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Assessing the Impact of Climate Variability on Hydropower Generation in Parts of the Lower Niger River Basin, Nigeria

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Abstract: This paper is on the assessment of the changing World climatic situation and the attendance consequences on water resources and hydropower generation. Thus the specific objectives is to assess the impact of changes in hydroclimatic variables on hydropower generation in the study area. Subsequently, Multiple correlation and multiple regression analyses were used to determine the relationship between hydroclimatic variables and power generation. Also, Water balance analysis was carried out to examine climate and water yield relationships. Ultimately, the results indicate a correlation coefficient of between 0.73 and 0.85 on power output and hydroclimatic variables. It is therefore recommended that alternative water optimisation procedures be provided for the dams based on the knowledge of the association between hydroclimatic variables and power generation. Also, continuous monitoring of changes in the hydroclimatic variables be intensified to provide early warning for effective performance of the dams and to protect downstream environment of the dams.

Introduction

Water is a vital component of the climate system and important to all sectors of national economic development particularly energy development. It is of course a basic resource for hydropower generation and adequacy of this environmentally friendly energy source is of utmost necessity. Hydropower supplies at least 50 percent of electricity production in 66 Countries and at least 98 percent of energy in 24 countries; out of the 194 Countries of the World (Whittington et al., 1998). Hence, negative impact of climate on water availability represents a big threat to the hydropower development.

Evidence of variability in climate abounds across the world. These include steady increase in temperature, erratic precipitation patterns and increasing incidences of weather related disasters such as flooding and drought among others. These have consequences for water resources and by extension, hydropower production. Whittington et al.(1998) opined that the world is faced with considerable risk and uncertainty about variability in climate of which particular attention has increasingly been paid to hydropower generation in recent years because it is renewable energy source that is climate dependent.

Hydropower is among the most vulnerable power sources to variability in global and regional climate. Hydroclimatic variables such as rainfall, temperature, runoff and evaporation have impact on water resources and by extension, hydropower. The trends of climate variability have led to a continual loss of water. Since the power output of hydropower plants are dependent upon the flow of the rivers, with less water, there is less potential energy to harness, making hydropower generation a less desirable energy source.

The variable duration of the rainy season and significant rainfall deficits in the Niger Basin, result in hydrological deficits that are not necessarily reflected in a direct response of the base flow. Studies on climate variability in West Africa show a significant decrease in both the amount of annual rainfall and the duration of the rainy season. Carbonnel and Hubert (1992) detect a 19-year climate variation for the period 1970–89. L'Hôte and Mahé (1996) compare the rainfall average during the period 1951–69 with the period 1970–89 and determine a southward movement of isohyets in the range of 150–250 kilometers, depending on the Basin climate zone.

Furthermore, analysis of monthly rainfall data for the whole region by Le Barbe and Lebel (1997) shows that the dry period is characterized by a decrease in the number of rainy events, but the mean storm rainfall varies little. A deficit of 10 percent to 30 percent in rainfall generally leads to a deficit of 20 percent to 60 percent in river discharges, confirming that rainfall in the Basin varies considerably but river discharges vary still more. Olivry (1998) noted that the long-term relationship between rainfall and river flow is largely influenced by groundwater base flow, as is the case of the Niger River. Cumulative dry periods contribute to a reduction in base flow, and a return to sustained river flow requires replenishment of the aquifers, which is possible only with cumulative rainy years. Also, Olivery (1998) asserted that because groundwater base flow varies with, and responds to the rainfall from previous years, the river flow in turn fluctuates with the level of aquifers, especially during a series of dry years. The dry years in the early 1970s, known in western Africa as the great drought, saw the flow of the Niger River decline to unprecedented low levels. Drought condition, which is a unique spell on weather, has serious consequences on man, vegetation, animals and water resources. The effect of drought on hydropower generating stations is obvious. The water inflows to the power dams are reduced and for severe drought conditions, power generation may be forced to a halt. Yet a subsequent decrease in the rainfall deficit, or increase in rainfall, in the latter half of the 1980s does not correlate with the flow variation. The Niger River's delayed hydrological responses illustrate that it takes more than a good rainy year to return the river to its previous flow.

Several studies on the Niger River and its tributaries confirm the correlation between decreased rainfall and Low River flows. This study which specifically center on detail examination and identification of key hydroclimatic variables influencing hydropower generation in part of the Lower section of the Niger Basin utilizes long term records of hydroclimatic data to ascertain in proper perspective of the impact of these variables on hydropower generation in the study areas.

