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Climate Elasticity of Streamflow to Climatic Variables and Implications for Hydropower Generation in Kainji and Jebba Hydropower Stations, Nigeria

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ABSTRACT

This study was conducted to examine the potential influence of climate change on stream flow peaks in Kainji and Jebba Hydropower Projects, Nigeria for the period 1967-2024 and implications for hydropower generation. The study uses long term historical data on rainfall, minimum and maximum air temperature, runoff peak discharge and evapotranspiration to investigate climate elasticity of rainfall and evapotranspiration to climate change and implications for hydropower generation. The study uses Mann–Kendall and Sen's slope estimator tests to detect monotonic trends in the hydro-climatic variables. Climate elasticity of rainfall and evapotranspiration was examined using the non-parametric method to determine the response of streamflow to climate change. The results shows that streamflow the median elasticity of rainfall and evapotranspiration in Kainji was 0.76 and -0.05 while streamflow elasticity of rainfall and evapotranspiration in Jebba were 0.63 and 5.4 indicating that a 10 percent increase in rainfall in Kainji lead to 7.6 percent increase in runoff while a 10 percent increase in rainfall in Jebba lead to 6.3 increase in stream flow. The changes in elasticity of rainfall and evapotranspiration implies that climate change will lead to increased rainfall and runoff for hydropower generation. This requires optimizing the increase in rainfall and runoff for improved hydropower generation.

Keywords: Runoff, Climate Change, Elasticity, Trend and Implication

INTRODUCTION

The production electricity from hydropower depends on stream flow which is influenced by weather in a great variety (Beniston et al., 2013; Roudier, Ducharne & Feyen, 2014; Oswald & Vonsee, 2016. According to Uhorakeye and Möller (2017), climate change is significantly threatening hydropower supply systems around the world, and will continue to do so especially in countries where the share of hydropower in the total electricity supply mix is high. Climate change is likely to alter hydropower generation through increase in temperature and precipitation patterns which will alter river systems. Increase in temperature is expected to increase evaporation from reservoir and rate of water withdrawals. Lower discharges will lead to less electricity generation as hydropower generation depends on river flows. Changes in precipitation patterns will alter outputs and seasonal variation of hydropower generation. Increase in drought and floods will lead to physical damage to hydropower infrastructure. Streamflow depends directly on climate conditions which affect water balance (Wang and He, 2017)

Climate elasticity measures the degree of proportional change in hydrological variables due to a proportional change in climatic variable. Climate elasticity helps to quantify how sensitive water resources are shifting due to shifting climatic conditions. Schaake (2001) adopted the concept of elasticity to evaluate the sensitivity of stream flow for climate. Several studies have used the concept to investigate the simulated impacts of climate change on annual stream flow. For example, Sankarasubramanian and Vogel (2003) used it to document the

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precipitation elasticity of stream flow for 1337 basins in the USA showing that a 1 percent change in precipitation results in a 1.5-2.5 percent change in basin runoff, depending upon the degree of buffering by storage processes and other factors. Fu et al. (2007) have extended into elasticity into a two-parameter index, i.e., climate elasticity of stream flow as a function of both precipitation and temperature. The method has a weakness of having different results depending on applied models and parameters for estimating the stream flow. Sankarasubramanian, Vogel and Limburner, (2001) proposed a new index in which concepts of a median and a mean value and named it a nonparametric method. The study used the non-parametric estimator proposed by Sankarasubramanian et al. (2001) to estimate the climate elasticity of streamflow. Sankarasubramanian et al. (2001) proved that the non-parametric estimator is a robust estimator, and has low bias compared to a broad range of hydrological models, in particular, the model-based approaches and traditional models which tend to be mainly expensive and complex. This index quantifies the variations of annual data on mean values. The elasticity of runoff to rainfall and evapotranspiration. Chiew, Peel, Mcmahon & Siriwardena (2006) used estimates of the sensitivity of stream flow to climate to make informed decisions for managing water resources and environmental systems to cope with hydro climatic variability and climate change. The precipitation elasticity of stream flow (εP), defined as the proportional change in mean annual stream flow divided by the proportional change in mean annual precipitation, is a measure of the sensitivity of stream flow to precipitation. The elasticity method was first used by Schaake in 1990 and is commonly used in the United States and Australia. Grijsen, Tarhule, Brown, Ghile, Taner, Talbi-Jordan, Doffou, Guero, Dessouassi, Kone, Coulibaly and Harshadeep (2013a, 2013b) assessed the climate risk of water resources development in the River Niger Basin. The papers estimated the risk (probability) of exceedance of critical impact levels for various impacted sectors. Such probabilities provide better insights about the likelihood that a specific climate change impact may occur, contributing to informed decisions on investments and adaptations. Grijsen (2014) in a study presented a Climate Risk Assessment (CRA) for the five main river basins in Cameroon, focusing on climate change impacts on water resource availability for power generation mostly in the Sanaga, Benue, Nyong, and Ntem River Basins. The study recorded a 16 percent reduction in runoff from the Sanaga basin due to decrease in precipitation around 1970. Munang & Ayongue (2010) cited in the study recorded an increase in temperature of 0.8ºC, a decline in rainfall by 112mm/yr. (6.5 percent) and reduction in runoff by 142 m^3/s (7.5 percent) for the Sanaga Basin. According to Grijsen (2014), the cumulative effect of these variability in climate will either reduce power production of the Lagdo dam in the Niger Basin by 35 percent or increase it by 15 percent by year 2050. The study also found a possible 15 percent reduction or 5 percent increase in the power generated by the Edea, Song Loulou, Lom Pangar and Nachtigal power plants in the Sanaga Basin by 2050. Minor to moderate impacts were also recorded for power generation from the other basins.

