SCIENTIFIC ACTIVITIES FOR

THE AFRICAN NETWORKS OF CENTRES OF EXCELLENCE

(ACE WATER 2)

WEFE ASSESSMENT IN THE NIGER-DELTA BASIN, SOUTHERN NIGERIA

PREPARED BY

PROF J. O. EHIOROBO

(Expert consultant)

AND

PROF O. C. IZINYON

DEPARTMENT OF CIVIL ENGINEERING

FACULTY OF ENGINEERING

UNIVERSITY OF BENIN

BENIN CITY

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List of Acronyms

ACE	African Centre of Excellence
ACP	African, Caribbean and Pacific
AGRHYMET	Agriculture, Hydrology Meteorology
AMD	Annual Maximum Discharge
BAU	Business as Usual
BCWSS	Benin City Water Supply System
BORBA	Benin-Owena River Basin Authority
CCP	Change in Cropping Pattern
CCWY	Climatic Change Water Year
CoE	Centre of Excellence
CTA	Centre for Agriculture
DEM	Digital Elevation Model
DPSIR	Driving Force-Pressure-State-Impact-Response
DSS	Decision Support System
EU	European Union
FFA	Flood Frequency Analysis
GCM	Global Climate Model
IPCC	Intergovernmental Panel on Climate Change
IPGR	Increase in Population Growth Rate
ITD	Inter Tropical Discontinuity
IWRM	Integrated Water Resources Management
IWU	Increase in Water Use
m^3/s	Cubic metre per second
MINT	Minimum Increase in Temperature
MIT	Maximum Increase in Temperature
mm	Millimetre

NDRBA	Niger Delta River Basin Authority
NEPAD	New Partnership for African's Development
NIHSA	Nigeria Hydrological Agency
NIMET	Nigerian Meteorological Agency
NWRI	National Water Resources Institute
REGWS	Removal of Groundwater Source
RIA	Reduction in Irrigation Area
RIG	Reduction in Groundwater
RIP	Reduction in Precipitation
SSTA	Sea Surface Temperature Anomaly
SWAT	Soil and Water Assessment Tool
WEAP	Water Evaluation and Planning
WEFE	Water, Energy, Food and Ecosystems

1.0 Introduction

In line with the NEPAD-EU ACEWATER Phase II scope of work, part of the activities involves carrying out research in Water, Energy, Food and Ecosystems (WEFE) nexus assessment in the Niger Delta Basin of Nigeria covering the area from Lokoja in Kogi State down to where the River Niger empties into the Atlantic Ocean. It is in Lokoja that the study area over laps with the part of the Niger Basin being covered by the National Water Resources Institute, Kaduna, the second CoE in Nigeria.

1.1 Aim and Objectives

The aim of the study is to provide baseline data for climate variability analysis, climate risk assessment and WEFE Nexus interdependence evaluation for the creation of scenarios and tools for decision making in respect of water, energy and agricultural management in the lower Niger river basin to improve the living condition of the people.

The objectives include

a) Collect meteorological and hydrological data for climate variability analysis and risk assessment.
b) Carryout modelling and simulation of climate variability/change induced events particularly flooding and their impacts on food and water security.
c) Carry out inventory of dams and reservoirs within the study area and the potentials for their use in meeting water demand, for household and industrial use, agriculture and irrigation, hydropower generation and flood control.
d) Carry out hydrological analysis and modelling of selected sub catchments for scenarios modelling to determine the impact of land cover / modifications on food and water security.

1.2 Scope of Work

The scope of work includes but not limited to the following;

i) Desk studies to identify the data sources, types of data to be collected, data availability etc.
ii) Collection of meteorological data including rainfall, temperature, relative humidity etc. from relevant agencies.
iii) Collection of data on topography, land use/land cover including archival satellite images.
iv) Collection of data on reservoirs and dams covering the study area.
v) Modelling and analysis for climate variability and extreme events, hydrology and reservoir management agricultural and water supply and water use.

Although the study area is southern Nigeria, emphasis will be placed on the Niger river Basin from the tributary of the Niger-Benue river down to the Gulf of Guinea where the rivers empties into the Atlantic Ocean.

2.0 The Study Area

In the Niger Delta Basin of Nigeria, the catchments of interest are the Benin Owena River Basin and the Niger Delta River Basin. These basins consist of a network of meandering rivers and creeks with Mangrove Swamp and Rain Forest vegetation. The lower Basin of the river Niger flows and discharges through a massive delta known as the Niger Delta into the Gulf of Guinea in the Atlantic Ocean. The extent of the basin covers 42,874 square kilometres and is situated strategically on both sides of the Niger River.

The catchment extent is bounded to the North by Niger state, North West by Edo and Kogi states, South by Bayelsa, Rivers and Delta states, and East by Anambra state. It is characterized by wide extreme floodplain formed by rivers Niger, Benue and Anambra (see Figure 1). The study will be confined to downstream of Niger River from the confluence between River Niger and River Benue in Kogi state to Delta state.

The National Water Resources Institute (NWRI) in Nigeria will be working on the upstream section of the Niger River from the country boundary, to the confluence at Kogi state. Output hydrological results from their analysis especially for the Water sub-component of the NEXUS would be used as an input for the downstream section starting from the River Niger and River Benue confluence to the Niger Delta axis to the Atlantic Ocean which we will be considering. The major area of collaboration between our team and the National water resource institute is in the area of data sharing for analysis.

The major agencies for data collection in Nigeria are The Nigerian Meteorological Agency (NIMET) and The Nigeria Hydrological Science Agency (NIHSA), whose head offices are both located in Abuja the federal capital of Nigeria as well as River Basin Development Authorities located in different state capitals. Data collected by our team and the National water resources institute Kaduna were expected to be shared and compared before being used for analysis. Results were also compared for completeness and reliability by the two teams from Nigeria. We intend to share our methodologies and result with the National Water Resource Institute Kaduna.

The area of collaboration with AGRHYMET is to exploit the possibility of filling gaps in data available from local agencies in Nigeria including NIMET and NIHSA. The possibility of acquiring satellite data, and ground observation survey data in respect of hydrology, meteorology and Agriculture were exploited for possible Drought and Flood modelling, water resources in agriculture and livestock breeding etc.

We intend to collaborate with AGRHYMET and other western African Centers of Excellence (COE) in the development of regional models for hydro-meteorological and crop yield forecasting and water availability for water supply, irrigation and power generation

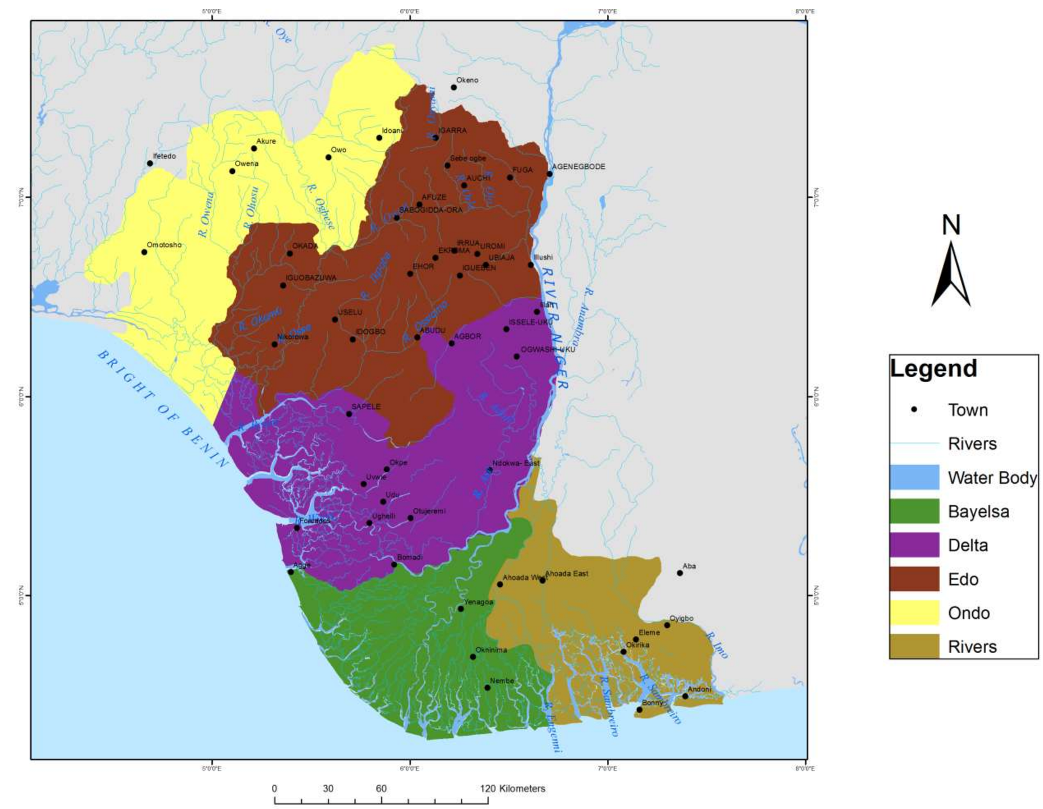


Figure 1: Overview of the Study Area (The flood plain ranges from less than 10meters in the south to 500m above Sea Level in the North).

2.1 Climate

The climate condition around the area is typically humid tropical climate with high rainfall for most parts of the year and dry harmattan from November to January which accounts for the dense mangrove and rainforest vegetation which characterize the basin. The average annual rainfall is 2000mm, temperature range is 22^o to 27^o during the raining season and between 28^o to 35^o during dry season.

2.2 Hydrology

Nigeria occupies an area of 923,800 square kilometres and 800 square kilometres coastline to the Gulf of Guinea. The surface water resources in the country are grouped into 8 hydrological areas (HAs) while the groundwater resources are also subdivided into 8 hydrogeological areas (HGAs). Due to financial and time constraints the study area will be limited to Niger-Delta and Benin - Owena River Basin. (see Fig1) The study area in the main is located in hydrological zone v (see Figure 3) which overlaps into hydrological zone II and III while to the SW and SE, the area overlaps into zone VI and VII respectively.

These two river Basins are located partly in hydrological Zones V and VI and comprise of Edo, Delta, Bayelsa, Ondo, Ekiti and Rivers states. For the area within hydrological Zone V, the geology is 90% sedimentary and 10% basement. This area is drained primarily by River Niger, Anambra, Osse, Nun and Forcados rivers. The geology of the areas within Zone VI is 60% basement and 40% sedimentary. Principal rivers within this area include Osse, Ossiomo, Oyan, and Owena. Almost all the Nigerian rivers with the exception of the Chadian system drain into the Gulf of Guinea.

River Niger and Benue have built-up the huge Niger Delta due to the combined action of sea waves and depositional action of the river emptying into the sea. Rivers systems within the proposed study area present rich runoff due to the high annual rainfall from 1500-2000 mm.

The large flood caused by high rainfall intensity often takes place and brings about flooding problem in urban areas located in the lower basin. This is particularly the case with coastal towns such as Warri, Port Harcourt, Patani, Forcados, Benin City, Yenegoa etc.

The river's mouth is clogged by transported sediment load from the upstream and a number of lagoons are formed along the coastline. It is to be noted that this is the area in Nigeria where most of the hydrocarbon exploration and exploitation activities take place and there has been a high level of pollution of both surface and ground water within the study area.

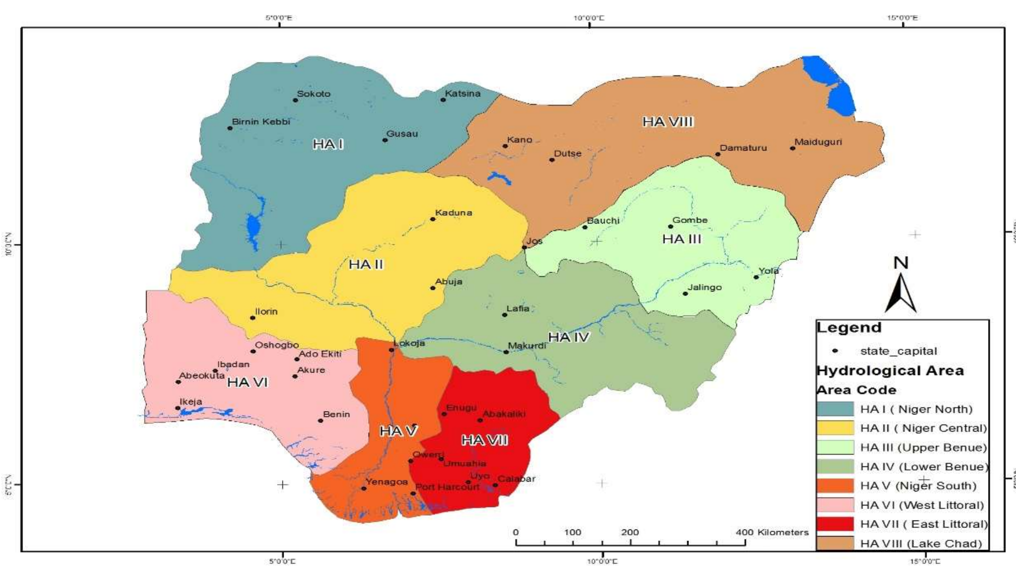


Figure 2: Nigeria Hydrological Zones

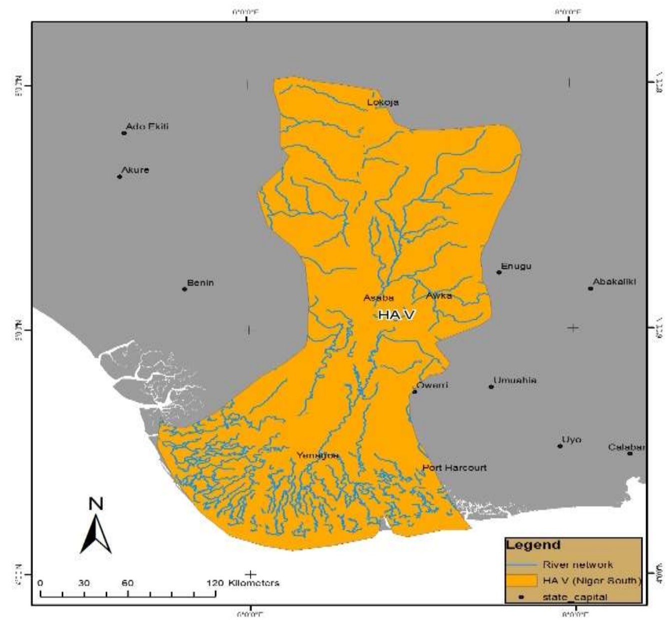


Figure 3: Hydrological Zone V

3.0 Meteorological Data Collection and Analysis

3.1 Meteorological Data Collection

The meteorological data that were obtained included Rainfall, Temperature and Relative Humidity, the major sources being:

- NIMET Agency
- Central Bank of Nigeria Meteorological Data Base.

These agencies observe, collate, collect, process and disseminate all meteorological data and information within and outside the country.

3.2 Meteorological Data Processing and Analysis

The data that were gathered (on a monthly basis) including the stations, duration and number of years covered are summarised in Table 1.

Table 1: Summary of Meteorological Data in Niger Delta Basin

Type of Data	Stations	Latitude (˚N)	Longitude (˚E)	Duration covered	Number of Years Covered
Rainfall	Akure	7.25	5.19	1981-2016	36
	Benin City	6.35	5.65	1981-2016	36
	Calabar	4.95	8.32	1981-2016	36
	Ikom	5.96	8.71	1981-2016	36
	Lokoja	7.82	6.73	1981-2016	36
	Ogaja	6.65	8.79	1981-2016	36
	Port Harcourt	4.79	7.01	1981-2016	36
	Uyo	5.05	7.93	1981-2016	36
	Warri	5.52	5.75	1981-2016	36
Temperature	Akure	7.25	5.19	1961-2000	40
	Benin City	6.35	5.65	1961-2000	40
	Calabar	4.95	8.32	1980-2010	31
	Warri	5.52	5.75	1961-2000	40
	Port Harcourt	4.79	7.01	1961-2000	40
Relative Humidity	Calabar	4.95	8.32	1980-2010	31
	Port Harcourt	4.79	7.01	1961-2000	40
	Warri	5.52	5.75	1961-2000	40

Only rainfall data were analysed because data were available for more stations, unlike temperature and relative humidity. Rainfall data were analysed in order to evaluate the rainfall seasonality in Niger Delta Basin and these included:

- Assessing the pattern of rainfall distribution in the study area
- Examining the percentage contribution of seasonal rainfall to the total annual rainfall in the study area
- Identifying the causes of the pattern of rainfall distribution in the study area

- Examining rainfall attributes in the study area.

The location of the meteorological stations in which data were available is shown in Figure 4.

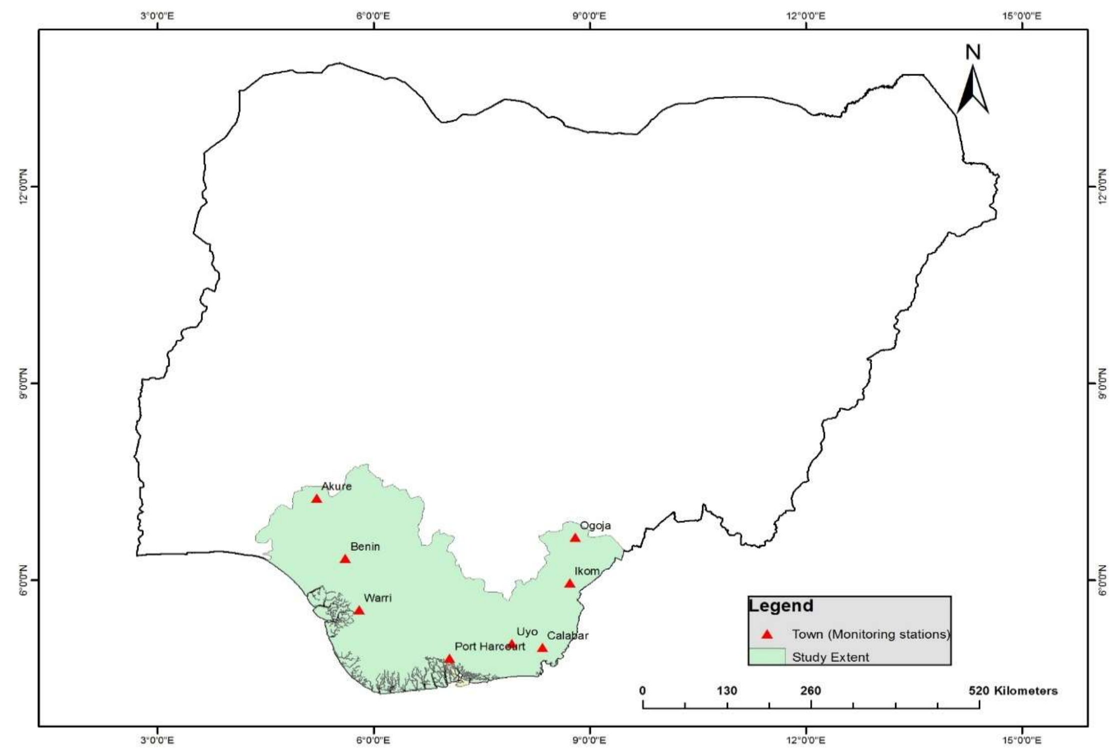


Figure 4: Map Showing the Niger Delta Towns with Meteorological Data

3.3 Rainfall Seasonality

Rainfall seasonality is the pattern of distribution of rainfall on monthly basis in a defined geographical area (Ayoade, 1974). The method used to examine rainfall seasonality in the study area involved computing of average monthly and annual rainfall in each of the stations. Percentage of mean was the statistical tool employed for seasonal variation. In this case the mean rainfall figures during the wet season and the dry season months were added to get the wet and dry season totals. The percentages of both the wet and dry season totals in relation to the mean annual totals were calculated. The extent of seasonality period was determined based on Nigeria climatic seasons.

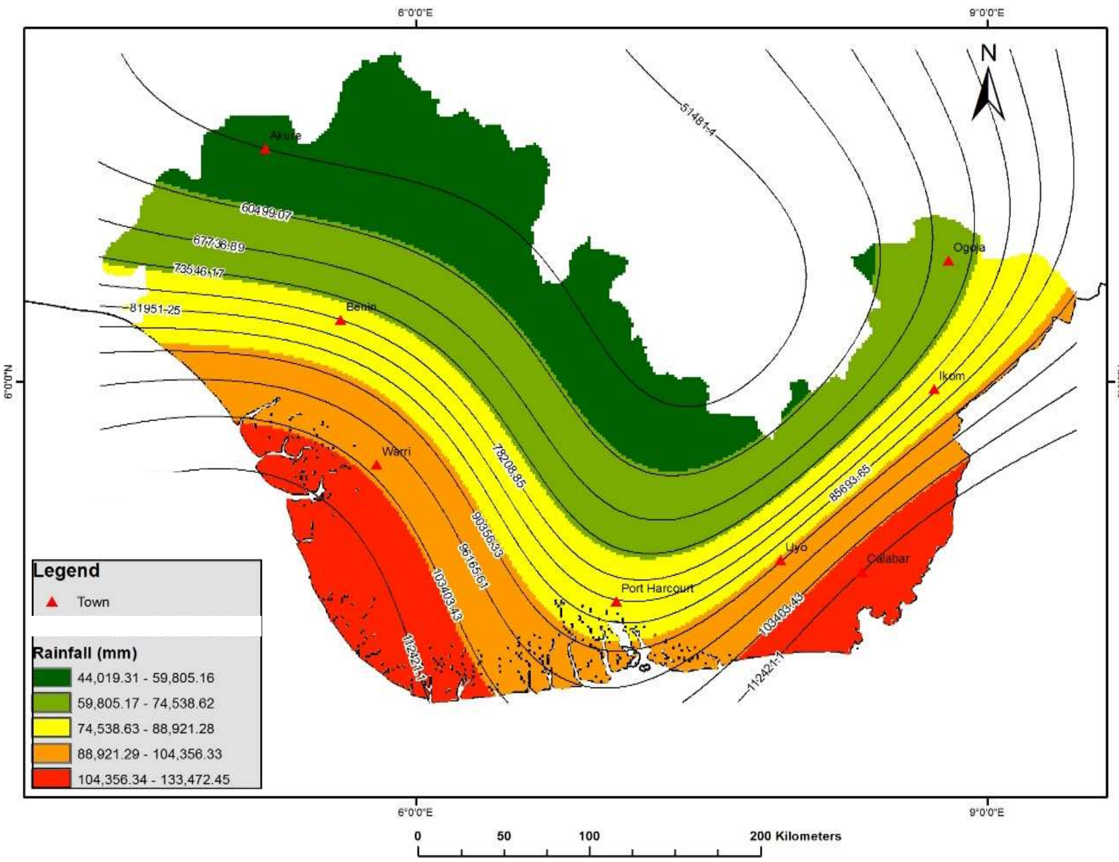


Figure 5: Total Rainfall (mm) in Niger Delta Basin (1981-2016)

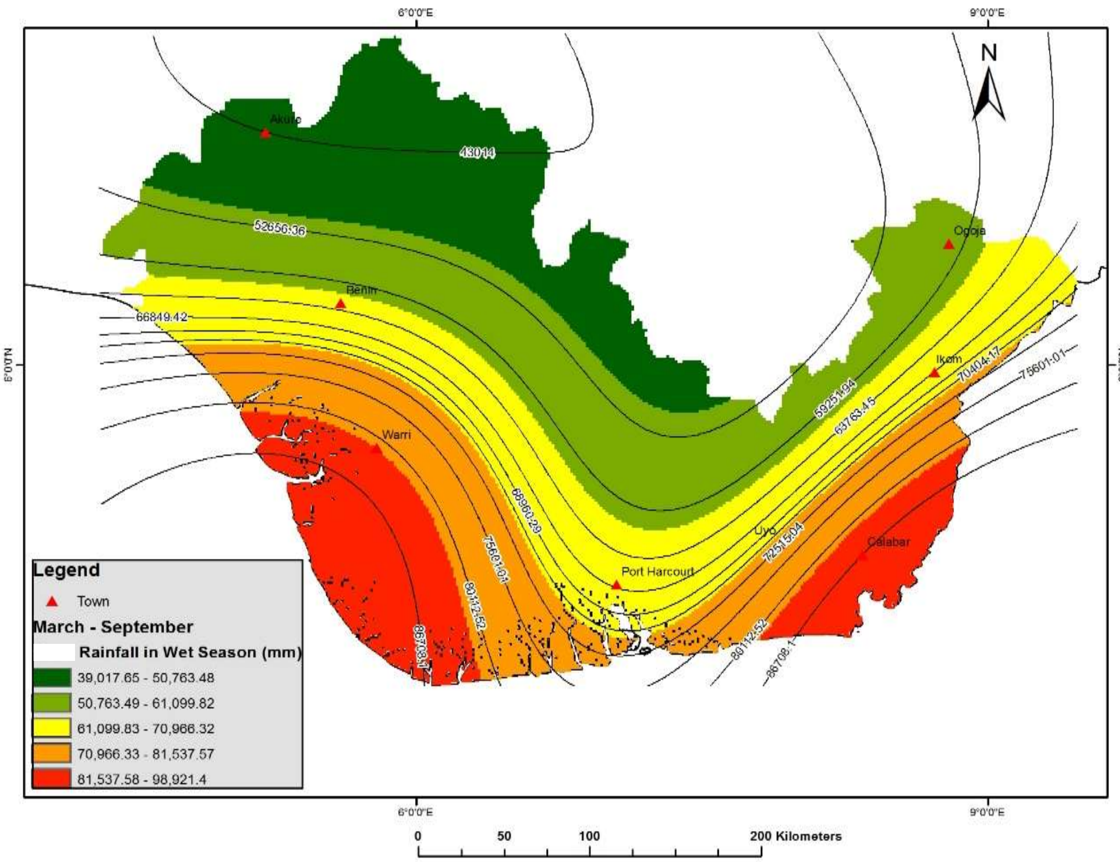


Figure 6: Total Wet Season Rainfall in Niger Delta Basin (1981-2016)

Results (as shown in Figures 5 and 6) indicated a northward increase and decrease in the total wet season rainfall (for the whole number of years covered: 36 years). Initially, the increase in total rainfall was from Ogoja (70,384.5 mm and 58,082.30 mm) to Calabar (112,421.10 mm and 86,708.10 mm) and then the decrease in rainfall was from Uyo (89,933.7 mm and 72,328.80 mm) to Port-Harcourt (82,210 mm and 66,579.60 mm). Thereafter, there was a northward increase in rainfall in Warri (101,284.20 mm and 81,373.40 mm) followed by a sudden decrease from Benin (78,166 mm and 62,583.50 mm) to Akure (51,481.40 mm and 43,014 mm). According to Adejuwon (2012), the South- North rate of change in rainfall experienced in the Niger Delta Basin may be attributed to Inter-tropical discontinuity (ITD), which migrates gradually northwards and more rapidly southward through the whole wet season period. Besides ITD, Cameroon mountain may also influence the northward increase in rainfall from Ogoja to Calabar area (Adefolalu, 1983). Relief is another factor that brings about an increase in rainfall when meteorological conditions are favourable (Adejuwon, 2012). Uplift of any air body over high relief affects moist, warm air susceptible to instability and rainfall and as a result of this, relief record maximum influence on rainfall in the wet season. The percentage contribution of total wet season rainfall (for the whole 36 year covered) to the total rainfall (for the whole 36 year covered) was highest in Akure with 83.55% and lowest in Calabar with 77.13%.