Nigeria is endowed with sufficient energy resources to meet its present and future development requirements. The country possesses the world's sixth largest reserve of crude oil. It is increasingly an important gas province with proven reserves of nearly 5,000 billion cubic meters. Coal and lignite reserves are estimated to be 2.7 billion tons, while tar and sand reserves represent 31 billion barrels of oil equivalent. Identified hydroelectricity sites have an estimated capacity of about 14,250 MW. Nigeria has significant biomass resources to meet both traditional and modern energy uses, including electricity generation. The country is exposed to a high solar radiation level with an annual average of 3.5 to 7.0 $kWh/m^2/day$. Wind resources in Nigeria are however poor to moderate and efforts are yet to be made to test their commercial competitiveness. Hydropower which is being considered in this study is the leading source of electricity production in many countries including Nigeria. It is clean and renewable.

Surface water is the main natural source of water for hydropower generation. Nigeria is blessed with a number of rivers and streams which are either seasonal or perennial. The Rivers Niger and Benue with several tributaries such as Sokoto, Gurara, Gongola and Kaduna constitute the Nigeria river systems which offer some potential renewable source of energy for economically viable large hydropower development. The total potential surface water resources of Nigeria from these rivers and streams are estimated at 240,464 m^3/sec (JICA, 2003).

There are many problems associated with hydropower generation in Nigeria; the current infrastructure of the hydropower plants are in dire need of rehabilitation and the actual energy output of the plants are far below their projected capacity. The current installed capacity of grid electricity is about 6,000 MW, of which about 67 percent is thermal and the balance is hydro-based. The combined installed capacity of the three major hydropower dams (Kainji, Jebba and Shiroro) is 1,900 MW. The systems have been performing below expectation and could be as low as 30 percent (BPE, 2008). For example, power output in Nigeria in recent times has been erratic despite the fact that electricity came to Nigeria in 1896; 15 years after it was introduced in England. However, to date, the total electric energy generated in Nigeria has been lingering between 3,000 megawatts and 4,000 megawatts. Climate form a significant part of this problem. Other causes include maintenance, financial and political problems. Generating plant capability is low and the demand and supply gap is crippling. This Poor performance has negatively affected the industrial, commercial and domestic sub-sectors of our national economic lives.

Adequate preparations to forestall the adverse impact of climate on power generation output in Nigeria can only be meaningful if they are backed by proper scientific research. Jimoh (2008), Salami et al. (2010), Ifabiyi (2011) among others have studied various aspects of hydroclimatic impact on power generation in the power dams. However, most of these studies were based on short term records and center on one or two of the power dams. Long term studies are required to form the basis for proper understanding and management of existing power dams and development of the many untapped potential hydropower sources. This research work is intended to advance the frontiers of knowledge in this direction.

The Study Areas

The Study areas are part of the Lower Niger River Basin within Niger State, North Central Nigeria, accommodating the three major hydropower generating stations namely Kainji, Jebba and Shiroro dams. The study covers part of the Lower reach of the Niger River Basin. However, since the focus of the study is on hydropower generation, it center essentially on the three hydroelectric power generating stations (The Kainji, Jebba and Shiroro dams) located between latitude 09° and 12°N and longitude 03° and 10 ° E precisely in Niger State, North Central Nigeria.

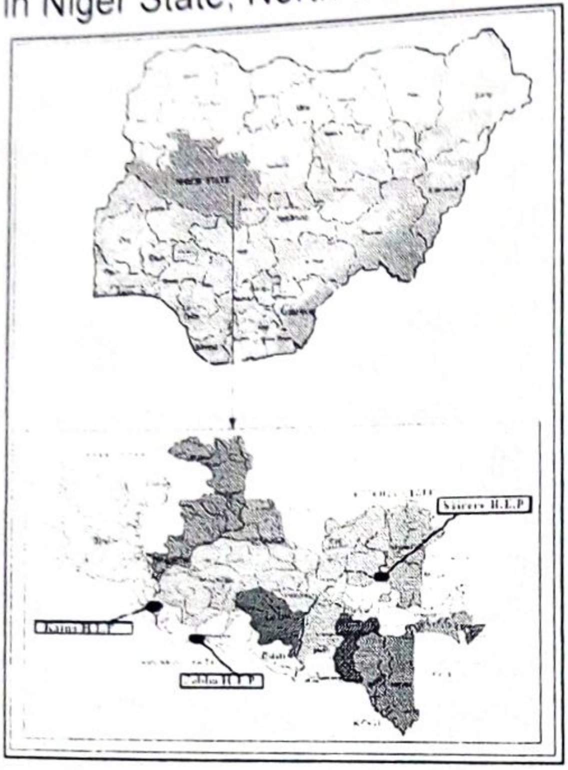


Fig1: The Part of the Lower Niger River Basin (The Study Area)

