAT model

Prediction of the Streamflow of Hadejia-Jama'are-Komadugu-Yobe river basin, North Eastern Nigeria, using SWAT model was conducted by Ejieji, et al, (2016).The study summarized that the Hadejia-Jama'are-Komadugu-Yobe river basin (HJKYRB) is one of the major river basins the water resources of which are vital to sustenance of the livelihood of the growing population in Northern Nigeria. It is however among those of which the proper management of the scarce resources among competing demands is of growing concern. The SWAT model which could potentially be useful as a decision support tool was therefore evaluated for applicability in the basin. Thirty years (1971 to 2000) of daily meteorological data were used for the model sensitivity analysis. The model was calibrated and validated using in each case 12 years of observed streamflow data from a gauging station. The periods covered by the calibration and validation data were 1974 to 1965 and 1989 to 2000 respectively. The sensitivity analysis identified 17 model parameters as important with Moisture Condition II Curve Number (CN_2) as the most sensitive. The coefficient of determination (R^2) and Nosch-Sutcliff Efficiency (NSE) obtained during calibration were 0.57 and 0.51 respectively. For the validation, R^2 was 0.71 while NSE was 0.65. The values of R^2 and NSE obtained were within the acceptable range. It was concluded therefore that the SWAT model could be useful as a decision support tool for water resources management policies in the basin.

The Soil Water Assessment Tool (SWAT) is an example of such model (Srinivasan and Arnold, 1994; Neitsch *et al*., 2011). The SWAT model is a continuous-time, semi-distributed, physically-based model which can predict the effects of alternative management decisions on water resources and nonpoint source pollution in large river basins (Arnold *et al*., 2012). The major components include those simulating weather, hydrology, soil erosion, sediment yield, vegetation and crop; nutrient and pesticide cycles; land management and, channel and reservoir routing. It divides a basin into sub-basins and Hydrologic Response Units (HRU). The HRUs are defined as lumped areas having unique land cover, soil and management combinations within the sub-basin. It has-been reported to have a substantial reputation as a model to quantify the impact of land management practices in large, complex watersheds and to have been used in many developing countries and the United States of America (George and Leon, 2008).

A review of its development history and applications has-been provided by Saleh *et al.* (2009) while George and Leon (2008) described the Water Base Project of United Nations University, Macao, China which provided an open source Geographic Information System (GIS) support and a setup interface for SWAT resulting in the tool known as Map Window SWAT (MWSWAT). Data sources and procedures for using MWSWAT were also discussed by George and Leon (2008). SWAT is however being continuously improved and updated with better features and capabilities (Arnold *et al*., 2012). The applicability of the SWAT model to HJKYB however needs to be ascertained. Furthermore, on account of their limitations in the representation of

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complex natural processes, models such as SWAT require calibration before application. The aim of this study therefore was therefore the evaluation of the prediction of surface runoff by SWAT in HJKYB. The specific objectives were to determine the relative sensitivities of the model parameters important to runoff, calibrate the model for the basin, and compare the predicted runoff with observed historical data.

Hadejia-Jama’are-Komadugu-YobeBasin (HJKYB) is located in the north eastern part of Nigeria and covers the whole of Jigawa and Kano and States. Parts of Bauchi, and Plateau and Yobe States also fall within the basin. It is bounded between latitude 10.036ºN and12.976ºN and longitude 7.3360ºE and11.6310ºE. It is about 54, 920 km^2 in area with a perimeter of 1,437 km. The highest point in the basin is about 1570m, while the lowest is 325m above sea level. About 54, 105 km2 representing 98.52% of the total area has it slopes within 0 to10%, only about 814 km^2 representing about 1.48% of the total area has slope above 10%. The area covered by this study is dendritically drained by two major rivers namely the Hadejia and the Jama’are Rivers and their tributaries (Figure 3.40). Both Rivers have the Jos plateau in Plateau State as their source and flow in the northeast direction, eventually meeting in an extensive floodplain called Hadejia-Nguru Wetlands, west of Gashua town. The two rivers with the Yobe River after their confluence with the latter are collectively known as the Komadugu-YobeRiver which eventually empty into Lake Chad.

The required input data include the Digital Elevation Model (DEM), land use and land cover map, soil map and meteorological data. The Map Window GIS (Leon, 2014) interface of the MWSWAT was used to discretize the catchment area and extract the SWAT input files. The topography data used were that at 90mresolution extracted from the Shuttle Radar Topography Mission (SRTM) version 4 (The Consortium for Spatial Information, CGIAR-CSI, 2012). The final DEM obtained for the basin was used for delineation and for obtaining topographical parameters such as overland slope, stream network and slope length for each sub basin. The basin was delineated into 139 sub basins with Automatic Watershed Delineation (AWD) tool of the GIS interface using a threshold sub basin size of 200 km^2. The sub-basins were further divided into 289 HRUs. Land use and land cover map of the Global Land Cover Characterization, GLCC, database (United States Geological Survey, 2012) was used to estimate vegetation and other parameters representing the watershed area.

The GLCC database has a spatial resolution of1km and 24 classes of land use representation (Loveland *et al*., 2000).Digital soil data were extracted from the Food and Agriculture Organization’s harmonized digital soil map of the world (HWSD) version 1.1. (Nachtergaele, *et al*, 2009). The database provides data for 16, 000 different soil mapping units for two soil layers 0 - 30 cm and 30 - 100 cm depth. Soil data extracted from the database were supplemented with additional information gathered from the soil report and map of Federal Department of Agricultural Land Resources (FDALR), (FDALR, 1990).

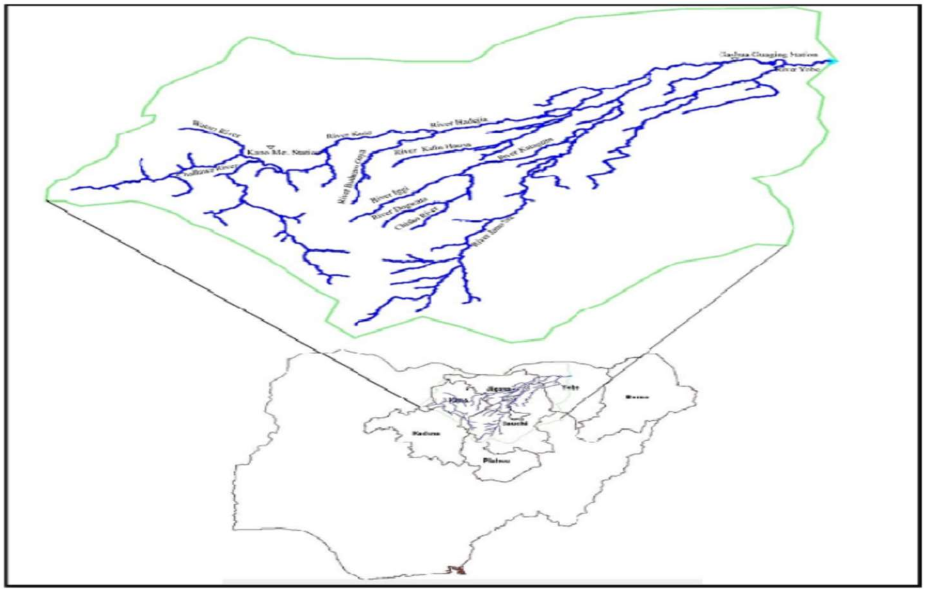


Figure 3.40: Map of Hadejia-Jama'are-Komadugu-Yobe Basin (The states covered by the basin and the adjoining states are indicated)

The weather data used were from Nigeria Metrological Agency, Kano State meteorological station for the period 1971 to 2000, which comprised of daily rainfall, maximum and minimum temperatures. Run off data in terms of stream discharges were obtained from Nigerian Hydrological Services Agency for the Gashua gaugingstation for the period's 1974 to 1985 and1989 to 2000 and employed in the model calibration and validation.

The SCS curve number procedure (SCS, 1972; cited by Neitsch, *et al*., 2011) was employed in surface runoff estimation while the variable storage method (William, 1969; cited by Neitsch,*et al*., 2011) was used for flow routing. The Hargreaves method was used for estimating potential evapotranspiration. Preparation of necessary input files and execution of the necessary steps in running the model were as outlined in Leon (2014) and Arnold *et al*. (2011). The model sensitivity analysis was performed using 30 years (1971 to 2000) daily meteorological data. The MWSWAT interface which combines the Latin Hypercube (LH) and One-factor-At-a-Time (OAT) sampling (van Griensven *et al*., 2006) was employed considering 42 parameters and 10 loops of simulations. This resulted in 430 simulation runs that included one baseline simulation per loop. Calibration was performed using the auto calibration tool in MWSWAT and observed discharge data for the period 1974 to 1985 while those for 1989 to 2000 were used in the model validation. The indices used for the evaluation of the model calibration and validation results were coefficient of determination (R^2) and Nash-Sutcliffe efficiency (Nash and Sutcliffe, 1970).

(a) Weather, Relief and Land Cover

The rainfall and temperature records (Table 3.17) for the period covered by the model calibration and validation showed that rainy period from April to October was the hotter part of the year with the most significant rainfalls occurring from June to September. The DEM obtained for HJKYB and the delineated 139 sub-basins are shown in Figures 3.41 and 3.42 respectively. Savannah and Cropland wood mosaic categories dominate the land cover of the watershed constituting, respectively 32203.74 km^2 or 58.64% and 21262.99 km^2 or 38.72 % of the total watershed area.

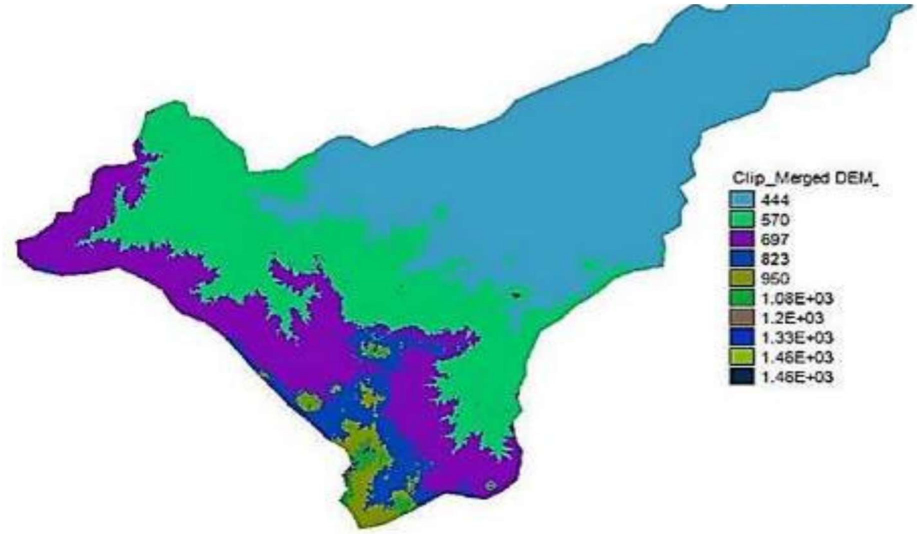


Figure 3.41: Digital Elevation Model of Hadejia-Jama'are-Komadugu-Yobe Basin (Elevations are in meters a.m.s.l.)