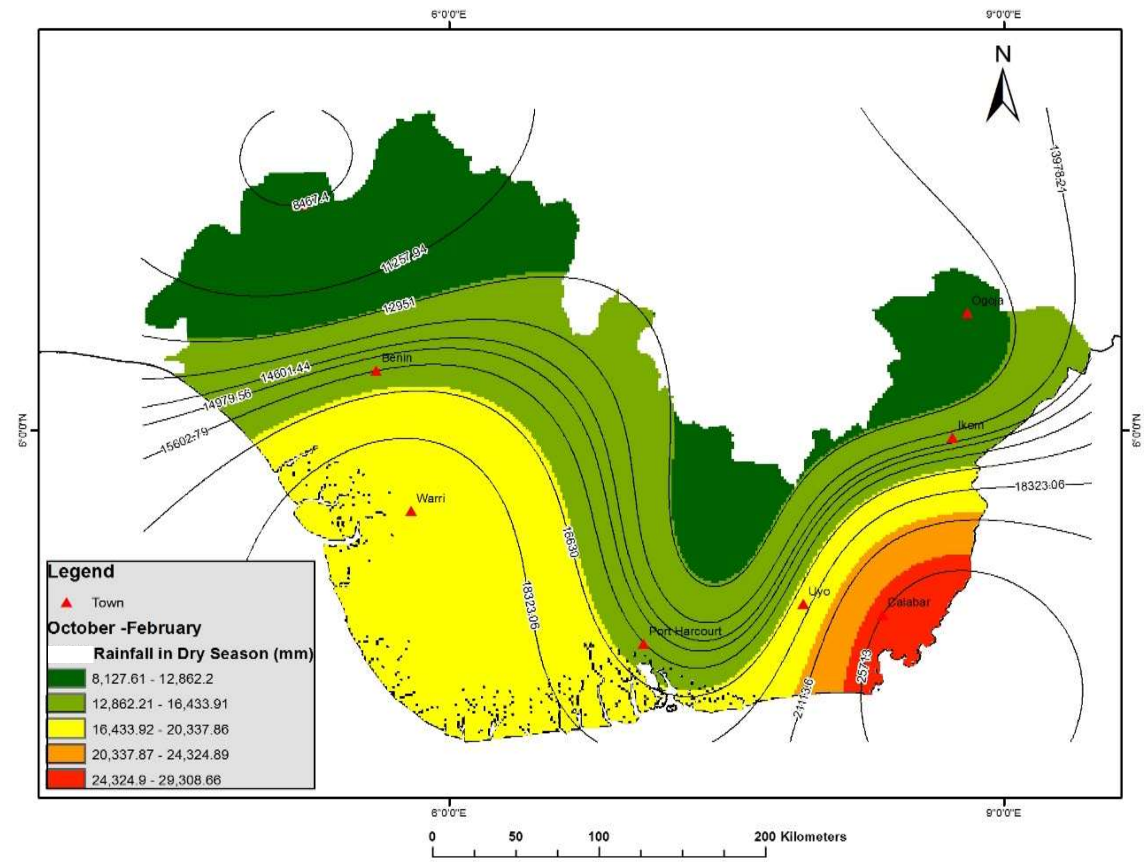


Figure 7: Total Dry Season Rainfall in Niger Delta Basin (1981-2016)

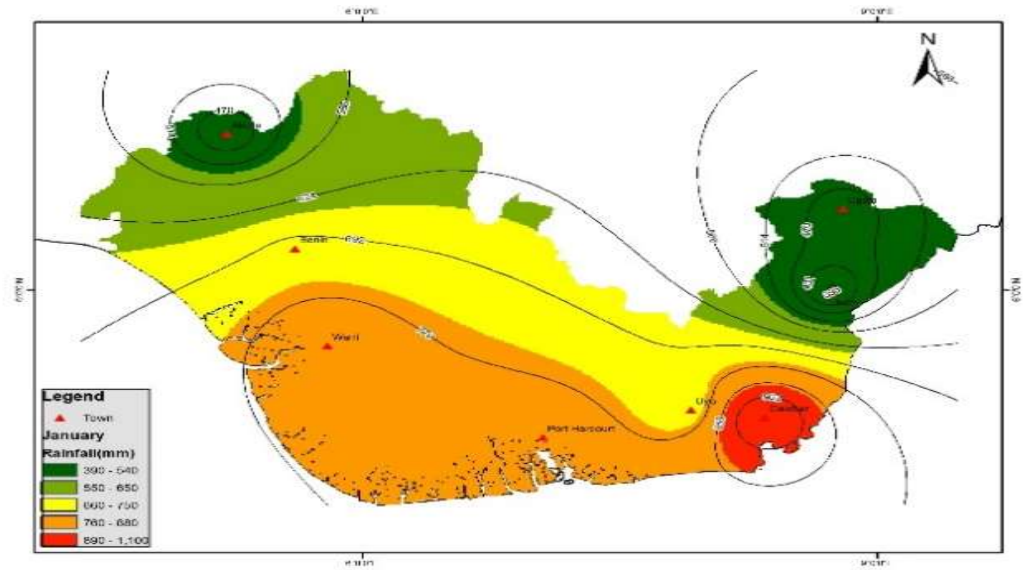


Figure 8: Total January Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

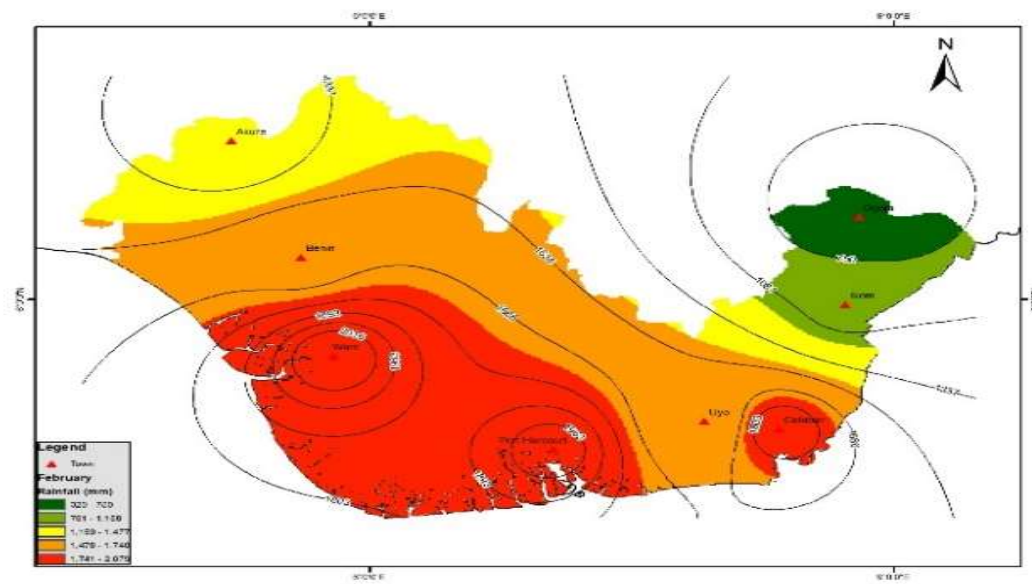


Figure 9: Total February Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

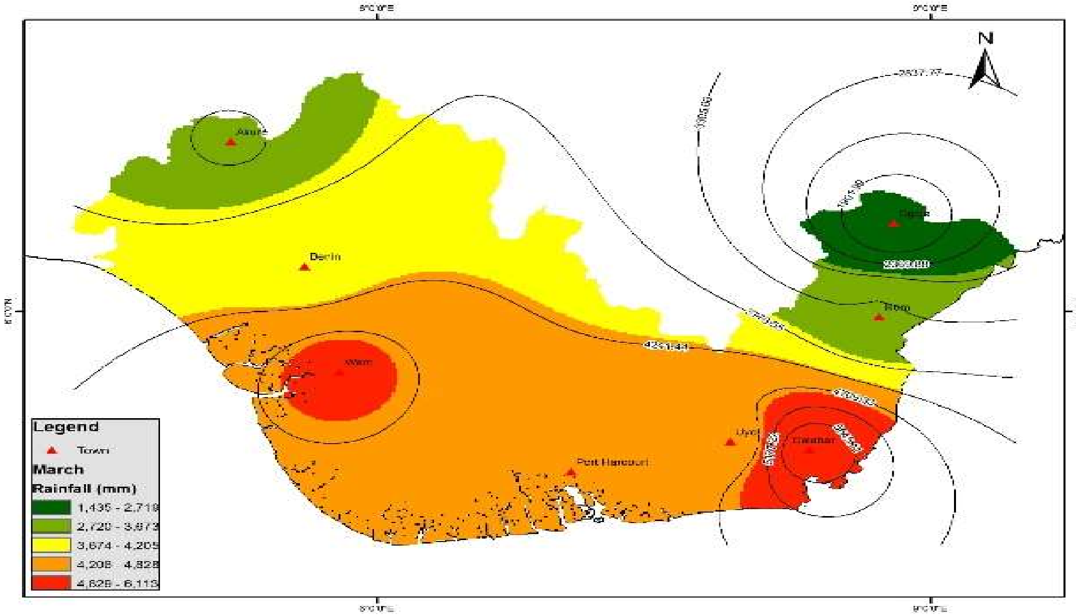


Figure 10: Total March Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

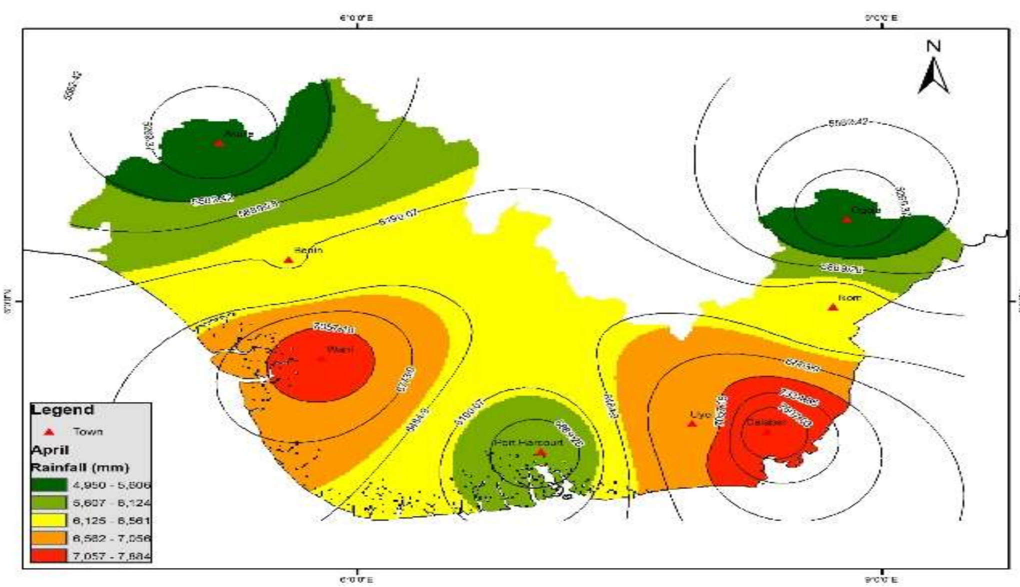


Figure 11: Total April Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

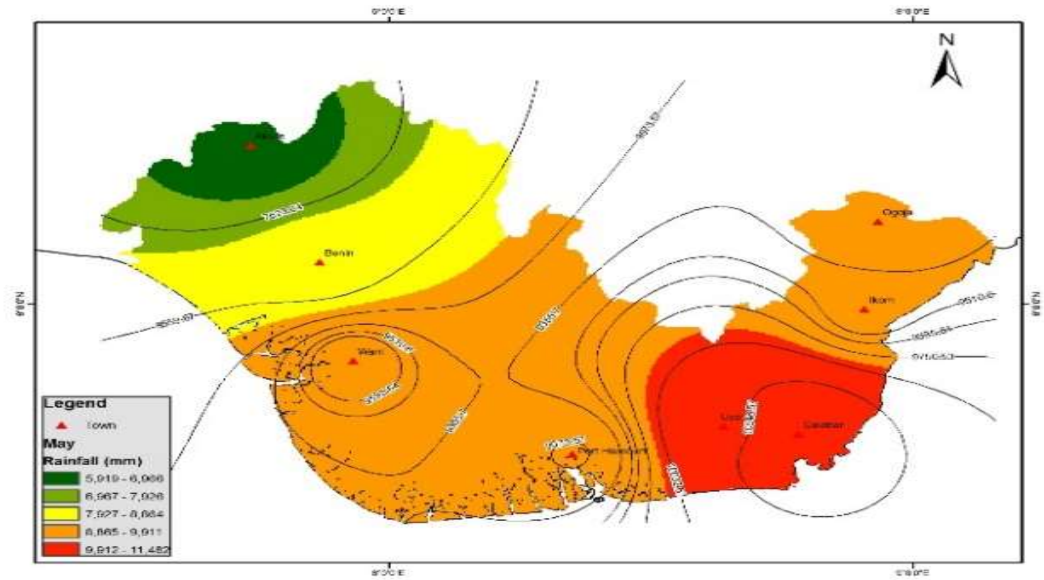


Figure 12: Total May Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

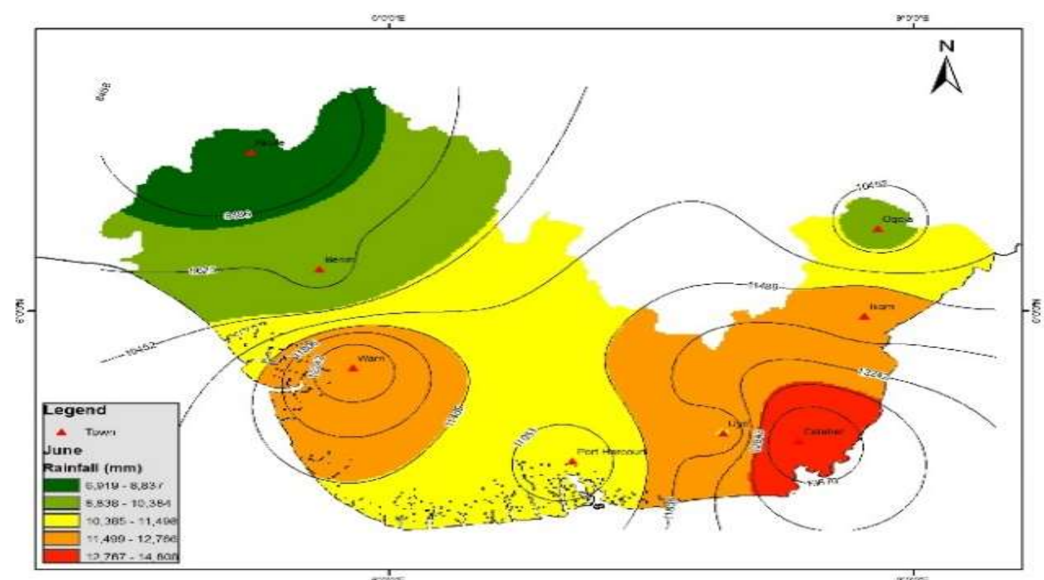


Figure 13: Total June Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

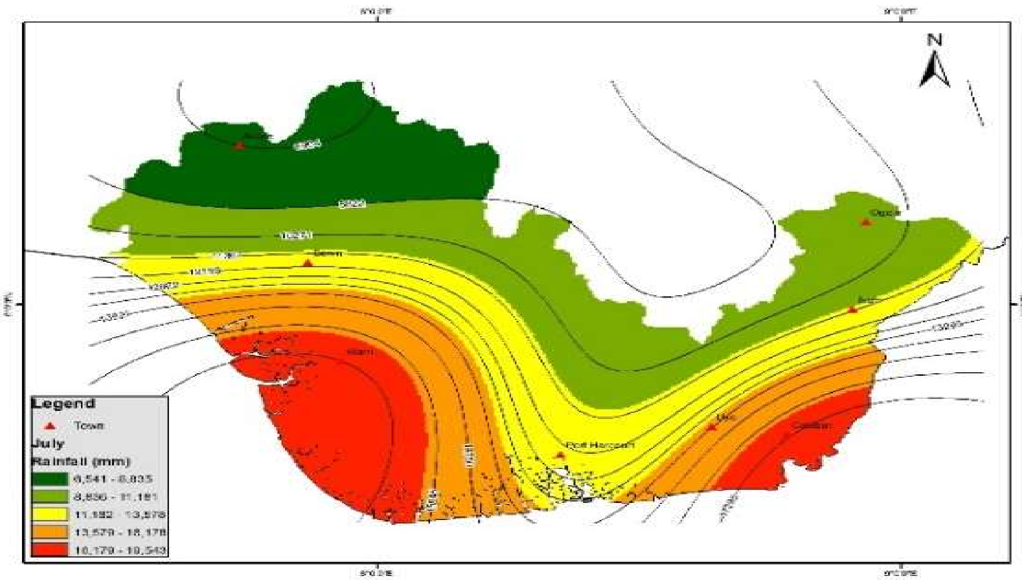


Figure 14: Total July Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

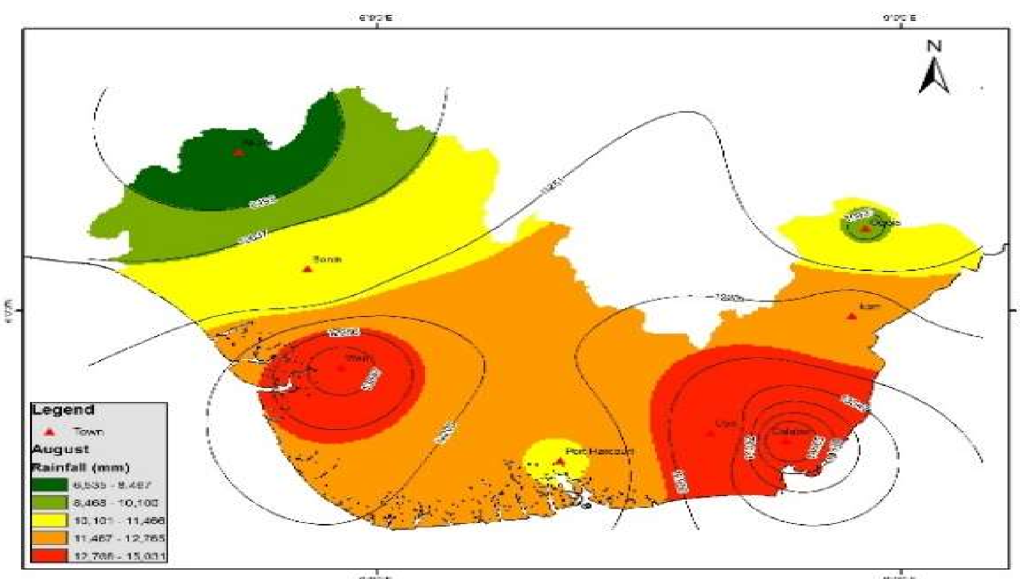


Figure 15: Total August Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

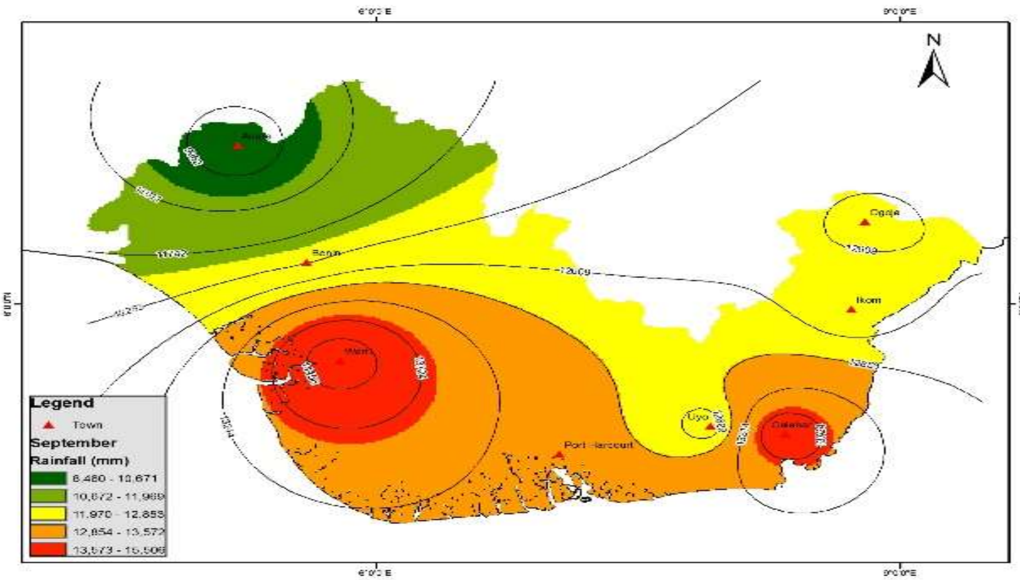


Figure 16: Total September Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

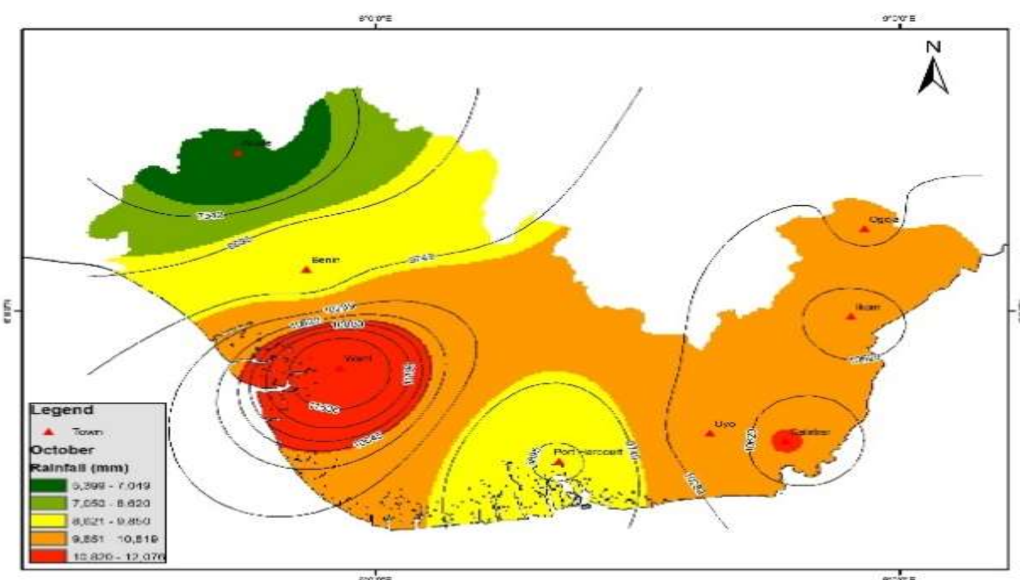


Figure 17: Total October Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

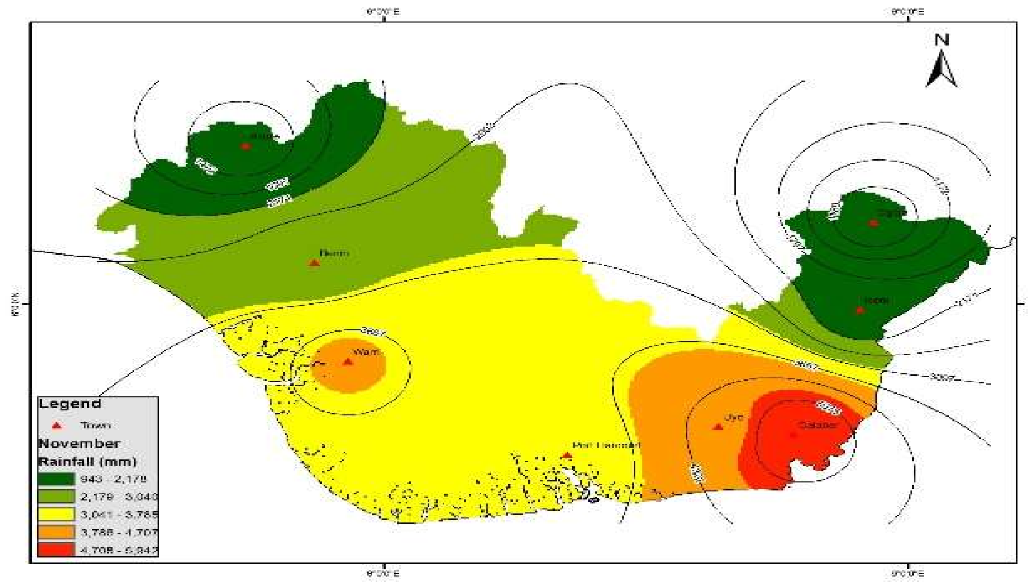


Figure 18: Total November Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

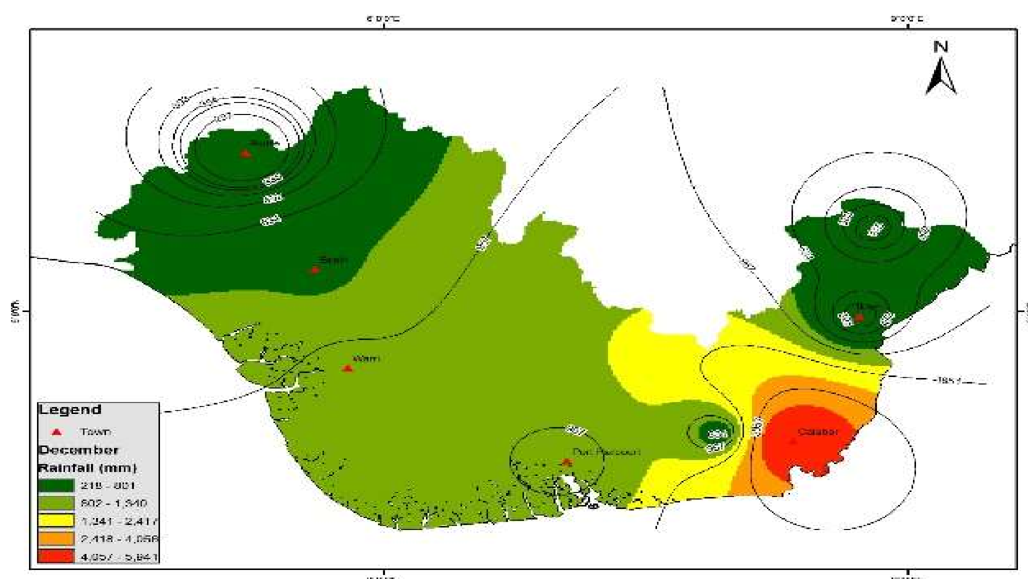


Figure 19: Total December Rainfall Distribution Pattern in Niger Delta Basin (1981-2016)

Generally, dry season is characterized by low rainfall. Like the total rainfall and the total wet season rainfall (for 36years), during the dry season period, results (as shown in Figure 7) indicated that the total dry season rainfall also increases northward from Ogoja (12,302.20mm) to Calabar (25,713mm) and then decreases from Uyo (17,604.90mm) to Port-Harcourt (15,630.40mm). There was an increase in total dry season rainfall again in Warri (19,910.80mm) and then a decrease from Benin (15,582.50mm) to Akure (8,467.40mm). Hence, the total rainfall, the total wet season rainfall and the total dry season rainfall indicate a similar rainfall distribution pattern. Akure experiences longer dry season than most of the stations in the region, possibly because of its location at the northern extreme and therefore responsible for the low rainfall amount received at this location during the dry season. The position of the ITD greatly determines the length of the dry season. The ITD is only a few kilometres from the coast in December when the whole region is under the influence of the dry harmattan and only a few showers occur along the coast (Adejuwon, 2012). The seasonal distribution of rainfall (Figure 8 to 19) shows that December and January rainfall are more restricted to the coastal stations like Calabar and Warri. At this period of the year, the ITD is located furthest south and most of the region is covered by the dry tropical continental air mass. By February, the areas receiving rainfall extend inland. The ITD remains in this coastal area until late February to early March when the northward movement begins (Adejuwon, 2012; Gbuyiro and Adefisan, 2007; Obasi, 1965). The percentage contribution of the total dry season rainfall to the total rainfall (for 36years) was highest in Calabar with 22.87% and lowest in Akure with 16.45%.