Changes in rainfall patterns lead to changes in volume and timing of water availability while changes in seasonal and interannual variation in inflows will lead to shift in seasonal and annual hydropower outputs. Lower precipitation rate will lead to decline in streamflow and runoff which reduces hydropower generation. An increase in temperature and a decrease in rainfall will reduce streamflow and lead to lower generation. Trace (2019) and Kuo (2016) observed that hydropower generation in Africa has declined due to reduced water availability. Nigerian's hydropower potential is high and hydropower currently accounts for about 32 percent of the total installed commercial electric power capacity. In 2018, the total installed energy capacity in Nigeria is 12,522 MW, of which 2,062 MW is hydropower. The total exploitable potential of hydropower is estimated at over 14,120 MW, amounting to more than 50,800 GWh of electricity annually (IHA, 2024). Despite this huge potential, only about forty five percent of the population of over one hundred and ninety-four million has access to electricity. The roughly 85 per cent of hydropower yet to be developed therefore offers solutions to address existing power shortages. (IHA, 2018; UNIDO, 2019). Hydropower generation offers about 32 percent of electricity generation in Nigeria in 2024 and new investments are been developed to increase enough electricity to meet demand (IHA, 2024). Nigeria's dependence on hydropower leaves the country vulnerable to climate-related disruptions.

The Kainji Hydropower and Jebba stations located along the river Niger with an installed capacity of 760 MW and 540 MW respectively. Recent studies showed that declining rainfall and increase temperature may lead to low inflow and reduced water levels reservoir inflow and hydropower generation in the area due to reduced rainfall in catchment area (Olofintoye and Adeyemo, 2011; Adegbihin, Yusuf, Iguisi and Zubairu, 2016,

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Salami, Mohammed, Adeyemo and Olanlokun, 2015; Zarma, 2006, Anieheobi, 2008 and Jimoh, 2010). The result of this assessment will be integrated in planning future hydropower development in Nigeria, minimize negative impacts, optimize hydropower generation and improve resilience on existing hydropower projects.

MATERIALS AND METHODS

Study Area

The Kainji and Jebba hydropower dams are located across the River Niger in Kainji and Jebba, Borgu and Jebba Local Government Areas of Niger State, Nigeria. The Kainji reservoir (Figure 1) is located on latitude $10^0 8'$N and longitude 4^0 37´E at an altitude of 495ft above the sea level while the Jebba Hydropower dam is located on latitudes 9° 10'N to 9° 55′N and longitudes 4° 30′E to 5° 00′E, as shown in Figure 2. It is located about 100 km downstream of the Kainji dam and has an elevation of 76 m above sea level (Liman et al. 2021). It is an earth dam and with a designed generating capacity of 960 Megawatts; however, only 8 of its 12 turbines have been installed capacity to reducing the capacity to 760 Megawatts. The Jebba dam has an installed capacity of 578.4 MW. The area has a tropical continental climate with wet (Apr-Nov) and dry (Nov-Apr) seasons and mean annual rainfall of 1100-1300mm with high maximum temperatures and an average daily maximum of 33.5 ^{0}C in the warmest month while the mean annual temperature is about 30 ^{0}C.

