Modelling the Influence of Climate Change on Runoff and Hydropower Generation in Kainji Hydropower Station, Niger State, Nigeria

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ABSTRACT

This study was carried out to examine the potential influence of climate change on hydropower generation in Kainji Hydropower Project, Niger State for the period 1967-2024 and predict its future effects on hydropower generation. The study uses long term historical data on rainfall, minimum and maximum air temperature, runoff peak discharge and evapotranspiration to investigate observed hydro-climatic variability and climate change and project future hydropower generation. The study uses Mann–Kendall and Sen's slope estimator tests to detect monotonic trends in the hydro-climatic variables and hydropower generation and their magnitude with MAKESENS_1_0 application. The Box-Jenkins methodology was used to build an Auto regressive Moving Average (ARIMA) model for mean temperature, peak runoff, annual rainfall and hydropower generation. The results indicate significant increase in temperature, rainfall, runoff, and hydropower generation while evapotranspiration declined. The ARIMA model identified for runoff is ARIMA (3, 3, 1) with R^2 of 0.519 while hydropower generation has ARIMA (2, 1, 1) model with an R^2 of 0.155. The different models were evaluated with the Bayesian Information Criterion (BIC) and Akaike Information Criterion (AIC) and validated. The models were therefore adequate and appropriate for the forecast of future runoff and hydropower generation. The results shows that runoff and hydropower generation will likely increase under current condition. The study recommends improving hydropower infrastructure to optimize increased water availability for hydropower generation in Kainji station.

Keywords: Hydropower, Climate Change, ARIMA, Trend and Runoff peak

INTRODUCTION

Energy is a key component of human lives and economic development. Energy generation and use is one of the major causes of greenhouse gas (GHG) emission which causes climate change (Edenhofer et al. 2011). Renewable energy sources play a role in providing energy services in a sustainable manner and, in particular, in mitigating climate change (Kumar, Schei, Ahenkorah, Rodriguez, Devernay, Freitas, Hall, Killingtveit and Liu, 2011). Hydropower is the leading renewable source for electricity generation globally but are vulnerable to climate change (Hamududu and Killingtveit, 2012). Hydropower is generated by water falling under the force of gravity that turns the blades of a turbine, which is connected to a generator. Hydropower offers a cheap, clean, environmentally friendly and renewable alternative source of energy that contributes significantly to greenhouse gas emission reduction and to climate change mitigation (Berga, 2016). Hydropower accounts for 16.4 percent of global electricity production in 2016 and 86 percent of global renewable energy production (Hamududu & Killingtveit, 2012; IEA, 2019). Figures published by International Energy Association (2019), International Hydropower Association (2018) and Kumar (2012) observed that the global hydropower generation has increased by 50 percent since 1990. In 2008, the generation of electricity from hydroelectric plants was 3,288 TW-h/year (11.8 EJ) compared to 1,295 TW-h/year (4.7 EJ) in 1973 (IEA, 2019). The highest absolute growth was observed in China; with production increase from 3,427 TWh to 4185 TW-h/year in 2016 (Berga, 2016; IHA, 2018). World Economic Council (2016) observed that the total installed capacity has grown by 39 percent from 2005 to 2015, with an average growth rate of nearly 4 percent per year and installed hydropower capacity is projected to reach 1,947 GW by 2050, about double current levels (IEA 2012; GEA, 2012). Hydroelectric power is a significant component of electricity production worldwide. In South America, hydropower generation provides 63 percent of the total electricity production (Van Vliet et al., 2016), 98 percent of Tajikistan's electricity; Norway gets 99 percent with 31837MW, Brazil 84 percent; Canada 58 percent and Nigeria 32 percent (IHA, 2024). Sub-Saharan Africa (excluding South Africa) is 60 percent dependent on hydropower for its power supply, and many individual countries are much more dependent with about 90 percent of national electricity generations in Ethiopia, Malawi, Mozambique, Namibia and Zambia (Beilfuss, 2012; Conway, 2017; Conway, Dalin, Landman and Osborn 2017).

Climate change is one of the significant challenges facing human development (Pilesjo & Al-Juboori, 2016). 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. Though all nations are susceptible to the effects of global climate change, developing countries are inherently more vulnerable to the effects of climate change disruptions because they have fewer disposable resources to spend on unexpected extreme weather events, higher level of water scarcity which is compounded by poverty, high vulnerability and low adaptive capacity to long-term alterations to climate change impacts (Enete et al., 2011). 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. Changes in climate is likely to increase in temperature which will increase the rate of water loss through evaporation. 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. The World Meteorological Organization (2024) reports that drought conditions caused a significant drop in hydropower production in 2022. The future of hydropower generation is uncertain. Reliance on hydropower generation without assessing the future impacts increases risks. IHA (2024) observed a decline in hydropower generation since 2022. According to the WMO (2024), 2023 was one of the three warmest years in the 124-year record in Africa with the mean temperature 0.61 °C higher than the 1991–2020 average and 1.28 °C higher than the 1961–1990 average. West Africa and Nigeria witnessed a much higher increase of 0.64^0C and 1.29^0C from 1980-2020 and 1961-1991 periods respectively.

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 (International Hydropower Association (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). 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. Unfortunately, the Nigeria hydropower has been challenged with hydrological shortfalls (Anieheobi, 2008). In recent years, the Kainji hydropower dam has witnessed a drop in water levels which has affected hydropower generation. Machina and Sharma (2017) predicted a decrease in hydropower generation from Kainji as a result of a decrease in rainfall and increase in temperature. Mohammed, Mustafa, Bashir and Mokhtar (2013) cited by Akorede, Ibrahim, Amuda, Otuoze and Olufeagba (2017) observed that installed capacity of the hydropower plants in Nigeria has continued to decline due to lack of proper maintenance leading to loss of generating units and seasonal fluctuations in the volume of water flowing into the reservoirs and thus poses risks for the generation of hydropower in Nigeria. The Kainji

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Hydropower Station is a reservoir storage hydropower dam built by the Nigerian government in 1964 at Kainji, along the river Niger with an installed capacity of 760 MW. 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, Salami, Mohammed, Adeyemo and Olanlokun, 2015; Zarma, 2006, Anieheobi, 2008 and Jimoh, 2010). The autoregressive integrated moving average (ARIMA) model is a statistical model to forecast data based on its long-term historical data. 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. Consequently, it becomes very necessary to assess likely effects of climate change on hydropower generation in order to help improve sustainability in the sector and boost economic production in Nigeria.

MATERIALS AND METHODS

Study Area

The Kainji hydropower dam is located across the River Niger in Kainji, Borgu Local Government Area of Niger State, Nigeria. The Kainji reservoir (Figure 1) is across the Niger River in Borgu Local Government Area, Niger State of Nigeria on latitude $10^0$8´N and longitude 4^0 37´E at an altitude of 495ft above the sea level. 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. It was designed to have a generating capacity of 960 Megawatts; however, only 8 of its 12 turbines have been installed, reducing the capacity to 760 Megawatts.

