International Journal of Engineering Technology Science and Research
IJETSR
www.ijetsr.com
ISSN 2394 – 3386
Volume 4, Issue 8
August 2017

# Assessment of Climate Change Impact on Hydropower Generation: A Case Study of Nigeria

**Mohammed Baba Machina[1], Satendra Sharma[2]**
Department of Physics, Yobe State University, Damaturu, Yobe State, Nigeria

*Abstract- The assessment of impact of climate change on the water resources of Kainji Hydropower Station, Nigeria is presented. The rainfall, temperature, generation, reservoir inflow, average turbine discharge and reservoir storage data are obtained from Kainji Hydropower station and analysed using Mann-Kendall, Correlation and Regression methods. The statistical analysis of hydro-meteorological data at Kainji dam was done with the aim of detecting trends. The non parametric Man-Kendall test was used to detect monotonic trends, correlation to show the relationship between the variables and regression analysis were used to develop models for the variables. The results showed that the rainfall has a negative trend which implies that there is tendency for the reservoir inflow to reduce drastically over time while temperature has a positive trend. A very low Man-Kendall statistic S = -282 and a low Z value of -2.351 for rainfall and S = 631 with high Z value of 5.287 for temperature reveals there is evidence of climate change in the areas around the dam. Microsoft Excel was used to calculate the trend lines, statistical values and plot the trends. This has produced unfavourable climate conditions as a result of decreased rain in the areas surrounding the dam as well as increase in temperature which aids in excessive evaporation from the reservoir. Excess water has to be released from the dam to sustain hydropower generation over the years. This has invariably affected storage at the dam as well as the energy generation. Recommendation was therefore made to the operators of the dam to optimize the release of water from Kainji dam to ensure ideal operation of the dam.*

***Keywords: Climate Change, Hydro Generation, Man-Kendall test, significant trend, Rainfall.***

## I. INTRODUCTION

Hydropower is currently the major renewable source contributing to electricity supply, and its future contribution is anticipated to increase significantly. However, the successful expansion of hydropower is dependent on the availability of the. Global warming and changes in precipitation patterns will alter the timing and magnitude of river flows. This will affect the ability of hydropower stations to harness the resource, and may reduce production. The very fact that renewable energy resources harness the natural climate means that they are at risk from changes in climatic patterns. As such, changes in climate due to higher greenhouse concentrations may frustrate efforts to limit the extent of future climatic changes. In recent times, stream flow and available head used in converting the potential hydraulic energy into electric energy are observed to have a downward trend due mainly to instability and unreliability of rainfall. This poses many problems in the hydro-energy sector [1].

Global warming or climate variability is expected to alter the timing and magnitude in runoff and soil moisture. As a result, it has important implications for the existing hydrological balance and water resources as well as for future water resources planning and management. Quantitative estimation of the hydrological effects of climate change is therefore essential for understanding and solving potential water resource problems that may occur in the future [2]. Global variations in climate have brought about extreme events like flood and drought which have had drastic impacts on river basin development structures. Such structures include dams on which Nigeria has depended for most of its renewable (green) energy generation [3]. According to Mehra et. al [4], total estimated electricity generated in the year 2007 in Nigeria is 21.92 billion KWh of which the hydro energy generated account for 38.1% of the estimated total electricity generated. For instance, Energy Digest [5] states the twin issues of climatic change and developing new infrastructure projects by neighbouring countries on the River Niger have been identified as factors that are threatening to the water levels and adequate water flow into Kainji and Jebba dams in Nigeria. The EPA [6] defines global warming as an average increase in the earth's temperature which in turn causes changes in climate, and reported that global warming enhances the water cycle by intensifying the cycle of water. It speculates that because of global warming, more cloud will form and there will be more rain and snow especially in areas closer to water whereas in areas away from water sources, excessive evaporation would dry out soils and vegetation, resulting in fewer clouds and less rain. Thus the area will probably get more droughts, rivers and lakes will become shallower and ground water decreases. Thus, analysing long-term series data for predicting the influence of potential climate changes is an important application of statistics in recent hydrologic researches. Global warming is no longer a speculation. The threat is real and has far reaching results. It is absolutely necessary therefore, to sensitize people of all nations about the imminent danger posed by global warming and depletion of water resources and to establish a suite of coordinated activities that will examine the serious and sweeping issues associated with global climate change, including the science and technology challenges involved, and provide advice on actions and strategies nations can take to respond to it (National Academy of Science, Washington DC, 2008).