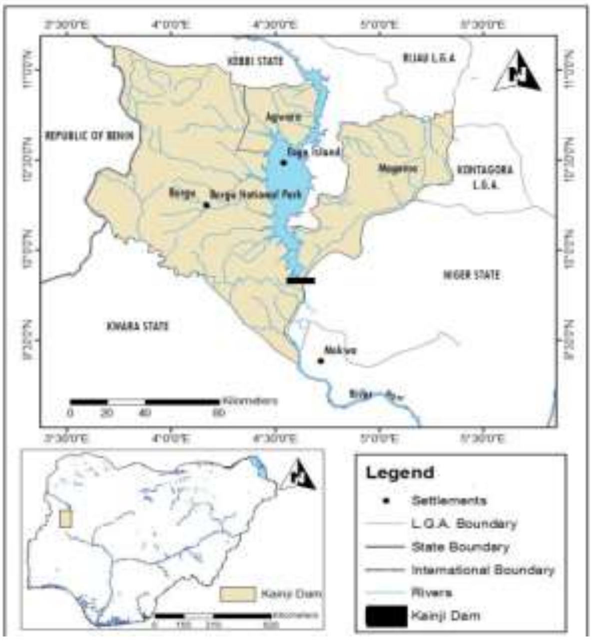

Figure 1: Map of Nigeria and Borgu Local Government Area showing Kainji Dam

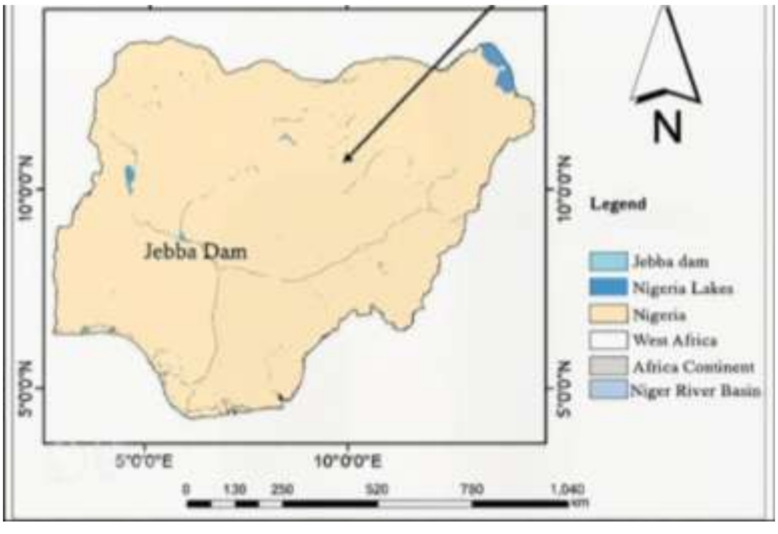

Figure 2: Map of Nigeria showing Jebba Dam

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Methods

The data required was fifty-eight years hydro-climatological data on monthly minimum and maximum air temperature, monthly rainfall, evapotranspiration and runoff peak discharge for Kainji and Jebba Hydropower stations. The climatological data required for the analysis was collected from Nigeria Meteorological Agency (Nimet) Data Management Unit, Abuja. The changes in the annual hydro-climatological data values at the study area was investigated using trend and climate elasticity coefficients.

Mann-Kendal Trend analysis

The non-parametric Mann–Kendall rank test identifies monotonic trends, over time, for given variables, and establishes whether the trend is upwards or downwards. The Mann-Kendall test statistic S is calculated using the formula that follows:

$$S = \sum_{k=1}^{n-1}\sum_{j=k+1} \text{sign}\,(\text{xj} - \text{xk}) \quad \ldots\ldots (1)$$

Where xj and xk are the annual values (years) j and k, j > k, respectively, and sign (x_j-x_k) is given by:

$$\text{Sign}\,(x_j\text{-}x_k) = \begin{cases} 1\ if \quad \text{xj} - \text{xk} > 0 \\ 0\ if \quad \text{xj} - \text{xk} = 0 \\ -1\ if \quad \text{xj} - \text{xk} < 0 \end{cases} \quad \ldots\ldots (2)$$

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). In MAKESENS the two-tailed test is used for four different significance levels α: 0.1, 0.05, 0.01 and 0.001. At certain probability level H_0 is rejected in favour of H_1 if the absolute value of S equals or exceeds a specified value S α /2, where S α /2 is the smallest S which has the probability less than α /2 to appear in case of no trend. A high positive value of S is an indicator of an increasing trend, while a low negative value indicates a decreasing trend. However, it is necessary to compute the probability associated with S and the sample size, n, to statistically quantify the significance of the trend. The variance of S is computed as:

$$\text{VAR (S)} = \frac{1}{18}\left\{n(n-1)(2n+5) - \sum_{p=t}^{q} t_p(t_p-1)(2t_p+5)\right\} \ldots\ldots (3)$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group. If n is at least 10 the normal approximation test is used. For n > 10, the test statistic Z approximately follows a standard normal distribution. The values of S and VAR(S) are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{VAR (S)}}},\ S > 0 \\ 0, \qquad S = 0 \\ \frac{S+1}{\sqrt{\text{VAR (S)}}},\ S < 0 \end{cases} \quad \ldots\ldots (4)$$

The Z values will be tested at the 95% ($Z_{0.025}$=1.96) and 99% ($Z_{0.001}$=2.58) level of significance. The trend is said to be decreasing if Z is negative and the absolute value is greater than the level of significance, while it is increasing if Z is positive and greater than the level of significance. If the absolute value of Z is less than the level of significance, there is no trend. Sen's estimator of slope, which is a non-parametric method is used to determine the magnitude of the trends. The Sen's method is given as:

$$f(t) = Qt + B \ldots\ldots (5)$$

Sen's non-parametric method was used to estimate the magnitude of trends in the time series data:

$$\text{Tt} = \frac{\text{xj} - \text{xk}}{j-k} \ldots\ldots (6)$$

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Where xj and xk represent data values at time j and k respectively. A positive Qi value represents an increasing trend; a negative Qi value represents a decreasing trend over time. The magnitude of the trend over time Qi is given by:

$$\text{Qi} = \begin{cases} \frac{T(N+1)}{2} & N \text{ is odd} \\ \frac{1}{2}\left(T\frac{N}{2} + T\frac{N+2}{2}\right) & N \text{ is even} \end{cases} \quad \ldots\ldots (7)$$

Climate Sensitivity of Runoff

To analyze the impact of climate change on hydropower generation, we will estimate the sensitivity of runoff to both rainfall and evapotranspiration. Numerous studies for basins across the world have documented the sensitivity of stream flow to climate change by estimating the precipitation elasticity of stream flow. The concept of elasticity was introduced by Schaake (1990) for evaluating the sensitivity of stream flow to changes in climate. This relates how a change in climate variable X of Δx will produce a change on stream flow ΔQ. The term εX is defined by the proportional change in stream flow divided by the proportional change in a climate variable(X), such as precipitation or PE. It can be expressed as:

$$\varepsilon_X = \frac{\Delta Q / \bar{Q}}{\Delta X / \bar{X}} \quad \text{------} \ (8)$$

Where ΔQ represents the stream flow runoff Q the (millimeters), while ΔX represents the dominant climate factors on the hydrological cycle (the Precipitation and Potential Evapotranspiration) and $\bar{Q}$ and $\bar{X}$ are the mean of both variables.