Table 3.17: Average daily air temperatures and monthly rainfalls for the period (1974 – 2000) of the model calibration and validation

Month	Daily Temperature (^{o}C)		Rainfall
	Maximum	Minimum	(mm/month)
January	29.0	14.2	0.0
February	32.2	16.7	0.4
March	36.1	20.8	0.9
April	39.0	24.1	10.9
May	38.0	24.7	51.4
June	34.9	23.3	112.2
July	31.4	21.6	223.0
August	30.6	21.2	294.4
September	33.3	21.6	133.0
October	34.8	20.9	15.1
November	33.0	17.4	0.0
December	29.6	14.9	0.0

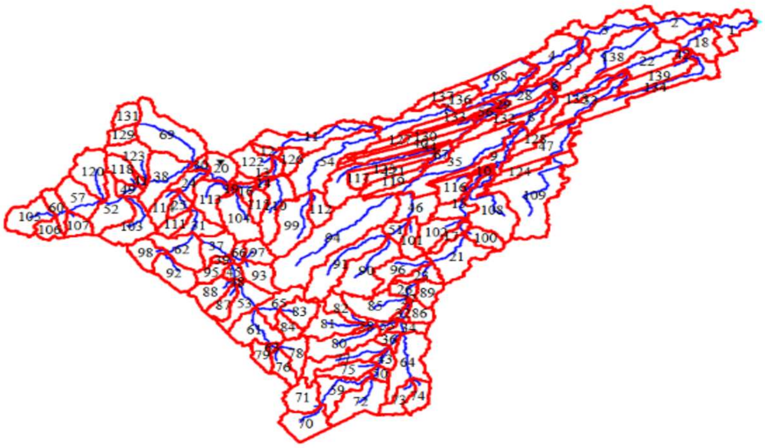


Figure 3.42: Delineation of the Study Area into Sub-basins

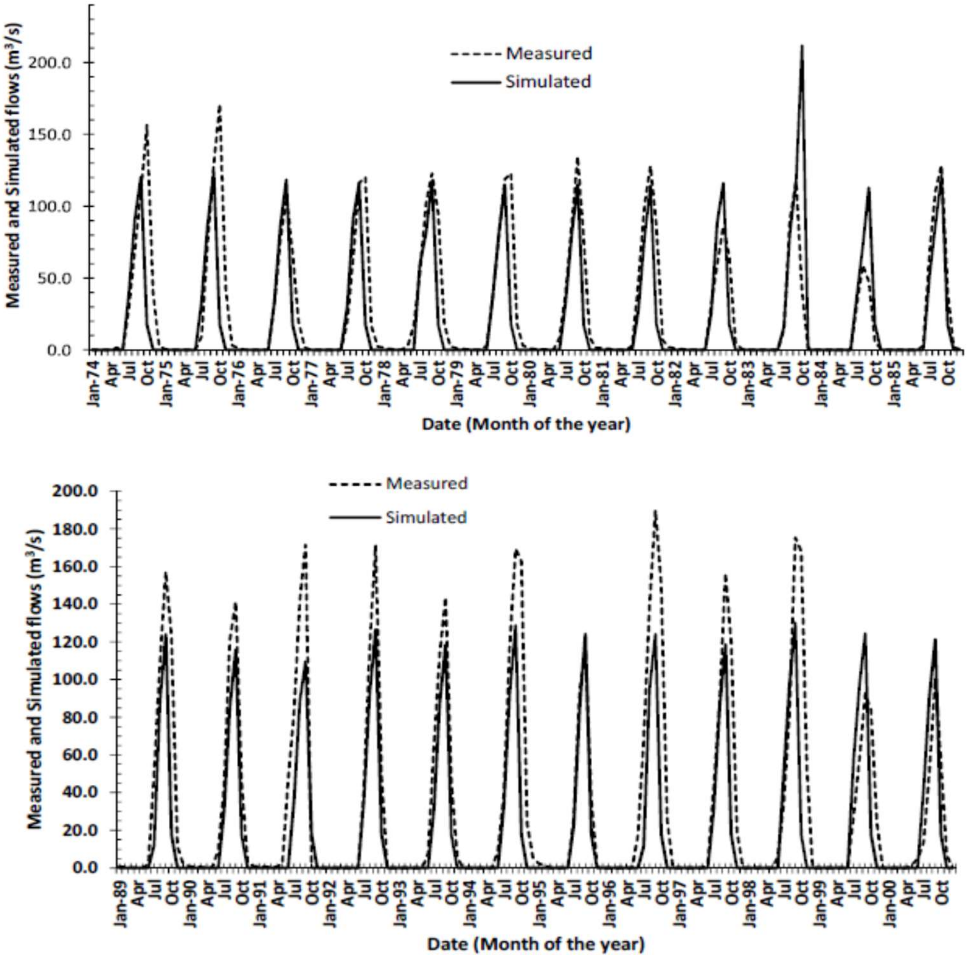


Figure 3.43: Measured average daily flows at Gashua and simulated flows

Based on the calibration and validation results the SWAT Model performed well in the simulation of runoff stream flow from the Hadejia-Jama'are-Komadugu-Yobe-River Basin (Figure 3.43). The R^2 and NSE obtained suggest that SWAT could be useful as a decision support tool for water resources management policies in the basin. The most sensitive of the 17 important model parameters determined during calibration was CN2 which relates to land cover and land use.

3.5 Issues of Climate Extremes: NIHSA Flood Outlook

The extremity of climate thus results into either high dryness or flooding on the earth. Floods especially have been occurring in most places in the world and in Nigeria in particular until it reached the high end in the year 2012, which caused so much devastation in the country and had become a hallmark of/baseline for floods in Nigeria. Since then, many places have been experiencing flooding cases. Hydrological hazards (floods, droughts, windstorms and mudslides) accounted for more than 55% of all the natural hazards in the world today. In Nigeria, flood and drought constitutes the major natural disaster that is plaguing the country. Drought and desertification are encroaching on arable lands in the northern Nigeria

Hence, the Annual Flood Outlook (AFO) of the Nigeria Hydrological Services (NIHSA) was established and started publication in 2013 with the aim to create awareness on flood events and to proffer some mitigation measures to flood occurrences. Therefore, the Publication has for intension to provide the necessary information to the public, especially those living in flood prone areas of Nigeria and to sensitize them in taking proactive measures that would ensure timely and adequate preparedness towards any probable flood event. The AFO said that in order to combat the menace of flood, accurate estimates of flood frequency and magnitude remains the key components of any effective nationwide flood risk management and flood mitigation program (AFO, 2018). It also maintained that climate change has been causing an exponential increase in flood risks, which has been as a result of increasing rainfall frequency, changes in land use and land cover pattern, continuous increase in population and assets in flood prone areas in Nigeria.

In order to fulfill the annual flood prediction, models were employed, which included the Geospatial Streamflow Model (GeoSFM) and the Soil and Water Assessment Tool (SWAT). These models make use of hydrological and hydrogeological data sets, Seasonal Rainfall Prediction (SRP), satellite rainfall data, Digital Elevation Model (DEM), topographical and soil and water index balance data. The annual prediction of floods and their extent serves as a useful decision support tools and provides an indication of areas likely to experience flood within Nigeria.

3.5.1 *The Evaluation of Year 2018 AFO*

The GeoSFM and the SWAT models were applied by the Nigeria Hydrological Services Agency (NIHSA) to the eight Hydrological Areas (Has) of Nigeria (NIHSA, 2018) (Figure 3.44) to predict occurrences of floods in form of hydrographs that were converted to a real extent of flood and intensity over the drainage networks. They were also applied to the analysis of river flows.

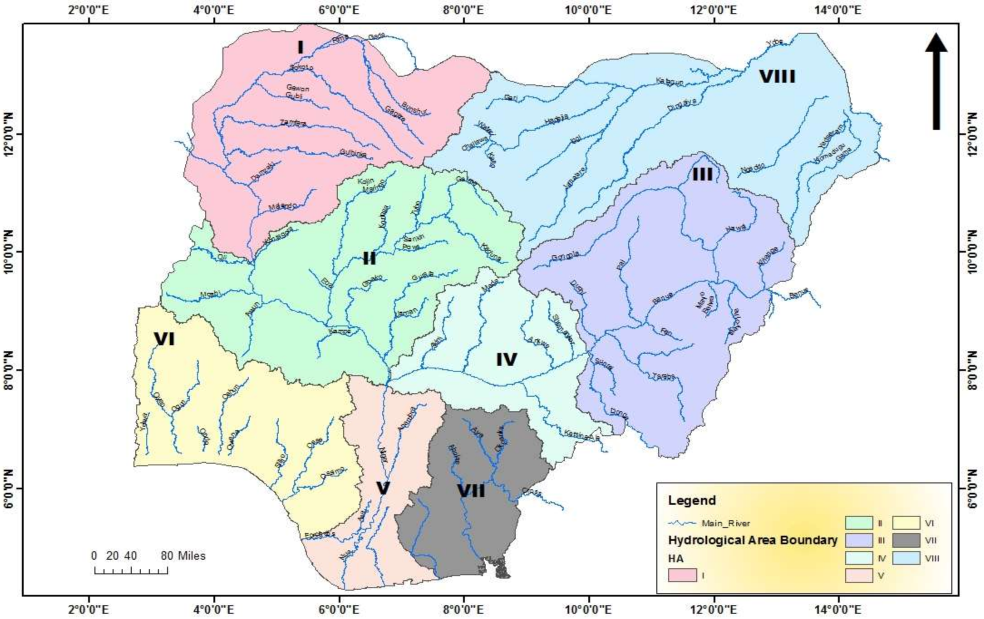


Figure 3.44: The Eight hydrological areas of Nigeria

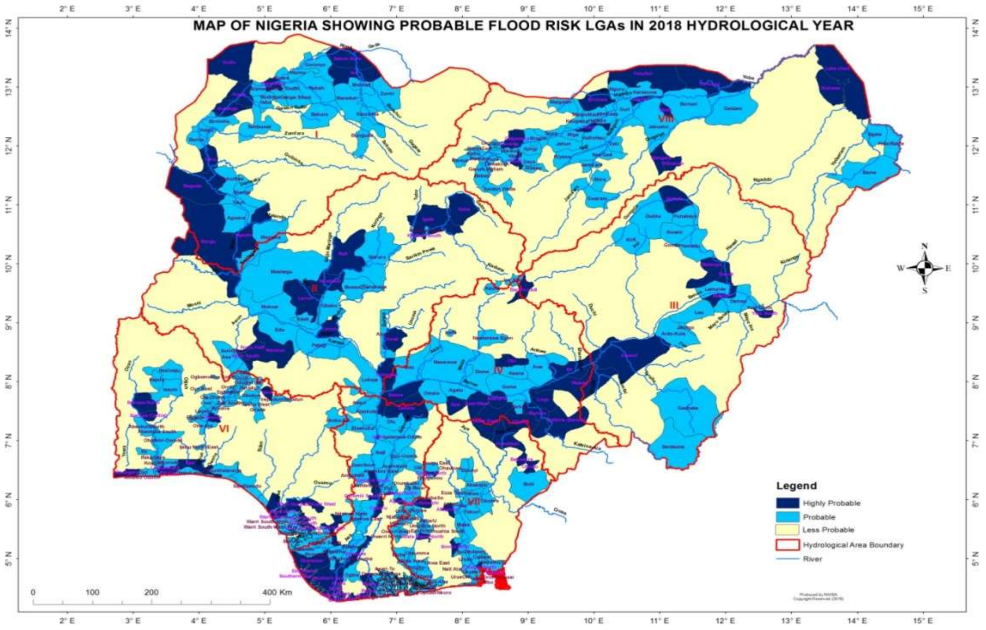


Figure 3.45: Map of flood risk areas of Nigeria in 2018

The forecast was classified into three main categories: Highly Probable, Probable and less Probable flood risk areas. Sub-basins of the country in each of the HAs that would be vulnerable to flood risks in 2018 were listed to include Niger, Benue, Sokoto-Rima, Anambra-Imo, Niger Delta, Ogun-Osun, Cross River, Komadougou-Yobe and other sub-basins in the country (Figure 3.45). The data used for the forecast included daily river flow, seasonal rainfall prediction, daily, monthly and yearly rainfall, satellite daily rainfall, daily potential evapotranspiration and the soil characteristics data. The Figures 3.46 - 3.49 are few of the simulated hydrographsat selected gauging stations. The peak flood for 2018 was expected to be significantly lower than the previous year. The resultant effects of these flooding are known usually in the havoc caused to lives and properties. In Nigeria alone, flood had affected more than 11 million lives by death, displacement, properties damaged and outbreak of diseased. Flooding has also been largely attributed to climate change, high rainfall, hydraulic structure failure and poor urban planning and management.