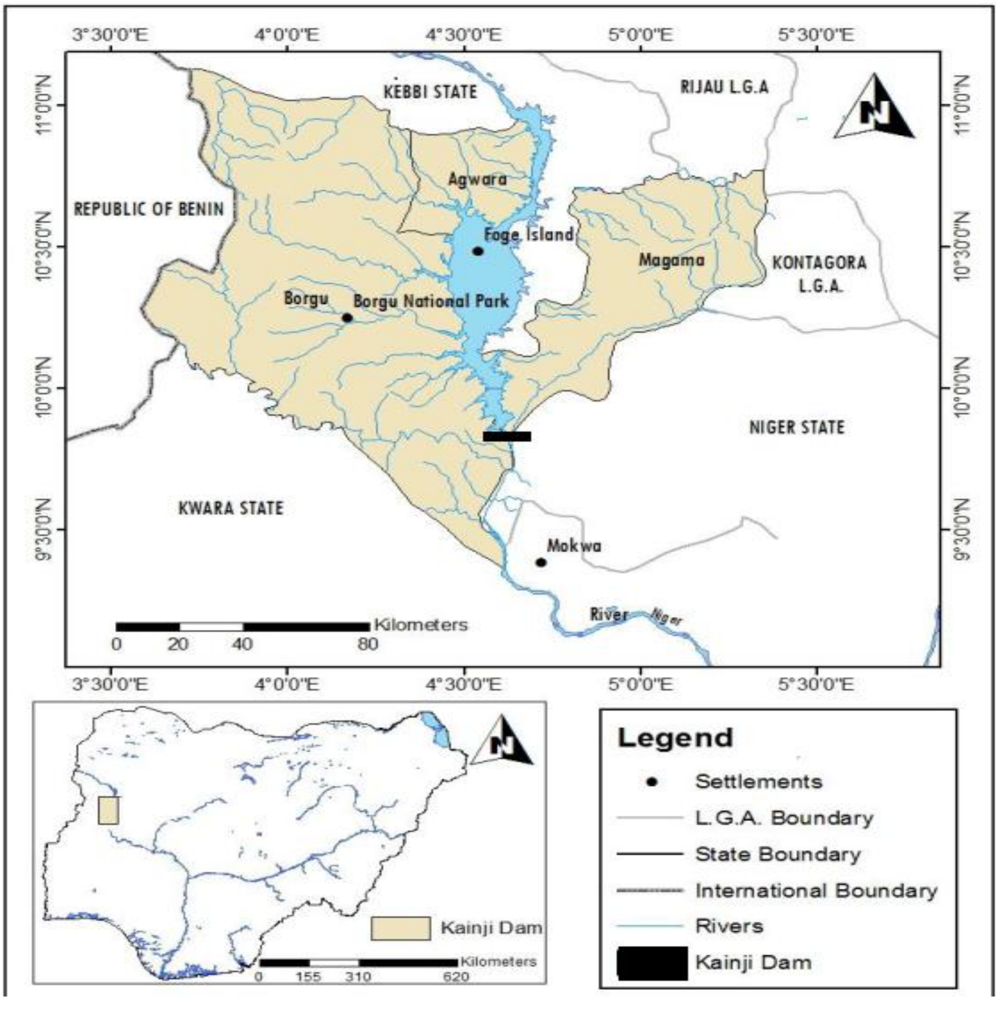

Figure 1: Map of Nigeria and Borgu Local Government Area showing Kainji Dam

Methods

The data required was fifty-eight year's hydro-climatological data on monthly minimum and maximum air temperature, monthly rainfall, monthly evapotranspiration and runoff peak discharge for Kainji Hydropower Station and energy production data from 1967-2024. The climatological data required for the analysis was collected from Nigeria Meteorological Agency (NIMET) Data Management Unit, Abuja while annual electricity generation in the power dam data was collected from Knoema.com, Energy Commission of Nigeria and Mainstream Energy Solutions Limited, Kainji Hydropower Dam Project. The changes in the annual hydro-climatological data values at the study area was investigated using trend while future impacts were predicted using Box-Jenkins's methodology. Statistical analyses of climate variables can help to identify the cause and consequence of a shift in climate pattern Dani and Pal (2017). Trend analysis is an important and efficient method of identification of changes in climate (Auffhammer et al., 2011. The data was analysed to determine any indication of climate change and trend in climate within the study area from 1967-2024 and the impacts of those changes on future hydropower energy generation in Nigeria.

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:

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

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

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

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:

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

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

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

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:

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

Forecasting Time Series: the ARIMA Model

Time series modeling is the analysis of a temporally distributed sequence of data or the synthesis of a model for prediction in which time is an independent variable. According to McCuen (2003),

Auto-regressive Moving average (ARIMA) model is useful for predicting future trends for various climate variables through analysis of existing data series; such information is particularly useful to policymakers in the development of mitigation plans. The ARIMA models was first described by Box and Jenkins (1976) and is also known as Box-Jenkins's methodology. The model consists of three parts, an autoregressive (AR) part, a moving average (MA) part and the third part integrated (I) in ARIMA model. The model is usually then referred to as the ARIMA (p,d,q) model where p is the order of the autoregressive part, d is the order of non-seasonal differences and q is the order of the moving average part. The ARIMA models allow the manager who has only historic data of say rainfall, to forecast future values without having to search for other related time series data, for example, temperature. Auto Regression (AR) is a linear regression of a value in a time series against one or more prior values in the series (autocorrelation). A Moving Average (MA) process expresses an observed series as a function of a random series. A combination of these two methods is called a mixed autoregressive and moving average (ARMA) model. An ARMA model that allows for non-stationarity is called a mixed autoregressive integrated moving average (ARIMA) model. Ghimire (2017) applied the auto-regressive integrated moving average (ARIMA) process to forecast the river discharges for a river in United States. Dani and Pal (2019) used the Auto-regressive integrated moving average to predict future trends of climatic variables (temperature, rainfall, vapour pressure and crop evapotranspiration from 2015-2025) in Angul District of India. The result showed an increasing significant trend of temperature which could lead to extreme events such as heat waves while the rainfall showed a statistically significant negative trend which indicate severe drought. The tools required for identification are correlogram, autocorrelation function and partial autocorrelation function. The partial autocorrelation (PAC) measures correlation between (time series) observations that are k time periods apart after controlling for correlations at intermediate lags (i.e., lags less than k). In other words, partial autocorrelation is the correlation between Yt and Yt−k after removing the effect of the intermediate Y's (measures the marginal impact).

RESULTS AND DISCUSSION

Trends Analysis of Hydro-Climatic Variables

The detection, estimation and prediction of trends and associated statistical and physical significance are important aspects of climate research. Time series for the hydro-climatic variables were tested for trends and slopes annually using the Mann–Kendall test. 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.

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2000). The Mann-Kendall trend analysis and Sen's slope estimator was done the result is shown in Table 1.

Table 1: Mann-Kendal trend statistics for Kainji Hydropower Station

Kainji Hydroclimatic Data						Sen's slope estimate
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
Mean Rainfall	*1967*	*2024*	*58*	1.74	+	0.191
Min Temp	*1967*	*2024*	*58*	5.43	***	0.020
Max Temp	*1967*	*2024*	*58*	1.93	+	0.011
Mean Temp	*1967*	*2024*	*58*	5.12	***	0.019
Annual ET	*1967*	*2024*	*58*	-2.43	*	-0.593
Annual Rainfall	*1967*	*2024*	*58*	1.74	+	2.291
Electricity Generation (GW/Year)	*1969*	*2024*	*56*	3.19	**	20.719
Annual Runoff	*1967*	*2024*	*58*	2.62	**	1.108
Average Runoff	*1967*	*2024*	*58*	2.62	**	0.092

(Source: 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 trend in Figure 2 shows that the total annual rainfall in the study area have shown a gradual increase over the years. The Mann-Kendall trend analysis also indicate that annual rainfall has increased with a Sen's slope of 1.543. 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. Thus, the rainfall trend from 1967 till present shows a significant increasing trend at 0.05 level of significance. 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.