In percentage terms, the percentage change in stream flow will be εp times the percentage change in precipitation (Schaake, 1990). Dooge (1992) and Dooge et al. (1999) termed this a ‘sensitivity factor’ and Kuhnel et al. (1991) termed it a ‘magnification factor. One difficulty with estimation of elasticity is that it is often estimated from a hydrological model and the mathematical form of the hydrological model is always an approximation with validation remaining a fundamental challenge (Fu et al., 2011). In order to solve this problem, Sankarasubramanian et al. (2001) introduced the non-parametric estimator. The non-parametric estimator can be expressed as:

$$\epsilon_p = Median\left(\frac{Q_t - \bar{Q}\bar{P}}{P_t - \bar{P}\bar{Q}}\right) \quad \text{------} \ (9)$$

Where εp is a climate elasticity, $\bar{P}$and $\bar{Q}$ are mean annual precipitation and stream flow for the whole period, Pt and Qt are annual precipitation and stream flow for the t-th year. To elasticity determine the output data are calculated for each pair of annual time-series (Pt, Qt) and the median of these numbers is defined as the non-parametric estimate of εp. Similarly, the evapotranspiration (ET) elasticity of streamflow can be calculated from the equation 9. in which precipitation will be replaced by ET. For this reason, the non-parametric estimator was defined at the median value of the hydro-climatic variable.

RESULTS AND DISCUSSION

Trends Analysis of Hydro-Climatic Variables in Kainji

Time series for the hydro-climatic variables were tested for trends using the Mann–Kendall test with MAKESENS_1_0 software. It has been carried out for various hydrological components such as rainfall data analysis, and stream flow analysis (Oguntunde et al. 2000; Oguntunde et. al.2012; Kumar et al. 2000). The Mann-Kendall trend analysis and Sen’s slope estimator for Kainji and Jebba dams were done using MAKESENS_1_0 software. The result is presented in Table 1 and 2.

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Table 1: Mann-Kendal Trend Analysis of Hydro-climatic Variables in Kainji Station

KAINJI HYDROPOWER				Mann-Kendall trend		Sen's slope estimate
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
Annual Runoff	*1967*	*2024*	*58*	2.62	**	1.108
Annual ET	*1967*	*2024*	*58*	-2.43	*	-0.593
Annual Rainfall	*1967*	*2024*	*58*	1.74	+	2.291
Min T	*1967*	*2024*	*58*	5.43	***	0.02
Max T	*1967*	*2024*	*58*	1.93	+	0.011
Mean T	*1967*	*2024*	*58*	5.12	***	0.019

n: Number of years, Z: Mann-Kendall test statistic; Q is the Sen's slope.

Source: Researcher's computation, 2024.

Table 2: Trend Analysis of Hydro-climatic Variables in Jebba Hydropower Station.

JEBBA HYDROPOWER				Mann-Kendall trend		Sen's slope estimate
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
Annual Runoff	*1967*	*2024*	*58*	1.82	**	0.482
Annual ET	*1967*	*2024*	*58*	-0.19	*	-0.034
Annual Rainfall	*1967*	*2024*	*58*	1.84	+	4.726
Min T	*1967*	*2024*	*58*	4.29	***	0.021
Max T	*1967*	*2024*	*58*	-0.49		-0.002
Mean T	*1967*	*2024*	*58*	5.12	***	0.019

Source: Researcher's computation, 2024

According to the results, there is a statistically significant positive trend for minimum and maximum temperature, runoff and annual rainfall data and a decline in evapotranspiration in Kainji and a declining trend for maximum temperature in Jebba. Thus, there was a significant change in climate in the study area. The increasing rainfall and declining evapotranspiration will increase water availability for hydropower generation. This implies that the changes in climate is having significant effect on runoff in the area.

Trend of Temperature

The temperature data collected from the study area was subjected to time series analysis in order to show trend of change for the time frame of study. From the results, it can be deduced that temperature has been increasing in the area. The Mann-Kendall trend analysis indicate that minimum temperature in Kainji and Jebba has increased with a Sen's slope of 0.020 and 0.021 respectively. The value of Z for Kainji and Jebba are 5.43 and 4.29 respectively (greater than $Z_{0.025}$) where with $Z_{0.025} = 1.96$ at 1 percent confidence interval, which makes it statistically significant, indicating that the increase in minimum temperature is significant.