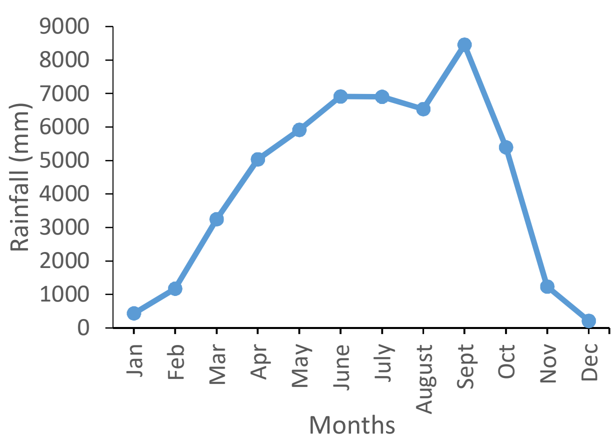


Figure 20: Total MonthlyRainfall(mm) Values in Akure (1981-2016)

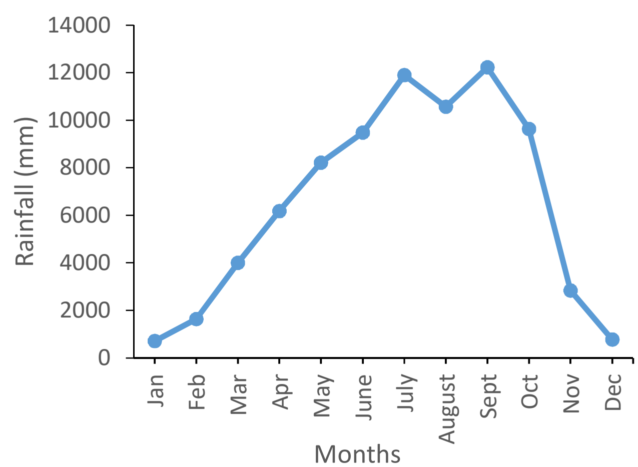


Figure 21: Total Monthly Rainfall (mm) Values in Benin City (1981-2016)

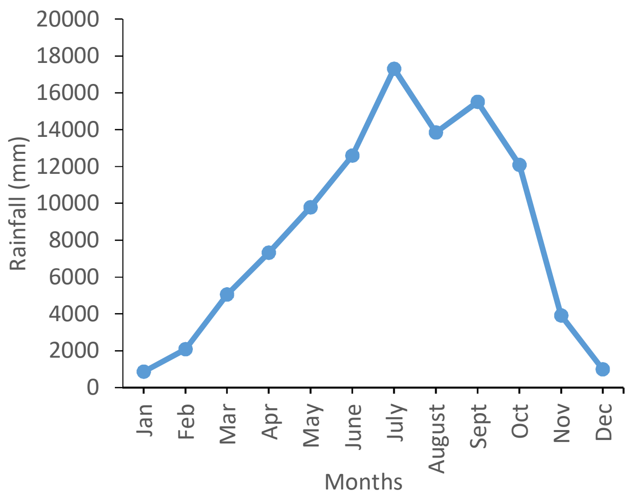


Figure 22: Total Monthly Rainfall (mm) Values in Warri (1981-2016)

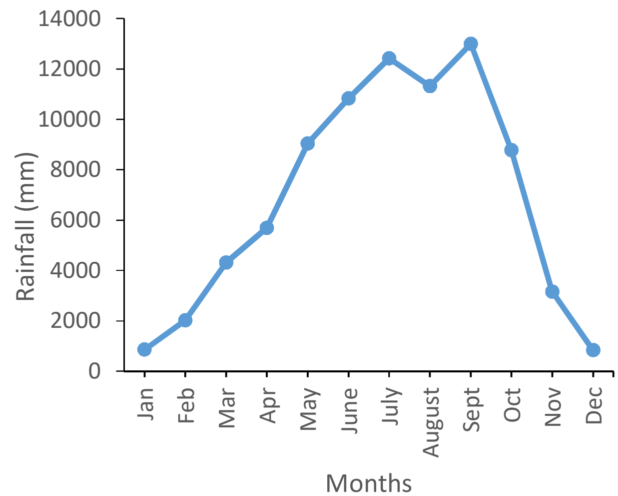


Figure 23: Total Monthly Rainfall (mm) Values in Port-Harcourt (1981-2016)

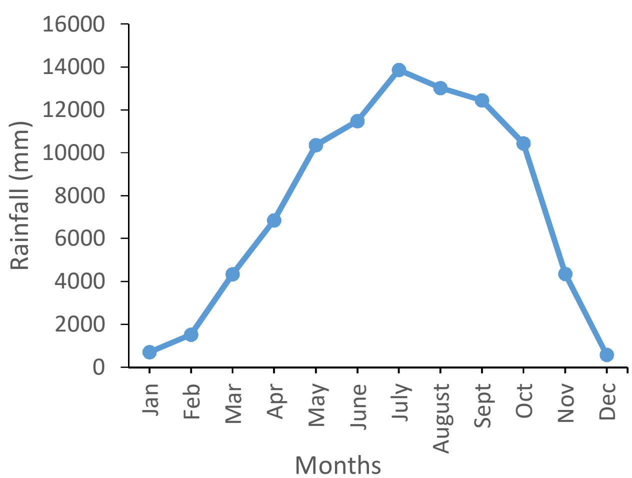


Figure 24: Total Monthly Rainfall (mm) Values in Uyo (1981-2016)

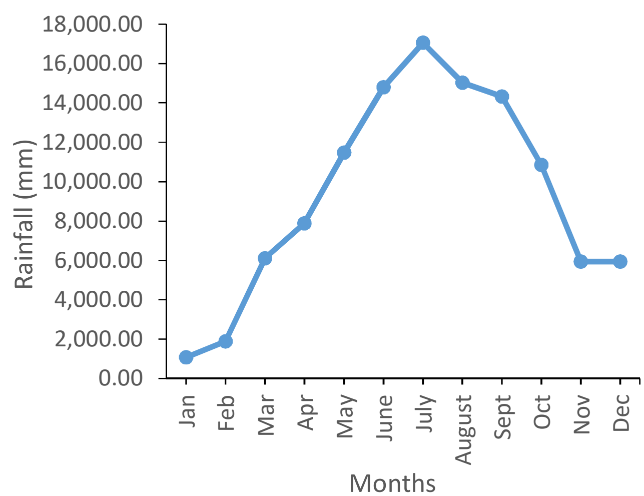


Figure 25: Total Monthly Rainfall (mm) Values in Calabar (1981-2016)

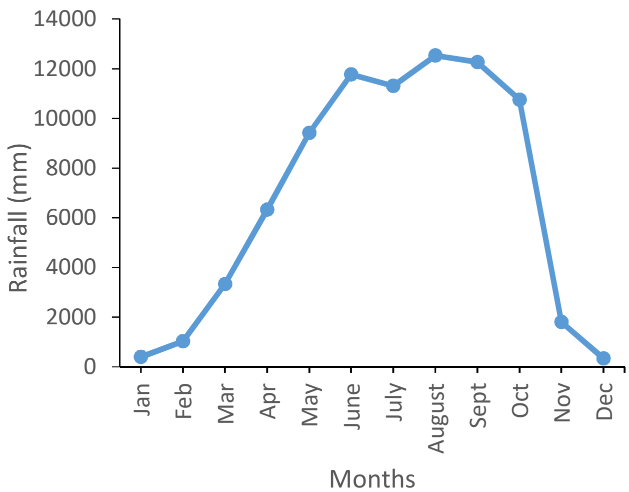


Figure 26: Total Monthly Rainfall (mm) Values in Ikom (1981-2016)

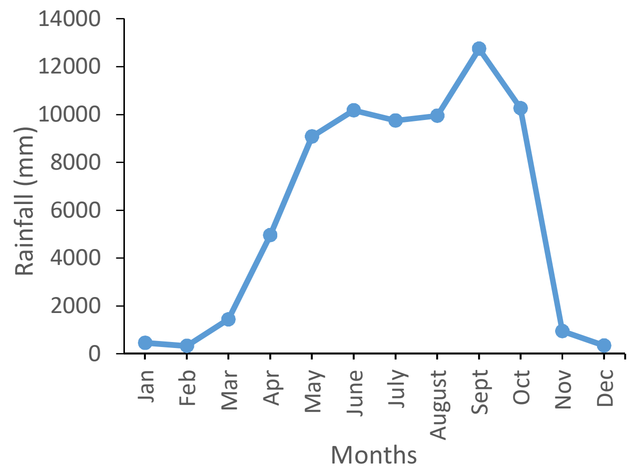


Figure 27: Total Monthly Rainfall (mm) Values in Ogoja (1981- 2016)

From Figure 20 to 27, results indicated that the total monthly rainfall in the Niger Delta Basin (1981-2016: 36years) was lowest in December and January which is in accordance with previous work done by Adejuwon (2012). There was a monotonic increase in rainfall at all stations until August when there is a modest general reduction in the amount of rainfall except for Ikom and Ogoja. The reduction may be attributed to the little dry season (July-August rainfall) at this period. July/ September marks the peak period of rainfall in all stations. In September there was an increase in rainfall in all stations followed by a general decrease till December. By this time, the whole Niger Delta Basin is under the influence of the dry harmattan air from the Sahara Desert. Hence, the climate of Niger Delta Basin is characterised as seasonal with a short dry season. The location of the ITD is at the coast. Beside these factors, other dominant factors controlling rainfall in the Niger Delta Basin include sea surface temperature anomaly (SSTA), and the local factors. According to Palmer (1986), the SSTA arises from the warming of the Tropical Atlantic Ocean south of the ITD and therefore leads to the weakening of the pattern of circulation of the atmosphere over the tropics. The weakened circulation reduces the intensity of the southwest monsoon flow into West and Central Africa and, consequently the rainfall over southern Nigeria (Bello, 2008). Local features also influence rainfall in the Niger Delta Basin. Heavy rainfall would be expected during wet season because the coast is crossed obliquely by rain bearing wind (Adejuwon, 2012).

3.4 Impact of Rainfall Seasonality on Agriculture

Climate change has altered not only the overall magnitude of rainfall but also its seasonal distribution and inter-annual variability worldwide (Feng et al.,2013; Easterling, 2000; Zeng et al., 1999). In the tropics, seasonal rainfall has distinctly shaped a mosaic of highly diverse ecosystem from the tropical dry forests to open woodland forests to savannahs (Dirzo), that support species with a variety of adaptive strategies. Most of these ecosystems are extremely sensitive not only to the annual rainfall amount but also to other aspects of seasonal rainfall such as the arrival of rain at the beginning of the wet season, which determines the timing of important life stages such as leaf flushing and flowering; and the wet season length, which contributes to the timing of leaf fall and thus the total transpiration period (Borchert, 1994 and Schwartz, 2003). The same rainfall seasonality, with its associated drought and flood risks, also poses huge challenges to local populations, making agricultural efforts and sustainable management of soil and water resources more difficult (Rockstrom et al., 2003 and Wani, et al., 2009).

According to Bewket (2009), in Sub-Saharan Africa, rainfall is the most important climatic factor influencing the growth characteristics of crops. Rainfall provides the water that serves as a medium through which nutrients are transported for crop development. In view of this significant role, clearly, inadequate water supply has adverse effects on efficient crop growth, resulting in low productivity. von Braun (1991), has observed that a 10% decrease in seasonal rainfall from the long-term average generally translates into a 4.4% decrease in food production. Also, Wood (1977), and Pankhurst and Johnson (1988), have observed that food shortages and famines in sub-Saharan Africa are mostly a result of rainfall uncertainties and associated drought. Considering that the farmers in the Niger Delta Region rely solely on rain-fed agriculture, crop production is vulnerable to rainfall variability. Extreme variations to agro-climatic conditions, such as droughts and floods could directly affect the livelihood of the people in the region.

The Niger Delta area of Nigeria, which contains one of the highest concentrations of biodiversity on the planet, in addition to supporting abundant flora and fauna, arable terrain that can sustain a wide variety of crops, agricultural trees, and more species of freshwater fish than any ecosystem in West Africa, could experience a loss of about 40% of its inhabitable terrain in the next thirty years (Finance and Development (F&D), 2008). This perceived situation can be attributed to unfavourable farm practices found in the area among other factors (including the carelessness of oil industries in oil spillage, natural gas flaring, over exploitation of natural resources and natural changes over time). As majority of the people living in the Niger Delta are farmers and fishermen, the environmental and social consequences of climate change is putting livelihoods at serious risks.

According to IPCC (2007b) recent studies indicate that increased frequency of heat stress, droughts and floods negatively affect crop yields and livestock beyond the impacts of mean climate change, creating the possibility for surprises, with impacts that are larger, and occurring earlier, than predicted using changes in mean variables alone. This is especially the case for subsistence sectors at low latitudes. According to Technical Centre for Agriculture and Rural Cooperation, CTA (2008) the principal impacts of climate change on cropping systems which has direct effect on food production particularly in the Niger Delta region of Nigeria include:

- Reduced production due to changing rainfall pattern
- Emerging diseases, pests and vectors

- Spatial redistribution of pests and
- Erratic rainfall patterns etc.

The impacts of climate change are not limited to cropping and agro-pastoralism, it is being felt on fisheries and aquaculture. There is need to focus on the impact on fisheries ecosystems and the food and nutritional security and livelihoods of fish dependent communities. In African, Caribbean and Pacific (ACP) countries, fishing communities are impoverished and ill-prepared to adapt to the negative impacts of climate change. According to CTA (2008) the main impacts of climate change on fisheries and aquaculture include:

- Disturbances in fish fertility;
- Increased mortality among young fish due to rising water temperatures, particularly in lagoons and rivers;
- Effects of strong salinity in these surroundings exacerbated by the penetration of sea water that seriously affects fishery resources and already fragile ecologies; and
- Frequent fish migration into deep water.

All the above factors have particularly contributed to improverishing the people of the oil rich Niger Delta region of Nigeria. Evaluating rainfall seasonality will be useful for agricultural planning.

4.0 Hydrological Data Collection and Analysis

4.1 Hydrological Data Collection

River discharge data were obtained from Nigeria Hydrological Service Agency (NIHSA), Benin-Owenna River Basin Authority (BORBA) and Niger Delta River Basin Authority (NDRBA) and they included daily stream flow measurement obtained from the different gauge stations.

4.2 Hydrological Data Processing and Analysis

The stations with hydrological data are shown in Table 2.

Table 2: Summary of River Discharge Data in Niger Delta Basin

Type of Data	Gauging Stations	Rivers	Latitude (˚N)	Longitude (˚E)	Duration covered	Number of Years Covered
Discharge	Benin City	Ikpoba	6.35	5.65	1989-2000	12
	Ologbo	Ossiomo	6.05	5.67	1989-2000	12
	Owena	Owena	7.20	5.02	1989-2000	12

	Onitsha	Niger	6.17	6.75	1960-2014	55
	Lokoja	River Niger	7.82	6.73	1960-2013	54
	Ossisa	Adofi	5.92	6.47	1989-1997	9
	Ugbonoba	Okhuwan	6.32	6.85	1993-2000	13
	Owan	Owan	6.77	5.77	1989-1999	11

Daily stream flow measurement obtained from the different gauge stations (Lokoja, Onitsha and Ugbonoba) were analysed. The data were used for flood frequency analysis, hence estimation of extreme flood discharge of known return period is paramount in the design of hydraulic structures such as culverts, dams, bridges and drainage systems. Owing to the stochastic nature of the hydrologic phenomena that governs extreme flood discharge, it is fundamental that we investigate most hydrologic processes such as rainfall and droughts by simply analysing their records of observations (Ehiorobo and Izinyon, 2013). Effective analysis and determination of extreme flood discharge requires the use of statistical frequency analysis or fitting of probability distribution models to the series of recorded annual maximum discharge (AMD) (Sharma and Singh, 2010). One of the widely used statistical frequency analysis methods is univariate frequency analysis technique. Univariate frequency analysis is widely used for analyzing hydrologic data, including rainfall characteristics, peak discharge series and low flow record of observations. Univariate frequency analyses are primarily employed in the estimation of exceedance probabilities and variable magnitudes. The basic assumption is that the data to be used must be satisfactorily homogeneous otherwise; the estimated probabilities or variable magnitude will be inaccurate (Sharma and Singh, 2010). The versatility of statistical frequency analysis makes it the most commonly used procedure for the analysis of flood data. Due to its wide application in the analysis of flood data, univariate statistical frequency analysis is sometime designated flood frequency analysis (FFA).

4.3. Flood Frequency Analysis

Flood frequency Analysis employs statistical method (univariate analysis technique) in the estimation of how often a specific flood event will occur.

The flood frequency analysis was carried out by employing three probability distribution models namely; Extreme value type 1 (EV1) distribution, Uniform (U) distribution and Exponential (E) distribution all of which have two parameters each. The parameters of the distributions were estimated by method of *L*-moments. The annual maximum discharge data at each location were ranked in ascending order of magnitude and the corresponding probability weighted moments ie b_0, b_1, b_2 and b_3 for the sample data were computed using the following equations:

$$b_0 = \frac{1}{N} \sum_{j=1}^{n} X_{(j:n)} \quad (1)$$

$$b_1 = \frac{1}{N}\sum_{j=2}^{n} X_{(j:n)}[{}^{(j-1)}/_{(n-1)}] \quad (2)$$

$$b_2 = \frac{1}{N} \sum_{j=3}^{n} X_{(j:n)} \; [(j-1)(j-2)]/[(n-1)(n-2)] \quad (3)$$

$$b_3 = \frac{1}{N} \sum_{j=4}^{n} X_{(j:n)} \; [(j-1)(j-2)(j-3)]/[(n-1)(n-2)(n-3)] \quad (4)$$

where

$X_{(j)}$ represents the ranked annual maximum discharge series in which $X_{(1)}$ is the smallest stream flow data $X_{(n)}$ is the largest. The samples estimates of the L-moment (i.e.λ_1, λ_2,λ_3 and λ_4) were computed by replacing β_1, β_2 ,β_3 and β_4 of equations 5, 6, 7 and 8 with b_0, b_1,b_2 and b_3 respectively.

$$\lambda_1 = L_1 = b_0 \quad (5)$$

$$\lambda_2 = L_2 = 2b_1 - b_0 \quad (6)$$

$$\lambda_3 = L_3 = 6b_2 - 6b_1 + b_0 \quad (7)$$

$$\lambda_4 = L_4 = 20b_3 - 30b_2 + 12b_1 - b_0 \quad (8)$$

The corresponding L-moment ratios (L-CV,L-Skewness and L-kurtosis) are described as follows:

- *L*-CV (Coefficient of variability) = τ_2
- *L*-Skewness = τ_3
- *L*-kurtosis = τ_4

L-CV is a dimensionless measure of variability . For a distribution or sample data that only has positive values , *L*-CV is normally in the range of $0 < L\text{-CV} < 1$. Negative values of *L*-CV are possible if the at-site mean has negative value. The descriptions of the relative magnitude of variability used is presented in Table 3.

Table 3: Magnitude of *L*-CV

Range of *L*-CV	**Description of Relative Magnitude of *L*-Cv**
0.000< *L*-CV< 0.025	Minimal variability
0.025< *L*-CV< 0.075	Minor variability
0.075< *L*-CV< 0.15	Moderate variability
0.015< *L*-CV< 0.400	Large variability
0.400< *L*-CV	Very large variability

L-Skewness is a dimensionless measure of asymmetry, which may take on positive or negative values. For a distribution or sample data, *L*-skewness is in the range of 0< L-skewness< 1 (Bayliss and Reed, 2001). The descriptions of the relative magnitude of asymmetry used is presented in Table 4.

Table 4: Relative Magnitude of Asymmetry.

Range of *L*-Skewness	**Description of Relative Magnitude of *L*-Skewness**
L-CV = 0.0	Symmetrical distribution
0.000< *L*-skewness< 0.050	Minor skewness
0.05< *L*-skewness < 0.150	Moderate skewness
0.015< *L*-skewness < 0.300	Large skewness
0.300< *L*-skewness	Very large skewness

L-Kurtosis refers to any measure of peakedness of the probability distribution of a real valued random variable. The parameters (τ_2, τ_3, τ_4) were computed using the equation below (Hosking and Wallis, 1997; Gubareva and Gartsman, 2010).

$$\tau_2 = \frac{\lambda_2}{\lambda_1} = \frac{L_2}{L_1} \qquad (9\ )$$

$$\tau_3 = \frac{\lambda_3}{\lambda_2} = \frac{L_3}{L_2} \qquad (10)$$

$$\tau_4 = \frac{\lambda_4}{\lambda_2} = \frac{L_4}{L_2} \qquad (11)$$

Three probability distribution models (EV1, Uniform and Exponential) selected for the study were fitted to the observed annual maximum discharge data.

The probability distribution models, their quantile functions and the equations for estimating their parameters by the method of L-moments are presented in Table 5.

Table 5: *L*-Moment Parameter estimates for selected Probability distribution models (Maidment, 2003)

Distribution	**Quantile function**	**Parameter Estimates by *L*-moments**
Extreme value type 1	X(F) = ξ –α ln(-ln F)	$\lambda_1 = \boldsymbol{\xi} + 0.5772\boldsymbol{\alpha}$ $\lambda_2 = \boldsymbol{\alpha}\ln 2$ $t_3 = 0.1699$

(EV1)	F = 1-1/T	$t_4 = 0.1504$
Uniform Distribution (U)	X(F) = α + (β-α) F	$\lambda_1 = \frac{\beta+\alpha}{2}$ $\lambda_2 = \frac{\beta-\alpha}{6}$ $t_3 = t_4 = 0$
Exponential Distribution	$X(F) = \xi - \frac{Ln(1-F)}{\beta}$	$\lambda_1 = \boldsymbol{\xi} + \frac{1}{\beta}$ $\lambda_1 = \frac{1}{2\beta}$

The adequacies of the fitted probability distribution models were evaluated by the use of four (4) goodness of fit (GOF) criteria namely: Root mean square error (RMSE), Relative root mean square (RRMSE), Mean Absolute Deviation Index (MADI), Maximum Absolute Error (MAE). The definitions of the goodness of fit criteria are presented in Table 6.

Table 6: **Definitions of Goodness of fit statistics**

S/N	TEST	ABBREVIATIONS	MATHEMATICALEQUATIONS
1	Root Mean Square Error	RMSE	RMSE=$\left(\frac{\Sigma(x_i-y_i)^2}{(n-m)}\right)^{\frac{1}{2}}$
2	Relative Root Mean Square Error	RRMSE	RRMSE =$\left(\frac{\Sigma\left(\frac{x_i-y_i}{x_i}\right)^2}{(n-m)}\right)^{\frac{1}{2}}$
3		MADI	

	Mean Absolute Deviation Index		$MADI = \frac{1}{N}\sum_{i=1}^{N} \lvert \frac{x_{i-} y_i}{x_i} \rvert$
4	Maximum Absolute Error	MAE	MAE = max $\lvert(x_i - y_i)\rvert$

The best fit distribution at a station was selected based on a scoring and ranking scheme. Ranking of the distribution at a station was based on the relative magnitude of the results of goodness of fit test results. The distribution with the lowest RMSE, lowest RRMSE, lowest MADI and lowest MAE at a station were considered the best fitting probability distribution model with respect to the test criteria and was assigned a score of 3, the next was given a score of 2 and the least probability distribution was given a score of 1. The overall score of each distribution at a location based on Goodness of fit (GOF) test criteria was obtained by summing the individual point scores of the different tests at the stations and the probability distribution with the highest total score at each station was judged as the best fit probability distribution model for the station. The best fit probability distribution model at a station was utilized to estimate quantiles for different return periods. The return periods of interest that were utilized were T= 2 years, 5 years, 10 years, 25 years, 50 years , 100 years and 200 years respectively.

