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ARTICLE

Impact of Climate Variability on Reservoir Based Hydro-power Generation in Jebba Dam, Niger State, Nigeria

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ABSTRACT

This study examined impact of climate variability on reservoir-based hydro-power-generation in Jebba dam, Niger State of Nigeria. Data of rainfall, temperature, evaporation, reservoir inflow and outflow and power output for thirty-one years were obtained from Jebba Hydropower Station [JHP]. The Man-Kendall and Pearson's Product Moment Correlation Coefficient (PPMCC) were used to establish the influence of weather parameters on the reservoir inflow and outflow. Findings showed increased electricity generation during dry season than wet season. The highest annual mean amount of the electricity generated was in 2016 having mean of 689.12 mwh, dry season (352.26 mwh) and wet season (336.86 mwh). Reservoir inflow showed a negative trend with severe fluctuations in 1998 (1436.42 M3/Sec), 1999 (1581.08 M3/Sec) and 2010 (1641.08 M3/Sec) with a steady increase in 2016 (1556.0042 M3/Sec), 2017 (1556.4242 M3/Sec) and 2018 (1635.7542 M3/Sec). The reservoir outflow pattern showed tremendous and negative trend in fluctuation with increase in 1998 (1421.75 M3/Sec) 1999 (1581.58 M3/Sec) and 2010 (1641.16 M3/Sec) and a steady increase in 2016 (1535.00 M3/Sec), 2017 1558.83 M3/Sec and 2018 (1632.00 M3/Sec). Thus, rainfall and reservoir inflow had strong relationships with the amount of power generated than temperature and evaporation. Therefore, the government should increase the water carrying capacity of the reservoir construction by storing water to be used during dry periods.

1. Introduction

Climate is the average atmospheric condition of a particular place at a particular time over a long period of time ranging from 30-35 years [1]. Also, [2] reveals that climatic conditions of a geographic location will determine the availability of water resources from 30-35 years. Rainfall, evaporation and temperature have more influence and affect hydroelectricity performance since they are inter-related with other elements of weather [3]. It is predicted that in the world, energy consumption will double between the years 2007 and 2035 [4]. Researchers have projected that the population of the world will be above 10 billion persons around 2050 and will rise above 11.2 billion in the year 2100 [5]. Thus, it is very clear that the present population of people is severely demanding energy service and water resources resulting from the rise in population. However, the next four decades will witness pressure in energy and water resources as various dams will influence power demand and control water supply in some regions.

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However, evaporation, temperature, rainfall pattern alters global hydropower production. The changes in these patterns are mostly caused by climate change. The rise in demand for electricity will continuously put pressure on electric power decision for countries, especially with the increased pollution by the greenhouse gas [6].

According to [7] temperature and reservoir inflow are also important in the generation of electricity; due to the fact that rise in temperature will result in higher evaporation from water bodies thereby reducing the quantity of available water. When the rate of evaporation is greater than the rate of precipitation, it will result in water scarcity. Thus, this process needed to be investigated in a drainage basin where hydroelectric power dam is usually hosted by the reservoir as there is suspected loss of water through evaporation and their effects in loss of water. The phenomena of evaporation and water loss are very crucial in understanding the amount of reservoir discharge and energy supply in the study of dams. These have yielded to the interest in the study of climatic systems and biophysical modifications of drainage basins in order to cope with the problems of electric power generation and management.

However, hydropower stations are facing tremendous challenges as a result of climatic change; communities, companies and businesses are affected because of the fluctuation of electric power. This has effects on small- and large-scale businesses, and, consequently the Gross Domestic Product (GDP) of Nigeria. However, [3] studied weather elements, inflow of reservoir and their patterns in Kainji dam of Niger State, Nigeria, where rainfall, temperature, evaporation and inflow parameters were considered, neglecting the effect of outflow on energy discharged. But in the case of this research, rainfall, temperature, evaporation, inflow and outflow were considered, though they have an element of similarity but in different locations.