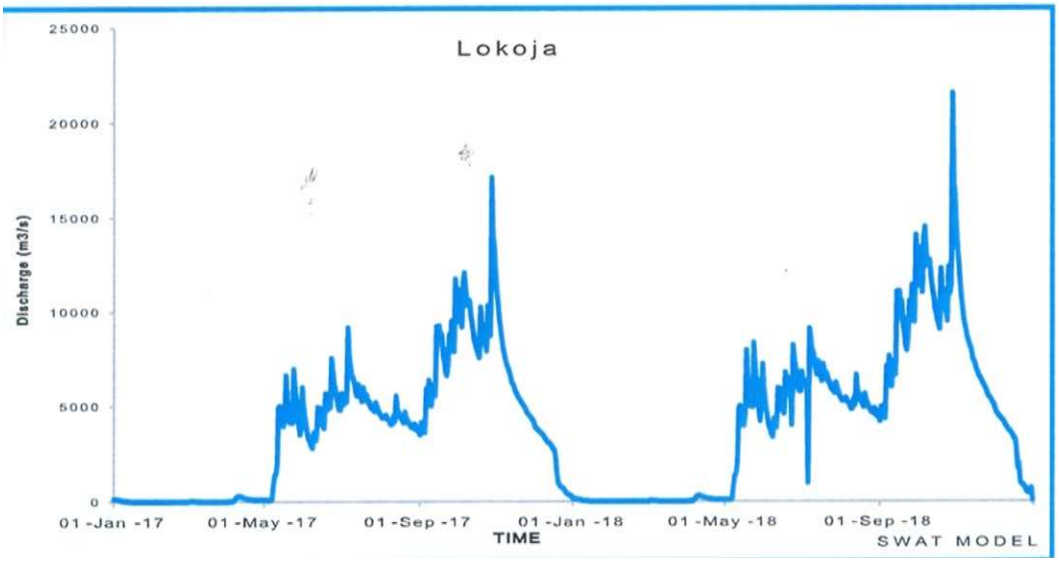


Figure 3.46: Simulation flow at Lokoja, River Niger

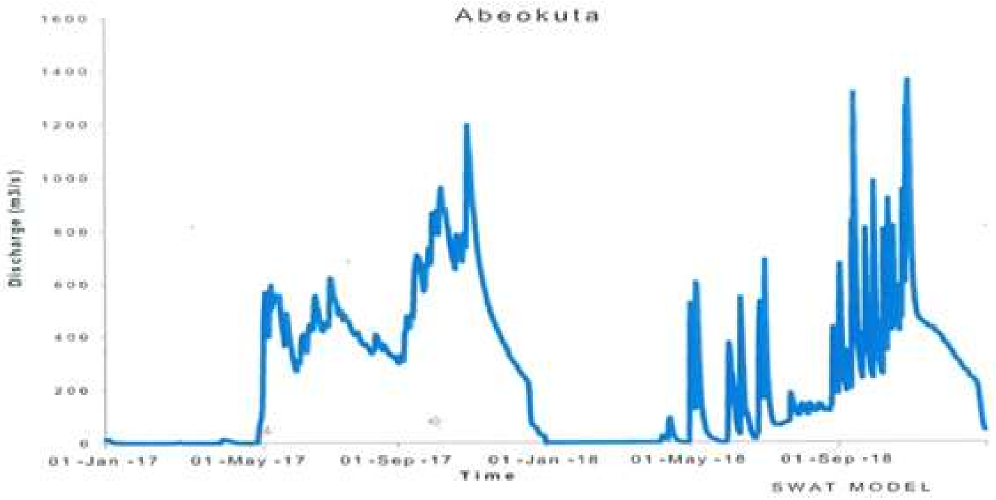


Figure 3.47: Simulation flow at Abeokuta, Ogun River

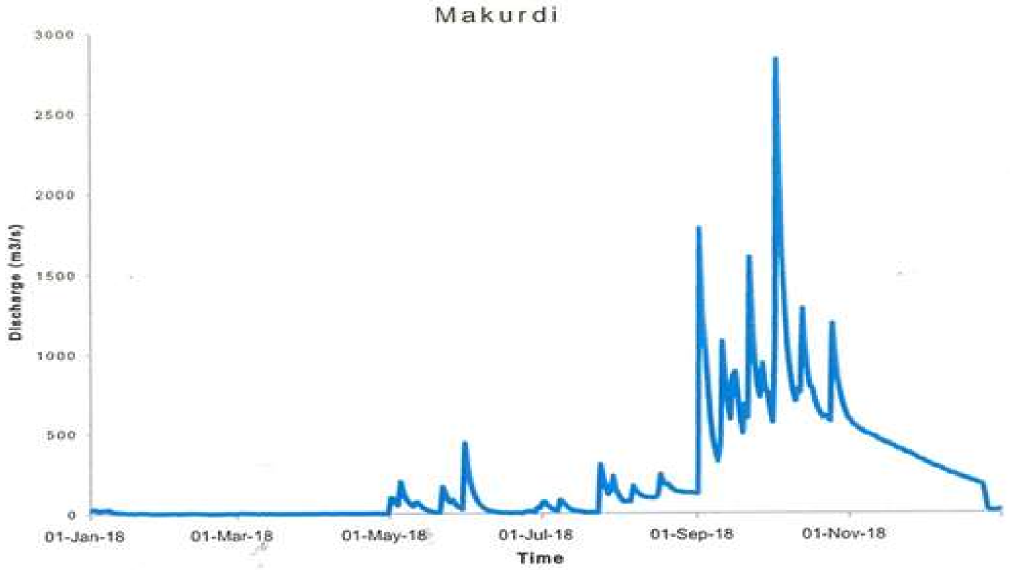


Figure 3.48: Simulation flow at Makurdi, River Benue

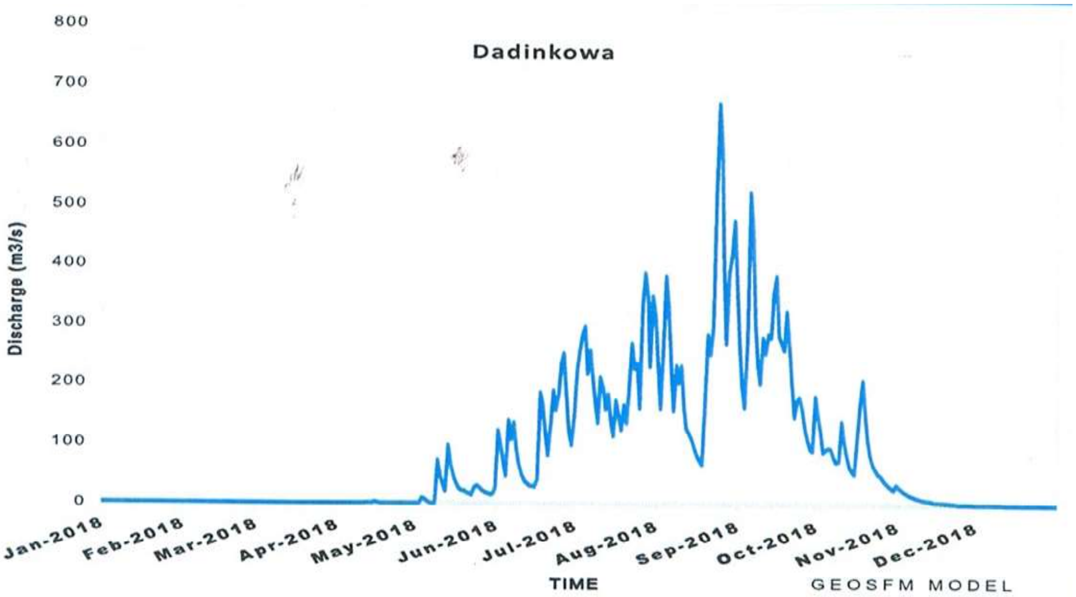


Figure 3.49: Simulation flow at Dadinkowa onGongola River

3.5.2 Water Level and Flood Frequency Analysis over Bakolori and Zobe DamReservoirs

A feasibility report presented by the Federal Ministry of Water Resources (FMWR, 2013) on the Transforming Irrigation Management in Nigeria (TRIMING) Project for the Bakolori Irrigation Project and other interventions in the Sokoto Rima Basin was explicit on the development of surface irrigation at Bakolori and other components covered by the Feasibility Study, which formed part of the Programme. TRIMING covers the irrigation projects shown in Table 3.18 with components and sub-components.

Table 3.18: Irrigation Projects under TRIMING

Basin (hydrological area)	Sub-basin	Intervention Sites
Sokoto-Rima	Sokoto	Bakolori Irrigation Scheme
	Rima	Middle Rima Irrigation Valley Scheme
Hadejia-Jama'are Komadougou Yobe	Hadejia Jama'are	Kano River Irrigation Scheme
		Hadejia Valley Irrigation Scheme
Upper Benue	Gongola	Dadin Kowa Irrigation Scheme

(a) Bakolori Dam

The daily reservoir water level information for 25 years (Figure 3.50) was acquired and transferred to an Excel workbook. A frequency analysis of the annual maximum water levels was carried out and the data were fitted to a generalized logistic distribution as shown in Table 3.19.

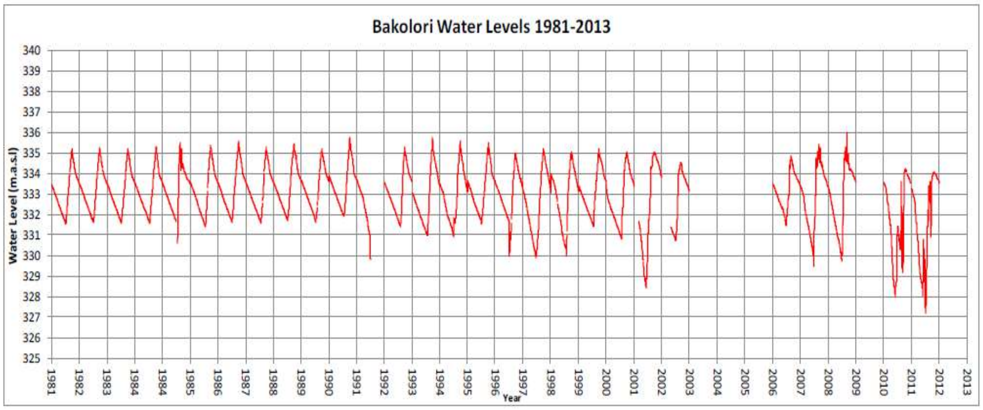


Figure 3.50: Bakolori daily water levels 1981-2013

Table 3.19: Bakolori dam maximum water level frequency analysis

Return Period	Height Above 334m (Free Discharge Spillway Level) (m)	Water Level (m AD)
2	1.4	335.34
5	1.63	335.63
10	1.77	335.77
25	1.93	335.93
50	2.02	336.02
100	2.11	336.11
200	2.19	336.19
500	2.28	336.28
1000	2.34	336.34
5000	2.46	336.46

The predicted 100 year and 1,000 year water levels shown in Table 3.19 were 336.11m and 336.34m respectively. These levels were significantly lower than those estimated by routing the 100 year and 1,000 year floods through the reservoir. The operation of the radial gate was likely to have influenced the water levels and thus the comparison of the water levels from the two sources might not be meaningful.

The flood magnitudes and return periods were estimated. The results are summarized in Table 3.20, which includes the coefficients from the Creager and Francou-Rodier empirical methods of estimating extreme floods.

Table 3.20: Bakolori - Summary of Feasibility Stage Flood Estimates

Return Period (years)	Peak Inflow (m3/s)	Creager C value	Francou-Rodier K value
100	4,577	32	4.6
1,000	6,922	49	5.0
10,000	9,297	66	5.3
PMF (1.5x10,000)	13,946	99	5.7
PMF (2x10,000)	18,594	132	6.0

Note: Catchment area 4,466km^2.

The PMF was estimated as a multiple of 10,000 year event. The PMF estimates were compared with estimates from the empirical methods of Creager (1947) and Francou - Rodier (1967). Values of the Creager coefficient, C, and Francou – Rodier coefficient, K, corresponding to the above flows are summarized and shown in Figure 3.51 and Figure 3.52.