The results of the descriptive statistics of the annual maximum series of the discharge data. are presented in Table 7

Table 7: Descriptive statistics of Annual Maximum series of Daily discharge data

Gauging station	**Mean ($\bar{X}$)**	**Standard deviation (S)**	**Skewness Coefficient (G)**	**Coefficient of Variation (S/$\bar{X}$)**
Lokoja	17,187.633	6182.39	**-** 0.67099	0.3596
Onitsha	15,864.35	6785.33	**-** 0.86069	0.4277

As indicated previously the discharge data at each location are ranked in ascending order. The corresponding probability weighted moments (PWMs) and *L*-moments and *L*-moment ratios for each sample data were computed using MS- EXCEL programming and the results are presented in Tables 8 and 9 respectively.

Table 8: Computed sample probability weighted moments

Station	River	Sample probability weighted moments.			
		b_0	b_1	b_2	b_3
Lokoja	Niger	17,187.63	10,279.87	7323.235	5711.06
Onitsha	Niger	15,864.35	9800.213	7032.27	5488.76

Table 9: Computed sample *L*- moment values and *L*-moment ratios at stations

Station	River	Sample *L*-moment values				*L*-moment ratios		
		L_1	L_2	L_3	L_4	L-Cv (τ)	L-Cs(τ_3)	L-Ck(τ_4)
Lokoja	Niger	17,187.63	3372.11	-29845.60	724.96	0.1962	-8.8507	0.21498
Onitsha	Niger	15,864.35	3736.08	-28872.40	545.41	0.23550	-7.728	0.1458

After obtaining sample L-moments the parameters of the Extreme value type 1 (EV1), Uniform (U) and Exponential (EXP) probability distributions were estimated with the governing equations given in Table 4 and using MS-EXCEL programme. The estimated parameters of the selected probability distribution models are as presented in Table 10.

Table 10: Estimated Parameters of the selected 2 parameter probability distribution models

STATION	EV1 distribution		Uniform distribution		Exponential distribution	
	ξ	α	B	α	Ξ	β
Lokoja	14,379.60	4864.92	27,303.95	7071.31	10,443.18	1.483x10^ -4
Onitsha	12,753.23	5,390.02	27,072.58	4656.13	8392.2	1.338x10^ -4

The observed and predicted annual maximum discharge for each gauge station based on EV1, Uniform and Exponential distributions using *L*-moments approach are as presented in Tables 11 and 12.

Table 11: Observed and Predicted values for River Niger at Lokoja by the three Probability distributions

Discharge (Observed)	PREDICTED DISCHARGE BY DISTRIBUTIONS		
	EVI	UNIFORM	EXPONENTIAL
31692	33830.39706	26936.08778	37470.44632
27018	30413.03208	26568.22156	32795.54843
25929.41	28394.50154	26200.35535	30060.90847
24706.06	26948.23491	25832.48913	28120.65054
23797.98	25815.17541	25464.62291	26615.66957
23547.48	24879.91616	25096.75669	25386.01058
22827.27	24080.88102	24728.89047	24346.34872
22514.14	23381.30093	24361.02425	23445.75265
22138.38	22757.44619	23993.15804	22651.37062
22075.76	22193.1018	23625.29182	21940.77168
21598	21676.69004	23257.4256	21297.95675
21530	21199.65024	22889.55938	20711.11269
20986	20755.46918	22521.69316	20171.26849
20748	20339.07184	22153.82695	19671.45083
20442	19946.42263	21785.96073	19206.13172
20170	19574.25555	21418.09451	18770.85476
19830	19219.88612	21050.22829	18361.97491
19762	18881.07702	20682.36207	17976.47273
19535.33	18555.94002	20314.49585	17611.81895
19524	18242.86281	19946.62964	17265.87379
19422	17940.4536	19578.76342	16936.81087
19354	17647.49842	19210.8972	16623.05886
19328.5	17362.92765	18843.03098	16323.25608

19150	17085.7894	18475.16476	16036.2148
18810	16815.22813	18107.29855	15760.89282
18776	16550.467	17739.43233	15496.3706
18742	16290.79322	17371.56611	15241.83277
18640	16035.54564	17003.69989	14996.55294
18572	15784.1039	16635.83367	14759.88122
18266	15535.87883	16267.96745	14531.23383
18164	15290.30365	15900.10124	14310.08445
17892	15046.82568	15532.23502	14095.95687
17722	14804.89813	15164.3688	13888.4189
17359.33	14563.97181	14796.50258	13687.07702
16794.08	14323.48632	14428.63636	13491.57197
16124	14082.86031	14060.77015	13301.57484
15897.33	13841.48031	13692.90393	13116.78378
15614	13598.68758	13325.03771	12936.92107
15104	13353.76191	12957.17149	12761.73064
14745	13105.90131	12589.30527	12590.9759
14714	12854.19566	12221.43905	12424.43776
13846	12597.59179	11853.57284	12261.91298
13505	12334.84569	11485.70662	12103.21267
12699	12064.45562	11117.8404	11948.16097
11591.1	11784.56518	10749.97418	11796.59387
11166.4	11492.81827	10382.10796	11648.35819
10744	11186.13288	10014.24175	11503.31062
9978.4	10860.33126	9646.375527	11361.31692
6132.8	10509.49817	9278.509309	11222.25112
4954.467	10124.78014	8910.643091	11085.99493

4011.799	9691.902523	8542.776873	10952.43706
3706.799	9185.256444	8174.910655	10821.47272
3196.4	8550.390865	7807.044436	10693.00308
3038	7626.474386	7439.178218	10566.93488

Table 12: Observed and Predicted values for River Niger at Onitsha by the three Probability distributions

Discharge (Observed)	PREDICTED DISCHARGE BY DISTRIBUTIONS		
	EVI	UNIFORM	EXPONENTIAL
26100	32703.04781	26525.56829	36140.01048
25000	28899.16364	25978.83659	30960.81475
24500	26644.42938	25432.10488	27931.17946
23700	25023.01584	24885.37317	25781.61902
23100	23747.85873	24338.64146	24114.2904
22400	22691.04432	23791.90976	22751.98373
22000	21784.29508	23245.17805	21600.16985
21700	20986.81278	22698.44634	20602.42328
21200	20272.23988	22151.71463	19722.34844
20800	19622.53781	21604.98293	18935.09467
19829	19024.798	21058.25122	18222.937
19800	18469.44566	20511.51951	17572.788
19700	17949.16429	19964.7878	16974.70888
18815	17458.21909	19418.0561	16420.97412
18300	16992.01335	18871.32439	15905.45938
18159	16546.78729	18324.59268	15423.22755
18000	16119.4071	17777.86098	14970.24038
17900	15707.21283	17231.12927	14543.15271

17880	15307.90587	16684.39756	14139.16243
17773	14919.46307	16137.66585	13755.89893
17480	14540.06941	15590.93415	13391.33883
17025	14168.06313	15044.20244	13043.74127
16943	13801.88922	14497.47073	12711.5977
16629	13440.05769	13950.73902	12393.59226
16300	13081.10405	13404.00732	12088.57032
15410	12723.54891	12857.27561	11795.51315
15000	12365.85383	12310.5439	11513.51742
14725	12006.36953	11763.8122	11241.77838
14600	11643.27098	11217.08049	10979.57604
13566	11274.47152	10670.34878	10726.26365
13018	10897.50303	10123.61707	10481.25809
12078	10509.34055	9576.885366	10244.03182
11494	10106.13257	9030.153659	10014.10598
7442.9	9682.763481	8483.421951	9791.044642
3919.9	9232.098092	7936.690244	9574.449767
2873.8	8743.572269	7389.958537	9363.956974
2866	8200.284322	6843.226829	9159.231839
2440	7572.080195	6296.495122	8959.966697
2105.5	6795.115301	5749.763415	8765.877863
2002	5681.554836	5203.031707	8576.703201

Based on Table 11 and 12, the best fit from amongst the probability distribution models fitted to the observed data at the stations were selected by subjecting the respective predicted discharge values (based on EV1, Uniform and Exponential distributions) to statistical goodness of fit tests as defined in Table 6. The computed goodness of fit statistics for the distributions for River Niger at Lokoja and Onitsha stations is as presented in Tables 13 and 14 respectively.

Table 13: Goodness of fit test results for distributions of River Niger at Lokoja

Test criteria	Distribution values		
	EV1	UNIFORM	EXPONENTIAL
RMSE	2455.01	2195.44	3470.93
RRMSE	0.4667	0.3981	0.6426
MAE	5680.1	4755.91	7528
MADI	0.2199	0.1955	0.3057

Table 14: Goodness of fit test results for distributions of River Niger at Onitsha

Test criteria	Distribution values		
	EV1	UNIFORM	EXPONENTIAL
RMSE	3047	2307	4139.30
RRMSE	0.7767	0.6069	1.0840
MAE	6603.04	4516.16	10,040.01
MADI	0.3913	0.3054	0.5217

The overall goodness of fit of each distribution was judged using a ranking scheme by comparing the relative magnitude of the statistical test results obtained for the three distributions as presented in Tables 13 and 14. The distribution with the lowest values of RMSE, RRMSE, MAE and MADI was assigned a score of 3, the next was given a score of 2 and highest values was assigned a score of 1. The overall score of each distribution was obtained by summing the individual point scores and the distribution with the highest total point score was selected as the best distribution model. Hence from the results as given in Tables 15 and 16, the best fit distribution model for River Niger at Lokoja and Onitsha stations is the Uniform distribution.

Table 15: Scoring and ranking scheme for distributions of River Niger at Lokoja

Test criteria	Distribution values		
	EV1	UNIFORM	EXPONENTIAL
RMSE	2	3	1
RRMSE	2	3	1

MAE	2	3	1
MADI	2	3	1
Total score	**8**	**12**	**4**
Rank	**2nd**	**1st (Best)**	**3rd**

Table 16: Scoring and ranking scheme for distributions of River Niger at Onitsha

Test criteria	**Distribution values**		
	EV1	**UNIFORM**	**EXPONENTIAL**
RMSE	2	3	1
RRMSE	2	3	1
MAE	2	3	1
MADI	2	3	1
Total score	**8**	**12**	**4**
Rank	**2nd**	**1st (Best)**	**3rd**

The plots of the observed and predicted values for the stations using the best fit probability distribution models for the stations is as given in Figures 28 and 29.

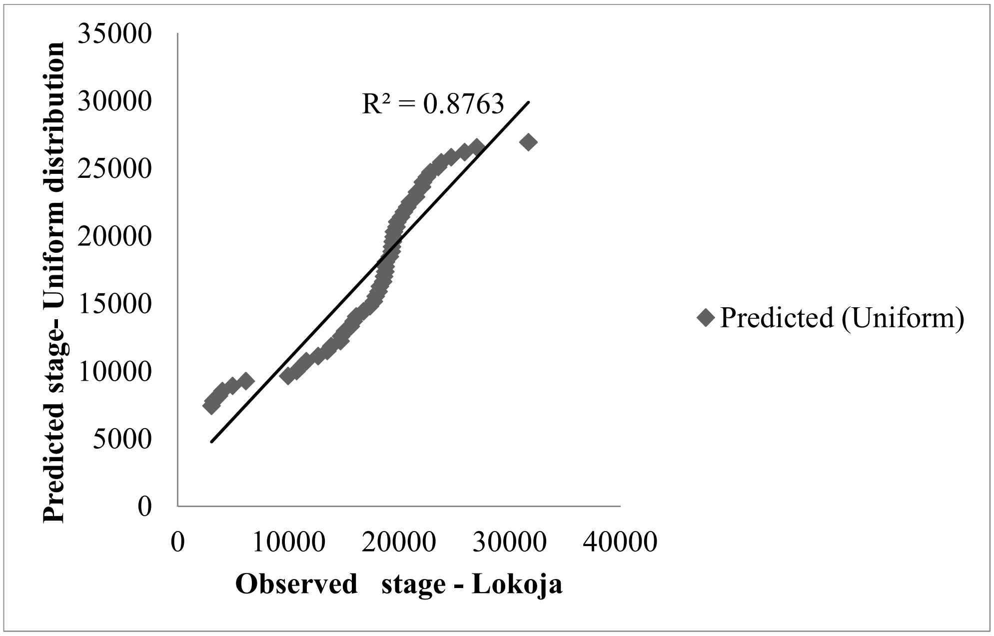


Figure 28: Plot of Observed vs Predicted discharge by Uniform distribution (Lokoja)

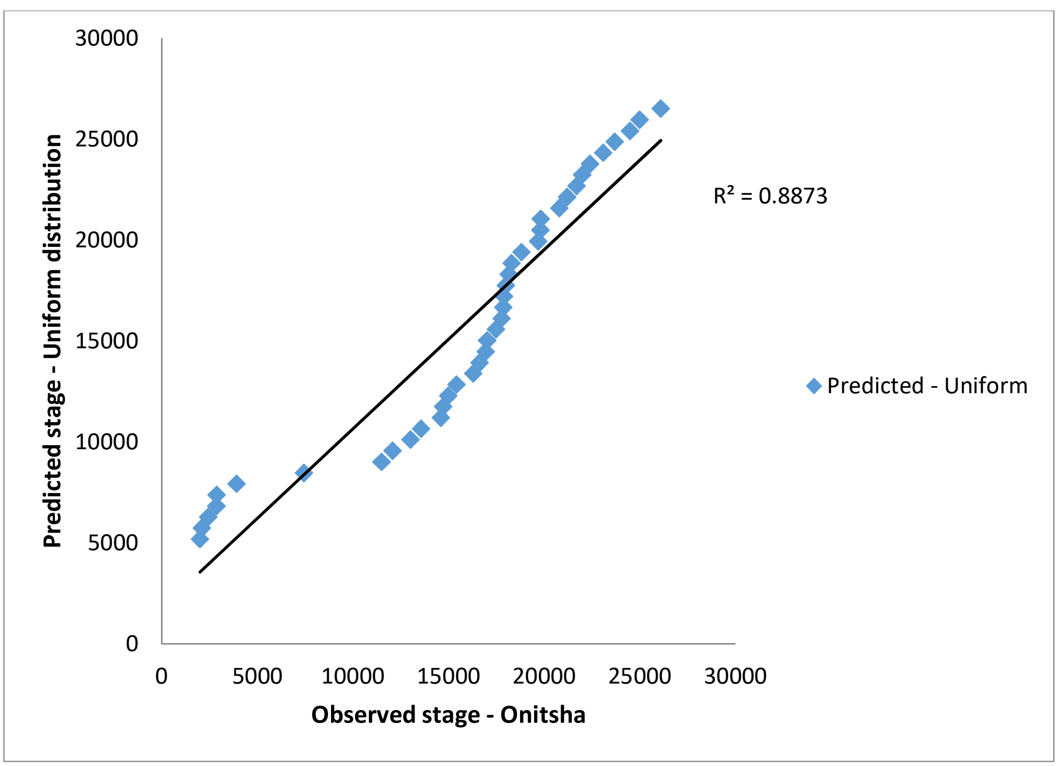


Figure 29: Plot of Observed vs Predicted discharge by Uniform distribution (Onitsha)

. Using the best fit distribution the predicted values for return periods of 2 years, 5 years, 10 years , 25 years, 50 years ,100 years and 200 years are summarized in Table 17.

Table 17: Predicted values for different return periods.

Station	**Best fit Distribution**	**Predicted gauge heights for return periods**						
		T=2yrs	T=5yrs	T=10yrs	T=25yrs	T=50yrs	T=100yrs	T=200yrs
Lokoja	Uniform	17,187.63	23,257.43	25,280.69	26,494.64	26,899.29	27,101.62	27,202.78
Onitsha	Uniform	15,864.36	22,589.29	24,830.94	26,175.92	26,624.25	26,848.42	26,960.50

In a previous study, Izinyon and Ehiorobo (2014) carried out flood frequency Analysis of River Okhuwan at Ugonoba in Benin Owena River Basin in Nigeria based on annual maximum discharge data at the site for 20 years (1989 - 2008) and utilizing three (3) selected parameter probability distribution models (namely Generalized Extreme Value (GEV) distribution, Generalized Logistic (GLO) distribution and Generalized Pareto(GPA) distribution) whose parameters were estimated by method of *L*-Moments. In the study, the best fit probability distribution model to the observed data at the site was found to be GPA, followed by GLO and GEV after subjecting the predicted discharge values by the distributions to four goodness of fit criteria namely: RMSE, RRMSE, MADI and PPCC (Probability plot correlation coefficient) and a scoring and ranking scheme. The quantiles predicted by the three probability distributions for the station for selected return periods of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years and 200 years as adapted from Izinyon and Ehiorobo (2014) are as presented in Table 18.

Table 18-: Quantile Estimates for River Okhuwan at Ugonoba for selected return periods (Izinyon and Ehiorobo, 2014)

Return Period (years)	2	5	10	25	50	100	200
F= (1- 1/T)	0.5	0.8	0.9	0.96	0.98	0.99	0.995
X(F) = Q_T (m^3/s) **-GPA**	69.81	100.27	107.27	110.38	111.12	111.39	111.49
X(F) = Q_T (m^3/s) **-GEV**	68.68	95.80	107.35	117.26	122.27	125.87	128.48
X(F) = Q_T (m^3/s)**-GLO**	68.39	92.85	105.75	120.09	129.73	138.62	146.87

As GPA is upper bounded beyond return period of 25 years (the distribution produces very minimal differences in quantile estimates beyond return period of 25 years), the study recommended that GPA should be utilized for analysis of annual maximum series data at the site up to 25 years return period and for return periods beyond 25 years, the GLO was recommended for use. It is to be noted that unlike the case of Lokoja and Onitsha, data availability and gaps in the existing data was a major constraint in this station.

4.4 Impact of Flooding on the Ecosystem and Agriculture

In Nigeria, the Niger Delta region suffered the most extensive devastation of flood because of its location in the lowest part of Nigeria where the Niger and Benue rivers empty their waters into the Atlantic Ocean (Akpokodje and Giadom, 2014). Flooding of low-lying areas have uprooted settlement in the coastal region. In some places, especially in Forcados, some oil wells have been lost to the ocean due to flooding. Flooding poses serious problem for the economic activities in the Niger Delta especially natural sectors such as farming and fisheries (about 50% of the fishes consumed in Nigeria is from the Niger Delta). Coastal vegetation especially the mangroves have been lost to flooding.

Generally, rise in sea level will exacerbate flooding of the coastal areas thereby dislodging coastal fishing settlements and infrastructure, as well as changing the general inshore and ocean dynamics. Coastal mangroves which serve as nursery grounds for a large variety of fishery organisms will also be decimated. Increased salinity of ground water, estuaries, creeks and deforestation are other adverse impacts of expected sea level rise. Flooding brings about changes in salinity of the aquatic environment of the Niger Delta. There are three main ecological delineations based on salinity; fresh, brackish and marine water environments. Highly important commercial fish species of the Niger Delta region such as the clupeids (Ethmalosa fimbrata), catfishes (Clarias and Bagrus spp.) and cartilaginous fishes such as sharks, skates and rays has adapted to these different salinity ranges. Thus, effects of sea level rise leading to inflow flooding in the Niger Delta results in increased salinity of both surface and ground water due to the intrusion of sea water. This will lead to the death of aquatic plants and animals that cannot tolerate high salinity. Most aqua-cultural facilities in the Niger Delta are impounded with water using mainly groundwater. The implications of this is that salt water intrusion in fresh water ponds beyond the tolerable limits due to flood water inflow from the sea unto the land leads to either impaired development or outright mortality of the cultured fish species. In most cases, because most mortality cases of cultured fish species are not subjected to post mortem examinations and water quality monitoring is not adequately done in the Niger Delta fish farms, establishing a link between them and salt water intrusion induced salinity changes is rarely implicated. This analogy elucidates an indirect ecological consequence of flooding that may have been very salient, but significantly and adversely affecting aquaculture yield in the Niger Delta region.

Rising temperatures and more frequent floods can compromise food security. Increase in malnutrition is expected to be especially severe in countries where large populations depend on rain-fed subsistence farming. In addition, flooding can be followed by outbreaks of diseases, such as cholera, especially when water and sanitation services are damaged or destroyed. Storms and floods are already among the most frequent and deadly forms of natural disasters. Flooding and heavy rainfall can cause overflows from sewage treatment plants into fresh water sources. Overflows could contaminate certain food crops with pathogen-containing faeces (USGCRP, 2009).

The economy can also be severely affected by flooding. Businesses may lose stock, patronage, data and productivity and disruption to utilities and transport infrastructure can have knock-on effects to a wider area. Tourism, farming and livestock can equally be affected. Vital infrastructure may also be damaged or disrupted. Electricity and gas supplies can be interrupted to individual properties but also to wider communities if sub stations and transformers themselves are flooded. Road links, railways, canals etc., may be blocked causing disruption to the wider transport network and accessibility severely disrupted for local inhabitants, especially amongst those considered most vulnerable and loss of communications networks (Adelye and Rustum, 2011).

Hence, flood frequency analysis will help to effectively manage flood. The results from the studies indicated that Extreme value type 1 (EV1), Uniform (U) and Exponential (E) distribution (with Uniform (U) distribution been the best) can be used to describe the discharge data for some areas within the Niger Delta Basin (Lokoja and Onitsha). Also the Generalized Pareto(GPA) distribution and the Generalized Logistic (GLO) distribution can be used for analysis of annual maximum series data at River Okhuwan at Ugonoba in Benin Owena River Basin. Thus these distributions can be used for future flood prediction within these areas.

4.5 Effect of Topography and LandUse on Flooding

The study area (Niger Delta River Basin) consist of a network of meandering rivers and creeks with mangrove swamp and rain forest vegetation. The lower basin of the river Niger flows and discharges through a massive delta known as the Niger Delta into the Gulf of Guinea in the Atlantic Ocean. The Niger Delta river basin lies between latitudes 4˚ 14’ 26’’ N to 8˚ 10’ 36’’N and longitudes 4˚ 2’ 50’’ E to 9˚ 19’ 5’’E. The lowest elevation in the area is about 78 meters below sea level and rises to as high as 1128 meters above sea level. The soil type in this region is lightly or average saturated ferralitic soils. In this region, the lower Delta River Basin formation is a layer of sedimentary origin which is Cretaceous deposits found from Onitsha. The tertiary marine layer which crosses the cretaceous layer and Quaternary sediments are found from the coastal plain and the Delta (Andersen, Dione, Jarosewich-Holder, & Olivry, 2005).

The Digital Elevation Model (DEM) for the study area was obtained from the Shuttle Radar Topographic Mission database (SRTM) at a spatial resolution of 30m with the use of Google Earth Engine interface. This was then used to delineate the sub-watersheds of the lower Niger Delta River Basin and extract major streams within the area (using ArcHydro extension in ArcGIS). The DEM with the defined streams and the delineated sub watersheds are shown in Figure 30 and 31.