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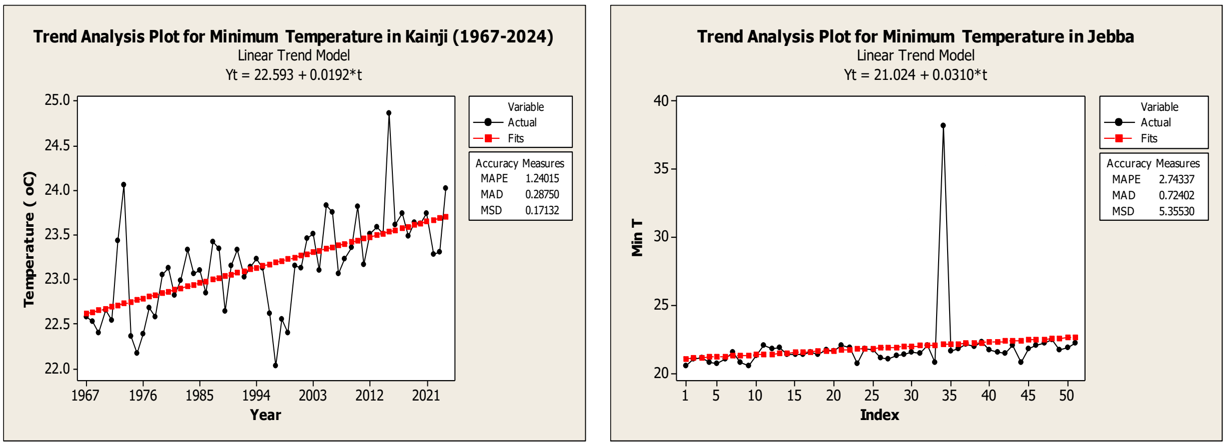

Figure 3. Trend of Minimum Temperature in Kainji and Jebba from 1967-2024.

Researcher's computation, 2024

The maximum temperature showed an increasing trend with Z score of 1.93 in Kainji and a decreasing trend in Jebba and a Sen's slope of 0.011 that is significant at 5 percent and is statistically significant. The Z score of maximum temperature in Jebba is -0.49 and a Sen's slope of -0.002 that is statistically insignificant. This indicates that the maximum temperature has been increasing in Kainji while declining in Jebba. The result is presented in Figures 4. This increase could be as a result of climate change.

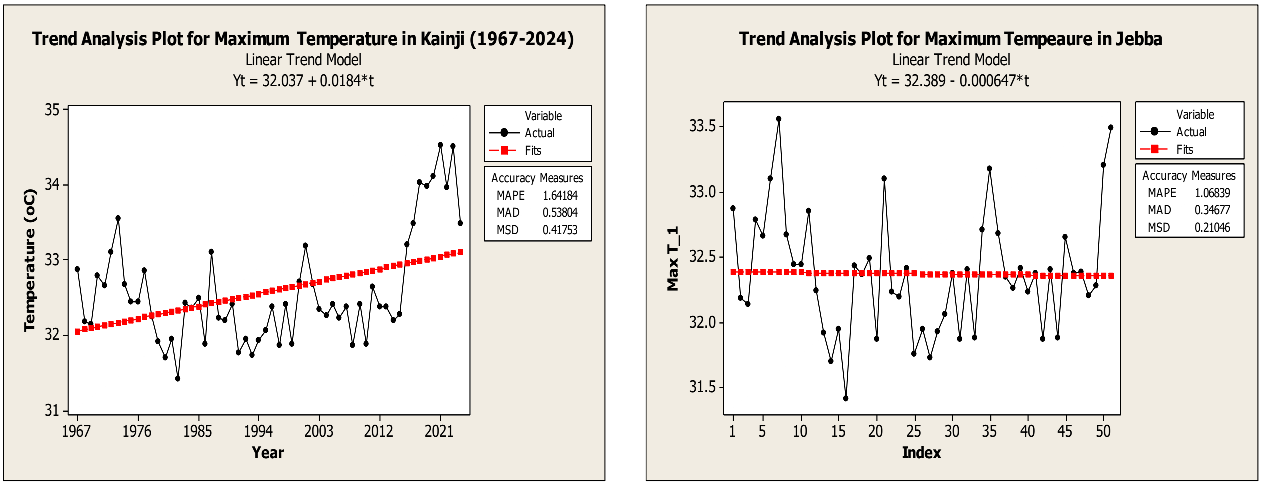

Figure 4. Trend of Maximum Temperature in Kainji and Jebba from 1967-2024.

Researcher's computation, 2024

Trend of Rainfall

The rainfall data collected from the study area was subjected to time series analysis in order to show the trend of rainfall for the time frame of study (1967-2024). The Mann-Kendall trend analysis also indicate that annual rainfall in Kainji dam has increased with a Sen's slope of 2.291. The value of Z is 1.74 (more than $Z_{0.025}$) where with $Z_{0.025}$ = 1.645 at 10 percent, which makes it statistically significant, indicating that the increase in rainfall is noticeable. The result also indicate that rainfall has been increasing at the rate of 2.291 mm per year and 22.9 mm per decade. In Jebba, the Mann-Kendal trend analysis indicate that annual rainfall has significantly increased. The value of Z is 1.84 (more than $Z_{0.025}$) where with $Z_{0.025}$ = 1.645 at 10 percent with a Sens slope of 4.726, which makes it statistically significant, indicating that the increase in rainfall is noticeable. Thus, the rainfall trend from 1967 till present shows a significant increasing trend at 0.05 level of significance. Figure 5 shows that the annual rainfall in the study area have shown a gradual increase over the years. The result is supported by the findings of Olofintoye and Adeyemo (2011) and Salami, Sule and Okeola (2011) who worked on assessment of climate variability on Kainji hydropower reservoir. They found out that

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there was increase in rainfall which demonstrates an existence of a positive trend that is statistically significant.