The climate of a place is normally concerned with the weather conditions of the place, over a long period of time. Since weather depends on numerous factors which vary with time, it is right to talk of a climate change. Climate change is bound to have some effects on the social and technological standards of living in the countries where it occurs. Madueme [7] indicated that the developing nations of Africa, Asia and South America are bound to be seriously affected, in the event of climate change, and so ought to be interested in the subject. The IPCC [8] described Africa as "one of the most vulnerable continents to climate change and climate variability", and within Africa, Nigeria is one of the countries expected to be worst affected. McBean and Motiee [9] assessed the impacts of climate change on the water resources of North America. Seventy years of historical trends in precipitation, temperature, and stream flows in the Great Lakes of North America were developed using long term regression analyses and Mann-Kendall statistics. The result they obtained demonstrated statistically significant increases in some precipitation and stream flows over the period 1930-2000. Kavvas et. al [10] assessed the impacts of climate change on the hydrology and water resources of Peninsular Malaysia. Climate change simulations of CGCM1 (Coupled General Circulation Model of the Canadian Centre for Climate Modelling and Analysis) were downscaled by a Regional Hydroclimate Model of Peninsular Malaysia (RegHCM-PM) to the scale of the sub regions and watersheds of Peninsular Malaysia in order to assess the impact of future climate change on the hydrologic conditions of Peninsular Malaysia. The assessment of the impact of climate change over Peninsular Malaysia was performed by the comparison of historical simulations of precipitation, evapotranspiration, and river flow by the CGCM1/RegHCM-PM combined models during the 1984–1993 period against their future counterparts, simulated by the same models during the 2041 – 2050 ten-year future period. Their results indicated that there is significant increase in the overall mean monthly stream flow during the 2041-2050 future periods. However, it is also clear that the high flow conditions will be magnified in Kelantan, Terengganu, and Pahang River watersheds, while low monthly flows will be significantly lower in Selangor and Johor watersheds. Generally therefore changes in climate resulting from increasing atmospheric concentrations of greenhouse gases could have significant effects on water resources of water bodies like the Kainji Reservoir. Therefore this study focuses on the specific impact of global warming as related to the drop in reservoir storage and energy generation at Kainji hydropower dam in Nigeria and to develop functional relationships for the time series of temperature and rainfall for areas around the dam. This will help in determining whether global warming has resulted in conditions that are unfavourable to rainfall and inflow to the dam.

## II. CLIMATE VARIATION IN NIGERIA

According to Ruti et. al [11], the characteristics of weather systems over Nigeria are usually driven by the pressure and wind systems whose dynamics depends on the surface pressure systems over North Africa and over the South Atlantic Ocean. During the first quarter of the year, the surface pressure over North Africa remained high most of the time as it fluctuated between 1024 - 1032hPa which caused the surface pressure values over the country to remain between 1012 and 1015hPa. This pressure build up resulted in the lifting of dust particles into the atmosphere over the Sahara Desert and the Sahel regions and the subsequent southward transport of the lifted dust particles into the country. The resultant effect was the occasional reduction in horizontal visibility to less than 1000m in parts of the country. At 1,500m above the earth's surface, the north easterly winds dominated the flow pattern but moist southwest winds with speeds of 10-20m/s (20-40knots) influenced the flow at lower levels except during periods when spells of dust haze prevailed. The second quarter witnesses the beginning of the seasonal weakening of the Saharan high and this resulting in further northward incursion of moist southwest winds from the South Atlantic Ocean into the northern parts of the country. The increase in the depth of moisture at 1,500m continues into the third quarter. By the end of September, the winds at this height penetrated inland to reach an average position of latitude 15.30N. Strengthening of the Saharan high pressure system began at the beginning of the fourth quarter. This led to the prevalence of north easterly winds over the country and the subsequent onset of the winter dust haze season in the country.