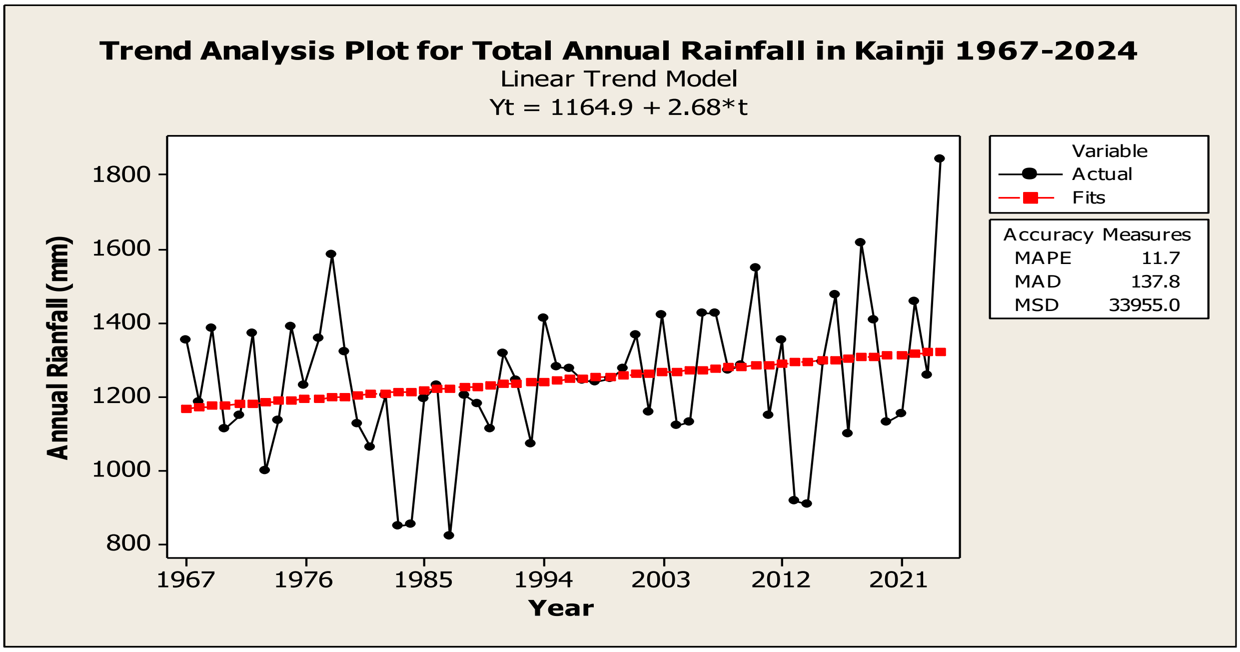

Figure 2. Trend of Total Annual Rainfall in Kainji from 1967-2024.

(Source: Researcher's computation, 2024)

Trend of Temperature

The minimum and maximum temperature data were subjected to trend analysis in order to show direction of change and their magnitude. The results were presented in Figures 3. From the results, it can be deduced that temperature has been increasing in the area. The Mann-Kendall trend analysis indicate that minimum temperature has increased with a Sen's slope of 0.020. The value of Z is 5.43 (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. The maximum temperature also showed an increasing trend with Z score of 1.93 and a Sen's slope of 0.011 that is significant at 5 percent while the mean temperature increased with a Z score of 5.12 and a Sen's slope of 0.019 and is statistically significant. This indicates that the minimum, maximum and mean temperature has been increasing. The mean temperature has been increasing at the rate of 0.02^0C per year and 0.2^0C per decade. The result is supported by the findings of Olofintoye and Adeyemo (2011) and Salami, Sule and Okeola (2011). Fig 3 shows that the minimum temperature and maximum temperature of the study area have been on the increase. The increase in temperature is responsible for an increase in water losses from evapotranspiration and decrease in available water for runoff observed in the area. This increase could be as a result of climate change. An increase in mean temperature is capable of increasing evaporation rate and precipitation which might lead to flooding thereby causing destruction and break down of equipment required for electricity generation.

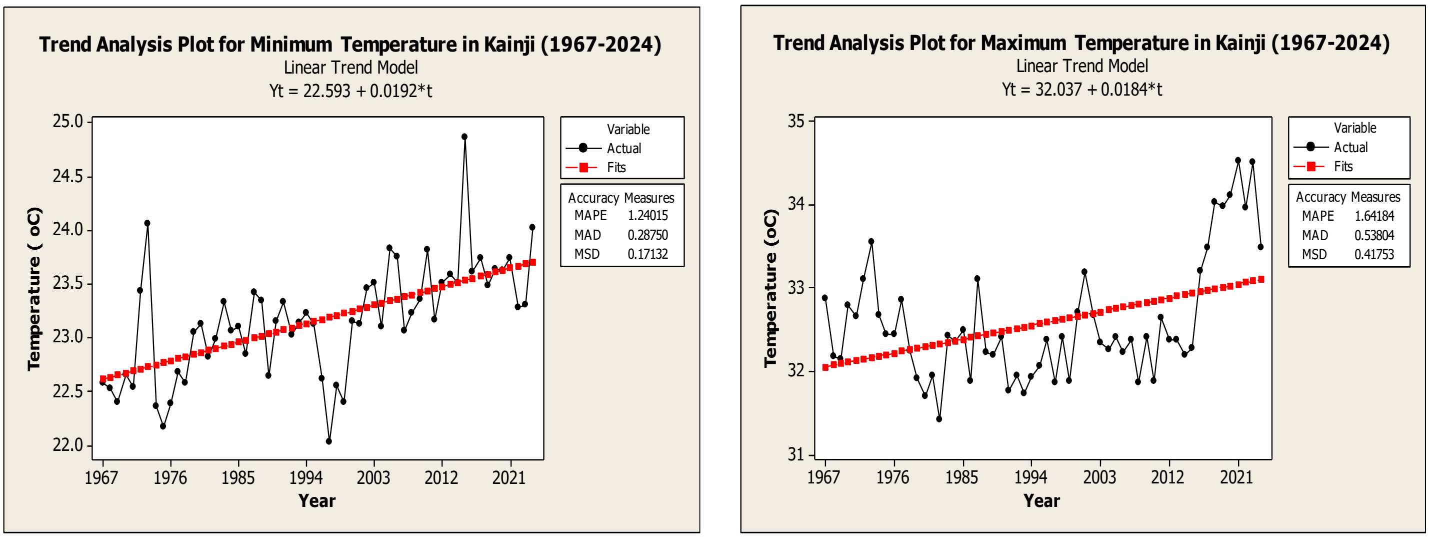

Figure 3. Trend of Minimum and Maximum Temperature in Kainji from 1967-2024.

Researcher's computation, 2024

Trend of Evapotranspiration

The evapotranspiration data collected from the study area was analyzed in order to show the pattern of change for the time frame of study. Figure 4 shows the trend of total annual evapotranspiration in the study area for the period of fifty-eight years. From the figure, it can be seen that the total annual evapotranspiration in the study area for the time frame of study has been fluctuating and gradually decreasing. The Mann-Kendall trend analysis also indicate that evapotranspiration has decreased. The value of Z is -2.43 (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. This indicates that evapotranspiration has declined by 0.583 mm/year and 5.83 mm per decade. The declining evapotranspiration despite increase in temperature might be due to increase in humidity over the area (Olofinyoye and Adeyemo, 2011). The increase in rainfall with a decrease in evapotranspirattion will increase water availability for hydropower generation.

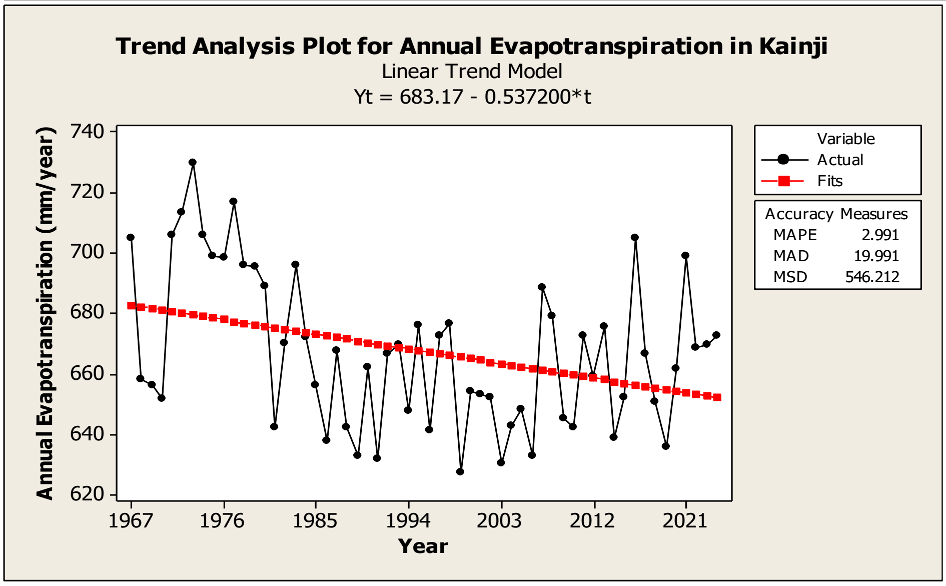

Figure 4: Trend of Annual Evapotranspiration in Kainji (1967-2024)