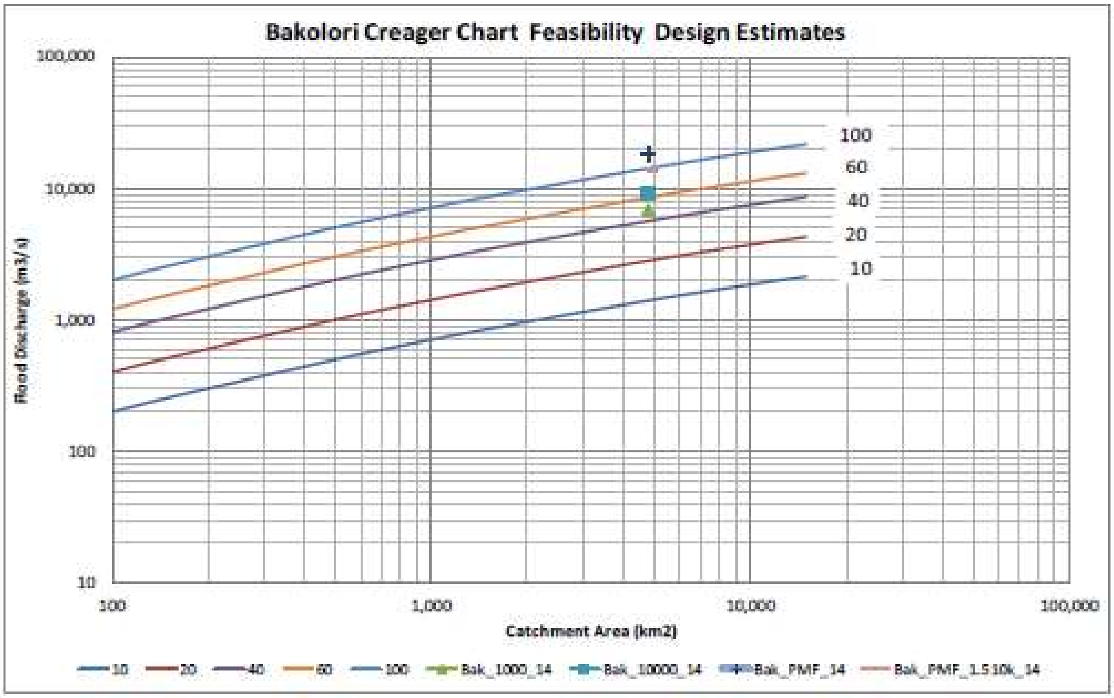


Figure 3. 51: Bakolori Creager chart

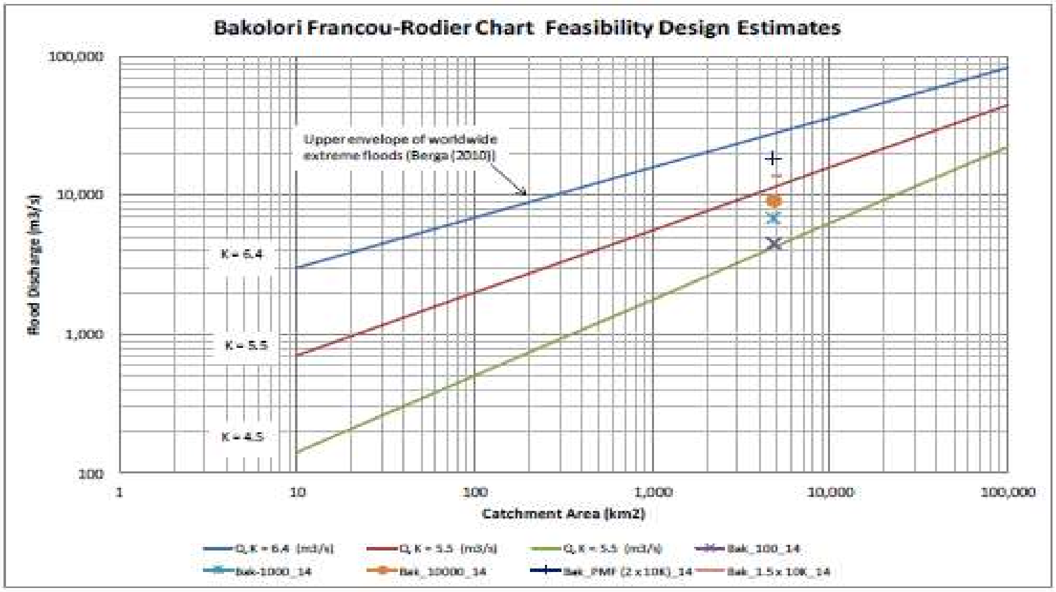


Figure 3.52: Francou-Rodier chart for Bakolori Dam to estimâtes feasibility design

Figure 3.51 shows that the Creager coefficient for the PMF = 2 x 10,000 year plots above the C = 100line which is a guide to the upper limit of extreme floods that could occur. Figure 3.52 shows that the Francou-Rodier coefficient for this flood was K = 6.0 and is close to the worldwide envelope (based on floods mostly in Asia and the USA). The empirical coefficients suggested that a PMF = 2 x 10,000 was on the high side and that it would be reasonable to adopt PMF = 1.5 x 10,000 year as the Safety Check Flood. The empirical coefficients corresponding to the smaller PMF were C = 99 and K = 5.7 and were considered appropriate for Bakolori Dam.

The flood routing was carried out with a baseline run in which all the outlet structures and radial gate were operational. The results are as shown in Table 3.21.

Table 3.21: Bakolori – Flood Routing with Outlet Structures Operating

Return Period (years)	Peak Inflow (m^3/s)	Peak Outflow (m^3/s)	Peak Flood Level (m)	Flood Rise (m)	Flood Freeboard available – 341.2 (m)* (main crest)	Flood Freeboard available – 340.0 (m)* (Bridge over Spillway)*
100	4,577	1,194	338.01	4.01	3.19	1.99
1,000	6,922	1,987	339.61	5.63	1.57	0.39
10,000	9,297	3,505	341.08	7.08	0.12	-1.08
PMF (1.5 x 10,000)	13,946	10,342	341.92	7.93	-0.72	-1.92

Table 3.21 shows that for the Design Flood (1:10,000) the bridge over the spillway would be overtopped and water would escape around the ends of the dam. Moreover, there is also inadequate freeboard to the embankment crest and the downstream slope would be vulnerable to damage from waves slopping over the crest. These results indicate that the spillway facilities need to be improved. The peak flood levels given in Table 3.21 indicate that it would be appropriate to set the invert level of additional spillway facilities at 338.0m, which should ensure that the structures would not come into operation before about the 100 year flood.

(b) Zobe Dam

Complete records for 25 years are as shown in Figure 3.53.

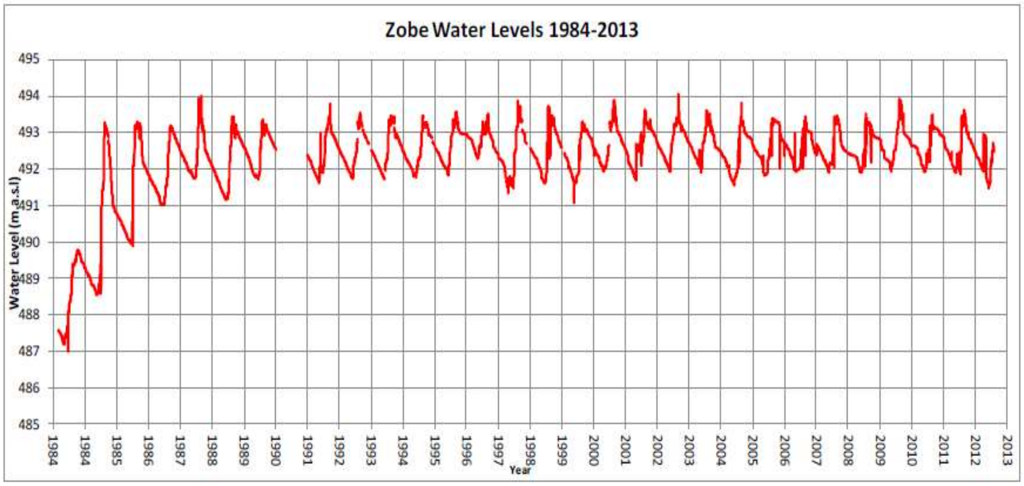


Figure 3.53: Zobe Daily Water Levels

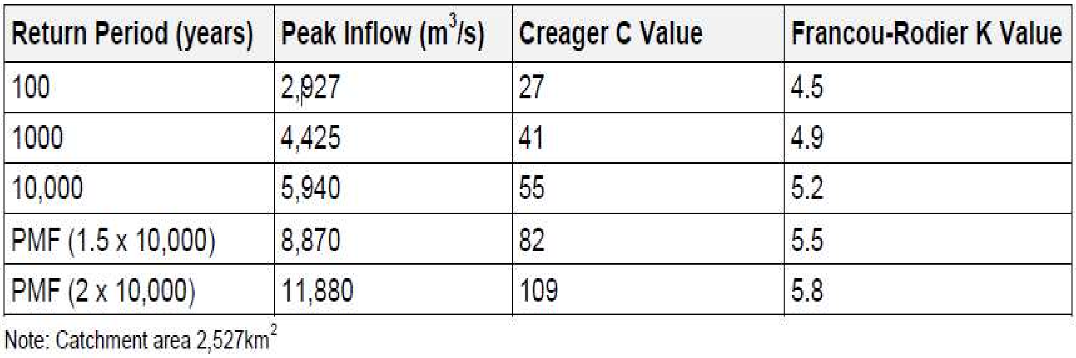
A frequency analysis of the annual maximum water level was carried out. The data appear to fit well into a generalized logistic distribution as shown in Table 3.22.

Table 3.22: Zobe Dam Maximum Water Level Frequency Analysis

Return Period	Height Above 334m (Free Discharge Spillway Level)	Water Level (m AD)
2	1.04	494.04
5	1.44	494.44
10	1.72	494.72
25	2.11	495.11
50	2.44	495.44
100	2.80	495.80
200	3.20	496.20
500	3.81	496.81
1000	4.33	497.33
5000	5.80	498.80

The predicted 100 year water level in Table 3.22 is about 0.39m lower than that predicted from the flood routing. For the 1,000 year water level, the flood routing predicts a water level about 0.07m higher than that shown above. Direct comparison of the water level predictions by the two methods is probably not meaningful as there are many factors that influence the flood estimates. The results of the flood magnitudes and return periods estimation are summarized in Table 3.23 which includes the coefficients from the Creager and Francou-Rodier empirical methods of estimating extreme floods.

Table 3.23: Zobe - Summary of Feasibility Stage Flood Estimates



Return Period (years)	Peak Inflow (m^3/s)	Creager C Value	Francou-Rodier K Value
100	2,927	27	4.5
1000	4,425	41	4.9
10,000	5,940	55	5.2
PMF (1.5 x 10,000)	8,870	82	5.5
PMF (2 x 10,000)	11,880	109	5.8

Note: Catchment area 2,527km^2

The PMF was estimated as a multiple of 10,000 year event. The PMF estimates were compared with estimates from the empirical methods of Creager (1947) and Francou - Rodier (1967). Values of the Creager coefficient, C, and Francou – Rodier coefficient, K, corresponding to the above flows are summarized in Figures 3.54 and 3.55.