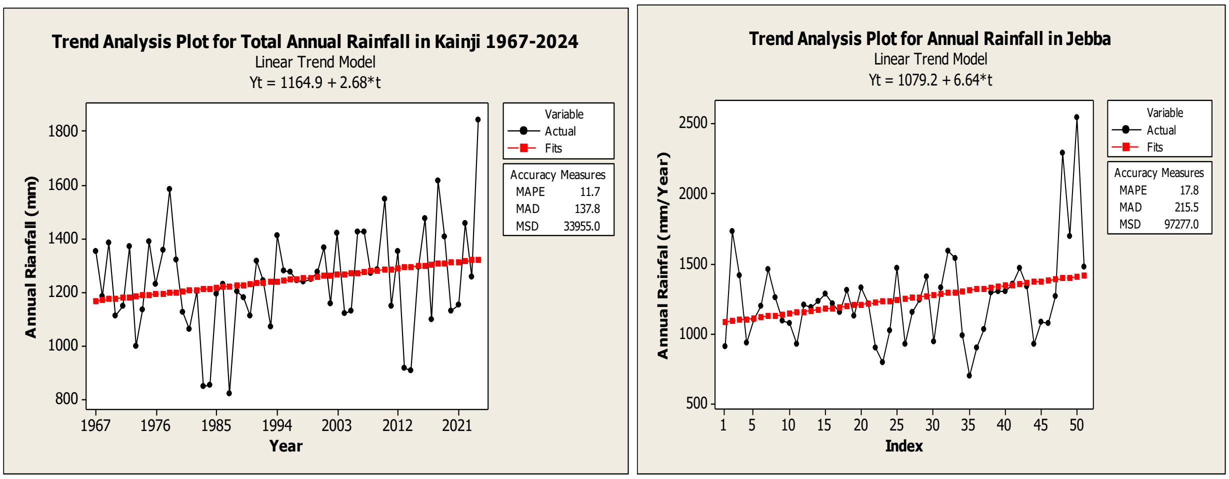

Figure 5. Trend of Annual Rainfall in Kainji and Jebba from 1967-2024.

Source: Researcher's computation, 2024.

Trend of Evapotranspiration

The evapotranspiration data was analyzed to detect trend of change for the time frame of study. The Mann-Kendall trend analysis also indicate that evapotranspiration has decreased in Jebba and Kainji. The value of Z is -2.43 in Kainji and -0.19 for Jebba (more than $Z_{0.025}$) where with $Z_{0.025}$ = 1.96 at 5 percent, which makes it statistically significant, indicating that the decrease in evapotranspiration is significant with a Sen's slope of -0.593 in Kainji and -0.034 for Jebba. the result is presented in Figure 6. The decrease in evapotranspiration might be due to increase in humidity which leads to increase in rainfall and the increase in rainfall with a decrease in evapotranspiration will increase water availability for hydropower generation.

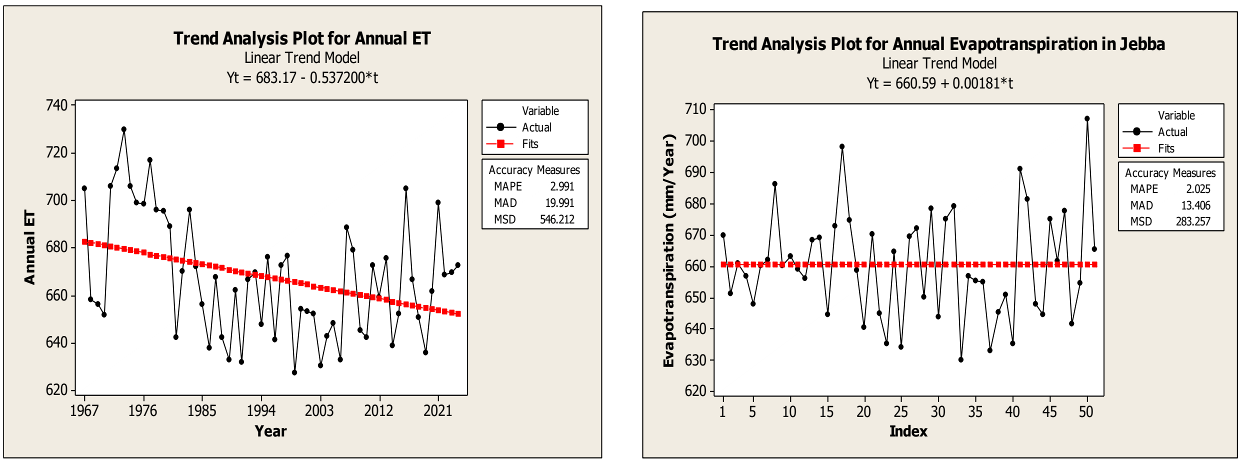

Figure 6: Trend of Annual Evapotranspiration in Kainji and Jebba (1967-2024)

Researcher's computation, 2024

Trend of Runoff Peak

The peak runoff data collected from the study area was subjected to trend analysis. The result is shown in Figure in Figure 7. From the figure, annual runoff peaks have shown significant increase in the area. The Mann-Kendall trend analysis also indicate that runoff has increased with Z-score of 2.62 in Kainji and 1.82 in Jebba (more than $Z_{0.025}$) where with $Z_{0.025}$ = 1.96 at 5 percent, which makes it statistically significant, indicating that the increase in runoff is significant with a Sen's slope of 1.108 and 0.482 respectively. This

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increase shows that the rainfall intensity in the area has also increased. The result is supported by the findings of Olofintoye and Adeyemo (2011 and Salami, Sule and Okeola (2011).