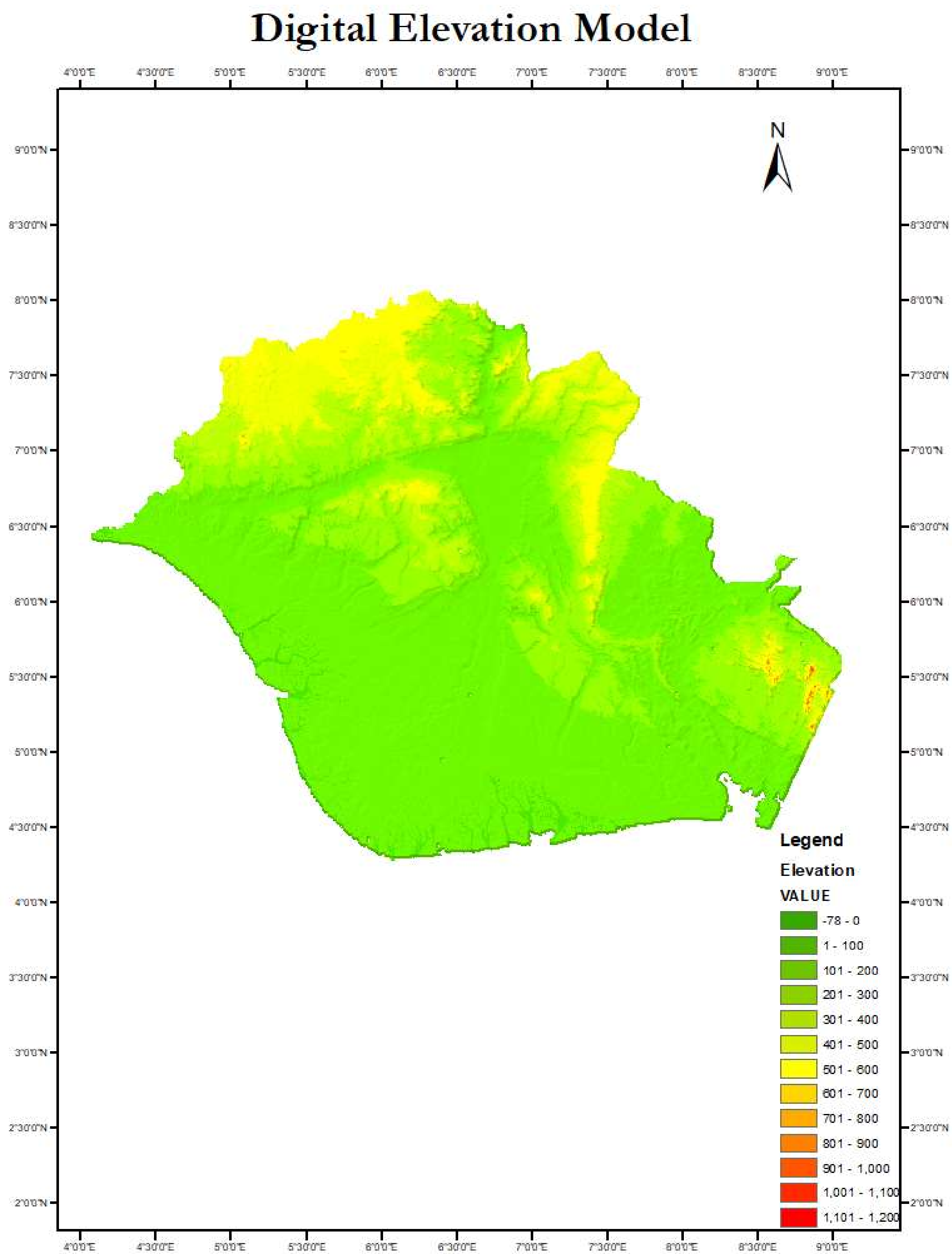


Figure 30: Digital Elevation Model (DEM) for Niger Delta River Basin

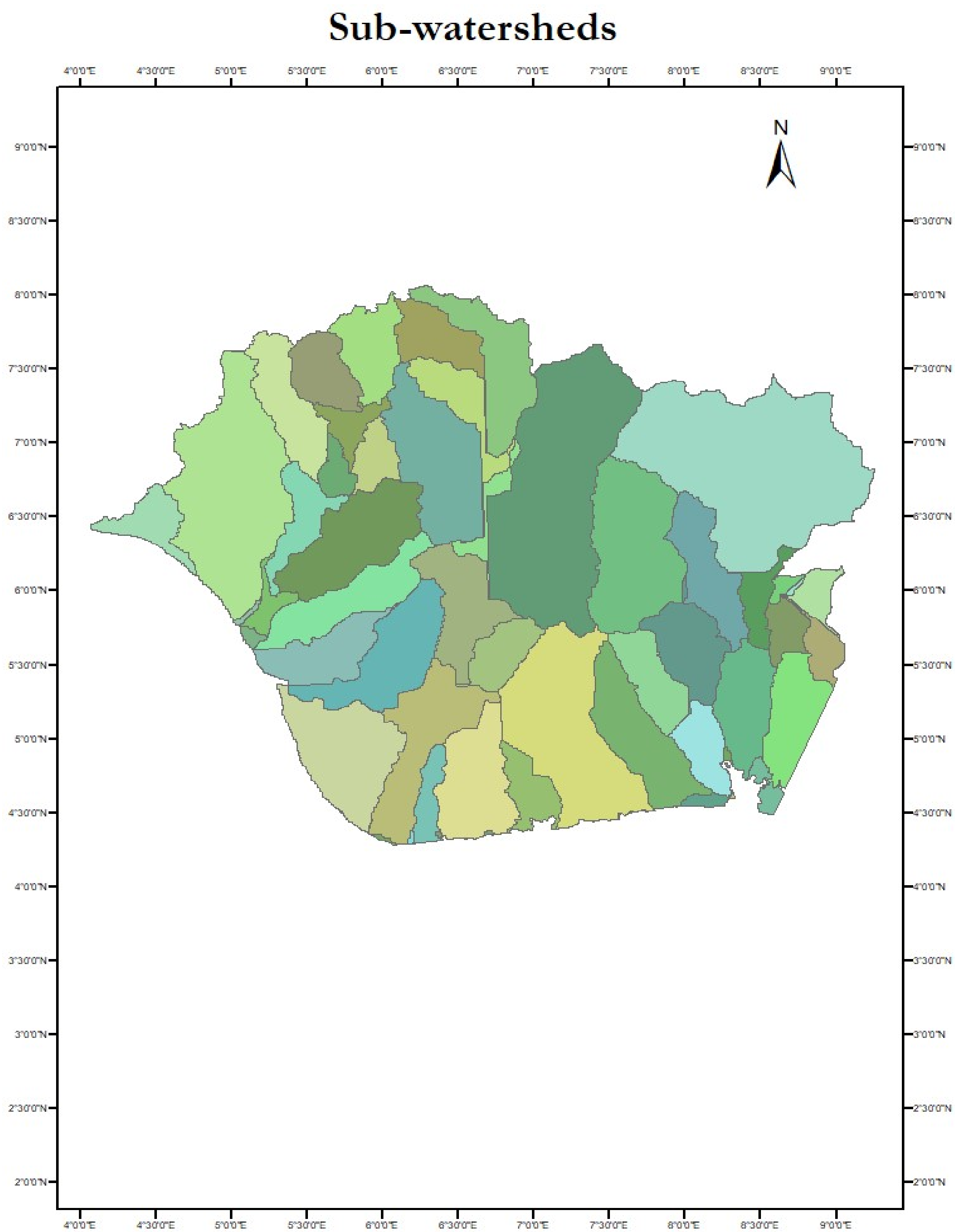


Figure 31: Sub-watersheds of the Lower Niger Delta River Basin

5.0 Dams and Reservoirs Operation in the Study Area

In a country like Nigeria, the demand for water, food and energy will continue to rise as a result of increase in population growth. With the rapid decline in revenue from crude oil (almost the sole export commodity) and mismanagement of the economy over the last few years, coupled with continuous bombing and destruction of crude oil and gas facilities, Nigeria have slide into recession (Ehiorobo and Izinyon, 2016).

There are increasing concerns on the demand side as essential food commodities are disappearing from the market and prices of available commodities are now outside the reach of the average Nigerian. Today, much of the energy supply in the country is expected to come from Hydropower as a result of the current unstable gas supply due to militancy in the Niger Delta Region.

In order to derive the needed energy supply, many more multi-purpose Dams need to be developed not only for water supply but Hydropower generation as well as for irrigation and fishery. In this complex system, reservoirs are expected to be used for irrigation (by use of pumps and irrigation ditches), provide potable water supply to communities and Power turbine for energy generation. As water becomes scarce as a result of the multiple usages there is competition between energy, agriculture and domestic water availability (Ehiorobo and Izinyon 2016).

There is therefore the need to develop effective cross-sectorial mechanism to address the problem and ensure that decisions taken on water release and water use are coordinated in such a way as to provide an integrated multi sectorial strategy. Data and geomatics tools are key components within cross sectorial outcome and acts as a key support mechanism for the development of an integrated multi-sectorial strategy for effective water use.

5.1 Existing Dams in the Lower Niger Basin

A compendium of Nigeria Dams compiled by the Department of Dams and Reservoir Operation put the number of Dams in Nigeria at 198 (Federal Ministry of Agriculture and Water Resources 2007).

Table 19: Classification of Dams in Nigeria Based on I COLD Classification

Dam Size	**Dam Height (Meters)**	**Reservoir Capacity (million cubic meter)**	**Flood discharge (cubic meters per second)**	**Crest Length (meters)**
Large	>15	>1	>2000	>700
Small	<15	<1	<2000	<500

Nigeria is divided into 8 hydrological zones and the number of large and small dam in each hydrological zones are shown in Table 20.

Table 20: Distribution of Dams Per Hydrological Zone

S/N	Hydrological Zone	No. of Large Dams	No. of Small Dams	Total No. of Dams	Remarks
1	1	8	15	23	
2	2	26	14	40	
3	3	3	4	7	
4	4	12	21	33	
5	5	1	6	7	
6	6	13	35	48	
7	7	2	9	11	
8	8	13	16	29	

From Table 20, it can be seen that zones 3 and 5 have the least number of dams while zones 2 and 6 have the highest number of dams. The limited number of dams in hydrological zone 3 and 5 is mainly due to the nearness of the area to sea level as well as the topographical and geological characteristics of the region (Ehiorobo, 2016).

Dams in the study area (Niger Delta Basin) exist within hydrological zone 6 and out of a total number of 48 dams in this zone, about 14 (comprising of both large and small dams) are in Niger Delta Basin. Table 21 shows the existing dams in the study area.

Table 21: Existing Dams and Reservoirs in Niger Delta Basin

S/N	Name	Category and Type	Geographical Location		Hydrological Zone (HA)	River	State	Reservoir Capacity	Purpose and Owner
			Longitude (˚E)	Latitude (˚N)					
1	Apariko-Aisegba dam	Large (Homogeneous)	5˚27'E	7˚34' N	6	Apariko	Ekiti	4.7 MCM	Irrigation & Water Supply
2	Awara dam	Small (Homogeneous)	5˚40'E	7˚30' N	6	Ashodi	Ondo	-	Water supply &Irrigation (OSWC)
3	Ayede dam	Small (Homogenous)	5˚56'E	7˚53' N	6	Ayede	Ekiti	1.5MCM	Water supply (EKWC)
4	Ikara dam	Medium	5˚45'E	7˚15' N	6	Asande	Ondo	7.7MCM	Water supply (OSWC)
5	Ikpoba dam	Small (Earth filled)	5˚38'E	6˚22' N	6	Ikpoba	Edo	1.5MCM	Water supply (ESUWB)
6	Itapayi dam	Large (Homogeneous)	5˚27'E	7˚57' N	6	Ele	Ekiti	1.5MCM	Water supply (ESUWB)
7	Egbe dam	Large (Concrete)	5˚58'E	7˚20' N	6	Little Osse	Ekiti	2.3MCM	Water supply (ESUWB)
8	Little Osse dam	Large Concrete (Homogenous)	5˚34'E	7˚36' N	6	Little Osse	Ondo	-	Water supply (ESUWB)
9	Ojirami dam	Large Earth fill	6˚09'E	7˚17' N	6	Oyanmi	Edo	4.5 MCM	Water supply (ESUWB)

		(Homogenous)							
10	Osse (Egbe) dam	Large Concrete/Earth Filled	5˚34'E	7˚36' N	6	Little Osse	Ekiti/Ondo	0.42 MCM	Water supply (ESWC)
11	Ogwashi-Uku dam (Under Construction	Large	-	-	6	Ubu	Delta	18 MCM	Water supply &Irrigation (BORBDA)
12	Owena dam	Large Earth fill (Homogenous)	5˚01'E	7˚11' N	6	Owena	Ondo (Idanre LGA)	36.25MCM	Multipurpose (BORBAD)
13	Owena Multipurpose dam	Large Earth fill (Homogenous)	5˚ 13'E	7˚16' N	6	Owena	Ondo (Ifedore LGA)	36.25 MCM	Multipurpose (BORBAD)
14	Ukhun/ Erha dam	Small	6˚ 10'E	6˚51' N	6	Okwego	Edo	0.8MCM	Irrigation

5.2 Multi-Purpose Utilization of Dams and Reservoirs- A Case Study of Ikpoba Dam in Benin City

For effective utilisation of dams and reservoirs in Niger Delta Basin, there is need for continuous monitoring and evaluation of the Dam and Reservoir in the following areas:

- Provision of sufficient potable and qualitative water from Reservoir
- Groundwater recharge from Reservoir
- Effectiveness of Dams and Reservoir utilization for hydropower development
- Study of siltation in Reservoirs
- Effective utilization of Dams in flood control and regulation of river flow

- Water storage in reservoir for water supply, irrigation and hydropower supply.

In Niger Delta region, particularly in Benin city water supply is sourced from two sources namely; surface water source and ground water source. The surface water source is obtained from the dam reservoir across the Ikpoba river operated by Edo state urban water board and ground water sourced from boreholes drilled to aquiferous Benin formation. The Ikpoba River Dam is presently non-functional.

Benin city has experienced its fair share of the changing global climatic trends (such as increase in rainfall and temperature) in recent years. The old or traditional methods of planning and management which is employed by Government owned water utilities had failed as evident is in the lack of water supply to the consumers. Among the several reasons for this failure are the deficiencies in the old method of planning, which relied on projecting future populations, per capita water demand, agricultural production and levels of economic productivity which is expected to rise. Then, large structures were built to solve water supply problem without thorough study of the catchment hydrology, land use, demographic trends, analysis of what water is actually used for and how water is required to meet different types of demands nor do they try to identify common goals for water development among conflicting stakeholders or seek agreement on principles to resolve conflicts over water if it arises. Stakeholders are not consulted in the planning process of water resources allocation and development. Demand management is regularly being left out and no conservation measures or policies in place which could help in sustainability of water resources (by reducing investment and maintenance cost). These had led to the non-sustainability and degradation of the system.

Water resource and infrastructure development is expensive and can require a decade or more to complete major projects. Developing too early can cause water utilities to lose money on unused facilities or developing too late risks economic and social impacts of water shortages arising. It is important that decision making be accurate and transparent to stakeholders (public and decision makers). To this end, water utilities are seeking better tools to guide and incorporate significant uncertainties. Therefore, it is proposed that with the use of Integrated Water Resources Management (IWRM) decision support system, supporting tools such as Water Evaluation and Planning (WEAP) software can be used by water utilities to better prepare themselves for uncertainties associated with climate change, demographic changes, economic changes and other planning elements.

Hence, this has led to the investigation of the present condition of Ikpoba river dam in terms of its capacity to deliver water to the Benin Community and its irrigation potentials. The areas that were investigated included:

- The existing condition of Benin City water supply system.
- The current and likely future challenges facing urban water management by the people and water operators in Benin City.
- The existing Water policies in place and their effectiveness.

- Hydrological study and water Demand and Supply balance analysis for Benin City catchment using WEAP software.
- The impact of climate change on water resources in Benin City Using WEAP.

5.3 Decision Support System (DSS) for Sustainable Water Supply

A method for the decision plan for Benin City Water Supply was developed by a combination of WEAP model and Multi-criteria decision making. The method adopted was the Traditional scenario which was used to describe circumstances of how variable could unfold over time and affect the water supply-demand balance. The areas evaluated included:

- Overview and assessment of Benin City water supply system
- Hydrological modelling of Benin City Catchment using WEAP to determine Water demand –supply balance
- Development of management framework for Benin City using DPSIR IWRM Framework

The Benin City Water Supply System (BCWSS) Managers and its customers were used as the main source of data and information. Semi-structured questionnaires were used to interview key staff and customers on the general performance of the utility, as well as an appraisal of the dam's operational and performance of water utilities. Questionnaires were administered to consumers to determine their level of satisfaction with water supply in Benin City. Interviews were also conducted with water supply managers to find out the present status of water supply system compared to standard utility. Visits were made to Ikpoba river dam to assess the water distribution facilities (such as pipes, storage tanks, pumps, their capacities, their age, etc.) and ascertain the type of water they distribute to the consumers (i.e. whether surface or ground water). In the process, a survey was conducted by administering questionnaires to each district manager in the reservoir stations visited to get basic information on the state of the facilities.

An inventory of indicators specific for Benin City was created from literature. Four general performance categories were selected, namely: Technical performance, customer care, and quality of service, and human resources development and capacity building.

Thereafter, the performance category was divided into corresponding or more appropriate performance indicators applicable for BCWSS including expected performance targets in line with international standards based on the Africa Utility Performance Assessment issued in 2009 by Water Operators Partnerships-Africa (WSP-Africa, 2009). The performance categories and the corresponding performance indicators are shown in Table 22.

Table 22: List of Selected Performance Indicators to Evaluate the State of Benin City Water Supply System

Category	**Performance Indicator and Unit**	**Description**	**Expected Benchmarking Target**
Technical Performance	Water coverage (%)	Percentage of households connected to WDS	90%
	Water production (litres/person/day)	Total annual water supplied to the WDS expressed by population served per day	Variable
	Water consumption (litres/person/day)	Average annual water consumed from WDS expressed by population served per day	76 l/c/d
	Metering level (%)	Total number of connections with operating meter/total number of connections	100%
Customer Care and Quality of Service	Continuity of service (hours/day)	Average hours of service per day for water supply	24hours
	No. of complaints/ 1000 connections	Average number of customer complaints per 1000 connections	Variable
Human Resources Utilization & Development	Staff /1,000 Water Connections (#/1,000 water conn)	Total number of staff expressed as per thousand Connections	7 Staff/1000 connections
	Staff Training Participation Rate (%)	Percentage of the staff participated in training	30%

Based on the feedback obtained from the district managers in the service stations visited, the responses to the questionnaire filled by water managers was weighted in percentages and compared with an ideal case of 20% defective allowance. Statistical analysis and mathematical computations were conducted for data obtained from consumer. For each of the performance indicators, the expected performance targets were set and the state and quality of water services delivered by BCWSS were evaluated. A visit was also made to Edo state urban water board headquarters, Benin City, where information about the water service stations in Benin City were obtained. An interview was conducted with the European Union state representative on water policy formulation to obtain information on the present planning/management and policies in place in the water supply sector in Edo state.

5.4 Assessment of Benin City Water Supply System

In developing a planning and management framework for a catchment, one of the necessary requirements is an assessment of the existing water supply system. The assessment on Benin City water supply system that was carried out included:

- Assessment of water supply infrastructure
- Assessment of consumer satisfaction

The Edo State Water Board in Benin City has several district stations (Iyaro, St. Emmanuel, Ikpoba Hill, Ugbowo, Adesuwa (GRA), Upper Sakponba, Useh and Okhoro (Ikpoba dam)); each district station has smaller substations under them. The district stations are usually smaller water works containing pumps, treatment facilities and reservoir which can satisfy the need of the immediate environment. Among the district stations existing presently, it was observed that Esigie, G.R.A, Iyaro and Ugbowo stations (see Figure 32 to 33) are in fairly (about 20%) good working condition. Most times these stations experiences power outage due to the epileptic power supply and in specific cases as a result of faulty transformers supplying power, other minor failures of facilities such as the high lift pumps that lifts water into the elevated tanks affects water supply often times direct pumping into the service pipelines is resorted to. Ideally, all these service stations serve as a boost to the supply from the Ikpoba dam and consequently all the service mains are interconnected to achieve this aim. From what was discovered on ground, most service stations do not receive water supply from Ikpoba dam due to many factors that cuts across obsolete of facilities in the Ikpoba dam, pipe breakages during road construction, obsolesce of pumping machines, etc. These factors put together make the general water distribution system of Benin City inefficient and inadequate.

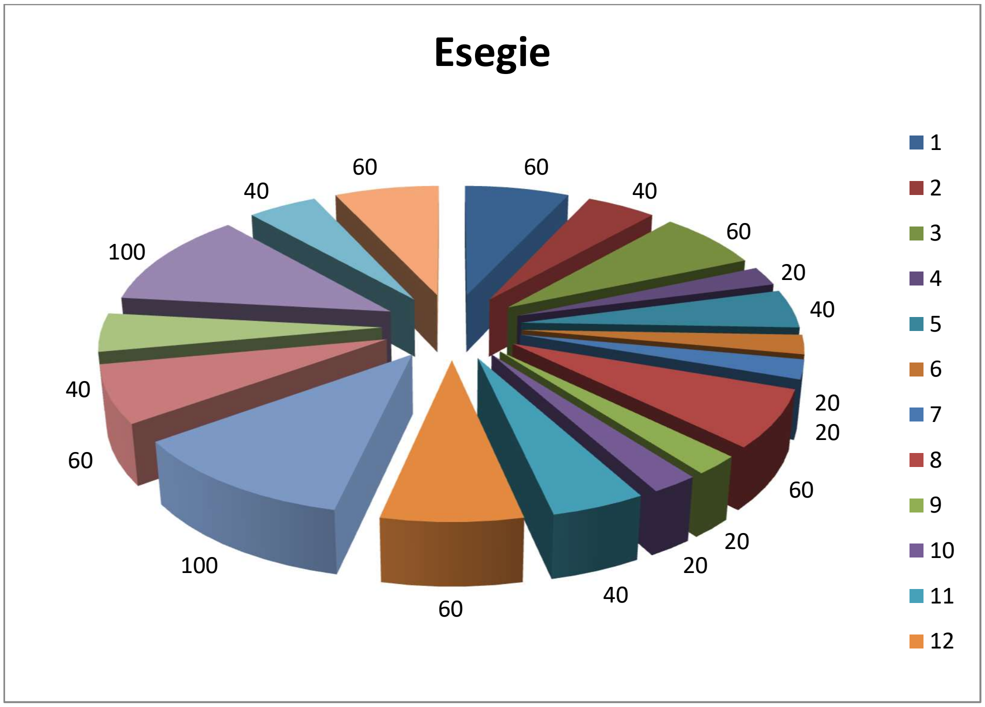


Figure 32: Present State Representation of Esegie Service Station in a Pie Chart

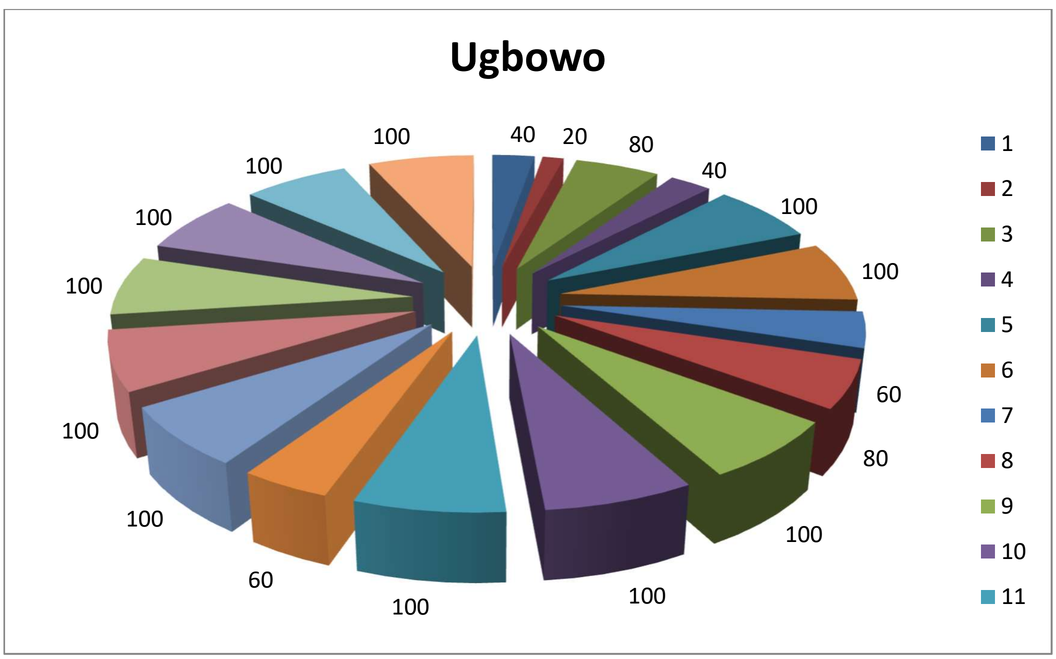


Figure 33: Present State Representation of Ugbowo Service Station in a Pie Chart

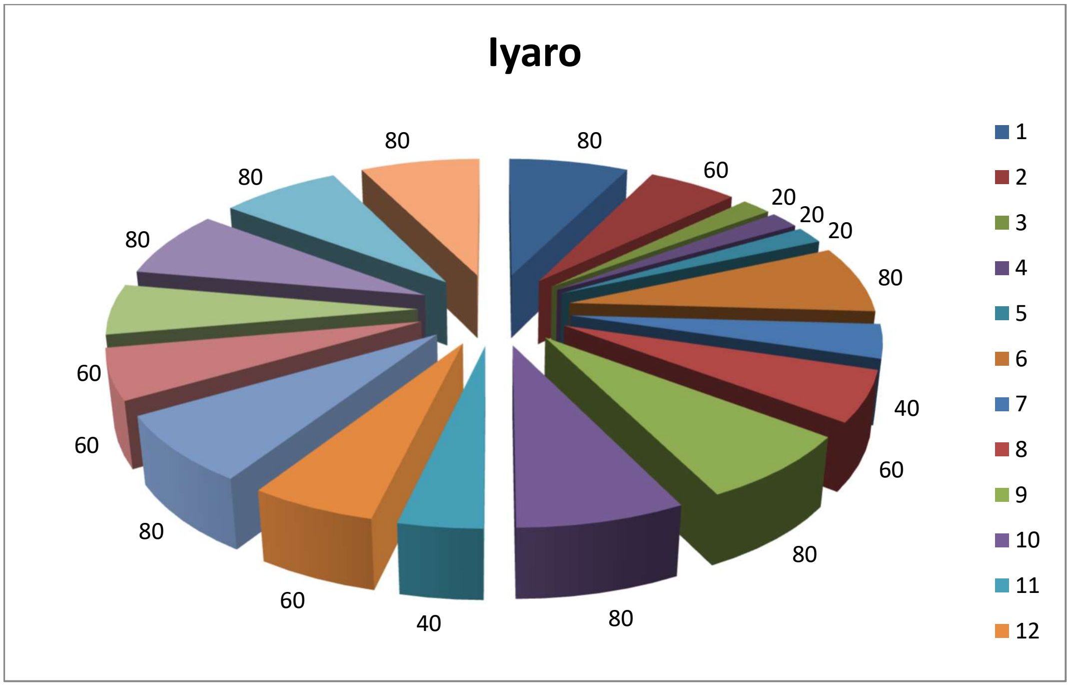


Figure 34: Present State Representation of Iyaro Service Station in a Pie Chart

Rapid population growth has not been accompanied by an increase in the delivery of adequate water supply facilities over the years and most facilities in place are in the state of obsolesce because of inadequate maintenance. The demand for potable water surpasses the provision made possible by the decayed water system. This in turn facilitates the mobilization of both public and private sector financing resources that are critical for infrastructure development.

From the research carried out and analysis done on the infrastructural assessment of the water supply facilities and appurtenances in the major public water supply stations in Benin city it can be concluded that the major source of water supply in Benin city is surface water but because of the poor funding and maintenance of the public water sector the facilities in place has overtime become obsolete. While some water service stations had the installed facilities in fairly good conditions, most facilities in place were discovered to be obsolete. Most of the water supply pipes have been exhumed during the recent road repairs

The phase two project at the Ikpoba dam, which has the same capacity with the existing dam at the moment is yet to be completed and when completed this will amount to a better and more efficient water supply distribution beyond Benin City to Edo State at large.

It is well known that water distribution project is very capital intensive, for example, the pipes are shipped from overseas and costs hundreds of thousands of dollars, desalting a filter bed as opined by a respondent, may take up to 2 months for completion and costs millions of naira and presently there are 12 filter beds in place, this brings to mind the need for sufficient funds to be made available to revamp the water facilities in Benin City.

The result obtained from analysing responses to the questionnaires issued to district managers indicates that on the average Benin City water supply system is 80% defective when compared to an ideal utility.

Questionnaires were used for assessing consumer satisfaction. These questionnaires were properly distributed to both sexes which indicate household head and their representatives, of which 52% were male and 48% females. The majority of respondents during the exercise were married, parents and working class adults between the ages of (31-60) years with the majority being formally educated (81.8%). Their nature of occupation was considered too. The number of persons per house gave (1-4) persons as 32.3%, (4-10) persons as 54.5, (11-15) as 8.1% persons and above 15 persons as 5.1%. 29.6% of those surveyed were house owner/landlord, 57.1% live in rented apartment and 13.3% non-paying tenants The educational qualification of the household heads indicates 8.1% primary, 10.1% secondary, 16.2% college, 35.4% tertiary, 12.1% others and 18.2% informal.

27% of the household heads are civil servants, 9% Technicians, 12.4% Medical personnel, 13.5% workman/labourers, 33.5% businessmen/women and 4.5% banker.