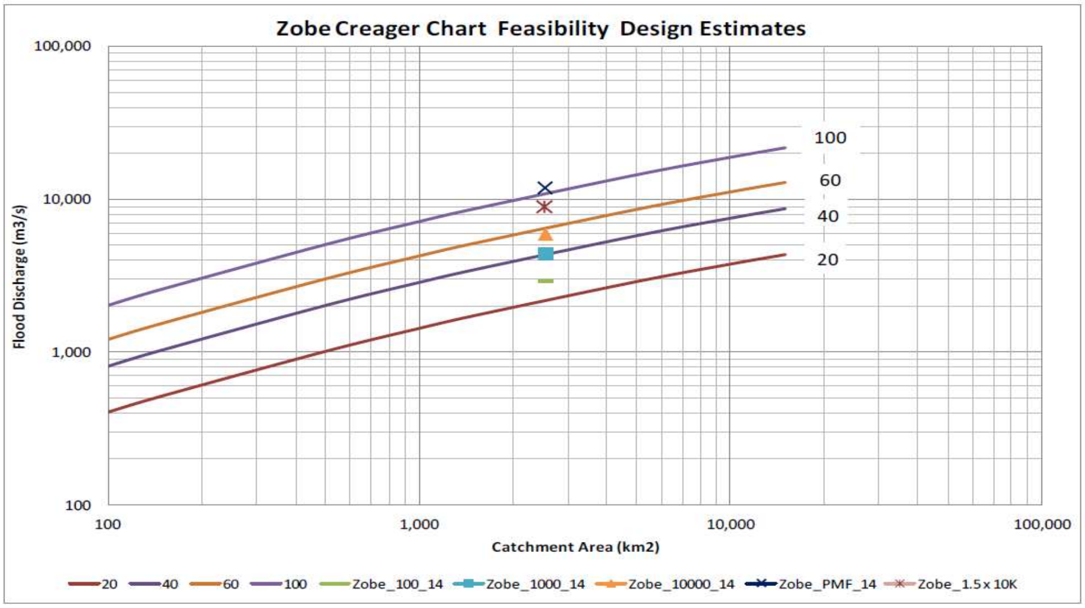


Figure 3.54: Zobe Creager chart design estimates

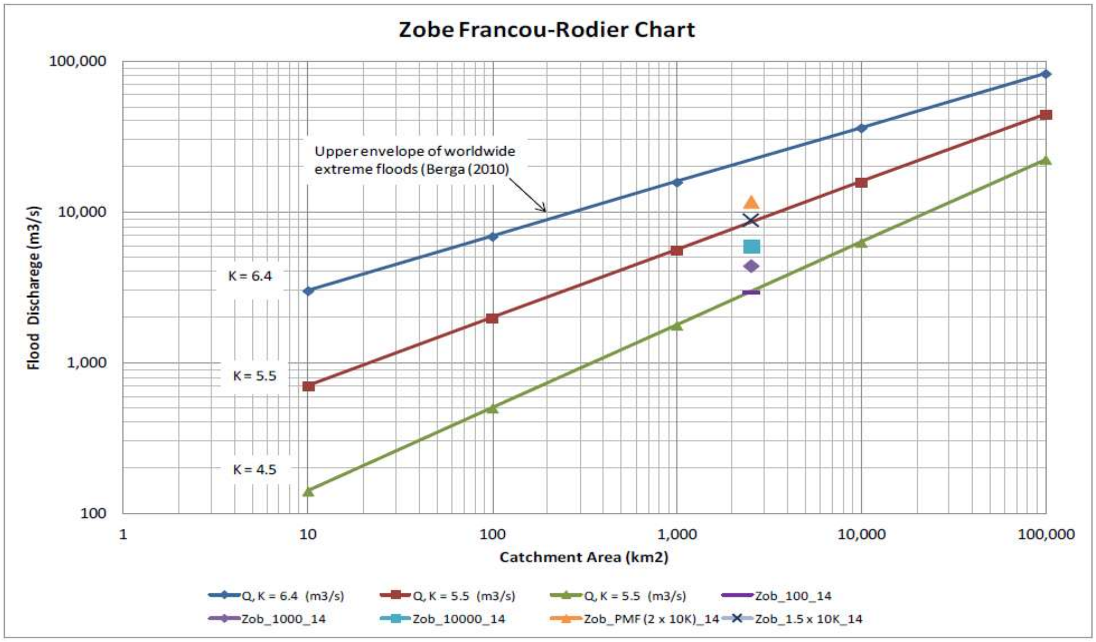


Figure 3.55: Zobe chart design estimâtes (Francou-Rodier)

Figure 3.54 shows that the Creager coefficient for the PMF = 2 x 10,000 year plots above the C = 100 line which was a guide to the upper limit of extreme floods that could occur. Figure 3.55 shows that the Francou-Rodier coefficient for this flood was K = 5.7 which was towards the upper end of extreme floods. It would be expected that the relationship between the 10,000 year flood and the PMF at Bakolori and Zobe would be similar and on this basis, the PMF = 1.5 x 10,000 year flood was adopted for Zobe. The empirical coefficients corresponding to the smaller PMF were C = 82 and K = 5.5 and were considered appropriate for Zobe Dam.

Based on the baseline Flood Routing carried out at Zobe dam, there was little capacity to manage outflows during floods. The maximum capacity of the draw off pipe work is about 22 m^3/s which would have little impact on inflows experienced during floods.

Table 3.24: Summary of Zobe Reservoir Routing – Existing Spillway

Return Period (years)	Peak Inflow (m3/s)	Peak Outflow (m3/s)	Flood Rise (m)	Peak Flood Level (m)	Flood Freeboard to crest (m)*	Flood Freeboard to top of rip rap (m)*
100	2,921	1,196	3.19	496.19	1.01	1.65
1,000	4,429	2,235	4.40	497.40	-0.20	0.44
10,000	5,941	4,346	4.89	497.89	-0.69	-0.05
PMF (1.5 x 10,000 year)	8,911	8,035	5.42	498.42	-1.22	-0.58

* Crest level 497.20m, Top of rip rap 497.84m (as surveyed). ** Negative value indicates overtopping.

Table 3.24 shows that the embankment would start to overtop in the 1,000 year flood which is significantly smaller that the Design Flood. This shows that the existing spillway facilities would need to be augmented. Increasing the spillway capacity by increasing the embankment height is not a viable option at Zobe owing to the foundation conditions at the dam. The provision of an auxiliary spillway is considered to be the appropriate solution.

In the event of the 1 in 100 year flood, the extent of the flood associated with the dams breach event was assessed using hydrological model and remotely sensed topographic data. And also the settlement within each of the flood zones were identified using the updated version of the 1991 census to estimate the population that were likely to be affected by the flood events at both Bakolori and Zobe. The results of the analysis are summarized in Table 3.25 and Figures 3.56 to 3.60 shows the settlements affected within the flooded areas.

The 100 year flood event at Zobe extends 100km downstream of Zobe dam to the confluence with the River Gagere, whereas the more extreme breach flood model was extended further downstream to Sokoto city and did not include the Goronyo reservoir or structures. The flooded areas for the two events, the number of settlements affected and the estimated population of these settlements is shown in Table 3.25.

Table 3.25: Impact of 1 in 100 year and dam breach events at Bakolori and Zobe dams

	Bakolori	Zobe
Impact area 1 in 100 event (km^2)	351[1]	337
Impact area Dam Breach (km^2)	3,783[2]	2,035
Settlements affected I in 100 event	120	45
Settlements affected by dam breach	140	220
Population affected I in 100 event	252,889	124,647
Population affected by dam breach	302,635	327,263

[1] The impact area for the 100 year event is taken as far as Sokoto city

[2] The impact area for a dam breach event is taken as far as the Sokoto state boundary

At Bakolori, the impact of the 100 year flood event was taken as far as Sokoto city. For the breach event the impact area was assessed as far as the Sokoto state boundary although it appeared that there would be a flood impact as far as Kainji Lake.The flooded areas for the two events, the number of settlements affected and the estimated population of these settlements are shown in Table 3.24. The extent of the flooded area from the Sokoto to state boundary to Kainji Lake was estimated to be approximately 3,000 km^2. However substantial urban areas could be affected at both Sokoto and Birnin Kebbi which could mean a further 1.5-2.0 million people would be affected by a breach at Bakolori in addition to the estimates shown in Table 3.25.