Energy is one of the commodities in which the provision of goods and services depends. Its availability and consumption rate are economic index for measuring the development of any community [8]. In Nigeria, there is a limitation to power supply from the national grid which has adversely affected the economic and social development of the populace. This really necessitates the need for decentralized power source as a viable alternative to which hydro power schemes readily fit in. Major rivers and dam development provide an enviable energy potential for the exploitation of hydro energy in Nigeria. The problem of electricity generation in the country is on the increase on a daily basis as both urban and rural dwellers need electricity. Jebba dam is one of the major producers of electricity in Nigeria though not enough to meet the demand of the growing population; this is why the need for the assessment of the water resources in some areas becomes so important in order to meet internal and external demands. Ever increasing demand for electricity has intensified the quest for generation per kw and for an increase in production. The dam, river discharge and turbines alone will not improve productivity if significant deterioration of natural condition occurs. It is in the light of this that this study is justified.

[9] revealed that Africa and other developing countries will incessantly have severe effects of climate change and water resources. [10] showed that Africa, especially Nigeria and other sub-Saharan countries will be knocked by climate change phenomenon due to their high values of climatic parameters. Generally, the effects of greenhouse gases will affect solar intensity, rainfall, temperature, humidity, pressure and other variables of climate, thereby influencing reservoir discharge and electric power supply in Jebba Reservoir [3]. This study explores the effects of various climatic variables of rainfall, temperature, evaporation and the inflow-outflow reservoir data to understand their relationships in order to manage Jebba dam hydro-electric power project in Nigeria. Therefore, this research focuses on the impact of climate variability on reservoir-based hydro-power-generation of Jebba dam, Niger State, Nigeria.

2. Methodology

The Jebba Hydroelectric Power Station is situated at the terrain of River Niger in Nigeria which is founded within latitudes 9°10’N to 9°55’ N and longitudes 4°30’E to 5°00’E (Figures 1 and 2). The area has an altitude of 76 meters Above Sea Level (ASL) which is approximately 100 kilometers downstream of Kainji dam [6]. The Jebba dam is an earth dam and the third functional hydro-power project in Nigeria with capacity to generate 578 MW power, having six (6) turbines of 96.4 MW each, distributed to over 364,000 households with operating-head of 27.6 m. Thus, the turbines are joined to a generator having 119 MVA maximum continuous rating and 103.50 MVA base load rating respectively [6].

Data for reservoir inflow, reservoir outflow and amount of power generated as well as climatic variables of rainfall, evaporation and temperature for the period of thirty years (1988-2018) were obtained from Mainstream Energy Solution Limited, Hydro-Power Plant, Jebba. The annual mean variable was computed using simple statistics. The amount of power generated during the rainy and dry seasons within the last thirty-one years was analyzed by getting the grand total seasonal mean of power generation within the study period. Man-Kendall analysis was

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adopted to understand the monotonic trend of rainfall, evaporation, temperature and reservoir flow patterns and displayed on the graph. The interactions of rainfall, evaporation and temperature patterns on the reservoir inflow and outflow were determined using the Pearson Moment Correlation Co-efficient in the environment of the Statistical Package for Social Scientist (SPSS).