Researcher's computation, 2024

Trend of Runoff Peak Discharge

The peak runoff data collected from the study area was subjected to trend analysis to show the pattern of reservoir peak runoff for the time frame of study. The result is shown in figure 5. From the figure, average runoff peak has shown a slight increase in the area. The Mann-Kendall trend analysis also indicate that runoff has increased. The value of Z is 2.62 (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 annual runoff is significant with a Sen's slope of 1.108. This 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). The value of Z for average annual runoff is 2.62 (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 0.092. The Mann-Kendall trend analysis also indicate that total annual runoff has increased. The result is supported by the findings of Olofintoye and Adeyemo (2011 and Salami, Sule and Okeola (2011).

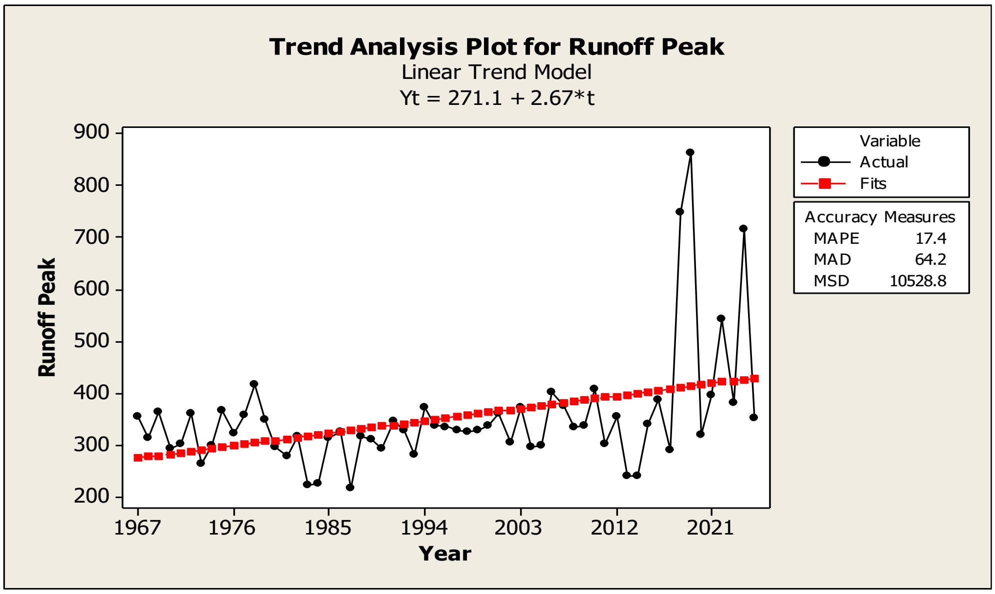

Figure 5. Trend analysis of annual Runoff Peak in Kainji from 1967-2024

Source: Researcher's computation in Minitab, 2024

The annual runoff disaggregated into two seasons- wet (April-October) and dry (November-March) seasons shows that runoff has been increasing during the wet season over the years while showing a decreasing trend in dry season over the period indicating that rainfall has been increasing in the area during the dry season while the dry season has been showing tendency for dryness. 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 ($\alpha = 0.1$ 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 ($\alpha = 0.1$ level of significance).

Analysis of Hydropower Generation data in Kainji Hydropower Station

The amount of hydropower generation was sourced from Energy Commission of Nigeria and Mainstream Energy Solutions Limited for the period 1969-2024. The annual power generation data for the Kainji Power Station from 1969 – 2024 (GWh/year) is shown in Figure 6.

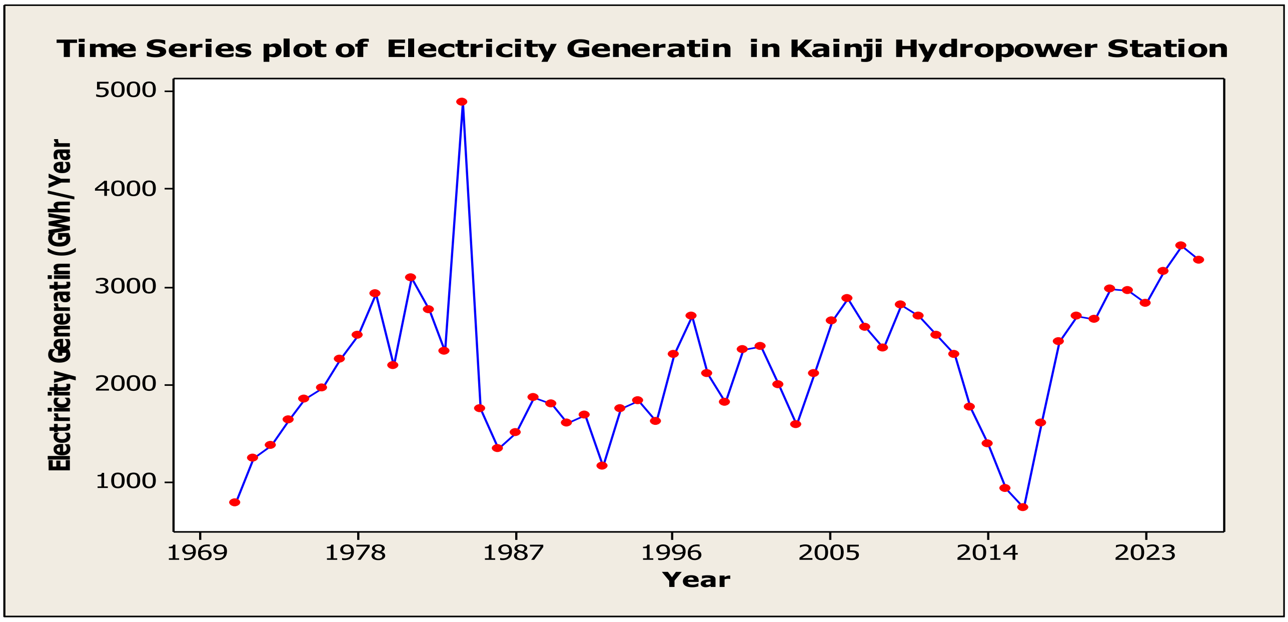

Figure 6: Time Series Plot for Hydropower Generation in Kainji from 1969-2024.

Source: Researcher's computation in Minitab, 2024.

According to the result, there has been a fluctuation in overall electricity production since 1969. The annual variation of hydropower generation in the area exhibits annual variation with maximum hydropower generation of about 4882.4 GWh/year recorded in 1984 while the lowest temperature is recorded in 2016 with about 735.1 GWh/year. The mean total annual runoff is 2187.7 GWh/Year while the standard deviation is 740.9 with a coefficient of variability of 33.87 percent. The result indicates that hydropower generation in the area fluctuates greatly between the mean values form year to year from 1969 to 2024. The result of the descriptive statistics of annual electricity generation is presented in Table 2.

Table 2 Descriptive Statistics: Electricity Generation (GWh/Year)

Variable	N	N*	Mean	SE Mean	StDev	CoefVar	Minimum
Electricity Generation	56	2	2187.7	99.0	740.9	33.87	735.1

Variable	Q1	Median	Q3	Maximum
Electricity Generation	1645.2	2216.0	2693.3	4882.4

Source: Researcher's computation in Minitab, 2024.

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The trend of hydropower generation from 1969-2024 is presented in Figure 7. From the figure, it can be seen that hydropower generation has been increasing.