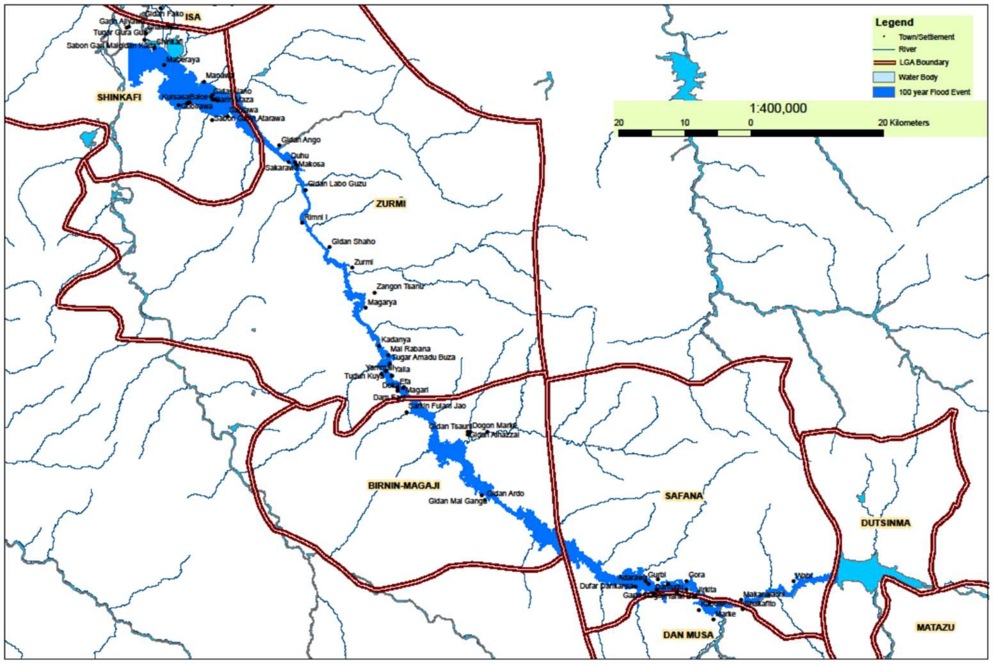


Figure 3.56: Extent of Zobe 1 in 100 year flood event

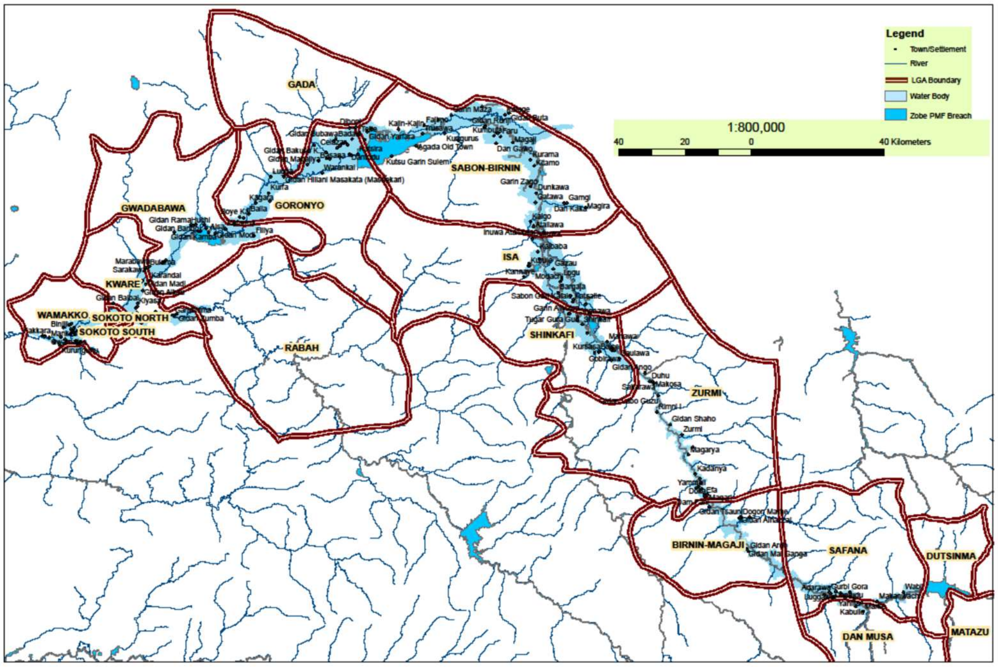


Figure 3.57: Extent of Zobe breach flood event

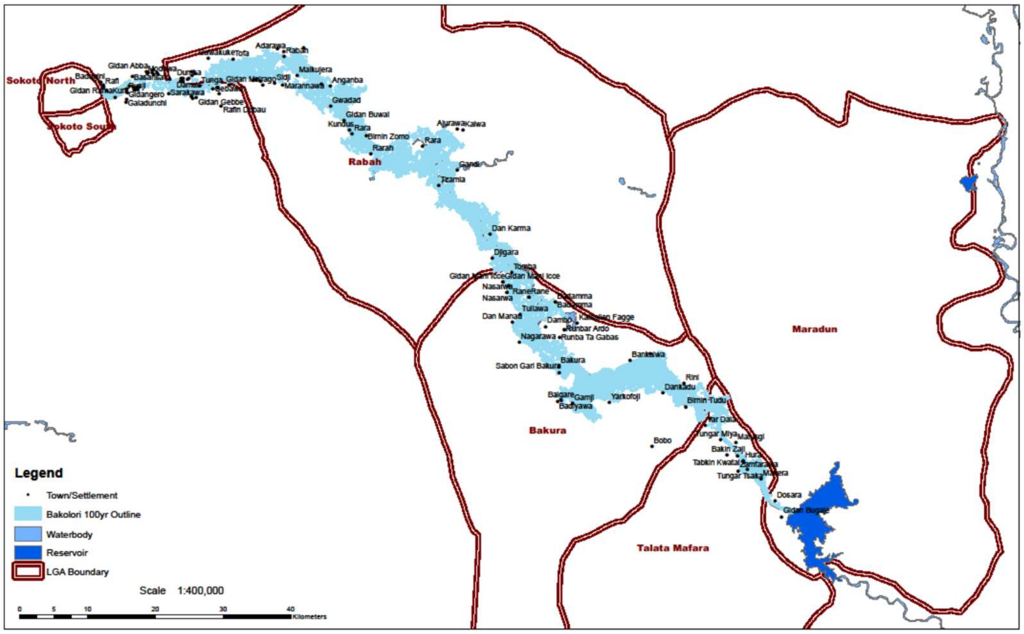


Figure 3.58: Extent of Bakolori 1 in 100 year flood event

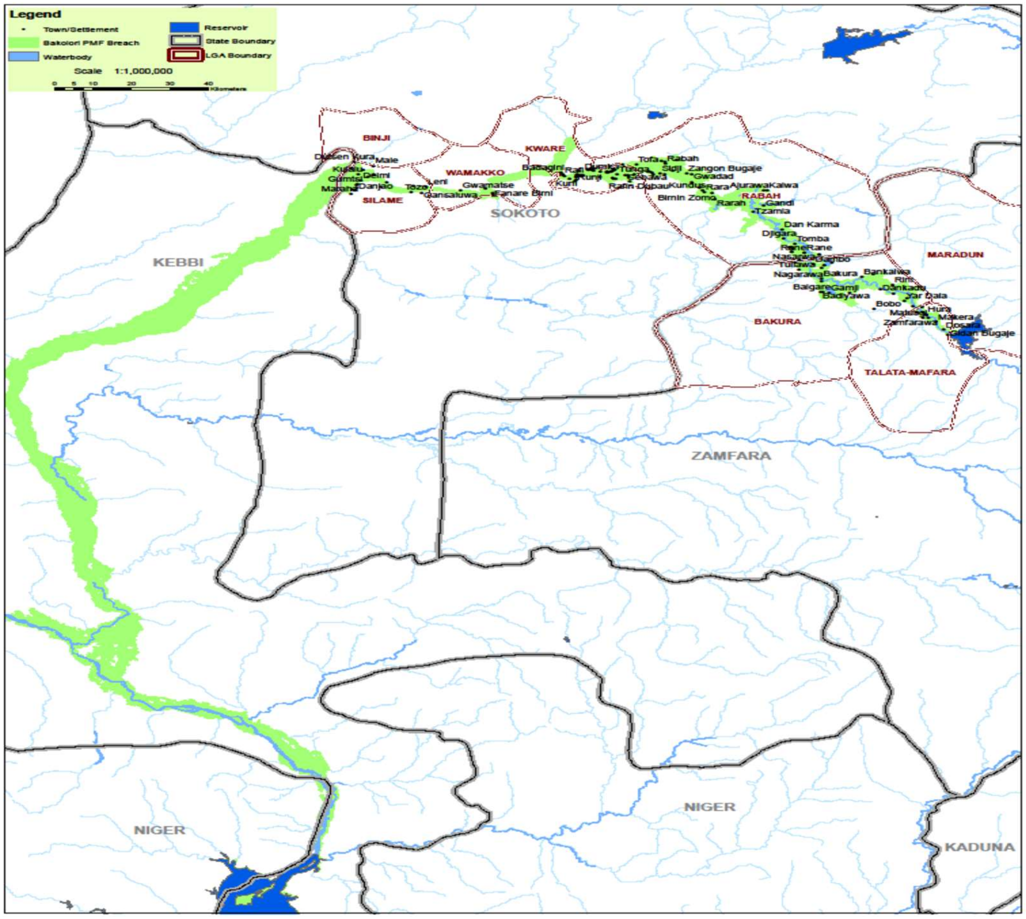


Figure 3.59: Extent of Bakolori breach flood event

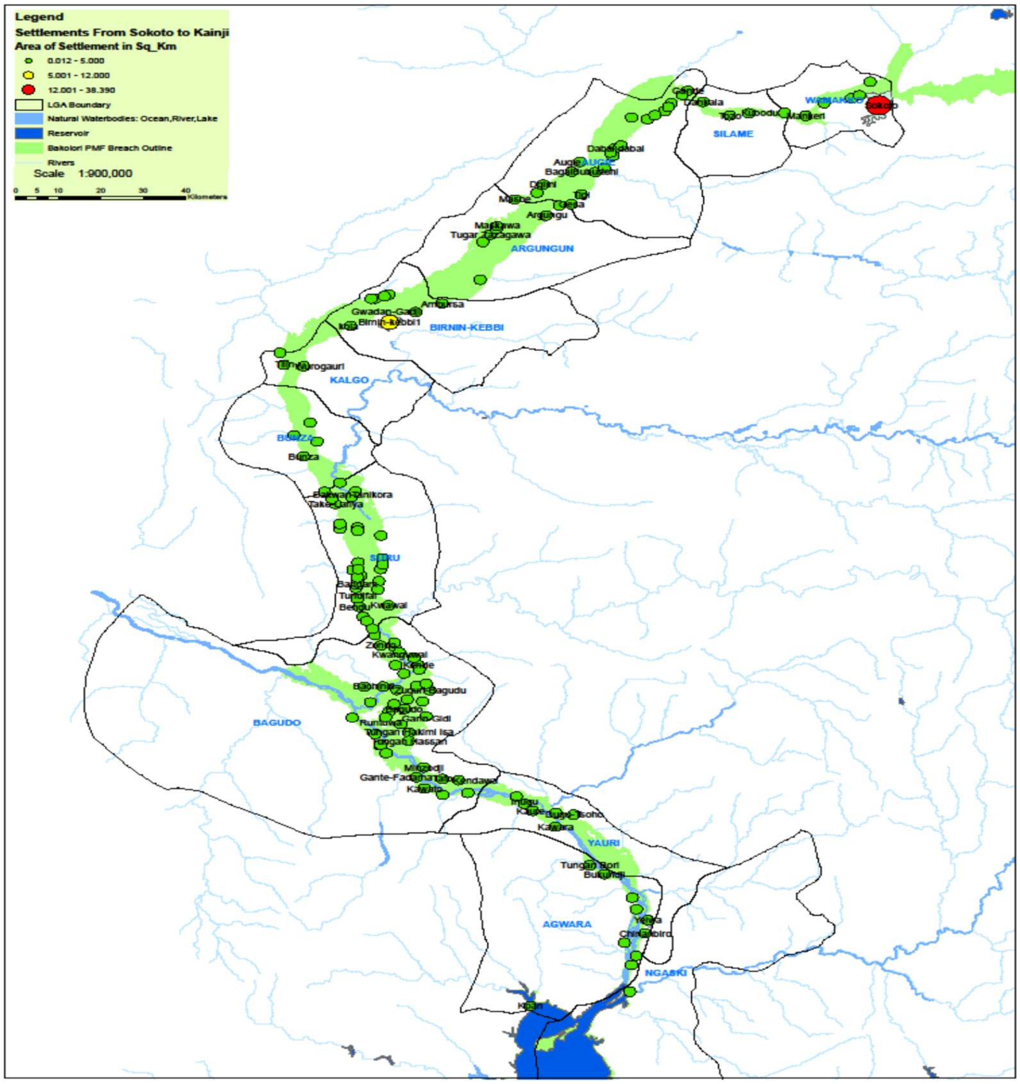


Figure 3.60: Extent of Bakolori breach flood event below Sokoto

3.6 Aspect of Water Quality Issues in northern Nigeria

3.6.1 Water Quality and influencing Factors

As water is essential and its quantity and quality are also equally crucial for human life, access to clean water is a basic need, which is still not available to a large population in the developing world. An assessment of quantity with consideration of quality requirements will therefore be important so that the intended benefits of better water supplies can be achieved at lower costs. Water pollution occurs when pollutants are directly or indirectly discharged into water bodies without adequate treatment to remove the harmful compounds. The effect is damaging not only to individual species and populations, but also to the natural biological communities. It has been stated that, water pollution is the leading worldwide cause of deaths and diseases, and that it accounts for the deaths of more than 14,000 people daily (West, 2006).

As the quality of water is controlled by many interrelated processes, it follows that some understanding of these processes is needed in order to act scientifically towards quality control and improvement (Foster et al., 2002). The occurrence of impurities in water depends on some factors including water supply source type, geological condition of the water source area, historical records on area, climate, influence of man, and the chemical reactions and constraints.

The specific contaminants leading to pollution in water include a wide spectrum of chemicals, pathogens, and physical or sensory changes such as elevated temperature and discoloration. Oxygen-depleting substances may be natural materials, such as plant matter (e.g. leaves and grass) as well as man-made chemicals. Other natural and anthropogenic substances may cause turbidity (cloudiness) which blocks light and disrupts plant growth, and clogs the gills of some fish species (EPA, 2005). Alteration of water's physical chemistry includes acidity (change in pH), electrical conductivity, temperature, and eutrophication.

3.6.2 Transport and Chemical Reactions of Pollutants in Water

Pollutants differ in mobility and persistence depending on their type and nature. However, chemical reactions such as precipitation and complexation as well as biodegradation, filtration and cation exchange play certain roles. Dilution will usually be the main attenuation process that operates in aerobic conditions in the aquifer and the overlying strata in chloride and nitrate pollutants. More readily degraded and retarded pollutants such as pesticides, bacteria and viruses can be significantly restricted from reaching aquifers if the overlying strata have adequate attenuation capacity in terms of clay and organic carbon content and microbiological activity.

In the very rapid groundwater flow conditions of karstic aquifers, water with microbiological and chemical pollutants may be moving so fast that the processes of elimination and retardation do not have time to operate. Even allowing for these cautionary notes, the likelihood of reaching groundwater can be assessed in qualitative terms for potential pollutants identified or anticipated from the situation assessment. The next characteristic of pollutant loading potential is the mode of disposition, i.e. how the pollutant enters the subsurface. This is a combination of the hydraulic loading or surcharge associated with or imposed by the pollution source, and the depth below the ground surface at which either effluent is discharged or leaching from solid residues occurs.

Many chemicals such as chlorinated hydrocarbons like trichloroethylene and tetrachloroethylene undergo reactive decay or chemically change process especially over long periods of time in groundwater reservoirs. Both of these chemicals, which are carcinogens undergo partial decomposition reactions, leading to new hazardous chemicals.

3.6.3 Water Quality Assessment

The parameters for water quality are determined by the intended use. Work in the area of water quality tends to be focused on water that is treated for human consumption, industrial use, or in the environment.

(a) Domestic Use

According to Diersing (2009), contaminants that may be in untreated water include microorganisms such as viruses, protozoa and bacteria; inorganic contaminants such as salts and metals; organic chemical contaminants from industrial processes and petroleum use; pesticides and herbicides; and radioactive contaminants. Water quality depends on the local geology and ecosystem, as well as human uses such as sewage dispersion, industrial pollution, etc. Drinking water, including bottled water, may reasonably be expected to contain at least small amounts of some contaminants. The presence of these contaminants does not necessarily indicate that the water poses a health risk, unless Maximum Permissible Limit is exceeded.

In urbanized areas, water purification technology is used in municipal water systems to remove contaminants from the source water (surface water or groundwater) before it is distributed to homes, businesses, schools and other users. Water drawn directly from a stream, lake, or aquifer and that has no treatment will be of uncertain quality.

Dissolved minerals may affect suitability of water for a range of domestic purposes. The most familiar of these is probably the presence of hardness which interferes with the cleaning action of soap, and can form hard sulfate and soft carbonate deposits in water heaters or boilers. Hard water may be softened to remove ions causing its presence. Hard water may be preferable to soft water for human consumption, since health problems have been associated with excess sodium and with calcium and magnesium deficiencies. Softening decreases nutrition and may increase cleaning effectiveness (World Health Organization, 2004).

(b) Water Sampling and Measurement

The complexity of water quality as a subject is reflected in the many types of measurements of water quality indicators. The most accurate measurements of water quality are made on-site, because water exists in equilibrium with its surroundings. Measurements commonly made on-site and in direct contact with the water source in question include temperature, pH, dissolved oxygen, electrical conductivity, Total Dissolved Solids, and turbidity.

More complex measurements are often made in a laboratory requiring a water sample to be collected, preserved, transported, and analyzed at another location. Many water sources vary with time and location. The measurement of interest may vary seasonally or from day to night or in response to some activity of man or natural populations of aquatic plants and animals (Goldman & Horne, 1983). The sample collection procedure must assure correct weighting of individual sampling times and locations where averaging is appropriate.

Water also begins to establish chemical equilibrium with its new surroundings as it is removed from the source. Sample containers must be made of materials with minimal reactivity with substances to be measured; and pre-cleaning of sample containers is important. Water collected from depths below the surface will normally be held at the reduced pressure of the atmosphere; so gas dissolved in the water may escape into unfilled space at the top of the container. Other chemical reaction equilibrium may change if the water sample changes temperature. Finely divided solid particles formerly suspended by water turbulence may settle to the bottom of the sample container, or a solid phase may form from biological growth or chemical precipitation. Microorganisms within the water sample may biochemically alter concentrations of oxygen, carbon dioxide, and organic compounds. Changing carbon dioxide concentrations may alter pH and change solubility of chemicals of interest. These problems are of special concern during measurement of chemicals assumed to be significant at very low concentrations. The water sample must be preserved with appropriate preservation agent from the point of collection to the laboratory (Goldman and Horne, 1983).