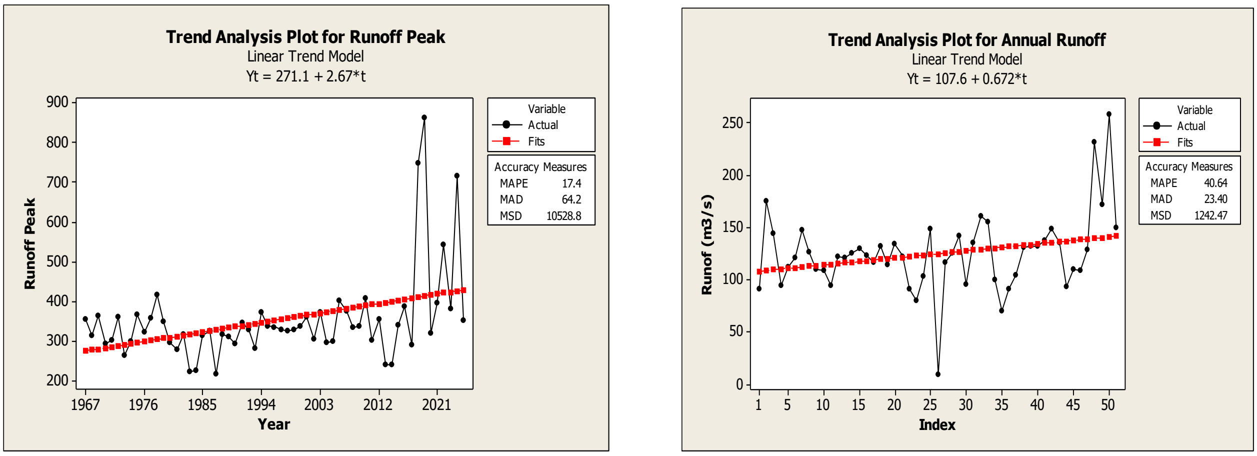

Figure 7. Trend analysis of Annual Runoff Peak in Kainji and Jebba Dams

Source: Researcher's computation in Minitab, 2024

The seasonal Mann-Kendall test value for Z statistics in the wet season is 2.98 with a Sen's slope value (Q) of 1.238 that is significant at 5 percent confidence interval (α = 0.1 level of significance) while the Z statistics for dry season (November-March) is -1.35 with Q of -0.011 that is not significant at 5 percent confidence interval (α = 0.1 level of significance). The result of the monthly runoff trend is shown in Table 3. This indicates that monthly runoff trend in Kainji showed significant increase for April, June, July and December while showing significant decreasing trend was observed in March, August and October.

Table 3: Mann-Kendal Trend Analysis of Monthly Streamflow Runoff in Kainji

Kainji Runoff Data						
						Sen's slope estimate
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
JAN	*1967*	*2024*	*58*	0.86		0.412
FEB	*1967*	*2024*	*58*	0.88		1.543
MAR	*1967*	*2024*	*58*	-3.02	**	-0.075
APR	*1967*	*2024*	*58*	4.73	***	0.021
MAY	*1967*	*2024*	*58*	-0.49		-0.002
JUN	*1980*	*2024*	*58*	3.8	***	0.09
JUL	*1967*	*2024*	*58*	3.34	***	0.011
AUG	*1967*	*2024*	*58*	-1.81	+	-0.103
SEP	*1967*	*2024*	*58*	1.22		1.881
OCT	*1967*	*2024*	*58*	-1.8	+	-0.027
NOV	*1967*	*2024*	*58*	1.22		0.494
DEC	*1967*	*2024*	*58*	2.44	*	5.083

Source: Researcher's computation in MAKESENS 1.0, 2024

Climate Elasticity of Runoff Peak Discharge in Kainji and Jebba Stations

Natural stream flow is the main source of water for hydropower generation. However, stream flow is threatened by climate change and increasing water demand by other sectors. Generally, rainfall and

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evapotranspiration are considered the most critical variables influencing changes in stream flow. Therefore, a sensitivity study of runoff is very important in understanding the influence of climate change on runoff and hydropower generation. The result of the analysis of runoff sensitivity to rainfall and evapotranspiration indicated that the runoff elasticity of rainfall in Kainji dam is varies from -75.00 to 9.97 with a mean of about -1.10 and median elasticity coefficient of 0.76 which implies that a 10 percent change in rainfall leads to 7.6 percent increase in runoff while the runoff elasticity of evapotranspiration has a mean of about -338.77 and median elasticity coefficient of -0.05 which implies that a 10 percent change in rainfall leads to 5 percent decrease in runoff . The streamflow elasticity of rainfall and evapotranspiration in Jebba were 0.63 and 5.4. This indicates that a 10 per cent change in rainfall led to a 6.3 percent increase in runoff in Jebba and a 10 percent increase evaporation rate leads to decrease of about 54 percent decline in runoff Jebba.