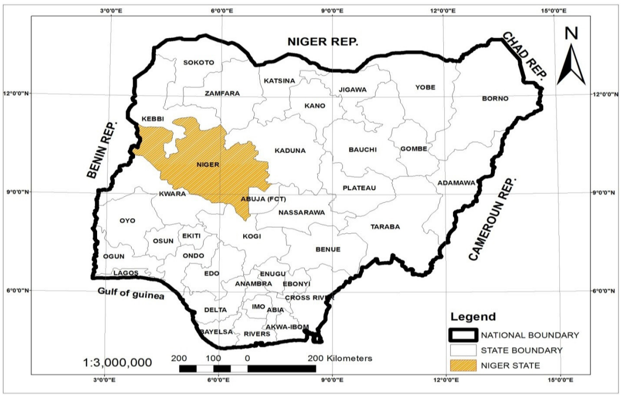

Figure 1. Niger State in Nigeria

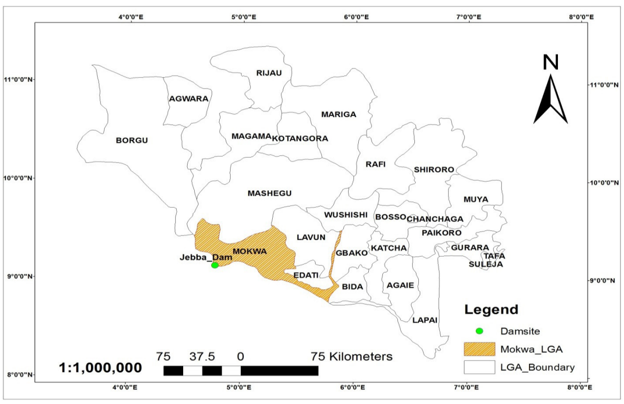

Figure 2. Jebba Dam in Mokwa LGA of Niger State

3. Results

The result in Figure 3 showed the trend in rainfall in the study area which fluctuated over the years and the pattern showed gradual steady increase between 1988-1991 (79.99 mm, 93.92 mm, 94.24 mm and 121.90 mm respectively) and decreases between 1992-1994 (86.54 mm, 82.93 mm and 81.37 mm respectively). However, amount of rainfall received in Jebba reservoir dropped drastically in 2009 (77.81 mm). The amount of rainfall received in Jebba reservoir was fluctuated throughout the study period. Thus, Figure 4 showed that the temperature of the study area was on a steady increase between 1991 and 2005 with little fluctuations in some years and decreased sharply in 2016 (33.00^{0}C) with a sharp increase in 2010 having 36.00^{0}C which could result from climate change.

It was shown in Figure 5 that the evaporation in the study area for the time frame moderately fluctuated and gradually increased and dropped significantly to an average of 16.16 M^3/Sec in 2011. Also, the average evaporation for 2004 was 10 mm while the amount of power generated in 2004 was one of the highest with 328.33 MWH recorded. High rate of evaporation was capable of reducing the amount of water in the reservoir, thereby resulting to shortage in power generation. Figure 6 displayed the inflow pattern in negative trends having different degrees of fluctuations between 1990 and 2015, rise in 1998, 1999 and 2010 (1436.42 M^3/Sec, 1581.08 M^3/Sec and 1641.08 M^3/Sec respectively) and a steady increase in 2016, 2017 and 2018 (1556.0042 M^3/Sec, 1556.4242 M^3/Sec, and 1635.7542 M^3/Sec respectively).

The Figure 7 indicated the outflow pattern showing negative trends in varying degrees of fluctuation between 1990 and 2015, rise in 1998, 1999 and 2010 at the rate of 1421.75 M^3/Sec, 1581.58 M^3/Sec and 1641.16 M^3/Sec, had stable increase in 2016, 2017 and 2018 at the rate of 1535.00 M^3/Sec, 1558.83 M^3/Sec, and 1632.00 M^3/Sec respectively.