(d) Water Quality Assessment Parameters of Health Concern

Water quality monitoring may be carried out with a view to detecting, predicting and preventing groundwater and surface water pollution (Catherine, 1989). Ground water quality in some parts of the country is good in terms of health criteria. Several studies have shown some areas are reported to have iron, nitrate, fluoride, lead, and faecal/total coliforms, at concentration above the World Health Organization (WHO) and National Standard for Drinking Water Quality (NSDWQ) Guidelines.

Data and information on water supplies are mostly obtained from the State Water Agencies (SWAs) and other sources such as the Federal Office of Statistics (Multiple Indicator Cluster Survey, 1999), the Federal Ministry of Water Resources and UNICEF. Urban water supply agencies carry out routine water quality analyses at the treatment plants on a daily or weekly basis, there was usually no record kept of the results of such analyses. The rural water supply and sanitation agencies (RWSSAs) do not carry out routine water quality tests, but usually does a quality test on inception of every borehole drilled to ascertain its suitability for human consumption. The data-gathering format is not uniform across the states that keep records of their water quality data and there are no specific guidelines as to what parameters are to be tested. Major water quality concern in Northern part of Nigeria includes but not limited to Fluoride, Arsenic, Lead and Microbiological (as a result of poor sanitary conditions/practices) complications.

(e) Fluoride Occurrences and Effects

High levels of fluoride are generally produced by precipitation, hence mostly abundant in sedimentary areas, occurring as intercalation and patches. However, fluoride is also present in small to minute quantities in hornblende and some mica. Furthermore, fluoride is also associated with volcanic gases and is a major constituent of the mineral fluorite and cryolite. Fluorides are also released in the waste discharges from process streams in a number of industries.

Rapid Assessment of Drinking Water Quality (RADWQ) Monitoring using the RADWQ methodology over 1,600 samples from certain protected sites in 58 clusters was visited as initiative for establishing drinking water quality protocol, samples from boreholes, dug wells, public utilities and water vendors showed fluoride problems are wide spread in Damaturu, Yobe State (25mg/L), Langtang Plateau (10.5mg/L) and Eruwa, Oyo State (6.5mg/L) States among others in Nigeria. NWRI Post Graduate project, Ango (2001) showed fluoride occurrence in Kaltungo, Gombe State (4.9mg/L). The Drinking Water Quality Assessment in Taraba State shows fluoride level of 8.0 mg/L in Zing (NWRI, 2011). Excess fluoride intake causes fluorosis - a serious dental and bone disease (See Figures 3.61 and 3.62).

Figure 3.61: Dental mottled persons from Zing, Taraba State and Damaturu, Yobe State

Figure 3.62: Skeletal Fluorised hands and legs of affected Children from Damaturu, Yobe State

(f) Arsenic Occurrences and Effects

Arsenic occurs naturally in sedimentary and hard rock aquifers, which are in many developing countries like India used as source of drinking water. Natural arsenic is also found in thermal and mineral waters, which reach the earth's surface either by natural discharge in springs or by geothermal exploitation, which may affect the environment if not treated. Elevated levels of arsenic in groundwater due to natural sources, are therefore an issue of primary environmental concern, and hinder the economic and social development.

Arsenic concentration was detected in Kaduna State at concentration within the range of 0.00 – 11.00mg/L was measured (NWRI, 2009c). Hence, it's essential that further mapping would help to focus sampling to identify arsenic risk. Ghadebo and Mohammed (2004) report arsenic concentrations ranged from below detection to 200 ppb with an average of 76 ppb. In a study mainly aimed at assessing the environmental impacts of a petroleum refinery at Kaduna in north-central Nigeria. Oke (2003) reports that arsenic concentrations in surface waters ranged from 500 to 10,500 ppb As; and in groundwater from below detection to 9,000 ppb As. On the other hand, Oke (2003) indicates that for groundwater a `natural source is strongly suspected for Pb, Fe, Cr and As contamination.

(g) Lead Occurrences and Effects

Field studies identified quartzites, schist and phyllites as the dominate rocks of the areas where the materials for artesian mining are obtained. The primary gold mineralization is associated with veins and lenses of the quartzites, phyllites and there are normally associated with some galena which is the lead oxide. Research has shown that, Lead contamination and complication is common in Zamfara State (Anka and Bukkuyum LGAs, etc).

Water sources investigated by NWRI (2010) in the Zamfara State study area had lead concentrations within the range of 0.04–0.062 mg/l. The results show that 83% sampled drinking water sources in the affected villages have lead levels above the NSDWQ and WHO recommended guideline value of 0.010 mg/L for drinking water. This certainly increases lead intake apart from the rock processing dust and the surrounding soils. The source of the lead in the water sources might be due to the intensive processing activities of mined rocks that were taking place even within the households.

(h) Microbiological Occurrences and Effects

The result of microbiological analyses carried out on Taraba State water samples signifies that the faecal coliforms content for the borehole water supplies ranges between 0 – TNTC cfu/100mL, with 26% had values above 0cfu/100mL faecal coliforms recommended by NSDWQ and WHO for drinking water thus potential health of the consumers. The total coliforms content for Borehole water supplies ranges between 0 – TNTC cfu/100mL, with 30% had values above 10cfu/100mL total coliforms recommended by NSDWQ and WHO for drinking water. Pipe borne water supplies had total coliforms content ranging from 0 – TNTC cfu/100mL, with 64% contains potential pathogenic organisms, as a result of their measured values above the 10cfu/100mL recommended by NSDWQ and WHO for drinking water. The cause of the total coliforms contamination is due to inadequate disinfection, improper connection, leakages, and

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intake malpractice activities. Those locations that recorded TNTC for the faecal and total coliform had very poor hygiene and sanitation practices within and around its surroundings, coupled with lack of protection to the pumping mechanism and its sited downhill/down slope of the area (See Figures 3.63 - 3.64).

Figure 3.63: Poor Sanitary conditions around some Boreholes in Taraba State

Faecal coliforms content for the Borehole water sources in FCT ranges between 0 – 20cfu/100mL, with 38% had values above 0cfu/100mL faecal coliforms recommended by NSDWQ and WHO for drinking water thus potential health of the consumers. The locations that recorded faecal coliforms had very poor hygiene and sanitation practices within and around its surroundings; coupled with lack or inadequate protection to some pumping mechanism; improper drainages for spilled water thereby stagnating and habouring mosquitoes. The total coliforms content ranges between 0 – 82cfu/100mL, with 40% had values above 10cfu/100mL total coliforms recommended by NSDWQ and WHO for drinking water thus potentially dangerous to consumers' health (Table 3.26).

Figure 3.64: Very poor sanitary status at pumping surrounding and inadequate protection of supply pipe

Table 3.26: Water Quality Assessment Parameters

S/N	Parameter	Taraba State		Nasarawa State		Kaduna State		FCT	
		Parameter Range	NSDWQ % Compliance	Parameter Range	NSDWQ % Compliance	Parameter Range	NSDWQ % Compliance	Parameter Range	NSDWQ % Compliance
1.	PH	5.0 - 8.4	40	4.0 - 6.4	0	3.3 - 11.1	26	4.4 - 7.7	58
2.	Electrical Conductivity (µS/cm)	49.9 - 1,822	90	ND	ND	ND	ND	14.49 - 1,530	96
3.	Total Dissolved Solids (mg/l)	25 - 917	90	24 - 1126	100	13.0 - 924.0	96	7.79 – 760	96
4.	Turbidity (NTU)	0.0 - 38.6	86	1.5 - 255	90	0.9 - 77	46	0.03 – 190	86
5.	Total Hardness(mg/l)	10 - 568	74	1.3 - 118	100	0.0 - 271.0	96	10 – 402	90
7.	Iron(mg/l)	0.0 - 0.5	94	0.02 - 55	54	0.0 - 10.9	36	0.0 - 1.5	86
9.	Manganese(mg/l)	0.00 - 0.63	94	0.01 - 0.95	88	0.0 - 0.2	90	0.00 - 1.10	84
10.	Chromium(mg/l)	0.01 - 0.05	100	0 - 0.41	80	0.0 - 0.091	96	0.00 – 0.05	100
11.	Lead(mg/l)	0.001- 0.004	100	0.21 - 0.39	0	0.0 - 0.003	100	0.000– 0.010	100
12.	Cadmium(mg/l)	0.000 - 0.012	84	<0.001 - 0.02	78	0.0 - 0.0381	98	0.000 – 0.002	100
13.	Mercury	ND	ND	0.30 - 1.00	7	<0.001	100	ND	ND
14.	Arsenic(mg/l)	0.00	100	<0.01	100	0.0 - 11.0	84*	0.00	100
15.	Fluoride(mg/l)	0.0 - 8.0	92	0.0 - 0.03	100	0.0 - 1.5	99	0.0– 1.48	100
16.	Nitrate(mg/l)	0.0 - 91	94	0.09 - 22.35	100	0.4 - 45.0	100	0.03 – 42.90	100
17.	Chloride(mg/l)	9 - 161.9	100	15 - 155	100	1.3 - 205.6	100	14.5 – 217	98
18.	Sulphate (mg/l)	3 - 170	96	ND	ND	ND	ND	4.0 – 98	100
19.	Faecal Coliform cfu/100 ml	0 - TNTC	74	0 - TNTC	63	0.0 - 64.0	97	0 – 20	62
20.	Total Coliform cfu/100 ml	0 - TNTC	70	ND	ND	ND	ND	0 – 82	ND

- In Taraba State, Sanitary Risk Analyses results signify that the assessed Borehole water sources had 22% High risk, 56% Medium risk and 22% Low risk.
- In FCT, Sanitary Risk Analyses results signify that the assessed Borehole water sources had 10% High risk, 48% Medium risk and 42% Low risk.
- In Nasarawa State, Sanitary Risk Analyses results signify that the assessed Borehole water sources had 24% High risk, 54% Medium risk and 22% Low risk.
- In Kebbi State, Sanitary Risk Analyses results signify that, the Borehole water sources had 10% Very High Risk, 32% High Risk, 46% Medium Risk and 12% Low risk

CHAPTER 4

4 Conclusion and Recommendations

4.1 Conclusion

This research work under the NEPAD ACE 2 was carried out over the Niger River Basin in the northern part of Nigeria in order to carry out WEFE assessment in the north of Nigeria addressing climate, hydrology, dams and agriculture issues and analysis of interlinks and implications. The major part of the north of Nigeria falls under influence of this Basin and hence lives and means of livelihood are affected by the hydrological, hydrogeological, socio-political occurrences in the basin, which have their impacts from the influence of climate change.

Since climate change has its effects, water demand becomes high for domestic, agriculture, hydropower, and industries. The effects have caused untold hardship on the people both economically, socially and health wise. Since demand control policies, however, it is important that water supply agencies in the basin area establish complete, accurate, and representative information about current water consumption patterns. Climate change has been a serious challenge and its predictions are associated with high uncertainties in West Africa. With the current global drive for cleaner energy sources, hydropower remains one of the sustainable renewable energy substitutes for fossil fuel.

At the downstream end of the Niger River is Nigeria, which contains 28.3 percent (424,500 square kilometers) of the Basin area. The Niger Basin covers five (5) River Basin Development Authorities in Nigeria, which are Sokoto-Rima, Upper Benue, Lower Benue, Upper Niger and Lower Niger River Basin Development Authorities. Both rainfed and irrigated agriculture are practiced within the confine of the Basin in Nigeria and is substantial. Rainwater harvesting should be intensified in for domestic purposes. A few examples of other rainwater harvesting for agricultural purposes from other regions of the basin has been highlighted. Irrigation expansion has been modest with most of the areas developed for the purpose had not been fully utilized. The agricultural crops cultivated under irrigation are mostly corn (maize), legumes and vegetables.

Wetlands are now recognized as one of the World's most productive ecosystems which through their functions provide goods and services for the health, safety and welfare of human populations. The functions which furnish wetlands with their important status include groundwater discharge and recharge, sediment trapping, flood storage, water quality improvement and fishery and wildlife habitat. It is uncommon for a single wetland to possess all of these values, while different wetlands perform the same functions to different degrees. However wetlands are often the only places where such values are to be found and, once lost following the destruction of a wetland, they are frequently lost forever. Unfortunately, as well as being some of the most productive ecosystems. Wetlands are also among the most threatened.

Threats facing the World's wetlands can be broadly categorized into those related to agricultural intensification, pollution, major engineering schemes or urban developments.