Results from the findings indicated that majority of consumers (50%) use boreholes as their source of water supply for various purposes except for drinking, (30%) from neighbor's wells/reservoir, (5%) from public standpipes, (10%) from public vendors, (5%) source from rain. The main source of drinking water is sachet water (70%), boreholes (20%), and piped water (10%). About 66.3% of consumers have their water source located less than 50meters indicating that part of this percentage are borehole owners while the other part source their water from close by neighbors, 24.8% were between (50m – 100m) and 8.9% were between (100 m– 200m). When asked how long it takes them to fetch water from their source, responses indicate that 47% takes less than 5min, 39% takes between (5 - 15) min and 14% takes between (15 - 30) min to fetch water from the existing source. Responses concerning the number of days in a week that water is available from the household source indicate 13% 2days, 11% 3days, 14% 4days 10% 5days 50% above 5days and 2% during weekends. While the number of hours in a day that water is available from the source indicate 8.9% between (1 - 5) hours, 10.9% between (5 - 10) hours, 16.8% between (10 - 15) hours and 63.4% (15 - 24) hours**.**
The study reveals that 30.9% use about two Jerry-cans (each can measure about 25litres) between (50 - 100) litres, 43.6% between (100 - 150) litres, 20.2% between (150 - 300) litres and 5.3% above 300 litres.

When asked about their satisfaction level with existing sources, 60.4% where not satisfied and 39.6% where satisfied. 22.8% were unsatisfied because of irregularity of supply, 18.8 due to poor quality and 8.9% due to distance from source, 9.9% due to the cost of water.

5.5 Hydrological Modelling of Benin City Catchment

WEAP modelling was used to carry out the water Demand and Supply balance analysis for Benin City catchment. This involved modelling the supply by representing the supply sources

(Ikpoba river, ground water and reservoirs) and relevant data in schematic option of WEAP, calibrating and validating the Model by ensuring that the model represented the catchment hydrology adequately (using the precipitation soil moisture method and its optimization to fit the observed stream discharge). This was then followed by modelling of demand sites (Domestic, Industrial and Commercial demand as well as Agricultural sectors) and then the final phase of scenario modelling (which also included climatic impact).

The following key assumptions were used in the WEAP modelling

- Population growth rate→ 3.3%
- Domestic Water use →120L/c/d (Water use rate for sanitation and health for domestic demand in line with World Health Organisation (WHO))
- Precipitation- (See Table 23)

Table 23: Monthly Rainfall Data (mm) of Benin City

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1960	0.42	0.11	1.24	12.52	10.27	9.82	12.33	14.02	14.70	7.18	1.13	0.37
1961	0.19	0.56	2.36	12.78	9.24	15.29	24.31	1.65	14.19	7.27	2.53	1.23
1962	0.06	0.44	3.52	7.45	5.33	11.20	18.47	9.45	9.02	11.72	5.53	0.48
1963	0.18	1.53	4.84	5.49	6.43	15.32	15.84	-	10.68	10.65	1.60	1.78
1964	TR	2.30	6.20	7.76	7.49	15.12	10.50	3.25	11.91	6.28	2.71	0.63
1965	0.14	1.60	3.04	9.63	5.64	12.29	40.72	21.30	14.11	5.47	0.11	0.39
1966	0.09	2.40	4.67	4.27	10.28	6.82	14.64	19.85	9.56	8.51	4.28	0.57
1967	0.00	0.29	5.12	3.74	7.02	5.72	13.55	2.56	20.61	13.73	3.55	3.61
1968	0.43	0.09	5.16	7.14	7.06	7.15	16.72	12.92	16.24	9.71	0.51	0.06
1969	0.00	2.62	9.07	7.91	5.79	7.86	14.28	10.14	-	-	-	-
1970	0.48	0.07	4.29	5.27	8.88	7.92	352.7	245.5	22.81	10.24	1.19	0.00
1971	24.0	20.4	142.4	115.2	108.8	229.8	373.1	288.2	539.3	224.0	10.4	23.1
1972	12.7	125.1	26.3	266.0	151.9	149.4	323.6	215.2	303.2	103.3	2.6	23.4
1973	TR	29.8	41.6	222.6	178.7	258.0	329.0	375.3	379.4	241.9	3.7	45.7
1974	TR	37.4	77.8	116.6	128.1	363.2	489.4	268.3	410.7	281.6	20.1	0.00
1975	0.00	55.0	56.8	218.6	226.7	334.8	501.4	232.2	292.3	149.1	162.8	42.8

1976	0.00	130.1	141.5	154.0	161.8	358.3	316.2	129.3	386.0	425.3	139.0	76.7
1977	7.50	58.7	68.0	107.3	125.8	351.4	229.7	153.4	276.1	258.0	38.1	41.9
1978	20.5	148.8	149.4	294.6	326.4	235.6	242.4	219.7	437.1	131.9	176.1	52.9
1979	0.00	89.1	44.2	303.9	123.0	233.2	359.5	529.0	309.3	252.5	40.4	TR
1980	3.20	58.3	77.8	140.4	296.3	298.5	407.8	482.3	445.8	300.1	120.1	14.7
1981	5.60	6.80	102.4	119.8	277.2	180.6	276.1	230.0	394.8	178.1	12.9	1.10
1982	101.9	111.4	98.2	211.4	146.0	174.1	243.9	66.8	391.0	381.9	42.4	20.0
1983	4.90	49.4	39.0	76.8	267.4	277.2	166.5	142.8	425.2	50.3	29.8	22.8
1984	6.40	45.8	87.3	59.3	120.4	134.1	223.8	181.8	235.1	154.8	4.40	2.50
1985	8.70	16.0	110.5	33.2	173.4	202.5	244.3	305.2	197.9	147.5	106.1	50
1986	5.60	45.1	109.4	52.3	162.7	65.1	214.2	117.7	231.3	166.5	67.1	30.2
1987	0.8	74.3	100.2	112.5	157.4	217.0	269.5	722.5	348.1	299.8	39.9	28.5
1988	7.0	71.1	154.8	136.5	168.0	227.0	393.0	191.2	445.4	273.2	23.2	58.6
1989	10.0	25.8	66.1	152.0	140.4	340.0	279.2	427.8	157.3	365.1	14.2	25.1
1990	19.6	18.8	55.0	256.8	181.4	204.1	353.4	614.5	296.9	289.9	33.7	68.9
1991	18.9	58.1	123.5	386.3	196.7	207.2	656.2	382.6	268.0	267.9	39.2	11.9
1992	0.30	6.20	41.4	222.7	240.0	335.8	515.9	76.4	256.3	292.2	35.6	16.1
1993	5.10	9.60	135.0	95.40	198.2	208.8	191.4	433.9	251.6	174.2	108.1	48.6
1994	27.5	14.6	111.4	149.8	327.9	351.3	444.4	461.2	391.8	204.5	43.0	21.8
1995	13.0	50.6	165.4	217.9	226.9	256.2	383.3	580.8	382.2	240.2	124.7	9.10
1996	7.0	92.6	188.2	298.2	322.2	281.1	182.3	392.3	476.0	292.7	3.60	1.10
1997	75.3	80.0	104.0	230.9	305.3	203.3	285.0	258.0	300.0	285.0	15.6	2.10
1998	44.1	1.80	104.6	104.8	214.6	214.4	506.1	95.6	387.9	244.0	58.8	42.0
1999	56.3	64.4	98.3	119.6	161.7	-	412.3	232.0	369.0	472.5	97.8	9.40
2000	4.0	73.0	60.8	170.0	191.8	413.7	294.7	237.9	345.0	351.2	49.0	48.7
2001	18.8	10.1	119.3	394.3	155.7	364.3	216.0	137.4	351.0	185.0	82.6	3.90
2002	-	115.0	163.5	278.1	199.4	344.9	411.3	491.8	294.8	149.5	101.0	9.90

2003	33.9	13.7	172.0	169.8	226.5	187.6	177.1	142.1	393.3	338.1	57.3	26.3
2004	28.8	28.3	68.4	118.9	250.7	448.9	288.0	403.0	297.6	299.8	94.3	1.60
2005	-	9.80	182.2	119.6	95.5	450.2	458.8	97.0	207.6	333.2	40.0	20.1
2006	33.1	22.3	146.0	117.1	394.0	240.2	462.4	359.2	334.4	217.8	32.0	-
2007	-	-	91.6	183.5	350.2	347.9	354.3	303.3	462.5	263.5	152.0	18.5
2008	10.3	2.80	146.1	160.1	215.6	272.9	413.6	319.7	199.3	90.6	95.4	-
2009	14.6	108.6	69.8	157.8	330.5	171.8	175.0	248.3	294.5	342.9	161.0	23.0
2010	15.5	68.6	55.3	321.5	79.6	145.4	91.6	332.2	615.1	267.4	306.5	40.7
2011	-	77.8	87.0	321.5	353.5	430.9	550.8	502.5	409.3	414.6	63.6	0.00
2012	47.7	53.2	74.8	157.1	383.7	490.4	395.3	124.9	255.5	283.4	186.7	0.00
2013	11.9	61.8	126.2	201.0	312.2	255.6	390.4	168.1	564.0	338.8	105.8	60.8

(Source: NIMET Agency, Benin City)

- Mean Temperature (see Table 24)

Table 24: Mean Temperature for Benin City

Month	Temp (^{o}C)
January	27.75
February	29
March	28.96
April	28.47
May	27.7
June	26.6
July	25.52
August	25.29
September	26
October	26.47
November	28

December	30.79

(Source; NIMET Agency, Benin City)

- Irrigation Area → 100ha (Hypothetical area)
- No monthly water demand variation, no data available.
- Monthly inflow to demand sites →6 CMS based on constraints of pump size
- Net Evaporation → 4.3mm (Annual mean) (NBS, 2010)
- Estimating Groundwater Recharge

Rainfall is the major source of groundwater recharge. The methods for estimating rainfall recharge involve empirical relationship established between recharge and rainfall developed for different regions. Kumar (1977) gave the following empirical relationship in 1970 to determine the groundwater recharge in limited climatologically homogenous areas;

R_r=K (P-X) (12)

The following relation is stated to hold good for different regions

R_r= 0.2(P-400) for areas with annual normal rainfall (P) between 400 and 600 m (13)

R_r= 0.25(P-400) for areas with annual normal rainfall (P) between 600 and 1000 m (14)

R_r= 0.35(P-400) for areas with annual normal rainfall (P) 2000mm (15)

Equation 15 was adopted for modelling Benin City groundwater recharge.

- Transmission links- To Domestic from BENRES =3.3 m^3/s (based on pump capacity) Maximum flow - no constraint, to Industrial demand site from BENRES = 3.3m^3/s Maximum flow – no constraint and to Agricultural site from IKPRES = 90% Maximum inflow - no constraint.

Five models were running for a period of 50 years' time step and each of the Model was having eighteen (18) hypothetical scenarios were cons they included:

- Reference Account – This scenario describes the water supply- demand balance based on current account information which is at the beginning of the year of modelling. The key assumptions for this scenario are;
  - Population growth rate – 3.3% (Ogunbodede et.al. 2013) (The major pattern of city expansion in Benin City is rural - urban migration and by natural population increase.)
  - Domestic water use rate- 120L/d
  - Precipitation (see Table 22)
  - Irrigation area 100ha
  - Cropping pattern includes Rice covers 20 of irrigated area, maize covers 40% of irrigated area, Cassava covers 40% of irrigated area
  - Method of irrigation is surface irrigation method

- Edo catchment contributing to head flow of Ikpoba River is 1000km^2. this value was obtained during calibration process.

- Increase in water use rate scenario (IWU) – This scenario assumes a change in water use rate from 120L/c/d which is the WHO record for Nigeria to 135L/c/d due to improvement in economic lifestyle as more people have washing machines, Jacuzi etc.
- Increase in population growth rate (IPGR) - This scenario assumes a one percent increase in population growth rate from 3.3% to 4.3%.
- Climatic change water year method (CCWY)-The water year method was used in this scenario The Water Year Method is a simple means to represent variation in climate data such as stream flow, rainfall, and groundwater recharge. The method first involves defining how different climate regimes (e.g., very dry, dry, very wet) compare relative to a normal year, which is given a value of 1. Dry years have a value less than 1, very wet years have a value larger than 1. Climatic change scenario.
- Maximum increase in temperature (MIT) - world climatic studies from Global Climatic Models (GCM), ECHAM model predicted changes of 2-2.5^{o}C temperature was used in this scenario. The maximum 2.5^o C predicted temperature increase was used. (Shuuaib et. al. 2012)
- Minimum increase in temperature (MINT) - world climatic studies from Global Climatic Models (GCM), CNRM model predicted changes of 2-2.5^{o}C temperature was used in this scenario. The minimum 2^{o}C predicted increase temperature was used. (Shuuaib et. al. 2012)
- Reduction in irrigation area (RIA10)- Irrigation area was reduced from 100ha to 10ha for sensitivity analysis
- Reduction in irrigation area (RIA50)- Irrigation area was reduced from 100ha to 50ha for sensitivity analysis
- Reduction in precipitation by 10 %(RIP10%) - precipitation was reduced by 10 % under Climatic change scenario
- Ten percent increase in precipitation (10%IP), under climatic change scenario.
- Increase in precipitation (IP) - GCM) CNRM model predicts increase of rainfall between 50-100mm across Nigeria (Shuuaib et. al. 2012) was used in this scenario. Under climatic change scenario.
- Increase in Irrigation Area (IIA) - This scenario assumes an increase in area irrigated from 100ha to 150ha. Sensitivity analysis
- Change in cropping pattern (CCP). This scenario assumes that only Rice is being cultivated in the whole area 100ha. And an increase in irrigation area to 150ha. Sensitivity analysis.
- Change in cropping pattern 3(CCP3). Assumes cropping pattern of Rice 40%, maize, 30%, Cassava 30%. Sensitivity Analysis
- Reduction in groundwater yield to 15m^3/(RIG15). Sensitivity Analysis

- Reduction of groundwater to 26m^3 (RIG26). Sensitivity Analysis
- Removal of groundwater source (REGWS).
- Increase in water use to 135l/c/day and increase in population growth rate by 1%(IWU/1%IP)

The models represented the present arrangement of the Benin City Water Supply System (BCWSS) and they are presented in Figure 34 to Figure 37.

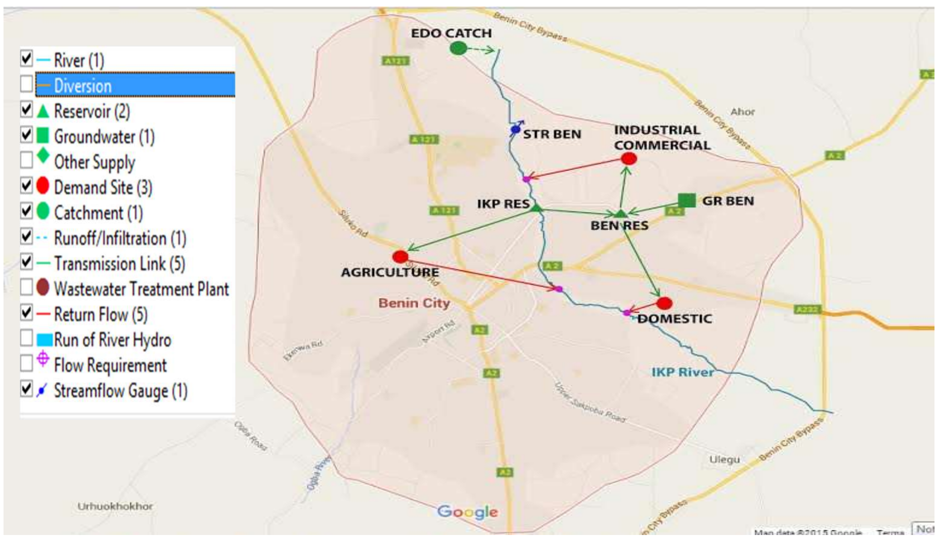


Figure 34: Schematic Diagram for Model One Showing the Channelling of Ikpoba river and ground water to Ikpoba main reservoir and six local reservoirs (which is represented by one reservoir)

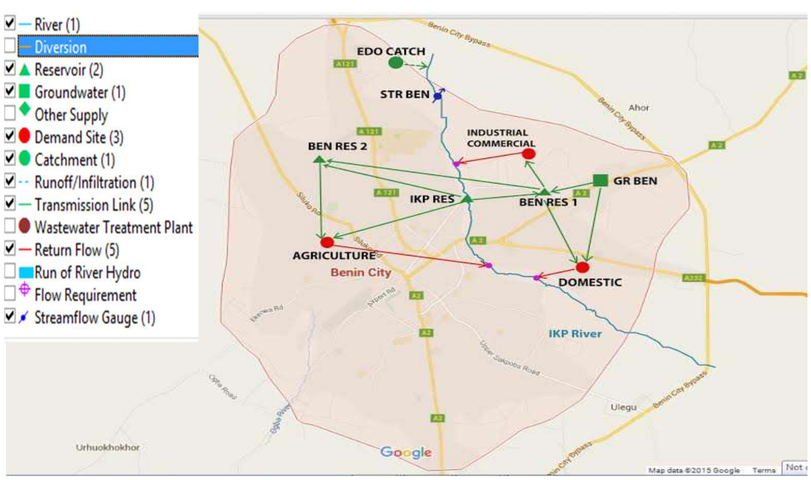


Figure 35: Schematic Diagram for Model Two Showing Additional Reservoirs for Agricultural Site Supplied from Groundwater

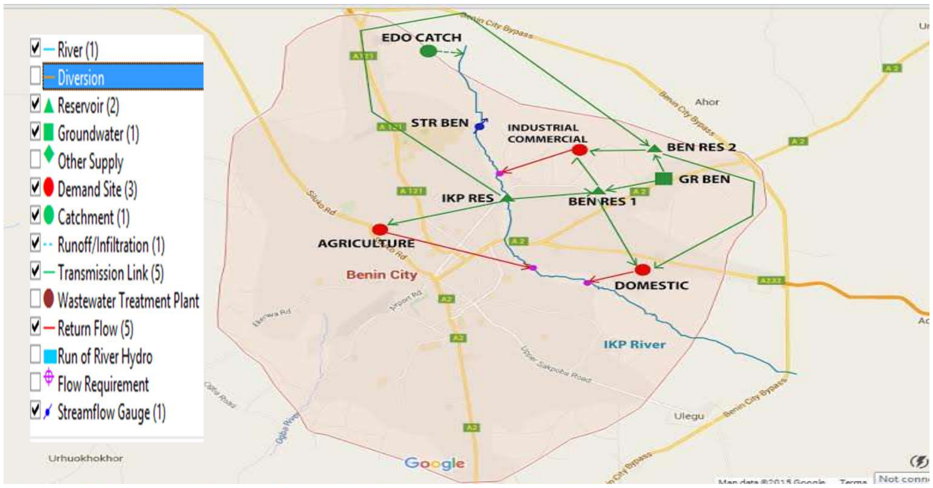


Figure 36: Schematic Diagram for Model Three Showing Additional Reservoir for Domestic and Industrial Demand Sites

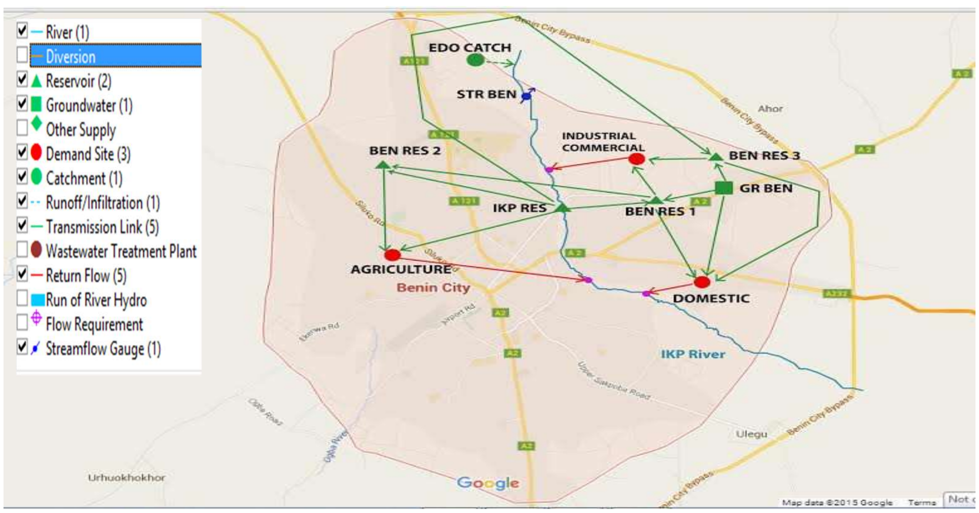


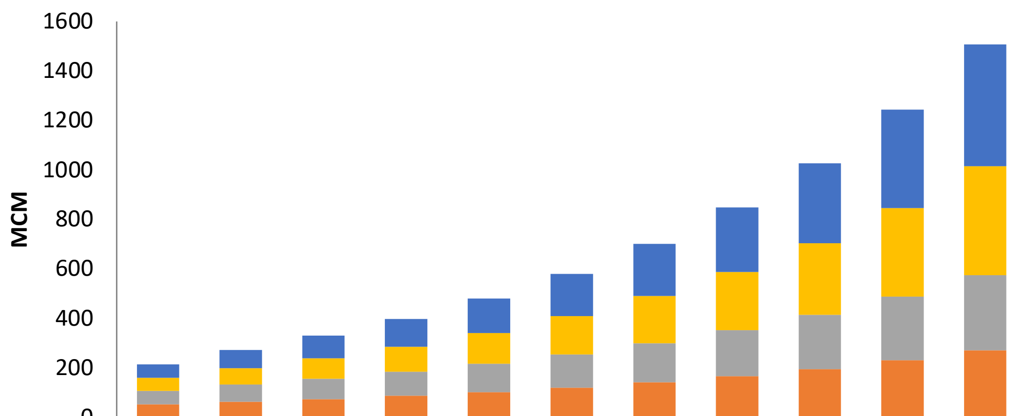
Figure 37: Schematic Diagram for Model four and Five Showing Combined Effects of all Additional Reservoirs with Linking Rules, Reservoir Operation and Priority

The results (Figure 38 to Figure 55) from WEAP modelling indicated that the five models modelled by WEAP showed similar trends in terms of high sesitivity to increase in population and increase in water use rate for domestic and others site . Climatic change scenerios had no significant change in all the scenerios(10%IP, MINT,MIT,RIP10%,CCWY) all the model behaved similarly as Business as usual scenerio(BAU). This could be as a result of high rainfall and high yied of Benin City Aquifer. Introduction of additional reservoir helped in reduction of unmet demand as seen in Model five but IPGR and IWU/1% IP scenerio after several years of demand met observed unmet demand. In Model two it was observed that removal of constraints for transimission lines reduced all unmet demand to Zero, but this is unrealistic because all water supply system have cconstraints which usually is the pump capacity. For

Agricutural site , unmet demand is sensitive to increase in irrigation area and combination of increase in Area and rice crop having the largest area creates highest demand. Water demand for rice is high and as far as it takes the largest area unmet demand could be high. Introduction of reservoir to Agricultural demand site reduced unmet demand to zero, but bearing in mind that for sustainability in any system, effective methods that will reduce cost are employed. Building a new reservoir (though it takes care of all the demand) is costly and incure a lot of debts on the government. Other measures like reduction in water demand should be employed (that is water conservation methods) these measures cost less and have huge success in several countries all over the world. In reality Agricultural site area that will be required if seriouse agricultural activitiies is to take place will be over 1000ha.

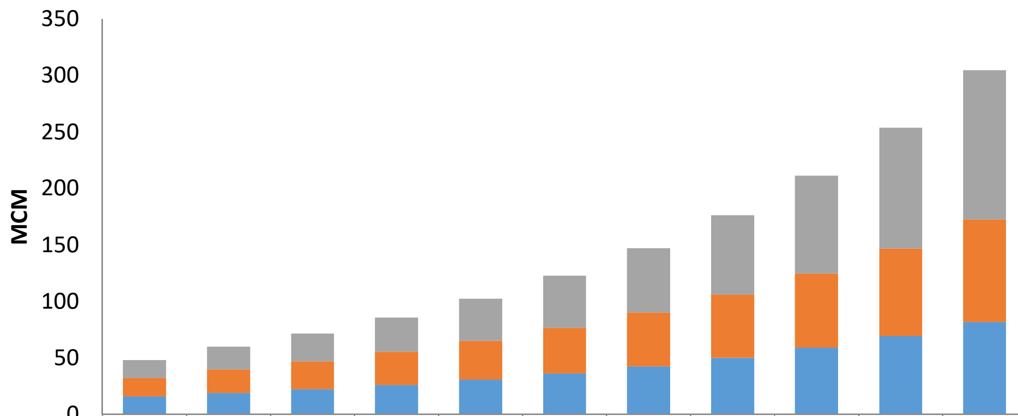
In general Demand site coverage for domestic site in Model one had 100% coverage for all scenarios up until the year 2025 , after then IWU, IWU/1%P and IPGR scenario coverage declined Steadily, by 2060 IPGR and IWU/1%P coverage would be about 20% while IWU would be about 34% coverage. The same trend was observed for Others demand site 100% coverage up until 2025 coverage for IWU/1%P and IPGR scenarios will decline to about 66 % and 75% respectively by 2060. Agricultural site coverage flunctuted between 89%-90% all throuh simulated years.

Models having introduction of reservoirs had high percentage coverage for all scenerios, however sustainability is requred since there is still a short fall in wate supply demand balance.