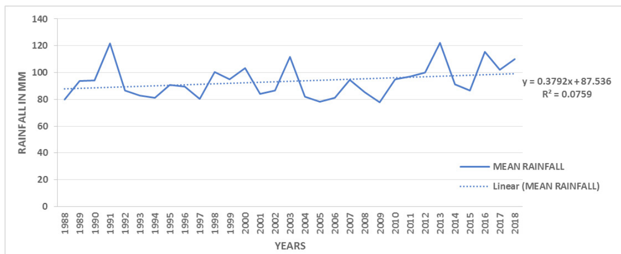

Figure 3. Trends of Rainfall in Jebba Dam from 1988-2018

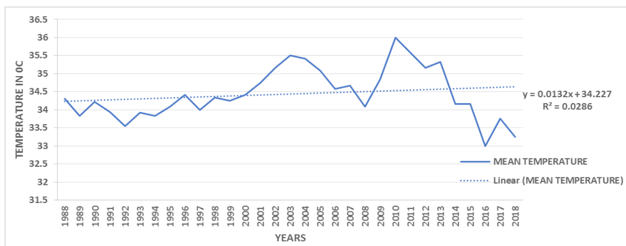

Figure 4. Trend of Temperature in Jebba HEP Station from 1988-2018

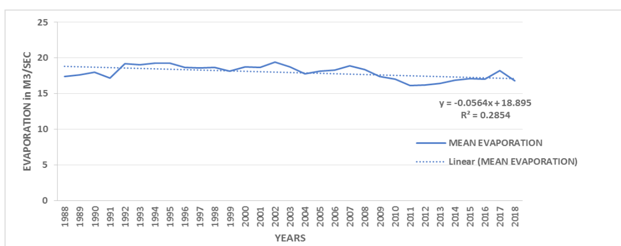

Figure 5. Trend of Evaporation in Jebba HEP station from 1988-2018

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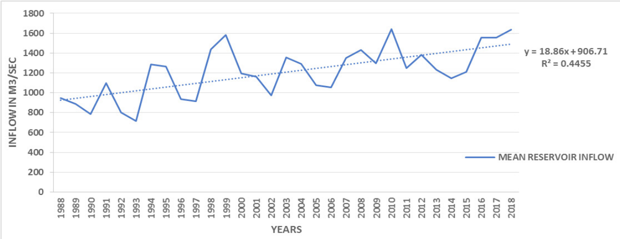

Figure 6. Trend of Reservoir inflow in Jebba HEP station from 1988-2018

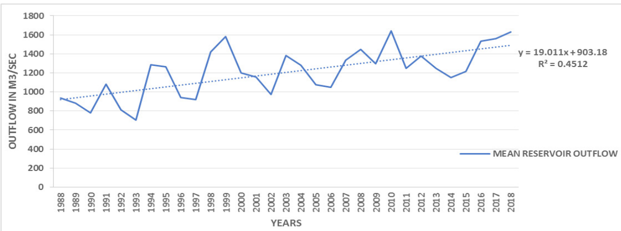

Figure 7. Trend of Reservoir outflow in Jebba HEP station from 1988-2018

There were trends and fluctuations in the amount of power generation in the study area. Figure 8 showed the trend and variations in the amount of power generated in both dry and wet seasons. The lowest amount of electricity was generated in wet and dry seasons in 1993 (182.00 mwh and 158.24 mwh) while the highest amount of electricity was generated during the wet season in 2016 (352.26 mwh) and 1999 (352.26 mwh) in the dry season. But the highest annual mean amount of the electricity generated was in 2016 with the average mean of 689.12 mwh for both dry and wet seasons (352.26 mwh and 336.86 mwh).

The correlations between various climatic variables, reservoir inflow, reservoir outflow and power generation were carried out at 0.05 level of significant. Table 1 indicated that the correlation between rainfall amount and power generation was 0.370. This showed a moderate positive correlation significance between rainfall and power generation which revealed that an increase in rainfall could result in an increase in the amount of power generated and vice versa. The Table 1 still showed the value of 0.178 correlation between temperature and the quantity of power discharged. This showed a weak positive significant relationship between temperature and quantity of power discharged. This revealed that temperature does not really affect power generation in the study area.

Furthermore, as still the Table 1 showed the correlation between evaporation and power generated was -0.268. This showed a weak negative correlation between evaporation and the amount of power generated. This revealed that evaporation had little or no impact on the amount of power generation in the reservoir. The table displayed reservoir inflow and quantity of discharged power were correlated at 0.875. This showed a strong significant positive relationship. It revealed that a change in reservoir inflow will surely affect the amount of power generated. The Table 1 showed that reservoir outflow and power generated had correlation of 0.878. This also showed strong significant positive relationship, indicating that change in reservoir outflow would significantly affect the amount of power generated.

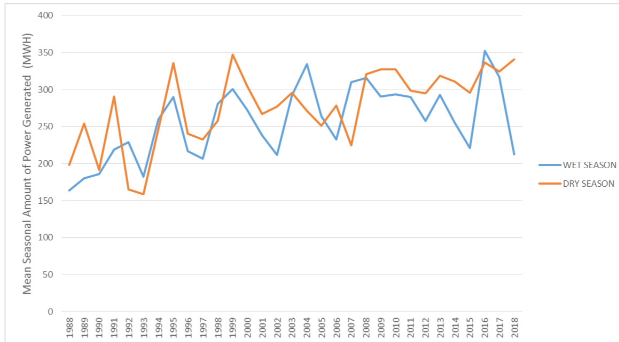

Figure 8. Variations in amount of Power Generated in the Wet and Dry seasons

Table 1. Correlations between Various Climatic Variables, Reservoir Inflow, Reservoir Outflow and Power Generation