4.2 Recommendations

To check the diminishing rainfall regime of the area, the study suggests the following, which if implemented, will impact positively on the regional weather and climate, improve the hydrological regime and stabilize the ecosystem. Hopefully, the desiccation of the last 40 years would be reversed, with droughts becoming less frequent:

i. local and regional development policies that recognize the fragile nature of semi-arid environments should be adopted in pursuing livelihoods especially in the area of agriculture;

ii. more effort should be made to discourage deforestation while encouraging soil and water conservation strategies;

iii. governments at both the local, state and national levels should embark upon massive tree planting projects throughout the northern parts of Nigeria;

iv. Water could be transferred from rivers with surplus yield in southern Nigeria to regions of water deficit in northern Nigeria.

In order to assuage the impacts of climate change in Nigeria, the following adaptation strategies should also be undertaken:

i. Provision of foot-bridges across road tracks/roads and road passages for use in times of floods especially in the farming communities;

ii. Rain-water collection systems should be provided for all stakeholders. Boreholes should also be provided outside the flood reaches of the possible flood belts and waterfronts;

iii. Improved presence of local government personnel to promote:
    a. Enlightenment/campaigns on public health needs of the communities.
    b. Provision of Insecticide Treated Nets (ITNs) and screened windows for households in the farming communities.
    c. Provision of revolving drugs fund for meeting the public health needs of stakeholders in the communities.

iv. Provision of government subsidized of all agricultural inputs (Seeds, Fertilizers, Agro-chemicals, improved local breeds of livestock, Outboard Engines, fishing nets, etc.) for all stakeholders in the farming communities. Community cooperative groups' formation, credit assistance and varied support for Women-in-Agriculture involved in post-harvest operations should be greatly improved;

v. Provision of appropriate community-led management for seaside/ coastal areas (particularly in the oil producing communities) to assure improved agricultural production through shrimp culture, cage fish culture, beel fisheries, and equipment and inputs provision;

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vi. Support for stakeholders through empowerment, training, equipment provision, credit assistance and training workshop support/provision;

vii. Strengthening of support for service providers at the community level through:
   - a. Credit assistance for seaside vehicle transportation systems especially for coastal oil producing communities.
   - b. Boat haulage systems
   - c. Establishment of technology development centers (for all agricultural sub-sectors: crops, livestock and fisheries alongside the gender specific processing and preservation operations).

viii. Provisions and strengthening of skill acquisition/development initiatives for all stakeholders through:
   - a. Agricultural extension training/workshops.
   - b. Health extension training/ services.
   - c. Equipment and inputs demonstration.
   - d. Seed-money provision for poverty reduction.
   - e. Community based organizations' support initiatives.
   - f. Skill development centers' provision.
   - g. Community markets provision/expansion.

ix. The federal, state and local governments should engage in participatory community projects' implementation through the management of policies and regulations relevant for the moderation of agricultural production laws that can assure sustainable livelihoods and as well help mitigate change impacts;

x. The federal, state and local governments should establish participatory community consultation systems for farming communities in Nigeria especially in the coastal oil producing states for assuring cost-effective, renewable and sustainable projects, planning and implementation that can help mitigate the impacts of incessant climate change;

xi. Governments should intensify efforts on tree planting. Trees have the capacity to trap carbon dioxide which would have otherwise escaped into the atmosphere. Trees can also reduce storm effects, loss of houses, processing sheds, etc.;

xii. Governments' new irrigation schemes to dry lands to improve water use efficiency and minimize moisture stress for crops particularly in the northern parts of the country should be greatly improved in scope, numbers and frequencies of provision for farming communities.

The water demand review should be done periodically since realistic assessment of regional water consumption is essential in understanding how water suppliers can accommodate variations in time and type of use. And much more in order to realize significant development and economic improvement, Integrated Water Resources Management (IWRM) should be practiced in all areas of water need.

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Annex 1. Summary of major dams and their description in Nigeria

S/No	Dam Name	State	Nearest city	River	Basin	Year of completion	Dam height (m)	Crest Length (M)	Reservoir capacity (million m^3)	Reservoir area (thousand m^2)	AMSL	SPILLWAY CAPACITY (M^3/S	Purpose							Latitude (N)			Longitude (E)		
													Irrigation	Water supply	Flood control	Hydroelectricity	Navigation	Recreation	Livestock rearing	Degree	Minute	Second	Degree	Minute	Second
1	Ankwil	Plateau	Bukuru	Tenti	Gongola	1964	26.00		31							x				9	45	53	8	58	24
2	Bagoma	Niger	Birningwari	Kusheriki	Kaduna	1974	17.00		5.46	2,024.			x	x						10	27		6	20	
3	Bakolori	Zamfara	Sokoto	Sokoto	Sokoto	1982	48.00	5,500	450	8,000.	351.	3,750	x							12	30	42	6	10	54
4	Balanga	Bauchi	Dadyia	Balanga	Gongola	1987	41.00		73	11,000.			x							9	55	22	11	36	2
5	Biu	Borno	Biu	Divama	Gongola				11.9	3,000.			x	x						10	38	18	12	5	27
6	Bokkos	Plateau	Jos	Maber	Benue		15.00		5				x	x						9	21		8	55	
7	Bosso	Niger	Minna	Karuko	Chanchaga	1946	17.00							x						9	7		6	8	
8	Challawa Gorge Dam	Kano	Kano	Challawa	Hadedja	1992	39.62	7,760	930	100,000.	538.	3,850	x	x						11	42	9	8	1	59
9	Dadin Kowa	Bauchi	Shani	Gongola	Gongola	1987	42.00	520	2,800	329,000.	247.	1,100	x	x		x				10	19	19	11	28	50
10	Doma	Plateau	Wamba	Ohana	Benue	1988	15.70	520	37.50	2,200.00	134.	63.00	x	x						8	20	59	8	17	54
11	Bagauda	Kano	Tiga	Kano	Hadedja	1970	20.00		22.14	3,760.			x	x						11	35	3	8	23	4
12	Gari	Kano	Danbatta	Gari	Hadedja	1980	22.00		214	33,180.			x							12	26	49	8	19	4
13	Goronyo	Sokoto	Goronyo	Rima	Rima	1983	20.00	5,285	942	200,000.	288.	1,540	x							13	31	55	5	52	57
14	Gubi	Bauchi	Bauchi	Gubi	Gongola	1990	27.00	3,820	38.40	179.00	552.	783		x						10	25	13	9	52	44
15	Gurara	Kaduna	Abuja	Gurara	Kaduna	2007	55.00	301	880.00				x	x	x	x		x	x	9	25	12	8	54	6
16	Gusau	Zamfara	Gusau	Dandume	Sokoto									x	x				x	12	8	2	6	40	11
17	Gusau	Sokoto	Gusau	Sokoto	Sokoto		22.00		3.00				x	x						12	8	47	6	40	13
18	Guzan	Niger	Bida	Yiko	Kaduna				20.00				x	x						9	17		5	39	
19	GuzuGuzu	Kano	Gwarzo	GuzuGuzu	Hadedja	1979	17.00		24.60	6,350			x							11	57	25	8	7	53
20	Iku	Fct	Suleja	Iku	Gurara		28.00		42.70	4,300			x							8	59		7	2	
21	Jabi	Fct	Abuja	Jabi	Gurara	1982	15.00		6.00							x				9	4	3	7	24	59
22	Jebba	Niger	Jebba	Niger	Niger	1984	40.00	670	38,000	360,000						x				9	8	12	4	47	18
23	Jekara	Kano	Minjibir	Jekara	Hadedja	1976	14.00		6,519	16,590	424.	2,200	x							12	8	13	8	41	34

24	Jibiya	Katsina	Katsina	Gada	Bunsuru	1990	21.50	3,680	942	20,000			x	x						13	4	19	7	14	34
25	KafinZaki	Bauchi	Bauchi	Buang	Jamare		40.00	11,000	2,700	250,000		1,460	x							10	47		9	37	
26	Kafin-Chiri	Kano	Sumaila	Jatau	Hadedja	1977	16.00	5,405	31.12	8,420			x	x						11	36	39	8	51	14
27	Kagara	Niger	Kontagora	Kagara	Kaduna		31.00	1,313	43	5,800				x						10	13		6	13	
28	Kainji	Niger	Kainji	Niger	Niger	1968	65.52	550	15,000	130,000		7,900	x	x	x	x	x	x	x	9	51	47	4	36	39
29	Kangimi	Kaduna	Kaduna	Kangimi	Kaduna	1977	19.00	1,525	74.10	11,140			x	x						10	38	25	7	35	43
30	Kango	Kano	Kano	Kango	WRECA		14.51	1,220	8.73											11	55	54	9	5	0
31	Karaye	Kano	Karaye	Kurma	Hadedja	1971	10.00	1,585	17.22	1,980				x						11	49	4	8	1	49
32	Kawali	Bauchi	Foggo	Bunga	HBRBDA/HJRBDA		15.00	4,500												11	20	0	9	55	0
33	Kiri	Adamawa	Numan	Gongola	Gongola	1982	37.00	1,300	615	11,500	745	4,000	x							9	40	51	12	0	57
34	Kontagora (1)	Niger	Auna	Kontagora	Niger	1988	20.00	1,000	17.70	3,700				x						10	5		4	51	
35	Kontagora (2)	Niger	Kontagora	Kontagora	Niger		32.00	1,400	350	39,000		209	x							10	24	22	5	20	53
36	Kubli	Niger	Babana	Svasei	Niger	1992	17.00	110	70	9,400	220	407	x							10	28	41	4	7	17
37	Kurra	Plateau	Jos	Tenti	Gongola	1929	19.00	106	17	4,800		571				x				9	50		9	13	
38	Lantang	Plateau	Langtang	Yolyem	Benue	1979	19.00		5.20	880				x						9	13		9	53	
39	Magaga	Kano	Gwarzo	Magaga	Hadedja	1980	19.00		19.68	3,720			x							11	57	3	8	2	43
40	Marashi	Kano	Gwarzo	Marashi	Hadedja	1980	11.00		6.77	2,145			x							11	55	54	7	49	42
41	Pada	Kano	Gwarzo		Hadedja	1980	14.00		12	4,090			x	x						11	55	36	7	53	2
42	RuwanKanya	Kano	Kano	Kanya	Hadedja	1976	22.00		33				x							11	30	7	8	26	53
43	Shen	Plateau	Bukuru	Shen	Benue	1979			3.40	3,600				x						8	53	32	9	31	53
44	Shiroro	Niger	Minna	Kaduna/Dinya	Kaduna	1984	115.00	700	6,000	320,000	389					x				9	58	24	6	50	5
45	Suleja	Niger	Suleja	Iku	Gurara		28.00		52	7,400.			x							9	13	11	7	14	21
46	Swashi	Niger	Babana	Swashi	Niger	1992	9.00		5.00				x							10	26	45	4	12	12
47	Tagwai	Niger	Tasabo	Tagwai	Chanchaga	1978	25.00		28.30	4,400.				x						9	34	0	6	39	38
48	Tiga	Kano	Chiroma	Kano	Hadedja	1975	47.20	5,790	1,874	178,000	542	3,257	x	x						11	27	53	8	24	28
49	Tomas	Kano	Kunya	Tomas	Hadedja	1976	14.00		60.30	14,970			x	x						12	18	26	8	31	33
50	Toro	Bauchi	Jos		Gongola								x	x						10	5		9	18	
51	Tudun Wada	Kano	Tudun Wada		Hadedja	1977	21.00		20.79				x							11	16	33	8	25	30
52	Lower Usuma	Fct	Abuja	Usuma	Gurara	1984	45.00	1,350.00	120.	10,000				x						8	52		7	3	
53	Watari	Kano	Bichi	Watari	Hadedja	1980	20.00		104.60	19,590			x		x					12	10	0	8	8	46

54	Waya	Bauchi	Bauchi	Waya	Gongola		23.00		21	4,500			x	x						10	20	43	10	0	51
55	Y. Gowon	Plateau	Jos	Shem	Gongola	1981	35.00		30	5,000				x						9	30		9	4	
56	Zaria	Kaduna	Zaria	Galma	Kaduna	1975	15.00		15.91	7,608				x						11	8	2	7	45	34
57	Zobe	Katsina	Musawa	Karaduwa	Bunsuru	1983	19.00		177	45,000			x	x						12	22	6	7	27	53
58	Zuru	Kebbi	Zuru	Girmache	Gulbinka	1978	15.00		5.85	22,500				x						11	37		5	38	