Implications of Climatic Variables on Streamflow in Kainji and Jebba Dams

The effects of climate change on the hydropower generation in Kainji Hydropower Station was evaluated using the multiple regression. A multiple regression analysis of the climatic variables was analyzed to determine the impacts of the climate variables on runoff and their significance. The result of the multiple regression analysis between climatic variables and runoff in Kainji is presented in Table 4.

Table 4: Regression Analysis of Runoff versus Rainfall, Min T, Max T, ET

The regression equation is

Annual Runoff = - 1756 + 2.2 Min T + 65.5 Max T + 0.401 SUM - 0.862 Annual ET

Predictor	**Coef**	**SE Coef**	**T**	**P**
Constant	-1756	502.7	-3.49	0.001
Min T	2.16	17.48	0.12	0.902
Max T	65.49	13.16	4.98	0
Rainfall	0.40069	0.04456	8.99	0
Annual ET	-0.8618	0.3553	-2.43	0.019

S = 63.5714 R-Sq = 71.2% R-Sq(adj) = 69.0%

Source: Researcher's computation on Minitab, 2024.

From the result, rainfall, maximum temperature and evapotranspiration have significant impacts on the runoff with evapotranspiration having a significant negative impact on runoff. The result indicate that minimum and maximum temperature and rainfall contributed positively to changes in hydropower generation while evapotranspiration contributed negatively to hydropower generation in Kainji. From the result, climatic variables contribute 71.2 percent of variation in stream flow into Kainji hydropower dam. To test the significance of the regression model, the ANOVA model was used. Table 5 shows that the result is significant and thus, changes in climatic variables contributed to changes in streamflow which influence hydropower generation in Jebba.

Table 5: Summary of one-way ANOVA for impacts of climate change on runoff

Analysis of Variance

Source	**DF**	**SS**	**MS**	**F**	**P**
Regression	4	528880	132220	32.72	0
Residual Error	53	214190	4041	—	—
Total	57	743070	—	—	—

Source: Researcher's computation, 2024.

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The result of the ANOVA table shows that the model is significant in explaining variation between runoff and climatic variables ($p<0.05$). The results shows that climate variables and runoff have an F-ratio of 32.72 with associated probability value of 0.000. Since the associated probability (0.000) was less than 0.05, the null hypothesis (H_{01}) was rejected. The p-value shows that the equation is significant. Thus, there was a significant impact of climate change on runoff in Kainji dam.

Again, the multiple regression analysis of the climatic variables was analyzed to determine the impacts of the climate variables on runoff and their significance in Jebba. The result of the multiple regression analysis between climatic variables and runoff in Jebba is presented in Table 6.

Table 6: Regression Analysis of Runoff versus Rainfall, Min T, Max T, ET

Runoff = 6 + 0.198 Min T + 1.00 Max T - 0.078 Annual ET + 0.107 Rainfall

Predictor	Coef	SE Coef	T	P
Constant	5.6	137.8	0.04	0.968
Min T	0.1982	0.7364	0.27	0.789
Max T_2	1	3.915	0.26	0.8
Annual ET_1	-0.0785	0.1041	-0.75	0.455
Sum R_1	0.10676	0.00555	19.22	0.000

S = 12.1595   R-Sq = 90.1%   R-Sq(adj) = 89.2%

From the result, rainfall has significant impact on runoff while minimum and maximum temperature and evapotranspiration have no significant impact on runoff. The result indicate that minimum and maximum temperature and rainfall contributed positively to changes in runoff while evapotranspiration contributed negatively to runoff in Jebba dam. From the result, climatic variables contribute 90.1 percent of variation in stream flow into Jebba hydropower dam. To test the significance of the regression model, the ANOVA model was used. Table 7 shows that the result is significant and thus, changes in climatic variables contributed to changes in streamflow which influence hydropower generation in Jebba. The p-value shows that the equation is significant

Table 7: Regression Analysis of Runoff versus Rainfall, Min T, Max T, ET

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	61,558	15,389	104.09	0
Residual Error	46	6,801	148	—	—
Total	50	68,359	—	—	—

The result of the ANOVA table shows that the model is significant in explaining variation between runoff and climatic variables ($p<0.05$). The results shows that climate variables and runoff have an F-ratio of 104.09 with associated probability value of 0.000. Since the associated probability (0.000) was less than 0.05, the null hypothesis (H_{01}) was rejected. Thus, there was a significant impact of climate change on runoff in Jebba dam.

CONCLUSION

This study investigated the elasticity of climatic variables on runoff and implication for hydropower generation in Kainji and Jebba hydropower stations, Niger State from 1967 to 2024. Investigation was

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conducted using data on rainfall, temperature, evapotranspiration and runoff peak. The result indicates that there has been a noticeable and significant increase of rainfall and runoff peak, minimum, mean and maximum temperature while evapotranspiration has declined from 1967-2024 as a result of changes in climate in Kainji. The result also indicates a spatial difference between the two stations. As a result of increase in rainfall and runoff, hydropower generation also showed a significant increase and high sensitivities implies high volatility of the reservoir, increasing risk to hydropower generation. This is consistent with the report by International Hydropower Association (2024) and Mainstream Energy Limited which shows that Nigeria is witnessing an increase in hydropower generation in recent times (Daily Trust, 2017).

RECOMMENDATIONS

Based on the result, the researchers recommend optimizing the increase in rainfall and runoff for improved hydropower generation and energy security in Nigeria.

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