VARIABLES	PEARSON PRODUCT MOMENT Power Generated Correlation (R)
Rainfall	0.370
Temperature	0.178
Evaporation	-0.268
Inflow	0.875
Outflow	0.878

**Significant at 0.05 level*

4. Discussion

The study has demonstrated that the trend of each variable (climatic and reservoir variables) for the period under study is subjected to fluctuation, which could be as a result of climate change over the years. Similarly, [11] studied the impacts of climate change on the water resources of Jebba hydropower reservoir. The study shows some no-

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table changes in the climate of Jebba hydropower station. It reveals that in the past few years, rainfall and relative humidity have exhibited negative trends in the area. This indicates that climatic parameters have the tendency to influence reservoir characteristics. In the study the evaporation loss shows negative trends resulting from low relative humidity. According to the result, there exist is a positive impact of climate variables on reservoir water discharge.

Thus, statistical analysis for the amount of power generation reveals that there is increased electricity generation during dry season than the wet season, though the two seasons exhibit fluctuations at different levels. This could be as a result of the high surface flows toward dry season period. This is in tandem with the findings of [3] and other scholars who show that months/period with higher inflow is expected to have a high amount of power generation. The study shows that since more inflow is being received towards months of dry season it is expected that more electricity will be generated in this period. Nevertheless, the amount of power generated in September and October is high and can be compared to the amount generated in the dry season months. While the month of July marks the period with the lowest amount of power generation with the lowest average mean in the study area.

Moreover, the result of the Pearson Correlation Co-efficient revealed that rainfall, reservoir inflow and outflow have a significant relationship with the amount of power-generated than other parameters. This means that, a drop in the amount of rainfall or inflow will definitely affect the amount of power-generation, which will consequently affect the outflow. In the same vein, [12] studied various parameters that influence reservoir discharge in Jebba hydropower. These elements include peak inflow, storage balance, evaporation, minimum inflow, average outflow, peak outflow, average inflow, reservoir level, discharge and minimum outflow. The results of the cumulative contributions show that December has the highest elements contributing to the explanations of electricity generation. Generally, months of high runoff are known to have lower numbers of elements contributing to electricity generation. This suggests that reservoir management in dry period is more challenging. Considerably, [13] investigated the impacts of decadal precipitation variations on reservoir inflow, flood releases and pool elevation in Fortcobb reservoir, at Central Oklahoma. The study shows that watershed runoff, reservoir inflow and flood releases are highly sensitive to decadal precipitation variations. Yet, the only reservoir operation that appears to be impacted by decadal precipitation variations is the frequency of flood release activities [14]. So, it is known that high reservoir inflows during wet periods leads to an increase in flooding that affects power generation.

5. Conclusions

Assessing the impact of climate variability on reservoir-based hydro-power generation in Jebba dam, Niger State, Nigeria has revealed the extent at which climate variables could influence hydro electricity generation. The interactions of rainfall, temperature and evaporation have shown that they are key factors to reservoir inflow and outflow of water resources. The finding establishes that the Jebba reservoir does have inflow in all seasons, resulting from constant upstream flow from Kainji Reservoir which sometimes brings about flooding. The inflow and outflow of reservoir which are determined by climatic variables of rainfall, temperature and evaporation have the capacity to influence electric power generation. The study unveiled the trend and fluctuation of electricity alongside the trends of climatic variables showing that hydro electric power generation is a phenomenon of the climate. The practice of climate change as a contemporary global phenomenon which has strong influence on power generation should be given adequate attention in order to survive in the Nigerian hydroelectric sector. The Nigerian government should review the current water resources and drainage basin management framework that will consider the present stage of development. Some of non-hydrological factors such as maintenance and spare parts problems, inadequate funds, human resources, and policy issues should be considered to avoid system collapse as in the case of the faulted sixth turbine. Therefore, ability of the government to improve the reservoir water capacity considering the current climate reality will accelerate electricity output during period of water scarcity.

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