River Niger Floods

Although, the River Niger has a well-defined regime but also has a double and complementary annual flood regime with corresponding two main periods of peak flows. These are the 'White flood' and the 'Black flood'. Ordinarily, these floods carry rainfall-induced flood water as well as sustain inflow into Kainji and Jebba dam reservoirs. Essentially, the White flood is as a result of rainfall which originates from the immediate catchment area of Kainji reservoir especially the Sokoto/Rima river basin in Nigeria and Niamey in the neighbouring Niger Republic. The flood occurs only during the rainy season between July and October to peak usually in September. The resultant runoff which is typically turbid because it carries large quantities of colloidal materials or suspended silt giving the flood water its "milky" (white) colour, because of this colouration, the term 'White flood' is applied. Further, the Black Flood derives its water from the rainfall near the Niger's headwaters in the Fouta D'jallon Mountains in Guinea and Mali; both of which are at the upper Niger. Due to the consideration length of the river it takes a very long time for rain water falling near its source to reach Nigeria. By the time the water travels a distance of nearly 3,000 km, it not only deposits most of its silt contents in the Inland Delta or interior lakes but is delayed and, as it journeys to Nigeria, further loss of silt, takes place. By the time the flood reaches Nigeria in November, about six months later, the water looks comparatively clean. The name 'Black flood' is thus applied. The Black flood operates between November and March of the following year.

Climatic Characteristics

The area lies within a region which has a Tropical Savanna (Aw) climate with distinct wet and dry seasons, the wet season occurring in the high sun period. The Niger River Basin is invaded by two distinct air masses, one from the north which is dry and continental in origin, the Saharan air mass and the other over the Atlantic in the south which is moist, cool and equatorial maritime in nature. The weather depends to a large extent on the air mass which covers the area and its depth. The two air masses form a discontinuity zone at their boundary.

The wet and dry seasons correspond to the north-south passage of the Inter-Tropical Discontinuity (ITD). In the southern parts of the study area, rainfall occurs for seven months (April to October) whereas in the northern portion rain falls for only five months (May to September) leaving six to seven months respectively dry without rainfall. Because the southward retreat of ITD is faster than the northward advance, the change from rainy season to dry season is rather abrupt while the onset to rains after the dry season is gradual. Figure 3 illustrate the distribution of annual rainfall over the basin. 1300mm annual rainfall maximum is observed along the central portion to east/south axis of the catchment basin. Lowest annual rainfall of 900 mm to 1000 mm occurs in south-west portion and northern extreme of the river basin. The month of maximum rainfall in the study area is September.

Around Bida in Niger State, the wet season lasts from mid April to mid October with duration of about 178 days on the average while in Kaduna; the season is shorter from mid May to early October, having an average duration of about 150 days (Suleiman, 1998, 2013). Annual rainfalls over the basin do not indicate a specific relationship with latitude. See Figures 3, 4, 5 and 6 for rainfall characteristics over the study area. The high relief areas of Abuja, Kafanchan, jos and Zonkwa are specifically responsible for the higher relief rainfalls and this explains localized rainfall patterns and also the lack of consistency of rainfall with the rise in latitude, (Umoh, 1995).