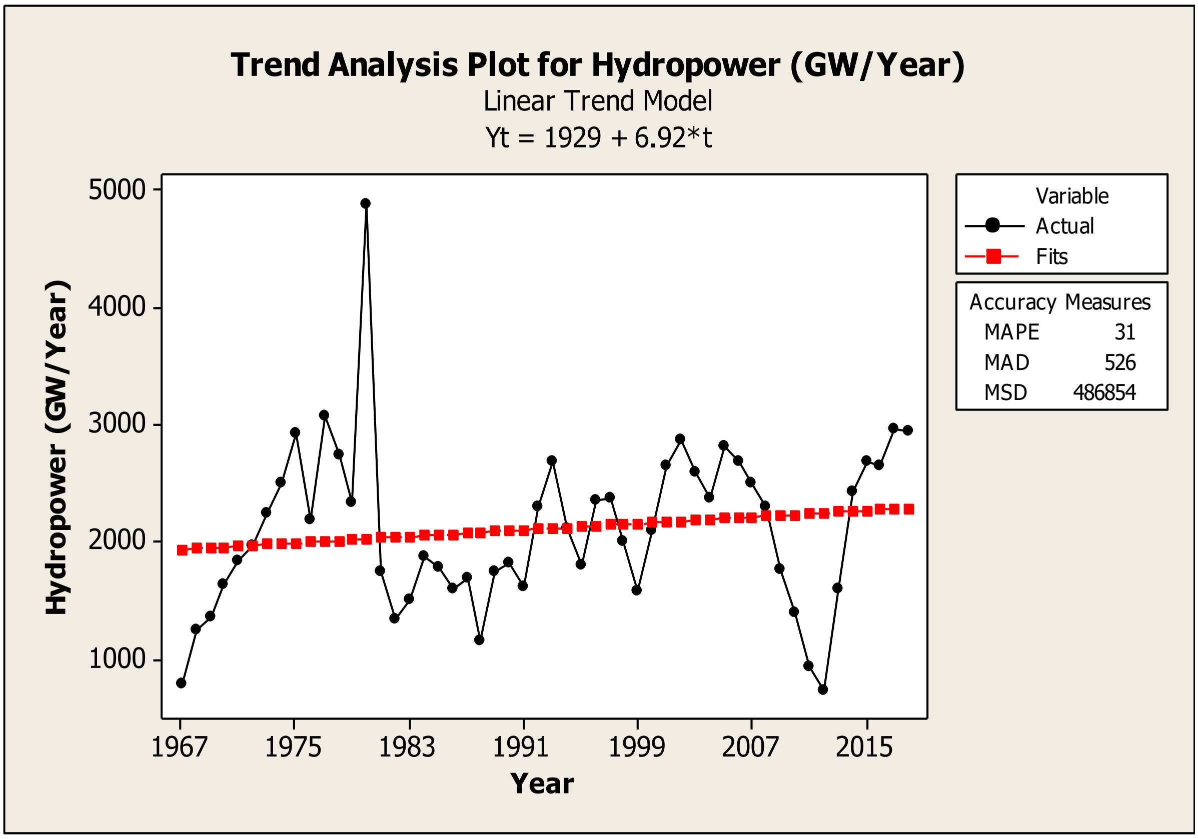


Figure 7: Trend of hydropower generation in Kainji, Nigeria from 1967-2024

(Source: Researchers Calculation, 2024)

The Mann-Kendall trend analysis indicate that hydropower generation has increased. The value of Z is 3.16 (greater than $Z_{0.025}$) where with $Z_{0.025}$ = 1.96 at 0.1 percent, which makes it statistically significant, indicating that the increase in power generation is significant with a Sen's slope of 20.719 indicating a 20.719 MW-hr increase per year. The result is presented in Table 3.

Table 3: The Mann-Kendall Trend Analysis of Annual Hydropower Generation in Kainji

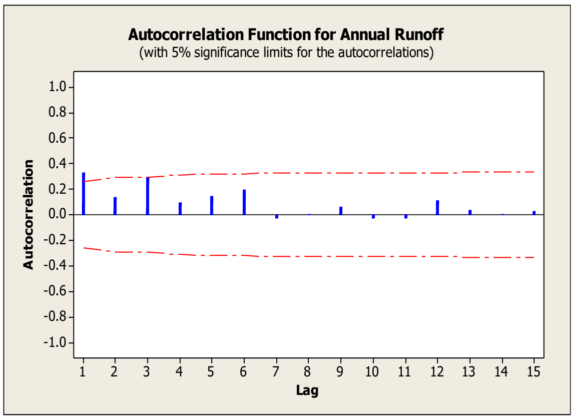
KAINJI HYDROOWER			Mann-Kendall trend			Sen's slope est
Time series	**First year**	**Last Year**	**n**	**Test Z**	**Signific.**	**Q**
Electricity Generation (GW/Year)	***1969***	***2024***	***56***	**3.19**	**	**20.719**

Source: Researcher's computation, 2024.

Times Series Modeling of Runoff and Hydropower Generation

Model for Runoff

Annual runoff peak tends to be a non-stationary process and thus, need differencing. We now look at the sample ACF and PACF plots. The ACF decays from the first lag up to the third lag while the PACF exhibit the same pattern. This suggests an AR (p) process of order 3. The PACF cuts off after lag 3 This suggests an MA (q) process of order 3. The mixed autoregressive integrated moving average process can be represented as ARMA (3, 1, 3). Thus, the runoff peak can be modelled by an ARIMA (3, 1, 1) model. The results are presented in Figure 8. Thus, there is a mixed autoregressive moving average model in the data



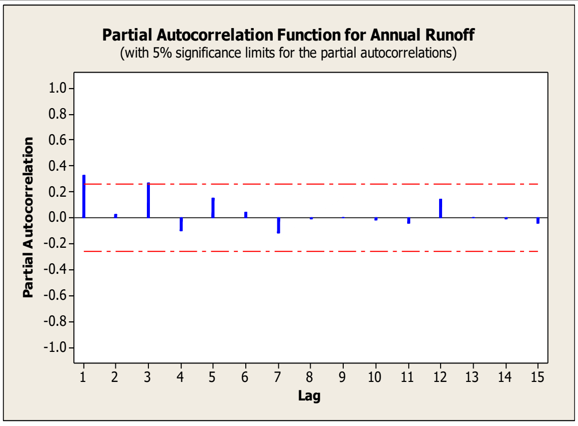


Figure 8: ACF and PACF Plot of Annual Peak Runoff from Kainji Hydropower Station

Source: Researcher's computation using Minitab, (2024)

A final realization of the model parameters is presented in Table 4.

Table 4: ARIMA Model of Annual Runoff

Final Estimates of Parameters

Type	Coef	SE Coef	T	P
AR 1	-0.6505	0.2107	-3.09	0.003
AR 2	-0.5004	0.1970	-2.54	0.014
AR 3	0.4516	0.1871	2.41	0.019
MA 1	-0.3192	0.1767	-1.81	0.077
MA 2	0.4629	0.1268	3.65	0.001
MA 3	0.7636	0.1508	5.06	0.000
Constant	5.072	1.139	4.45	0.000

Differencing: 1 regular difference

Number of observations: Original series 58, after differencing 57

Residuals: SS = 407180 (backforecasts excluded)

MS = 8144 DF = 50

Modified Box-Pierce (Ljung-Box) Chi-Square statistic

Lag	12	24	36	48
Chi-Square	3.2	5.4	13.3	19.3
DF	5	17	29	41
P-Value	0.676	0.997	0.995	0.998

The table indicates that runoff has a significant AR (3), a difference (1) and an MA (3) processes. The parameter estimates of the model are presented in Table 5, indicating that the model has an R^2 of 0.519 showing that the model explains 51.9 percent variation in runoff and the Root Mean Square Error = 92.154 indicating that model deviates by about 92.154 mm/year of runoff and the BIC is 9.614 indicate a better fitting model. The p-value of 0.928 is high, indicating there is no autocorrelation in the residuals.