The annual cumulative rainfall was shown by Easterling et. al [12]. Rainfall amounts of 300 – 1000mm were recorded in the northeast, parts of Katsina and Kano in the northwest and Ilorin in the central region. The entire southeast and parts of Akure, Benin, Ijebu Ode and Oshogbo in the southwest had 2000 – 3000mm of rainfall in the year. The rest of the country experiences rainfall between 3000 – 4500mm. The highest cumulative rainfall amount of 4224.0mm was recorded at Eket is about 269.3mm less than the 2009 record high at the same station. Nguru, like in the year past, records the lowest rainfall of 447.8mm as reported by Easterling et al. [12].

*A. Rainfall Anomalies in Nigeria*

Omotosho et. al [13] stated that wetter than normal conditions are experienced over the last ten years in the extreme Northeast, Northwest and cities such as Bauchi, Jos and part of Minna in the Central states. Other areas that recorded wetter than normal rainfall conditions included Southwest and Ogoja, Calabar and Eket in the southeast. Isolated case of drier than normal rainfall was recorded at Ilorin.

*B. Temperature Anomalies in Nigeria*

Mean maximum temperatures across the country ranges between 31.1 – 42.6°C during the hot season [12]. The highest temperature range of 40.0 – 45.0°C was recorded over the northeast and northwest zones of the country in the last ten years. The hottest areas included Maiduguri, Potiskum, Sokoto, Nguru and Yola. The extreme coastal areas, and Jos and its environs recorded the lowest temperatures in the range of 30.0 – 32.0°C, while other areas recorded 35.0 – 40.0°C maximum temperature in the season [14]. Monthly minimum temperatures ranges from 11.1 - 19.2°C over the north and central areas of the country, with the coldest areas located around Postiskum, Jos, Maiduguri, Kano and Kaduna. The southern region recorded minimum temperatures ranging from 20.0 to 24.1°C [12].

## III. DESCRIPTION OF THE STUDY AREA

Kainji Lake is a reservoir on the River Niger in Nigeria. It is formed by the Kainji dam which was built between 1964 and 1968. The reservoir is located on latitude $9^0$ 51`45` N and longitude $4^0$ 36`48` E, situated in Niger State, at the middle belt part of the country, along the River Niger and is the first, largest and only functioning Hydro Power Station in the country [15]. It is an earth dam with a 66 m high concrete centre structure housing the hydroelectric turbines. The Kainji reservoir is about 135 km long and about 30 km across at its widest point with a surface area of 1,250 $km^2$. Kainji dam or reservoir has a total capacity of 15 billion cubic meter of water of which 92 percent can be drawn down for power generation, with a penstock diameter of 9.7m, rated net head of 29.5m and a maximum net head of 38.1m and upstream of 136 km [4]. The spillway discharge is 9700$m^3$/s. There are 8 generating units commissioned thus;

- Installed capacity of 4x80MW was commissioned in the year 1968.
- Installed capacity of 2x100MW was commissioned in the year 1976.
- Installed capacity of 2x120MW was commissioned in the year 1978.

## IV. DATA AND ANALYSIS

Fifty years rainfall and temperature data (1961-2011) was compiled by the Nigerian Meteorological Agency (NIMET) [14], which is a federal government body responsible for providing weather, climate and hydrological information, NIMET is also responsible for the provision of accurate and timely weather/climatic data used for airline operations, maritime navigation and urban development. The fifty years weather data (1961-2011) was compiled at Minna, Niger State station where Kainji hydropower station is situated. It was observed on the data that the average temperature for Minna is $27^0$ C ($81^0$ F) with the range of average monthly temperature of $5.5^0$ C. Warmest average Max/High temperature of $37^0$ C ($99^0$ F) in March and the coolest average Min/Low temperature of $19^0$ C ($66^0$ F) in December. On balance there are 101 days annually on which greater than 0.1 mm (0.004 in) of precipitation (rain, sleet, snow or hail) occurs or 8 days on an average month. The month with the driest weather is January when on balance 2 mm (0.1 in) of rain, sleet, hail or snow falls across <1 days, while the month with the wettest weather is September when on balance 296 mm (11.7 in) of rain, sleet, hail or snow falls across 21 days. The mean relative humidity for an average year is recorded as 48.9% and on a monthly basis it ranges from 21% in February to 73% in August. There is an average range of hours of sunshine in Minna of between 3.6 hours per day in August and 9.2 hours per day in November. On balance there are 2672 sunshine hours annually and approximately 7.3 sunlight hours for each day [16]. There are also 0 days annually registering frost in Minna and in January there are on average 0 days with frost. It can be observed from the data that there has been a variation of precipitation, as the average monthly rainfall has decreased drastically over the years. This clearly shows that the amount of rainfall received by the reservoir of the hydrogenation station within theses area reduced over the years. If the present trend of climate variability continues, it will definitely have an impact on the hydro station located at this region.