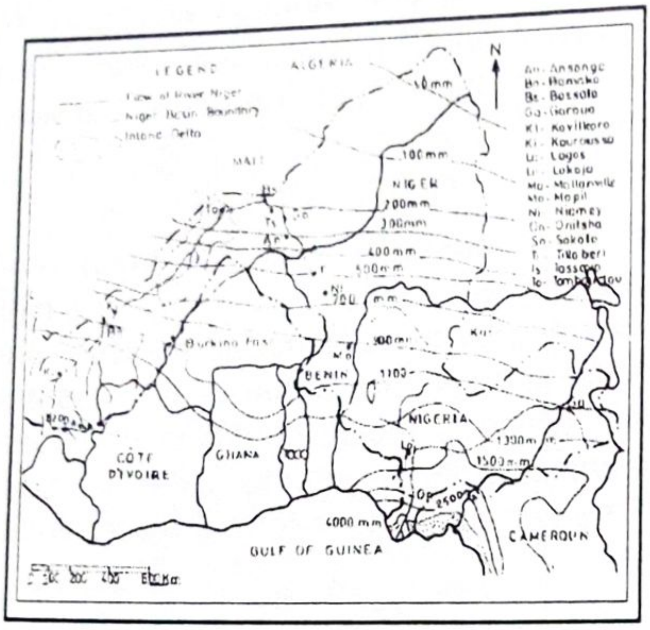


Figure 3: Rainfall Patterns over the Study Area

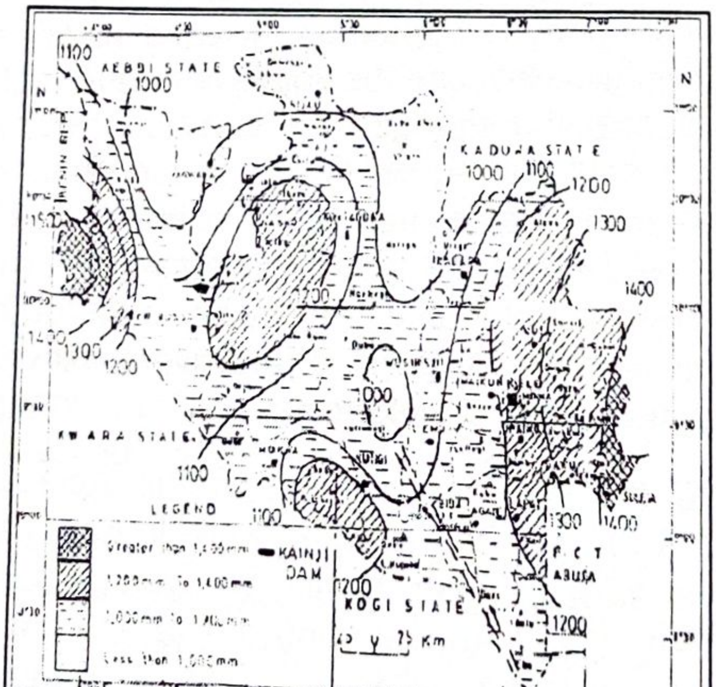


Figure 4: Mean Annual Rainfall over the Study Area

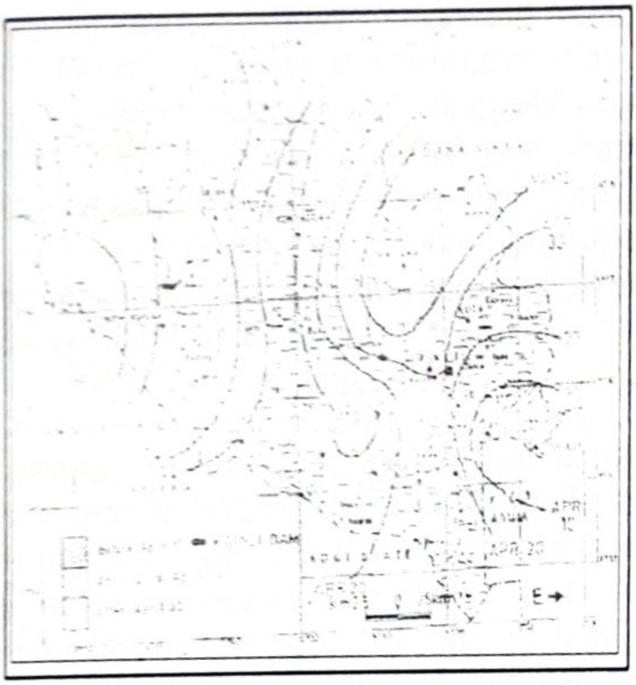


Figure 5: Mean Onset of Rains

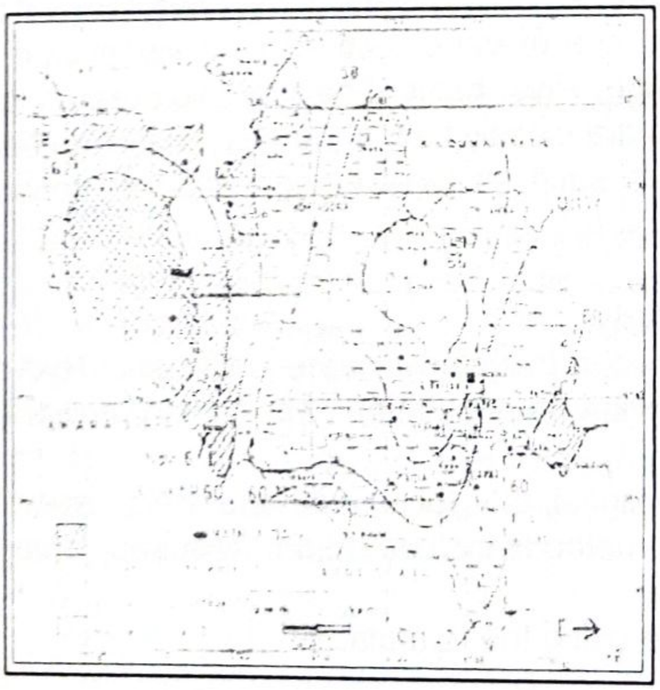


Figure 6: Mean Cessation Dates of Rains

Temperatures are high throughout the year. The hottest months of the year are February, March and April with temperatures ranging from 38 °C in the north to 27 °C in the southern part of Nigeria. The coldest month is August with temperature of 20°C in the South and 32°C in the North (Ojo, 1977). Local factors such as altitude have a moderating effect on temperature regime. In general, humidity decreases northwards in the basin. The lowest mean humidity at 1200 GMT is 39% in the south and 28% in the north while the mean annual humidity varies from 65% in the south to 50% in the north (Oguntoyinbo, 1978).

During the dry season, the moisture content of the air reduces to as low as 15% and soil moisture dries off. The high temperatures ensure that potential evapotranspiration (PET) is high throughout the year. The high PET rates lead to substantial water deficits during each dry season. Hayward and Oguntoyinbo (1987) have constructed isopleths of mean water balance for West Africa. In the dry season (as illustrated by January isopleths in that study) the entire catchment within the study area suffers from water deficit (Hayward and Oguntoyinbo, 1987). This is particularly important point in the context of this research where one of the objectives is to investigate rainfall-runoff relationships over the Niger River basin. The synoptic pressure systems and the associated air masses are closely tied to the seasonal migration of the ITD of this area. Other factors such as local topography and continentality affect the climate of the basin.

Materials and Methods of Study

Four classes of data were used in this study; namely: Climatic, Hydrological, Power (Electricity) and information on adaptation capacities of power dams to variability in climate.

Both descriptive and inferential statistical methods were used in data interpretation. The descriptive methods include mean, frequency analysis and graphs.

The calculated mean was done using the formula:

$$X = \frac{\sum^{N} \alpha}{N} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Where X is the observed parameter, Σ is the summation symbol and N is the number of observations.