Table 5: Model Statistics of ARIMA (3,1,3) Model for Runoff

Model	Number of Predictors	Model Fit statistics					Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	R-squared	RMSE	MAPE	Normalized BIC	Statistics	DF	Sig.	
AnnualQ-Model_1	1	.519	.440	92.154	17.440	9.614	5.764	12	.928	0

The Modified Box-Ljung-Pearce test confirms that there is no autocorrelation left in the residuals as the p-value of the lags are not significant. To check if there is an over-parameterized model, we run the ACF and PACF of the residuals of the ARIMA (3, 1, 3) model. as shown in Figure 9. From the figure, the residuals ACF and PACF are white noise which also confirmed that the model is good.

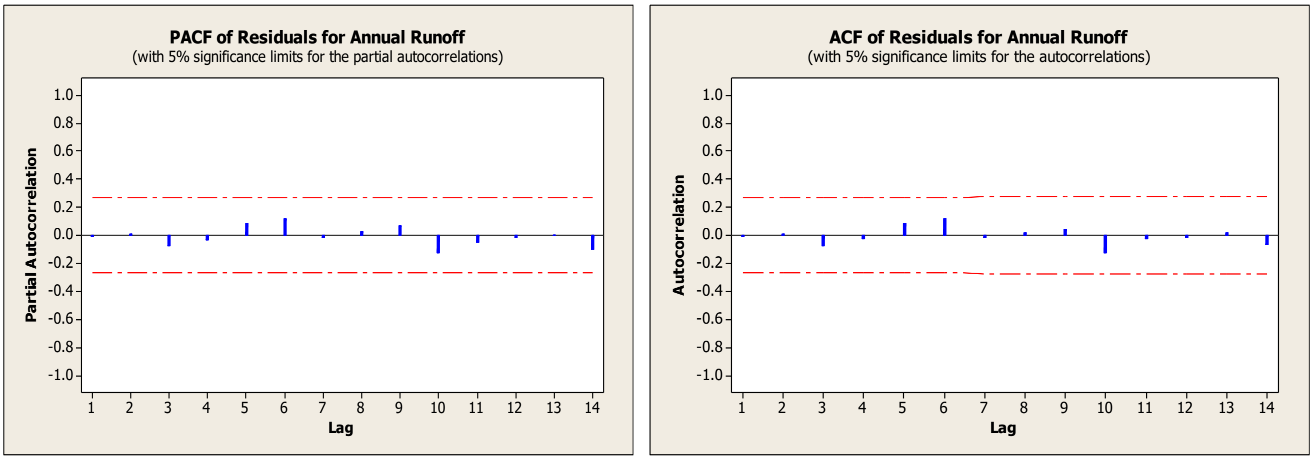
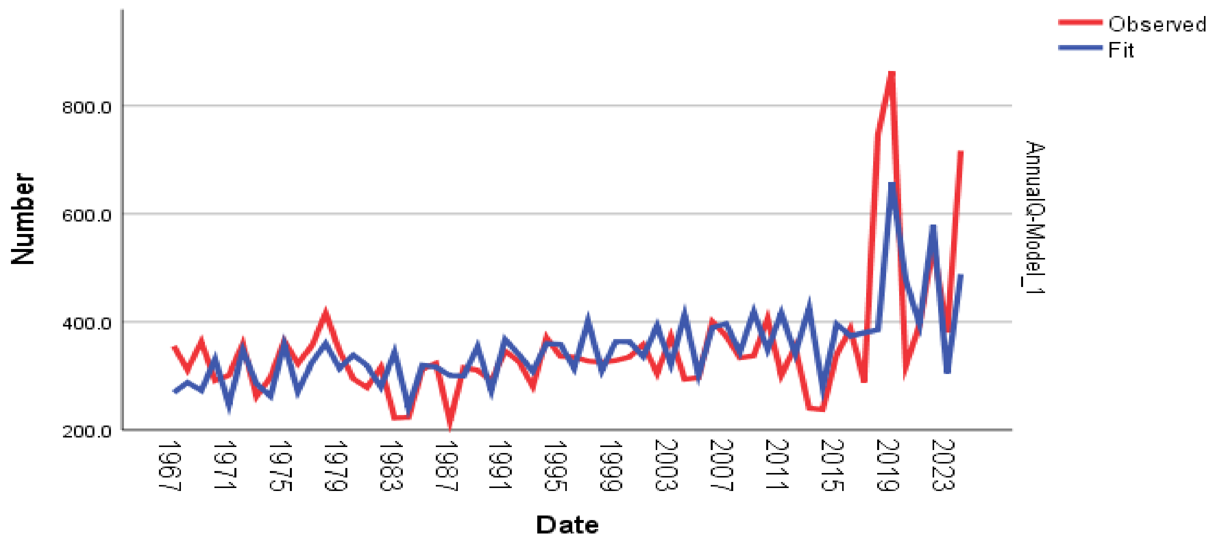


Figure 9: ACF and PACF Plot of the residuals of Annual Peak Runoff

Source: The researcher's computation using Minitab, (2024)

Based on the model parameters, the current and future times series for runoff is estimated using ARIMA (3,1,3). The result is presented in Figure 10.



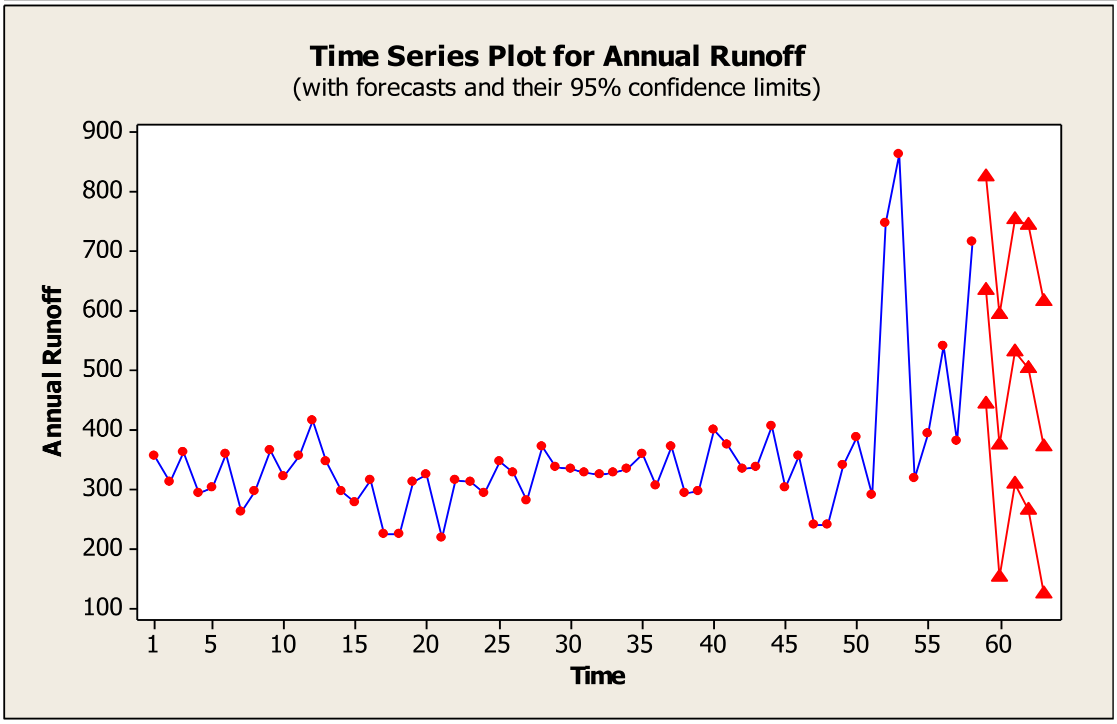
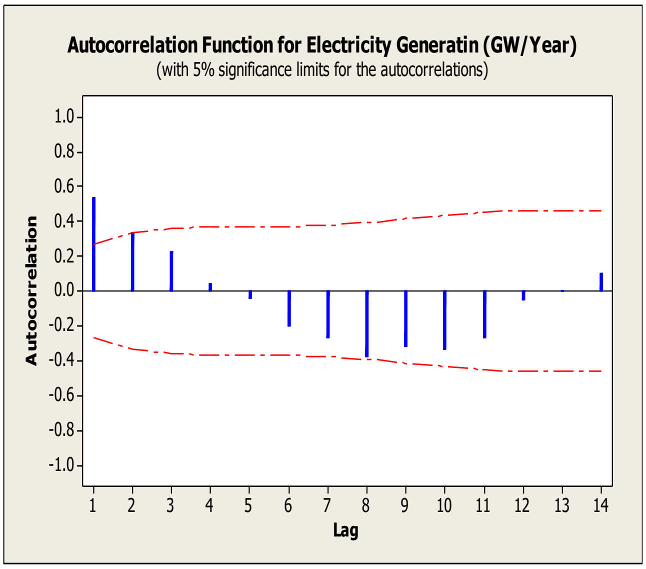