There is also the three years energy generation data (2009-2011) obtained from the Nigerian Electricity Regulatory Commission (NERC) which is an independent regulatory body saddled with the regulation of the electric power industry in Nigeria As well as the Computed inflow, Average turbine discharge and the Storage Differential of Kainji Dam obtained from Kainji Hydro Electric Plc a body responsible for upkeep and maintenance of the hydroelectric dam. The data obtained and their corresponding years of record are presented in Table I and the corresponding statistical summary of the variables in Table II.

TABLE I. HYDRO-METEOROLOGICAL DATA AND YEARS OF RECORDS.

| VARIABLES | PERIOD |
|---|---|
| Rainfall (mm) | 1961-2011 |
| Temperature ($^0$C) | 1961-2011 |
| Energy Generation (MW) | 2009-2011 |
| Computed Inflow ($M^3$/SEC) | 2009-2011 |
| Average Turbine Discharge($M^3$/SEC) | 2009-2011 |
| Storage Differential ($Mm^3$) | 2009-2011 |

TABLE II. STATISTICAL SUMMARIES OF HYDRO-METEOROLOGICAL VARIABLES AT KAINJI HYDROPOWER DAM.

| VARIABLES | STATISTICS | | | | |
|---|---|---|---|---|---|
| | **Monthly Mean** | **Variance** | **Standard Deviation** | **Slope** | **Kurtosis** |
| Rainfall (mm) | 37.287 | 1363.405 | 20.74 | -0.20321 | 1.7697 |
| Temperature ($^0$C) | 27.9 | 115.0239 | 1.226 | 0.0238 | 0.5827 |
| Energy Generation (MW) | 278.08 | 23703.47 | 92.138 | -10.924 | -1.419 |
| Computed Inflow ($M^3$/SEC) | 986.6613 | 506489.1 | 717.05 | 21.430 | -2.591 |
| Average Turbine Discharge ($M^3$/SEC) | 817.29 | 196055 | 214.55 | -23.041 | -1.713 |
| Storage Differential ($Mm^3$) | -223.4 | 32731.6 | 787.9 | 50.55 | 3.668 |

*A. Trend Analysis*

The trend analysis was done in three phases. First the presence of a monotonic increasing or decreasing trend was detected using the non parametric Mann-Kendall test, next the regression analysis of the time series were done to develop regression models. Correlation coefficients of the meteorological variables and time were also computed to determine the strength of the linear relationship between the variables and time. All parameters were subjected to statistical, Mann-Kendall, regression and correlation tests.

*B. Mann-Kendall Analysis*

More recent studies indicated that the most widely used method for trend analysis is the non-parametric Mann-Kendall trend test. Paulin and Xiaogang [17] reported that Mann originally derived the test and Kendall [18] subsequently derived the test statistic commonly known as the Kendall's Tau statistic. This non parametric test is commonly used for hydrologic data analysis, can be used to detect trends that are monotonic but not necessarily linear. The null hypothesis in the Mann-Kendall test is independent and randomly ordered data. It compares relative magnitudes of sampled data rather than the data values themselves [19]. The Mann-Kendall test does not require assuming normality, and only indicates the direction but not the magnitude of significant trends [9] . The Mann-Kendall test statistic ***S*** is calculated using the formula that follows:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(xj - xk), \tag{1}$$

Where xj and xk are the annual values in years j and k, j > k, respectively, and

$$sgn(xj - xk) = \begin{cases} 1 & if\ xj - xk > 0 \\ 0 & if\ xj - xk = 0 \\ -1 & if\ xj - xk < 0 \end{cases} \tag{2}$$