Correlation coefficients of the main meteorological variable (Rainfall) on hydrologic and reservoir variables were computed to determine the strength of the relationship between the variables. After, the regression analyses of the correlated variables were done to develop regression model. The regression model can be described by the equation that follows:

$Y - a x + b$ .... (2)

Where, X = time (year), a = slope coefficients and b = least square estimates of the intercept. Both the correlation and regression analysis were computed using Microsoft Excel Software Application and the Statistical Package for Social Sciences (SPSS) Version 16.0 for Windows.

The watershed or catchment method; where flow characteristics of the basin are related to climatic variables and other environmental factors that affect output to establish a physically based statistically significant relationship with the output is utilised.

Jackson (1989) gave the water-balance equation as:

$R = Et + \Delta S + \Delta G + Q + L$ ....(3)

Where:

Et = Evapotranspiration from the catchments (mm)

R = Rainfall (mm)

Q = Stream flow (m^3/sec)

ΔG = Water storage change beyond root range (mm)

L = Out flow/flow other than past stream measurement point.

ΔS = Water storage change within root range (mm)

The areal volume of the water balance parameters were calculated using Warehouse (1977) method of estimating volume of area precipitation which state that for a given area in square kilometers and an annual precipitation in millimetres per year, the volume of total rain will be in km^2 multiplied by mm or m^3 multiply 10^6. .... (4)

Results and Discussions

(I) Water Balance Analysis

Table 1: Annual Averages of Water Balance of the Lower Niger River Basin

Rainfall Variables	Kaduna	Kainji	Jebba	Mean
• Rainfall (mm)	1253	1285	1427	1321.7
• PET (mm)	1112	1053	1053	1072.6
• RAS (mm)	150	180	180	170.0
• Infiltration (mm)	646	647	742	678.3
• AET (mm)	541	662	704	635.6
• SMD (mm)	472	392	349	404.3
• SR (mm)	129	152	204	161.6

Source: The Authors

Table 1 summarize the annual averages of water balance of the study areas. The annual average areal rainfall is 1321.7 mm/m^2. PET is 1072.6 mm while AET is 635.6 mm/m^2. The soil moisture capacity or RAS is 170 mm on the basis of 1.0 m effective root zone, infiltration or recharge to ground water is 678.3 mm/m^2. SMD and surface runoff are 404.3 mm/m^2 and 161.6 mm/m^2 respectively.