Figure 10: Time series modelling of Current and Future Runoff Peak using ARIMA (3, 1, 3). Source: The researcher's computation using SPSS, (2024)

From the model, runoff peak will likely increase in the near future under the current climatic conditions.

Model for Hydropower Generation

The ACF and PACF of hydropower generation shown in Figure 11 show that annual hydropower generation data tend to be a non-stationary process and does need differencing (d=1). The ACF decays from the first lag up to the second lag while the PACF cuts off after lag 1. This suggests an AR (p) process of order 2 and MA (q) process of order 1. Thus, there is a mixed autoregressive moving average model in the data. The mixed autoregressive integrated moving average process can be represented as ARMA (2, 1, 1). Thus, the hydropower generation can be modelled by an ARIMA (2, 1, 1) model.



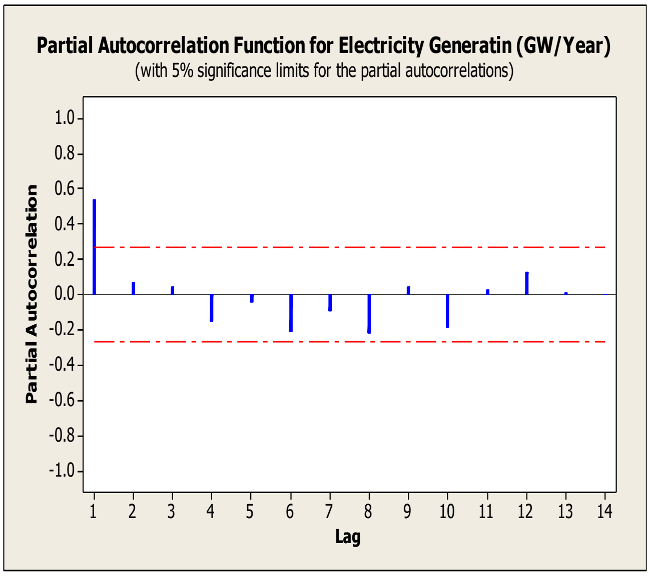


Figure 11: ACF and PACF of Hydropower Generation in Kainji Hydropower Station

Source: The researcher's computation using Minitab, (2024)

A final realization of the model parameters is presented in Table 6. The parameter estimates of the model indicates that the model has an R^2 of 0.155 indicating that the model explains 15.5 percent variation in power generation and a BIC is 27.221 indicate a better fitting model. The p-value of 0.852 is high, indicating there is no autocorrelation in the residuals. The parameter estimates indicate a fitting model

		Model Fit statistics					Ljung-Box Q(18)			
Model	Number of Predictors	Stationary R-squared	R-squared	RMSE	MAPE	Normalized BIC	Statistics	DF	Sig.	Numb Outli
Electricity-Model_1	1	.155	.137	671807.005	24.821	27.221	9.457	15	.852	

A final realization of the model parameters is presented in Table 7.

Table 7: Final Estimates of Parameters for hydropower generation

Final Estimates of Parameters

Type		Coef	SE Coef	T	P
AR	1	-1.1144	0.1932	-5.77	0.000
AR	2	-0.3960	0.1290	-3.07	0.003
MA	1	-0.8193	0.1747	-4.69	0.000
Constant		110.9	156.9	0.71	0.483

Differencing: 1 regular difference

Number of observations: Original series 56, after differencing 55

Residuals: SS = 20868803 (backforecasts excluded)

MS = 409192 DF = 51

Modified Box-Pierce (Ljung-Box) Chi-Square statistic

Lag	12	24	36	48
Chi-Square	5.7	13.9	21.7	24.4
DF	8	20	32	44
P-Value	0.686	0.834	0.914	0.993

The Modified Box-Ljung-Pearce test confirms that there is no autocorrelation left in the residuals as the p-value of the lags are not significant. To check if there is an over-parameterized model, we run the ACF and PACF of the residuals of the ARIMA (2, 1, 1) model. as shown in Figure 13. The result of the ACF and PACF of the residuals indicate that the residuals ACF and PACF is a white noise which also confirmed that the model is good and can be used for forecasting.

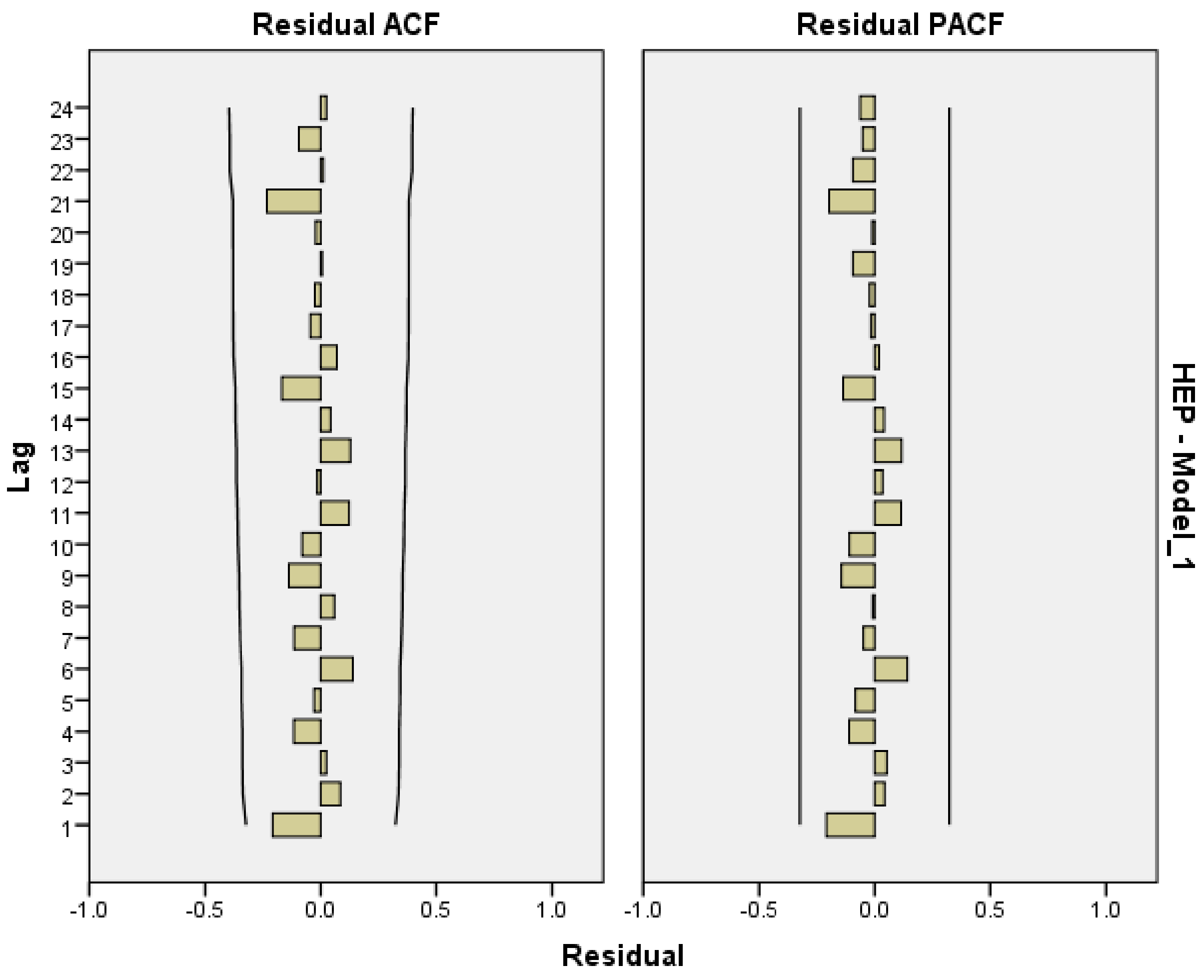


Figure 13: ACF and PACF residuals of Hydropower Generation in Kainji Hydropower Station. Source: The researcher's computation using SPSS, (2024)