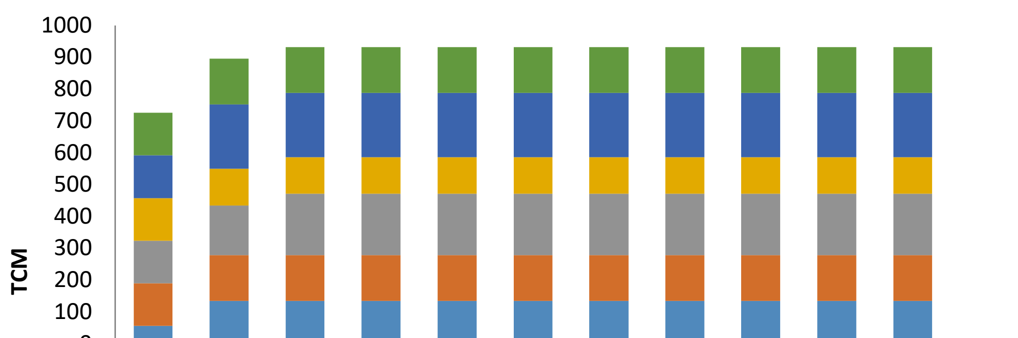
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	53.67	73.88	91.2	112.56	138.94	171.49	211.67	261.27	322.48	398.04	491.3
IPGR	53.67	66.25	81.77	100.93	124.58	153.76	189.79	234.26	289.15	356.9	440.52
IWU	53.67	70.41	82.82	97.42	114.59	134.78	158.54	186.48	219.35	258.01	303.49
BAU	53.46	62.89	73.97	87.01	102.35	120.39	141.6	166.56	195.92	230.45	271.07

Figure 38: Water Demand for Domestic Site



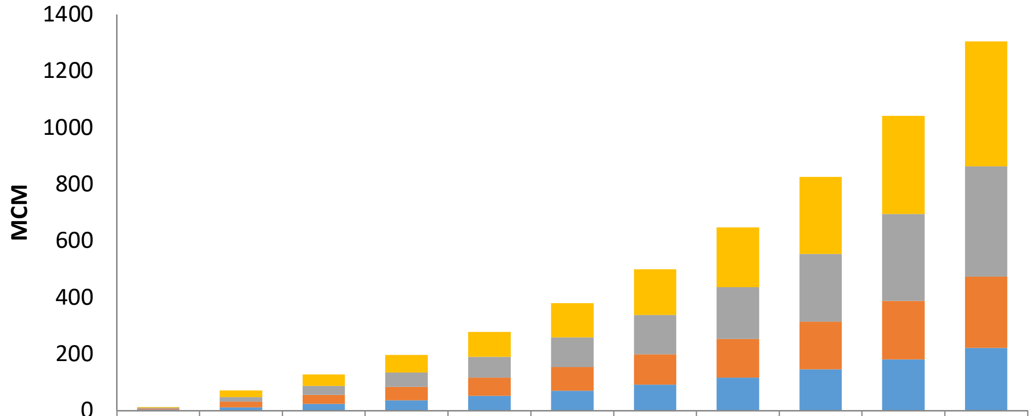
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IPGR	16.1	19.87	24.53	30.28	37.37	46.13	56.94	70.28	86.74	107.07	132.16
IWU	16.1	21.12	24.85	29.23	34.38	40.44	47.56	55.95	65.81	77.4	91.05
BAU	16.1	18.94	22.28	26.2	30.82	36.26	42.65	50.16	59	69.4	81.64

Figure 39: Industrial Site Water Demand



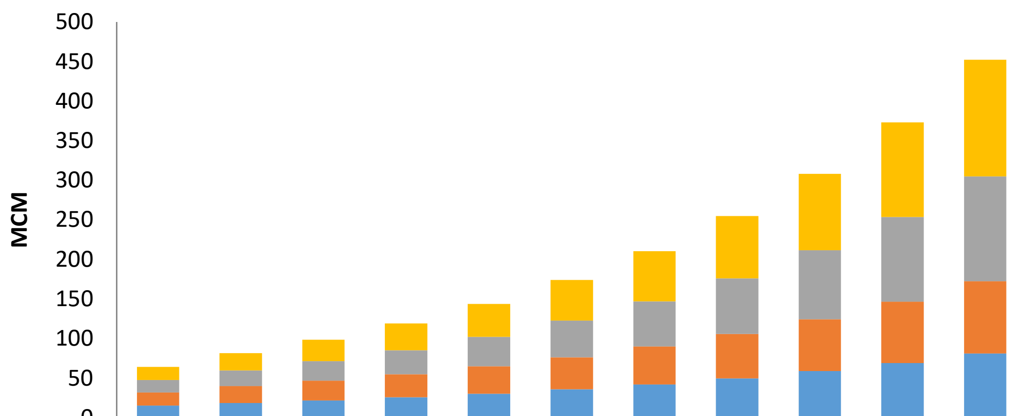
	2010	2015	2020	2025	2025	2035	2040	2045	2050	2055	2060
CCP	134	144	144	144	144	144	144	144	144	144	144
IIA	134	201.5	201.5	201.5	201.5	201.5	201.5	201.5	201.5	201.5	201.5
CCP2	134	115.4	115.4	115.4	115.4	115.4	115.4	115.4	115.4	115.4	115.4
CCP3	134	156	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4	192.4
CCP1	134	144	144	144	144	144	144	144	144	144	144
BAU	55.67	134	134	134	134	134	134	134	134	134	134

Figure 40: Agricultural Site Water Demand



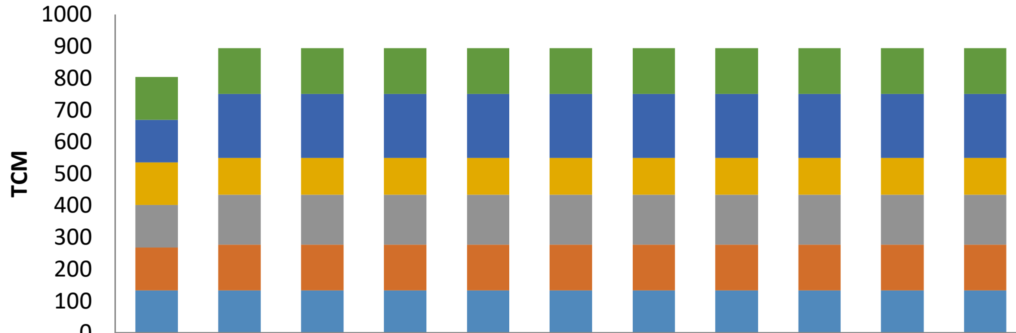
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	3.22	23.43	40.61	62.11	88.48	121.04	161.08	210.81	272.03	347.59	440.71
IPGR	3.22	15.8	31.18	50.48	74.12	103.31	139.2	183.81	238.7	306.44	389.93
IWU	3.22	19.96	32.23	46.96	64.14	84.33	107.95	136.03	168.9	207.56	252.9
BAU	3.22	12.68	23.67	36.9	52.29	70.4	91.56	116.76	146.23	180.89	221.53

Figure 41: Unmet Domestic Site Water Demand (M1)



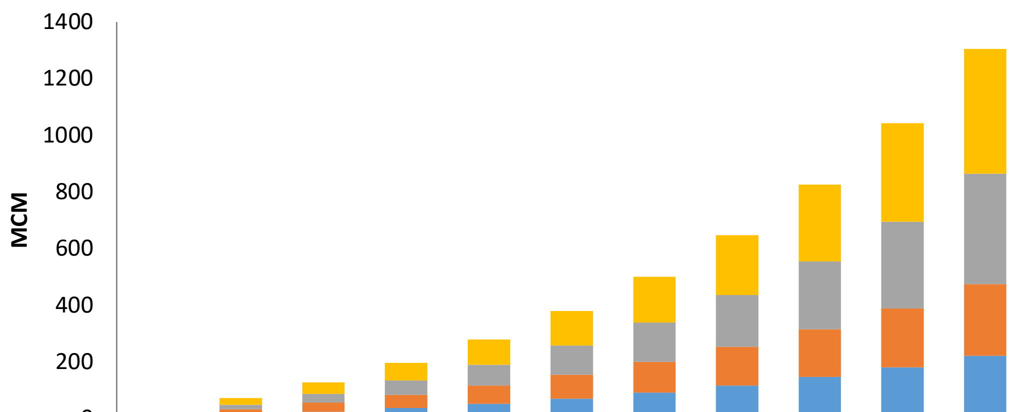
	2010	2015	2020	2025	2030	2035	2040	2040	2050	2055	2060
IWU/P	16.1	22.17	27.36	33.77	41.68	51.45	63.5	78.38	96.74	119.41	147.39
IPGR	16.1	19.87	24.53	30.28	37.37	46.13	56.94	70.28	86.74	107.07	132.16
IWU	16.1	21.12	24.85	29.23	34.38	40.44	47.56	55.95	65.81	77.4	91.05
BAU	16.1	18.94	22.28	26.2	30.82	36.26	42.65	50.16	59	69.4	81.64

Figure 42: Unmet Industrial Site Water Demand



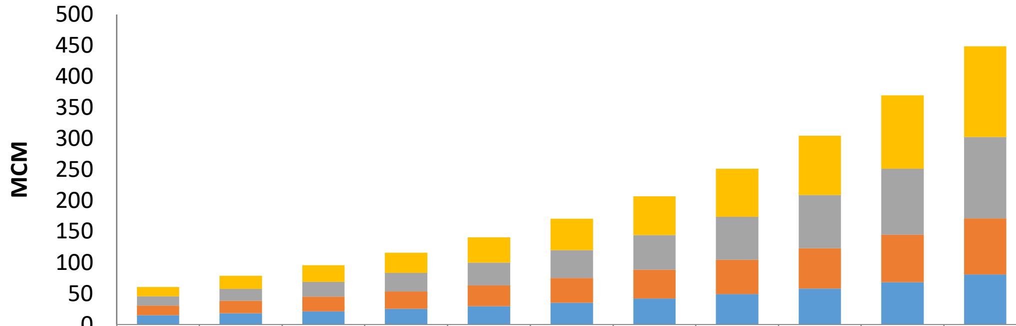
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
CCP	133.96	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97
IIA	133.96	201.12	201.12	201.12	201.12	201.12	201.12	201.12	201.12	201.12	201.12
CCP2	133.96	115.39	115.39	115.39	115.39	115.39	115.39	115.39	115.39	115.39	115.39
CCP3	133.96	155.98	155.98	155.98	155.98	155.98	155.98	155.98	155.98	155.98	155.98
CCP1	133.96	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97
BAU	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96

Figure 43: Unmet Agricultural Site Water Demand (M1)



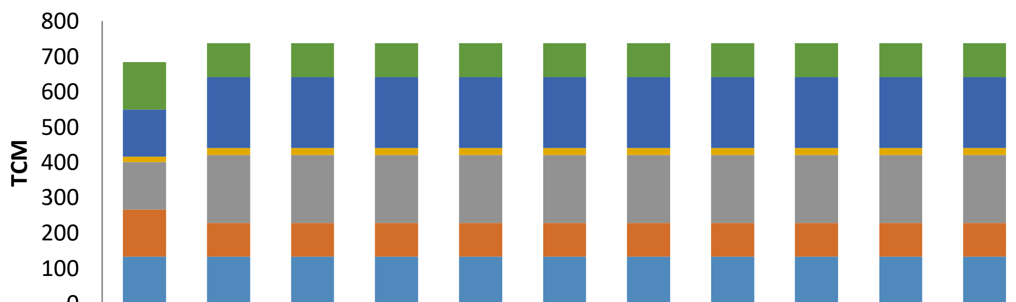
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	3.22	23.43	40.61	62.11	88.48	121.04	161.08	210.81	272.03	347.59	440.71
IPGR	3.22	15.8	31.18	50.48	74.12	103.31	139.2	183.81	238.7	306.44	389.93
IWU	3.22	19.96	32.23	46.96	64.14	84.33	107.95	136.03	168.9	207.56	252.9
BAU	3.22	12.68	23.67	36.9	52.29	70.4	91.56	116.76	146.23	180.89	221.53

Figure 44: Unmet Domestic Site Water Demands (M2)



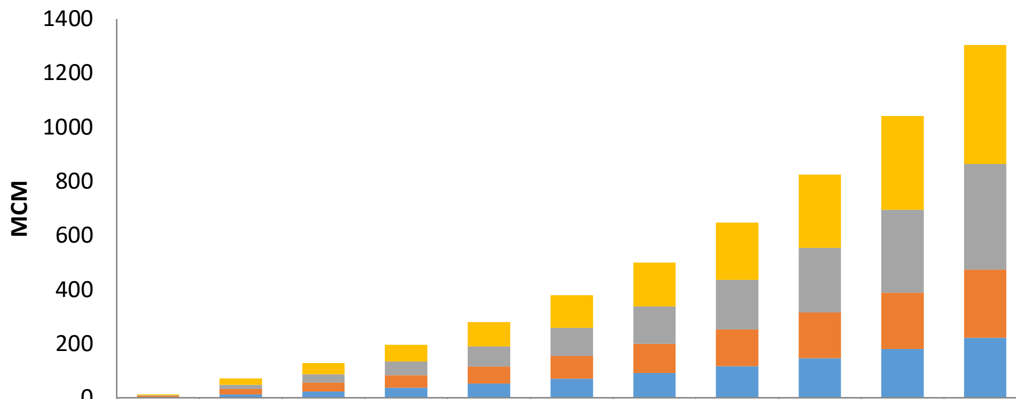
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	15.26	21.32	26.52	32.93	40.84	50.61	62.66	77.54	95.9	118.57	146.55
IPGR	15.26	19.03	23.69	29.44	36.53	45.29	56.09	69.44	85.9	106.23	131.31
IWU	15.26	20.28	24	28.38	33.54	39.59	46.72	55.1	64.96	76.56	90.2
BAU	15.26	18.1	21.43	25.36	29.98	35.41	41.8	49.32	58.16	68.56	80.79

Figure 45: Unmet Industrial Sites Water Demands (M2)



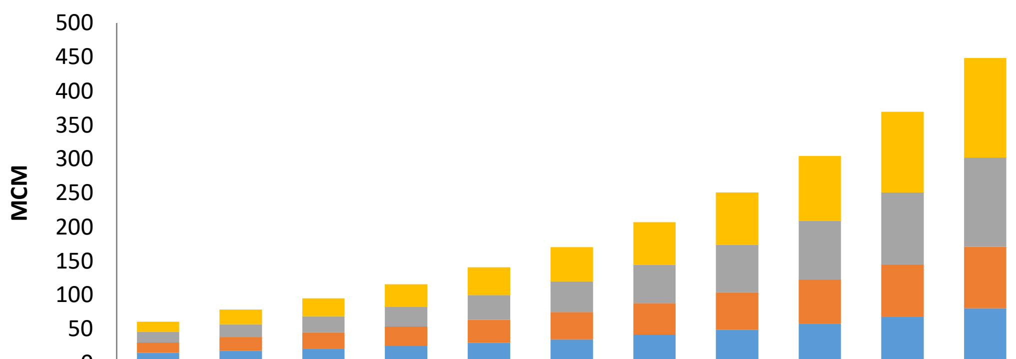
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
CCP	133.96	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86
IIA	133.96	201.12	201.11	201.12	201.12	201.12	201.11	201.12	201.12	201.12	201.11
CCP2	14.89	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72	19.72
CCP3	133.96	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08
CCP1	133.96	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86
BAU	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96

Figure 46: Unmet Agricultural Sites Water Demands (M2)



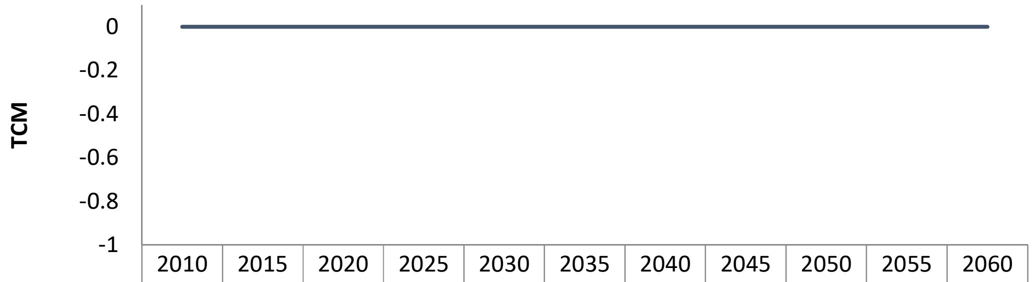
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	3.22	23.43	40.61	62.11	88.48	121.04	161.08	210.81	272.03	347.59	440.71
IPGR	3.22	15.8	31.18	50.48	74.12	103.31	139.2	183.81	238.7	306.44	389.93
IWU	3.22	19.96	32.23	46.96	64.14	84.33	107.95	136.03	168.9	207.56	252.9
BAU	3.22	12.68	23.67	36.9	52.29	70.4	91.56	116.76	146.23	180.89	221.53

Figure 47: Unmet Domestic Sites Water Demands (M3)



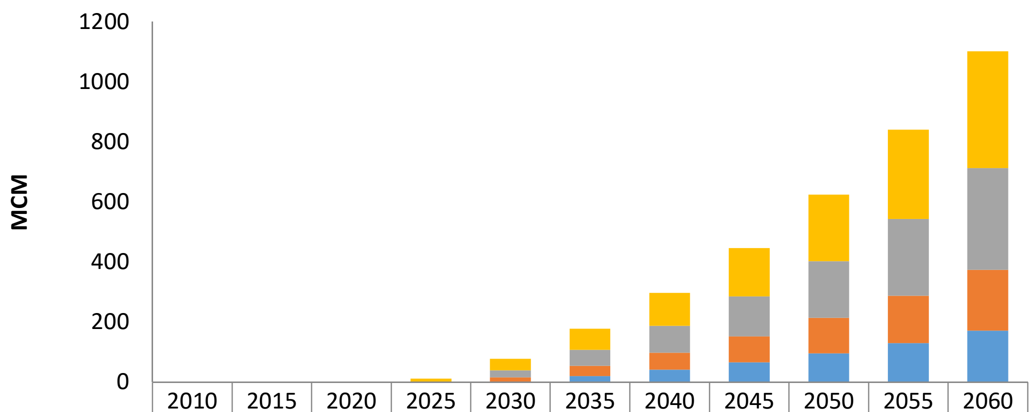
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/P	15.26	21.32	26.52	32.93	40.84	50.61	62.66	77.54	95.9	118.57	146.55
IPGR	15.26	19.03	23.69	29.44	36.53	45.29	56.09	69.44	85.9	106.23	131.31
IWU	15.26	20.28	24	28.38	33.54	39.59	46.72	55.1	64.96	76.56	90.2
BAU	15.26	18.1	21.43	25.36	29.98	35.41	41.8	49.32	58.16	68.56	80.79

Figure 48: Unmet Industrial Sites Water Demands (M3)



	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
BAU	0	0	0	0	0	0	0	0	0	0	0
CCP1	0	0	0	0	0	0	0	0	0	0	0
CCP3	0	0	0	0	0	0	0	0	0	0	0
CCP2	0	0	0	0	0	0	0	0	0	0	0
RIA	0	0	0	0	0	0	0	0	0	0	0
RIA50	0	0	0	0	0	0	0	0	0	0	0
IIA	0	0	0	0	0	0	0	0	0	0	0
CCP	0	0	0	0	0	0	0	0	0	0	0

Figure 49: Unmet Agricultural Sites Water Demands (M3)

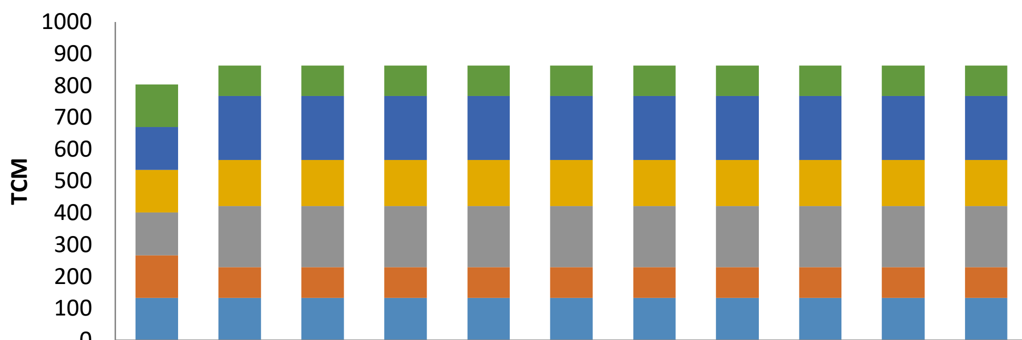


	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/IPGR	0	0	0	11.66	38.03	70.59	110.49	160.36	221.58	297.13	390.12
IPGH	0	0	0	0.02	23.67	52.86	88.61	133.36	188.24	255.99	339.34
IWU	0	0	0	0	13.68	33.88	57.36	85.58	118.45	157.11	202.31
BAU	0	0	0	0	1.84	19.95	40.97	66.3	95.78	130.44	170.94

Figure 50: Unmet Domestic Sites Water Demands (M4)

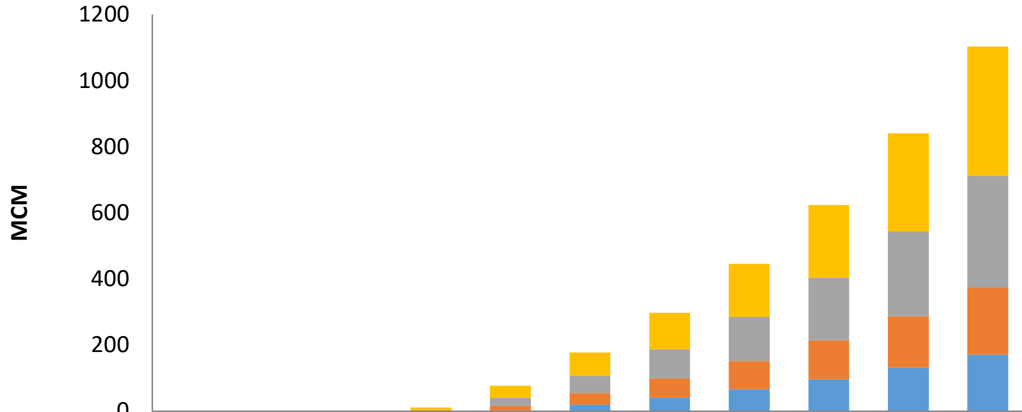
	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/IPGR	0	0	0	0	0	0.15	12.07	27.09	45.45	68.12	95.96
IPGR	0	0	0	0	0	0	5.5	18.99	35.45	55.78	80.72
IWU	0	0	0	0	0	0	0	4.65	14.51	26.11	39.61
BAU	0	0	0	0	0	0	0	0	7.71	18.11	30.2

Figure 51: Unmet Industrial Sites Water Demands (M4)



	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
CCP	133.96	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86
IIA	133.96	201.12	201.11	201.12	201.12	201.12	201.11	201.12	201.12	201.12	201.11
CCP2	133.96	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97	143.97
CCP3	133.96	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08	192.08
CCP1	133.96	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86	95.86
BAU	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96	133.96

Figure 52: Unmet Agricultural Sites Water Demands (M4)

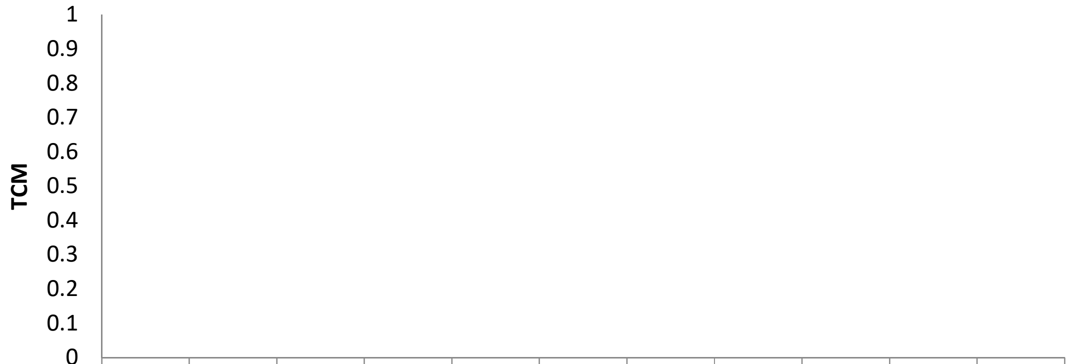


	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/IPGR	0	0	0	11.66	38.03	70.59	110.49	160.36	221.58	297.13	390.12
IPGR	0	0	0	0.02	23.67	52.86	88.61	133.36	188.24	255.99	339.34
IWU	0	0	0	0	13.68	33.88	57.36	85.58	118.45	157.11	202.31
BAU	0	0	0	0	1.84	19.95	40.97	66.3	95.78	130.44	170.94

Figure 53: Unmet Domestic Sites Water Demands (M5)

	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
IWU/ IPGR	0	0	0	0	0	0.15	12.07	27.09	45.45	68.12	390.12
IPGR	0	0	0	0	0	0	5.5	18.99	35.45	55.78	80.72
IWU	0	0	0	0	0	0	0	4.65	118.45	26.11	39.61
BAU	0	0	0	0	0	0	0	0	7.71	18.11	30.2

Figure 54: Unmet Industrial Sites Water Demands (M5)



	2010	2015	2020	2025	2030	2035	2040	2045	2050	2055	2060
CCP	0	0	0	0	0	0	0	0	0	0	0
IIA	0	0	0	0	0	0	0	0	0	0	0
CCP2	0	0	0	0	0	0	0	0	0	0	0
CCP3	0	0	0	0	0	0	0	0	0	0	0
CCP1	0	0	0	0	0	0	0	0	0	0	0
BAU	0	0	0	0	0	0	0	0	0	0	0

Figure 55: Unmet Agricultural Sites Water Demands (M5)

5.6 Impact of Dams and Reservoirs on the Ecosystem

Dams fundamentally alter river courses. Construction of dams particularly large dams involve trade-off between economic, social and environmental benefits and costs. With respect to environmental issues, local conditions and the size and type of dam all influence the environmental impact. It has been suggested that while reservoir have few negative effects on human water supply, they have a substantial impact on aquatic biodiversity and ecosystems. Such impacts can occur both upstream and downstream of the dam and in reservoirs.

Essentially, impact occur consequent upon inundation storage, changes to flow and the flow regime, water quality impact, and changes to the morphology of the river system. Other environmental consideration may be those attributable to climate change.

World economic forum 2011, argues that in the backdrop of climate change and climate variability, how should our water best be stored and which storage should be used to minimize risk due to long term climate variability and change?

Such storage guarantees reliability of water supply which in turn means food security, electricity generation and industrial growth. Climate change also has an implication for existing dam infrastructure i.e. dams designed in the past without accounting for the increasing variability of climate change are now at risk (i.e. 100-year flood may be more severe meaning that the infrastructure is under designed). Studies carried out by various researchers does suggest that climate change will increase the intensity of extreme weather events (Ehiorobo et al., 2012, 2013) and has the potential to cause mass migration, create food and water insecurity and cause several other environmental and social impacts (Voigt, 2009; Khagram et al., 200; Allonche et al., 2014).

Hence, the development of decision support system (DSS) for Benin City water resources planning and management revealed that the hydrological model of a catchment constructed in WEAP can adequately reproduce the response and dynamics of flow of the catchment (which can be utilized to assess developmental, economic and climate change under different scenarios) and can also be use in decision making in water supply planning and management. Therefore, this model can be utilized in the Niger Delta Basin for planning and management of water supply within the region and beyond.

6.0 HydroMet Analysis for Water Energy Food and Ecosystem (WEFE) Linkages

In order to define the Sub-basin for SWAT analysis, different study area boundaries were developed. This will aid for defining watersheds for the SWAT model (which is seen as the entire region contributing to a specific point of discharge or an entire region contributing to a single river network system during the SWAT analysis).