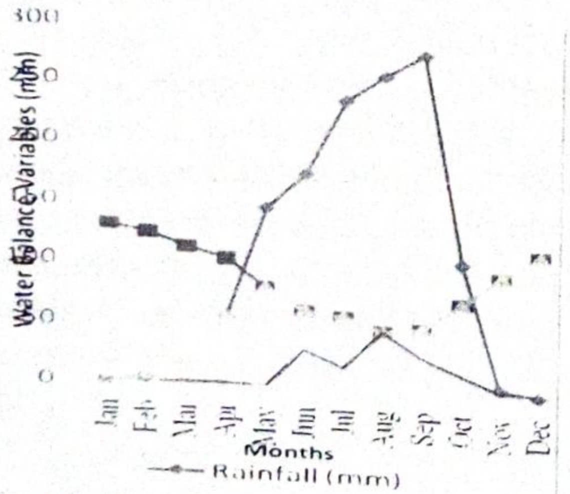


Figure7 Distribution of Water balance over the Basin

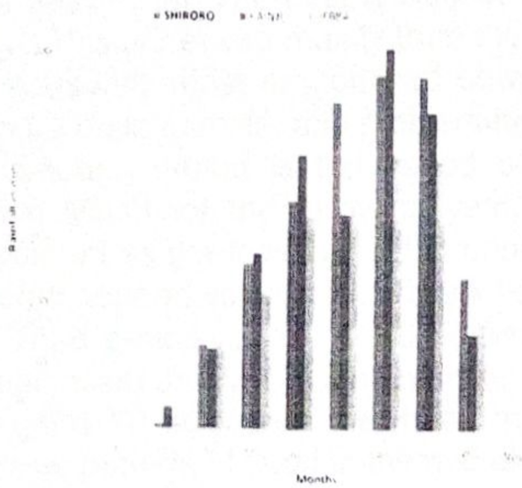


Figure 8: Mean Monthly Rainfall Distribution at Kainji, Jebba and Shiroro dam

Figure 7 illustrate Water balance analysis. It depicts three scenarios; moisture deficit, moisture recharge and moisture surplus, resulting in 7 months of moisture surplus and 5 months of moisture deficit.

The difference between rainfall and Potential Evapotranspiration defines two seasons in the study area. Six months of rainy season, when rainfall exceeds Evapotranspiration and six months of dry season, when the meteorological demand is not satisfied by rainfall that has fallen in the same month. The severity of the dry season increases during the sequence of months with excessive Potential Evapotranspiration.

At Kainji, Jebba and Shiroro dams, rainfall generally begins in March/April, increases until the months of September and decreases thereafter until cessation takes place completely in November. About 50 % of annual rainfall total accumulates on the three heaviest rainy months of July, August and September when values exceed 1500 mm. The months of November to February are dry (See Figure 8).

(ii) Flow Duration Characteristics

The Kaduna Sub-catchment Basin, upon which Shiroro hydropower dam is located, has a single flood regime. The Shiroro reservoir thus enjoys copious water inflow for only three months (from late July to early October) in any hydrological year. Water use pattern always takes cognizance of this trend in the annual reservoir filling and emptying cycles.

The Figure 9 shows the mean monthly inflow into Shiroro reservoir.