Based on the model parameters, the current and future times series for generation was estimated using ARIMA (2,1,1). The model is run on SPSS software and the result is shown in Figure 14. The observed and the forecast figures are so close.

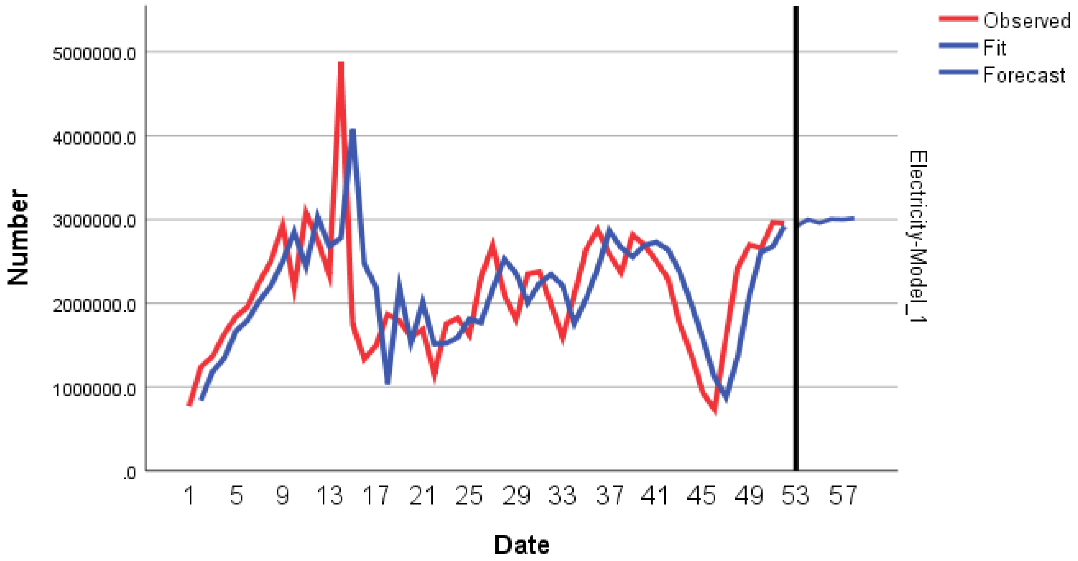


Figure 14: Time series model of current hydropower generation using ARIMA from 2025-2045

Source: The researcher's computation, (2024

From the figure, it can be observed that the model can predict that hydropower generation A time series forecast of the model is run in SPSS until 2045. The result is shown in Figure 15.

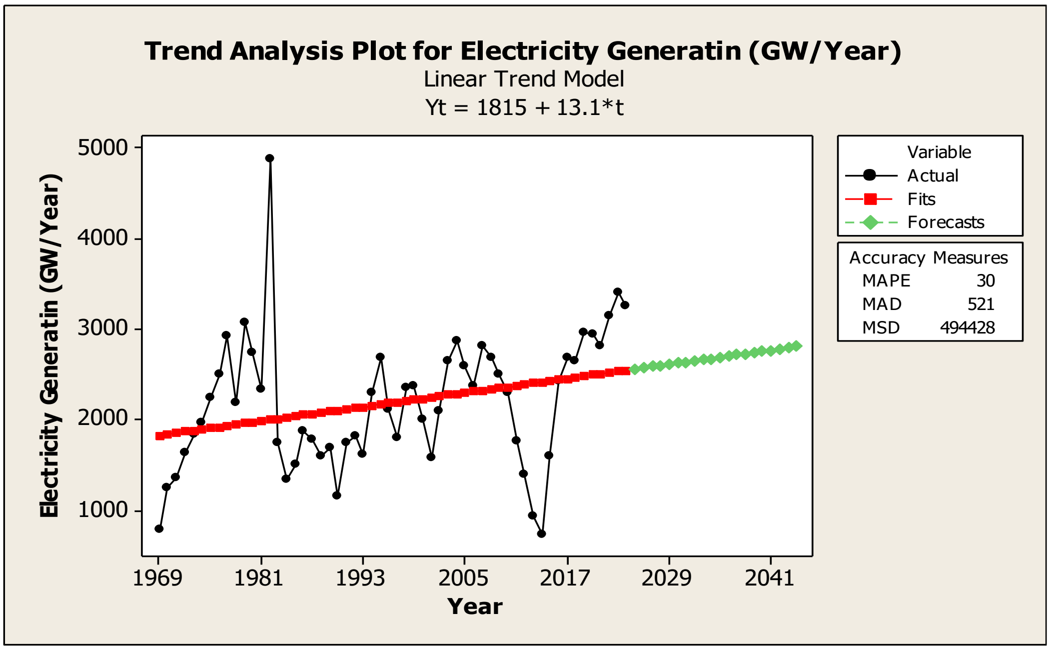


Figure 15: Time series model of future hydropower generation using ARIMA from 2025-2045

Source: The researcher's computation, (2024)

From the result, hydropower generation is likely to increase under the current conditions. The model is consistent with Global Circulation Model prediction for Nigeria under the A2 and B1 scenarios.

CONCLUSION

This study investigated the effects of climate change on runoff and hydropower generation in Kainji hydropower dam, Niger State from 1967 to 2024. Investigation was conducted using data on rainfall, temperature, evapotranspiration, runoff peak and the hydropower generation from Kainji Hydropower Station. The result of the Mann-Kendall trend analysis indicates that there has significant increase of rainfall, runoff peak, minimum and maximum temperature while evapotranspiration has declined from 1967-2024 as a result of changes in climate. The resulting decrease in evaporation rate despite increasing temperature is as a result of increasing humidity which contributes to increase in rainfall in Kainji dam. A result of increase in rainfall and runoff contributes to increase in hydropower generation. The ARIMA model for runoff and power generation showed an increase in future trends under current conditions. 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 and will add 320,000 KW/hr of electricity in Nigeria by 2027 (Punch, 2024).

RECOMMENDATIONS

The study reveals that Kainji reservoir experience inflow throughout the year. Climate change has led to an increase in temperature of the study area which resulted in an increase in the annual and mean amount of rainfall and runoff. The increase in rainfall also caused an increase in runoff which is necessary for hydropower generation. Thus, Nigeria will certainly benefit from the increase in runoff, if the government can increase the capacity of the reservoir, replace decaying infrastructure and probably finds a means of storing water during peak inflow and use to generate electricity in the periods of low inflow, as their will be enough water to produce electricity. The Mainstream Energy Services Limited has improved the management of the hydropower plants leading to an increase in the quantity of electricity generated in recent times and is planning to fix the remaining turbines in the Kainji and Jebba hydropower dams. The changes in seasonal and interannual variability of rainfall can be compensated by improving short term water flow forecasts, building additional storage capacity and enhance turbine capacity efficiency. Nigeria will witness an increase in hydropower generation.

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