6.1 The Study Area

The region was subdivided into smaller river basins. The river basins were downloaded from a continental watershed map from the HydreSHED website. The Nigeria map was used as a boundary guide to select watersheds within the Lower Niger Sector of the Country. A total of ten watersheds were selected for this study while other regions bounded by the country political boundary below the watersheds are considered as coastal regions as shown in the Figure 56.

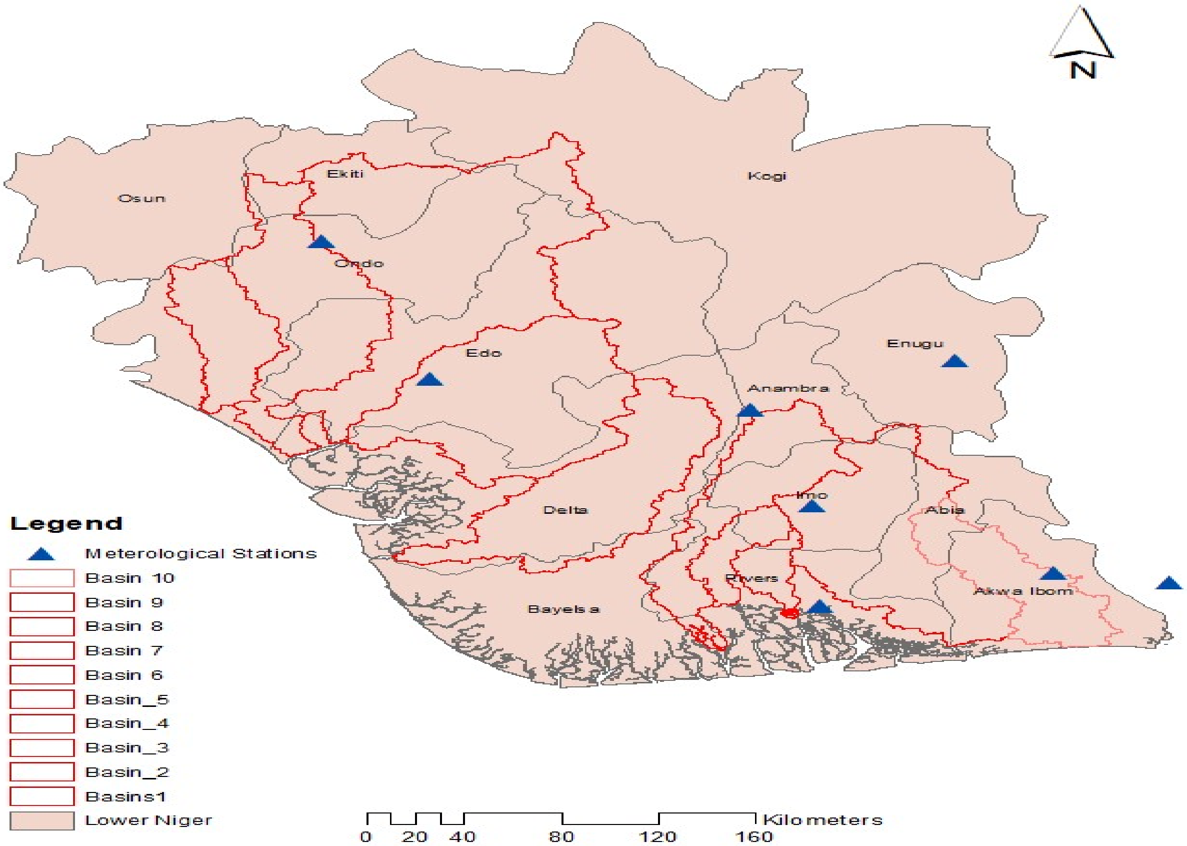


Figure 56: Study Area Showing the Sub basins and Coaster Areas in the Lower Niger Basin

Basin 1 (River Osse Basin) watershed is bounded by Ondo State and Edo State as the major states contributing to the rivers in the region as shown in the Figure 57. Other states are Ekiti state, Kogi state and Delta State as the least state and at the outlet portion of the basin. The region as an elevation profile ranging from -1m at the lower portion of the basin to as high as 728m at the top of the basin. The major rivers in the basin are River Osse, River Ala, Iporo River, Owan River and Ose River. The rivers originate from Kogi state at the North-Eastern part of the basin and Ekiti state at the North-Western part of the basin and discharges its runoff through Ondo State to Edo State and finally discharges it runoff into Delta State.

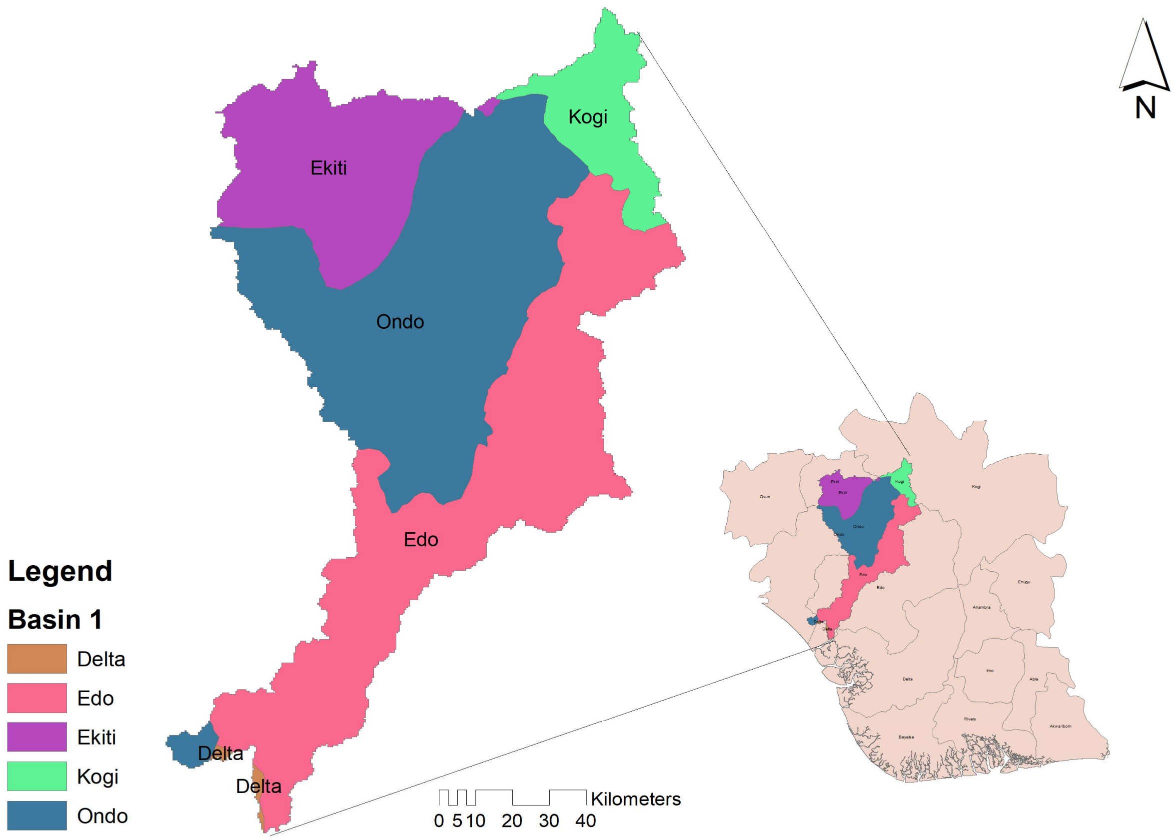


Figure 57: River Osse Basin Showing Political Boundaries Contributing Flows to the River.

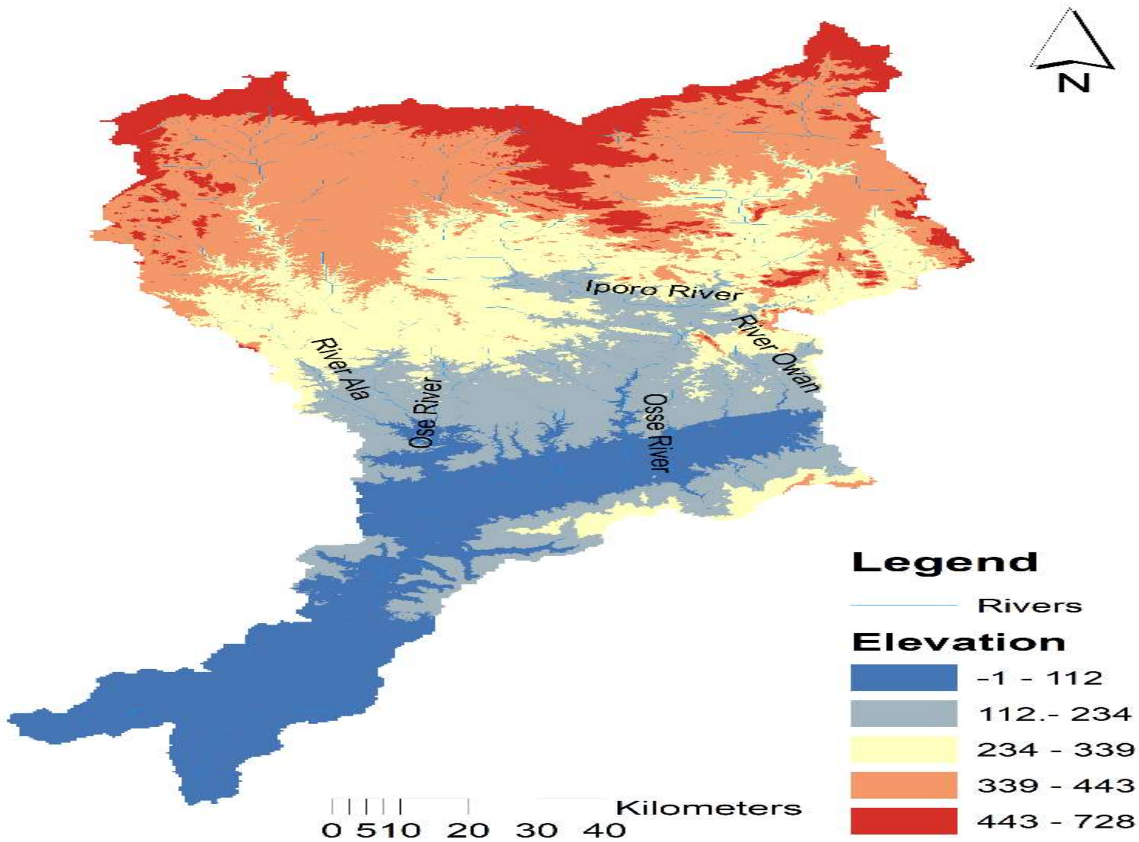


Figure 58: Elevation Model for River Osse Basin

6.2 Soil Type in River Osse Basin

The soil type data was obtained from the Harmonized World Soil Database (HWSD) (FAO and IIASA, 2009). The soil distribution in the basin are shown in the Figure 59.

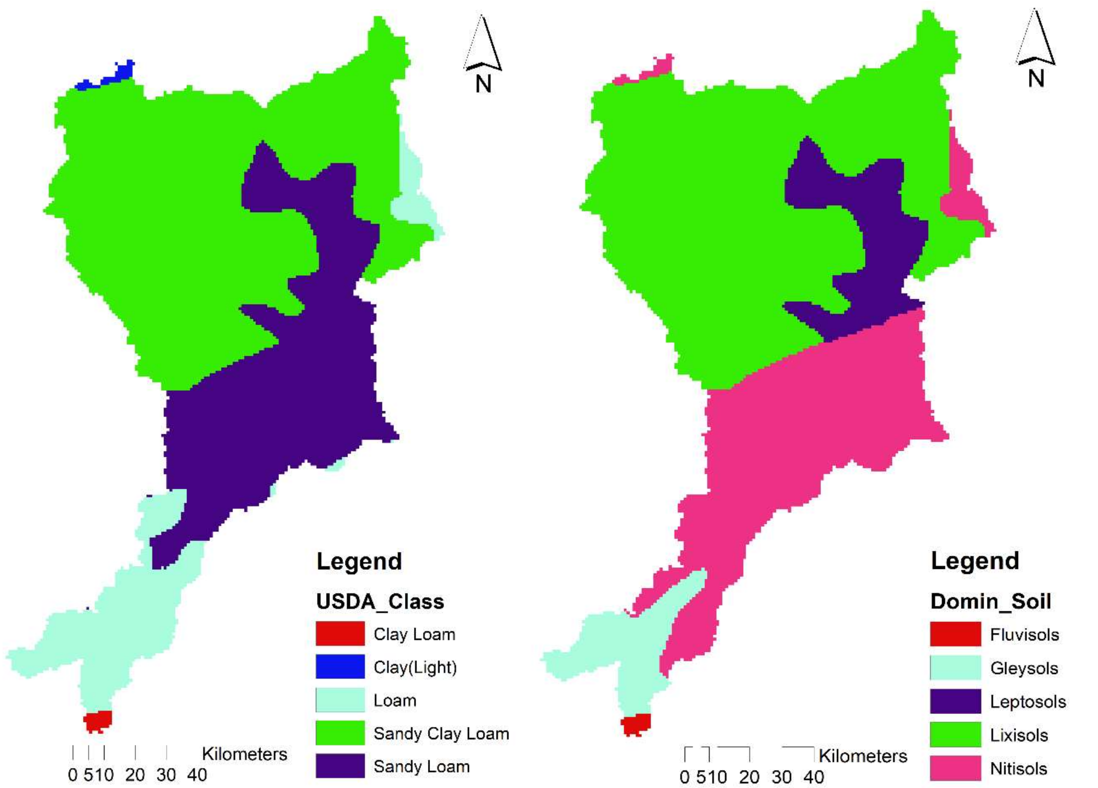


Figure 59: Soil Distribution in the River Osse Basin

From the Major soil groupings used in the HWSD map, the basin comprises of five soil types which are the Fluvisols, Gleysols, Leptosols, Lixisoils and Nitisols. The lixisols are the most commonly found soils in the basin followed by the Nitisol. The Lixisols are soils with subsurface accumulation of low activity clays and high base saturation. This soil types are highly weathered soils with an agricultural subsurface horizon with low activity clay and moderate to high base saturation (Jalloh et al., 2011). They occur in areas with pronounced dry seasons on old erosional depositional surfaces and are well drained. Their level of available nutrient is low but their chemical fertility is higher than other soils like ferralsols and Acrisols because of higher base saturation and pH and the absence of severe aluminum toxicity (Jalloh et al., 2011). The other most common soil type in the basin is the Nitisols. These soil types are deep, well drained, red tropical soils, highly weathered but more productive for agriculture than other red tropical soils. Their constituents are hard when dry, ranging from very friable to firm when moist and sticky and plastic when wet. Cation exchange capacity and phosphate retention capacity are relatively high (Jalloh et al., 2011).

6.3 Land Use/Land Cover

LandUse/landcover map was obtained from the European space agency climate change initiative (ESA CCLI) (Santoro et al., 2017). The landuse map was first extracted for the study area at basin level and imported into the Swat model, then the landuse changes over the years for 2015, 2010, 2006 and 2001 were analyzed for this study area. The maps for these years are shown in Figure 60 while the landuse changes in hectares are given in Table 25. Figure 61 shows the graphical representation of the changes in the study area.

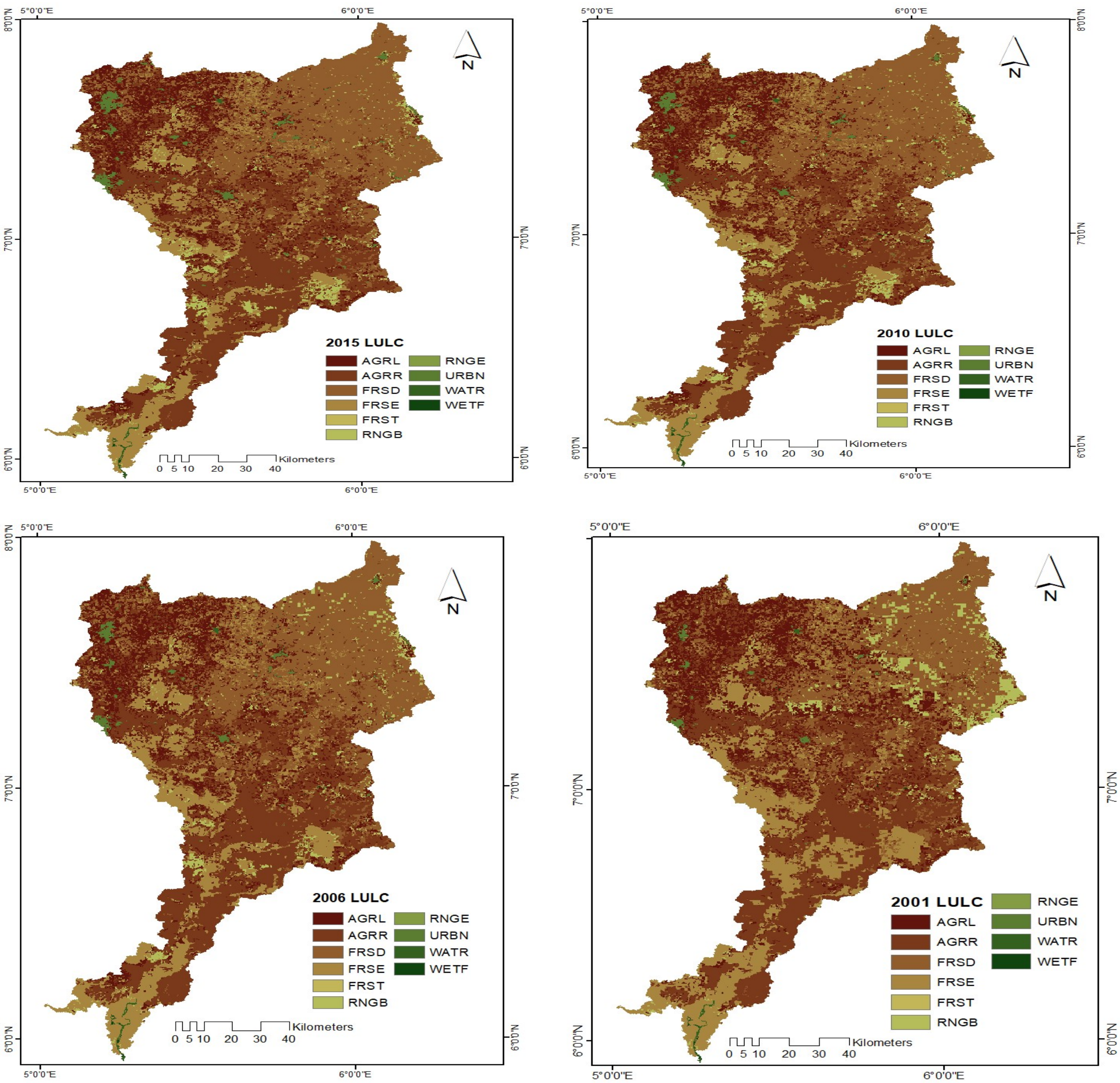


Figure 60: Landuse/Landcover Changes for 2015, 2010, 2006 and 2001 for the River Osse Basin.

Table 25: Landuse/LandCover Changes in Hectares for 2015, 2010, 2006 and 2001 for the River Osse Basin

S/N	LandUse Types	SWAT ID	Area(ha) 2001	Area(ha) 2006	Area(ha) 2010	Area(ha) 2015	2006-2001	2010-2006	2015-2010
1	Agricultural Land-Row Crop	AGRR	402528.80	414413.84	413404.37	410822.54	11885.03	-1009.46	-2581.83
2	Range-Brush	RNGB	62880.37	40771.33	44579.56	44454.12	-22109.04	3808.23	-125.44
3	Agricultural Land-Generic	AGRL	255739.21	226726.83	225080.51	222699.28	-29012.38	-1646.32	-2381.23
4	Forest-Evergreen	FRSE	261871.40	234460.76	224111.38	221787.12	-27410.64	-10349.38	-2324.25
5	Forest-Deciduouus	FRSD	369572.71	429361.23	434396.24	437354.60	59788.53	5035.01	2958.36
6	Forest-Mixed	FRST	1996.86	2252.98	2290.05	2271.97	256.12	37.08	-18.09
7	Range-Grasses	RNGE	56.07	18.99	18.99	18.99	-37.08	0.00	0.00
8	Wetlands-Forested	WETF	717.71	727.66	727.66	727.66	9.95	0.00	0.00
9	Residentail	URBN	6203.28	12832.88	16957.73	21440.07	6629.60	4124.85	4482.35
10	Water	WATR	2196.63	2196.63	2196.63	2186.68	0.00	0.00	-9.95

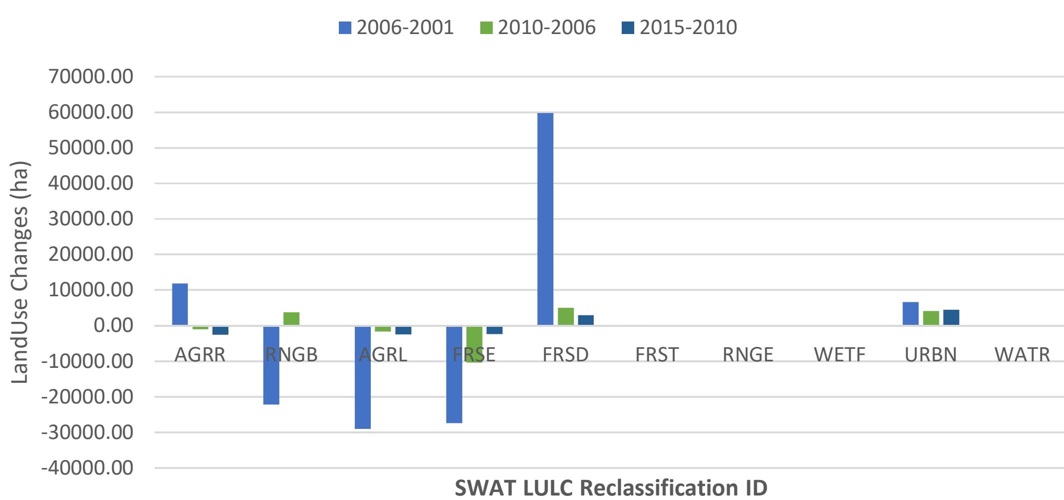


Figure 61: Graphical Representation of LandUse /Land Cover Changes in the River Osse Basin.

Table 25 shows the different land use types in the basin for year 2001 2006, 2010 and 2015 respectively and the corresponding change between preceding years. The changes between preceding years are either in a negative or positive sign indicating decrease or increase in land use types respectively. The changes are further decoded from Figure 61 which shows the changes for each land use type for the various years. It can be seen that the basin is losing its agricultural lands alongside its forest deciduous lands. It shows a decrease in urban land from 2006-2001 but a recovering Urban settlement from 2015 to 2010. There is no significant decrease in water bodies over the past years but for the year 2015 to 2010 with a decrease of 9.95ha of water bodies.

6.4 SWAT Modelling at River Basin Scale

Hydrological analysis was carried out in the basin using the SWAT model at river basin scales. The SWAT model belongs to the group of deterministic, distributed hydrological models. It is a continuous time model and operates on a daily time step at basin scale (Schuol et al., 2008). The SWAT model applies weather data which are rainfall, minimum and maximum temperature, relative humidity, wind speed and solar radiation. The hydrology, sedimentation, crop growth, nutrients, pesticides, agriculture management and stream routing are other components of the model. This study intends to utilize the hydrological, sediment and landuse management components of the model.

Swat considers the spatial heterogeneity of the basin using the elevation model, soil type distribution and land use land cover changes and distribution. The hydrological model consist of the water balance for the storage volumes snow, soil profile, shallow aquifer and deep aquifer and considers precipitation, interception, percolation and subsurface runoff, infiltration, percolation, evapotranspiration and surface runoff.

7.0 Problems Associated with Data Collection in the Niger Delta Basin

The problems associated with data collection in the Niger Delta Basin include:

- Data Availability: Data in many of the stations are not up to data as there are gaps in some of the stations within the study area (data were not available for many stations within the study area).
- Shell Petroleum Development Company (one of the agencies from which data were to be collected) policy is non-sharing of their data with a third party. This has been a major problem for us in respect of data sharing.
- Over the years, the River Basins in Nigeria have been poorly gauged and poorly mapped. Discharge measurements were neglected and poorly carried out and as a result, data were poorly managed and stored.
- The Nigerian Meteorological Agency (NIMET) that harvest data on Rainfall, Temperature and Relative Humidity etc. have decided to commercialise their data for research as a result of poor funding by government. The agency was demanding for as much as 4000€ for meteorological data of 50 years duration for 8 stations within the study area.

8.0 Conclusion

This study has assessed rainfall seasonality in Niger Delta Basin, frequency analysis of river discharge data for flood control in Niger Delta Basin, dams and reservoirs operations in the study area (comprising multipurpose utilization of dams and reservoirs- a case study of Ikpoba dam) and Hydromet analysis for WEFE linkages (comprising of collection of data for SWAT model). It was revealed that the mean monthly rainfall in the Niger Delta Basin was lowest in

December and January and that the ITD, SSTA and local features are the main factors controlling rainfall in the Niger Delta Basin.

The flood frequency analysis indicated that the Extreme value type 1 (EV1), Uniform (U) and Exponential (E) distribution (with Uniform (U) distribution been the best) can be used to describe the discharge data for some areas within the Niger Delta Basin (Lokoja and Onitsha). Also the Generalized Pareto(GPA) distribution and the Generalized Logistic (GLO) distribution can be used for analysis of annual maximum series data at River Okhuwan at Ugonoba in Benin Owena River Basin. Thus these distributions can be used for future flood prediction within these areas.

The development of decision support system (DSS) for Benin City water resources planning and management revealed that the hydrological model of a catchment constructed in WEAP can adequately reproduce the response and dynamics of flow of the catchment (which can be utilized to assess developmental, economic and climate change under different scenarios) and can also be used in decision making in water supply planning and management. Therefore, this model can be effectively utilized in the Niger Delta Basin for planning and management of water supply.

The assessment of Hydromet analysis for WEFE linkages has revealed the elevation model, soil type distribution and land use and land cover changes and distribution of the study area which is used in Swat Modelling, although we are yet to develop the SWAT model.

As Lokoja is an overlapping location between our CoE and the NWRI CoE, we will be sharing the data acquired from this location with them and other interested CoE. Lokoja station is strategic being at the confluence of the River Niger and the River Benue which take it source from neighbouring Cameron and both rivers contribute to the flooding experienced in the lower Niger Basin as a result of reservoir and dam Operations outside the shores of Nigeria.

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