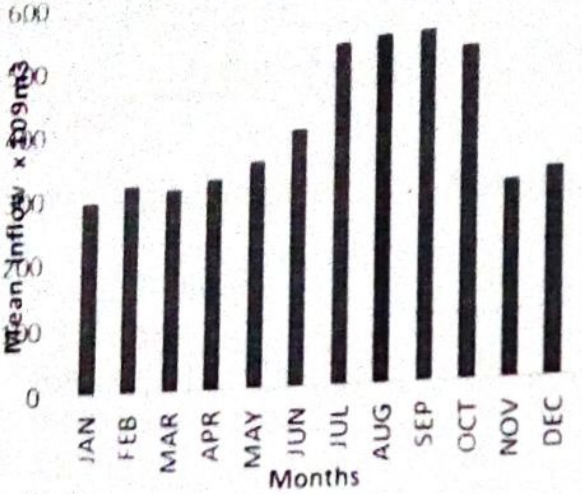


Figure 9. Monthly Inflow at Shiroro Dam

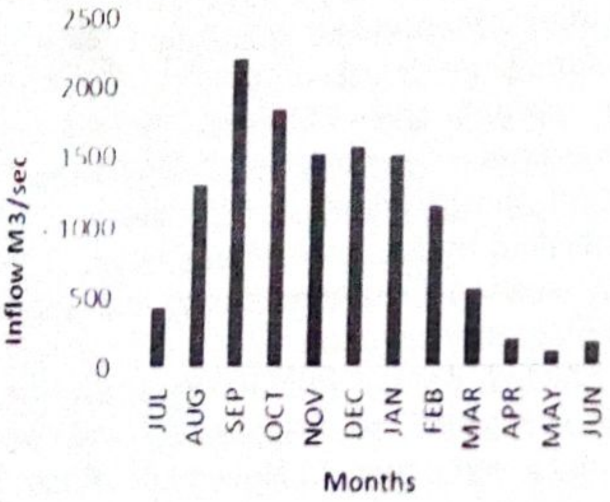


Figure 10. Monthly Inflow at Kainji Dam

The perennial constraints of low water levels in reservoir especially after rainfall cessation in October have therefore been accepted as normal. Since reservoir operation is usually patterned after a long standing water resource management experience. Consequently, between late October of any year and following rainfall cessation, until July of the following year, flow duration is usually at low ebb. The three months; August, September and October represent period of highest precipitation in the sub-catchment basin, consequently significant streamflow duration and inflow harvest.

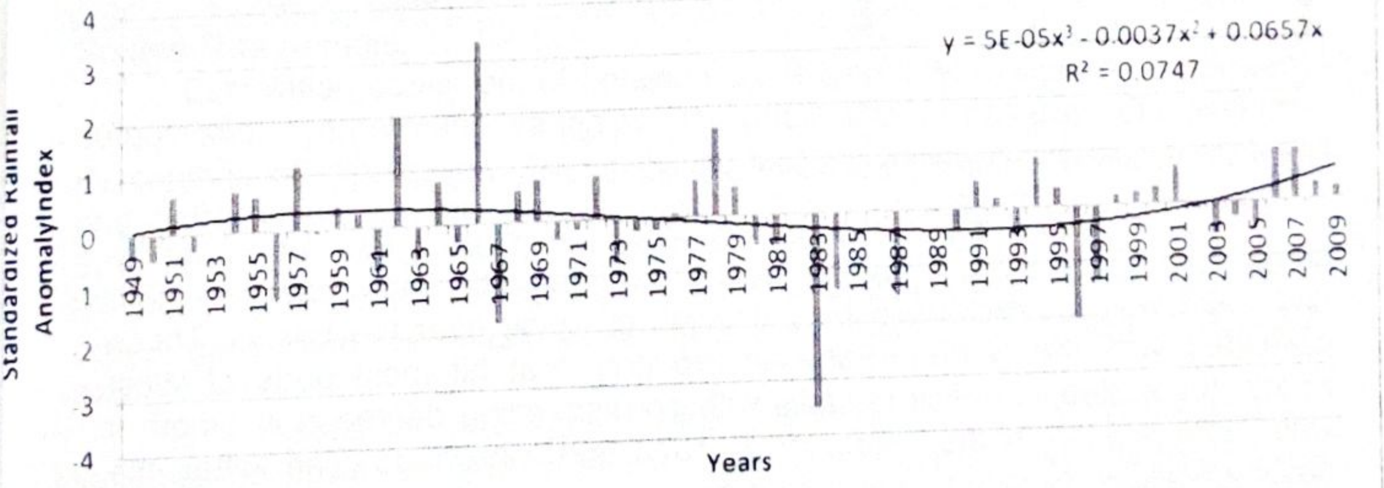
In the annual hydrological cycle of Niger River at Kainji and Jebba, e periods are critical. The First is August to October when the white flood be raging. This is derived mainly from the immediate vicinity of the lake in eria and is usually most pronounced between August and early October. yield can be quite plentiful and problematic at times.

The Second period is the period of the Black flood between late ember and March of the following year. This period demands careful er management as the local rains that brings the flood would have stopped Kainji would depend solely on the black flood.

The Third period is the period between March and July when inflow omes insignificant as black flood enters its recession.

The Figure 10 illustrates the mean monthly inflow into Kainji dam. It icts the three periods of flood in the hydrological year beginning in July of a vious year and ending in June of the following year. The month of tember and early October marks the peak of the white flood inflow into nji dam. The peak inflow usually follow accumulated peak rainfall period this is attributed to the time-lag factor between rainfall and peak flow.

) Climatic Patterns



ıre 11 Trends in Mean Annual Rainfall over the Lower Niger River Basin

Figure 11 shows the period between 1972 and 1980, when the Sudano ahelian drought lingered in West Africa with devastating effect on water ources. The flow regime of the River Niger and the annual rainfall totals, except in isolated cases were generally low. There was the situation in 1973, 1983 and 1987, with a discernible annual rainfall deficits in the basin degenerating to as low as 995 mm, 346 mm and 823 mm respectively, below the annual average value of 1192 mm known for the Basin (Nicholson, 1983; Suleiman, 1998).

The occurrence of drought has taken a pattern of 10 years interval period over the basin. Rainfall in the years 1953, 1963, 1973, 1983, 1993 and 2003 were below the known annual average for the basin. These include the two to three years that proceeded each of these identified years with the 1983 being the driest year. However, the years 1957, 1962, 1966, 1978, 1994, 2006, 2008 and 2009 were wet years. These periods coincided with the recovery years after imminent drought years.

Figure 12: Pattern of Annual Surface Runoff over the Niger River Basin

The year 1969 witnessed appreciable runoff and this was due to corresponding increase in rainfall during the year. The years between 1970 and 1993 was characterised by recession in runoff over the basin. These coincided with the Sudano-Sahelian droughts that hit most parts of West Africa. It resulted in deficit rainfalls with corresponding decrease in runoff. It was more severe in the years 1971, 1972 and 1982/1983. Thereafter, the basin witnessed recovery of sort from drought and runoff picked up as a result of uptrend in the rainfall over the basin from the 1990 s. This was not continuous as intermittent drought spells were also experienced from 1980 upwards (See Figure 10).

(iv) Climate and Power Generation Characteristics

The results indicate further the strong relationship between rainfall, which is the major climatic variable and reservoir operation in the Study Area. Though the Niger River upon which the three hydro-electricity dams under study are built, is perennial, they carry less water during the dry season and is bankful for greater part of the rainy season months of May to October. The observed inflows and erratic lake behaviour at the three dams in recent times occur in response to the rapidly changing intensities, duration and amounts of rainfall and runoff. These of course have implications for hydroelectric power needs, generation and supply. Table 2 illustrates the relationships between the hydroclimatic variables and power generation.

Table 2: Influence of Hydroclimatic Variables influence on Power Generation

ams	Predictive Equation		R^2	SE
iroro	(a)	Y=38249.027+13.551*RF-12.884*INFL-9.230*OUTFL+137.969RSVEL	0.819	1226.1969
	(b)	Y=-87203.432 + 0.729 RSVEL	0.532	1651.5397
bba	(a)	Y=-8.227E6-61.776*RF+32.544INFL+13.994*OUTFL+82811.681RSVEL	0.930	18309.6614
	(b)	Y=102795.408 + 0.957* RSVEL	0.916	16684.8844
ainji	(a)	Y=-1.934E7-281.49*RF+21.346*INFL+9817.648*OUTFL+1473.391*RSVEL	0.785	22992.674
	(b)	Y=228898 – 294.941*RF	0.655	24388.6351

Source: The Authors.

Correlation coefficient of between 0.727 and 0.847 obtained on power output and hydroclimatic variables, indicates strong positive relationship. Percentage of explanation of multiple regressions between power generated and hydroclimatic variables varies between 54% in Shiroro, 66% in Kainji and 92% in Jebba. Also, of all the analysed hydroclimatic variables, reservoir elevation stand out as the explanatory factor in Jebba and Shiroro influencing power generation, while rainfall remains the explanatory variable at Kainji dam.

The results indicate spatial variations in the effect of hydroclimatic variables on power generation at the three hydroelectric power dams in the Study Areas as this impact seriously on power delivery from the dams to Nigerians.

Recommendations and Conclusion

Variations in climate produced significant changes in hydroclimatic variables critical to hydropower generation; however, the magnitude of the impact varies across the three dams. Power generation may depend on a number of factors which include the national energy demands, but water availability is a major factor in determining power production capabilities and capacities of any hydroelectric power dam. This is because electric power production may suffer great deficits or be enhanced depending on the water situation in the reservoir. Availability or otherwise of water in basin is a function of rainfall and runoff into a reservoir that serves as storage for utilization by the turbines in a hydropower station. The observed uptrend in rainfall especially from the 1990 s in the Lower Niger River Basin is reflective evidence of regional climate variability. It is recommended that alternative water optimisation procedures be provided for the dams based on the knowledge of the association between hydroclimatic variables and power generation, small hydropower schemes and other renewable energy power sources be developed to augment power supply from these dams, and continuous monitoring of changes in the hydroclimatic variables be intensified to provide early warning system for effective performance of the dams and to protect downstream environment of these dams.

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