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 [20]. The variance of S is computed as:

$$VAR(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} tp(tp-1)(2tp+5)\right] \tag{3}$$

Here q is the number of tied groups and tp is the number of data values in the $p^{th}$ group. The values of S and VAR(S) are used to compute the test statistics Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(s)}} & if\ S > 0 \\ 0 & if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & if\ S < 0 \end{cases} \tag{4}$$

Z follows a normal distribution. The Z values are tested at the 95% ($Z_{0.025}$ = 1.96) and 99% ($Z_{0.001}$ = 2.58) level of significance**.** To compute the probability density function of the normalised test statistic. The probability density function for a normal distribution with a mean of 0 and a standard deviation of 1 is given by the following equation:

$$f(Z)=\frac{1}{\sqrt{2\pi}}e^{-\frac{Z^2}{2}} \quad (5)$$

The trend is said to be ***decreasing*** if Z is negative and the computed probability is greater than the level of significance. The trend is said to be ***increasing*** if the Z is positive and the computed probability is greater than the level of significance. If the computed probability is less than the level of significance, there is ***no trend.*** The results of the Mann-Kendall analysis for the variables are summarized in Table VI.

### *C. Regression Test*

One of the most useful parametric models used to develop functional relationships between variables is the “simple linear regression” model. The model for Y (e.g. precipitation) can be described by an equation of the form:

$$Y = a X + b \quad (6)$$

Where, X = time (year), a = slope coefficients and b = least square estimates of the intercept. The slope coefficient indicates the annual average rate of change in the hydrologic characteristic. If the slope is statistically significantly different from zero, the interpretation is that, it is entirely reasonable to interpret. There is a real change occurring over time, as inferred from the data. The sign of the slope defines the direction of the trend of the variable: increasing if the sign is positive and decreasing if the sign is negative [9]. For this research, the excel software was used to calculate the trend lines and to plot the figures. The results are shown in Tables V and VI.

### *D. Correlation Co-efficient*

The Pearson product moment correlation coefficient measures the strength of linear relationship between two variables [21, 22]. It always takes a value between -1 and +1, with 1 or -1 indicating a perfect correlation (all points would lie along a straight line, having a residual of zero). A correlation coefficient close to or equal to zero indicates no relationship between the variables. A positive correlation coefficient indicates a positive (upward) relationship and a negative correlation coefficient indicates a negative (downward) relationship between the variables. The correlation coefficients between the hydrological variables and time were computed using Microsoft Excel Software Application.

R-square ($R2$), or the square of the correlation coefficient, is a fraction between 0.0 and 1.0. A $R2$ value of 0.0 means that there is no any correlation between X and Y and no linear relationship exist between X and Y. On the other hand, when $R2$ approaches to 1.0, the correlation becomes strong and with a value of 1.0 all points lie on a straight line [9]. The results are shown in Table III.

## V. RESULT AND DISCUSSIONS

The correlation coefficients between the climatic variables and time for the stations are presented in Table I. The result of the Mann-Kendal analysis is presented in Table II. The Correlation co-efficient between meteorological variables and time at Kainji dam are given in Table III. The summary of parameters for Mann-Kendall analysis at Kainji dam are given in Table V. The developed regression model equations are presented in Table V and Table VI. The plots showing the time trend of the variable are presented in Figure 1 and Figure 2.

TABLE III. CORRELATION COEFFICIENTS BETWEEN METEOROLOGICAL VARIABLES AND TIME AT KAINJI DAM.

| | RAINFALL | TEMP | ENERGY GENERATED | COMP IMFLOW | TURBINE DISCHARGE | STORAGE |
|---|---|---|---|---|---|---|
| Rainfall | - | -0.2947 | -0.71913 | -0.24028 | -0.7238 | -0.03859 |
| Temp | | - | -0.53644 | -0.69232 | -0.51895 | -0.59637 |
| Energy Generated | | | - | 0.45965 | 0.99145 | 0.18935 |
| Comp Imflow | | | | - | 0.43583 | 0.94857 |
| Turbine Discharge | | | | | - | 0.16646 |
| Storage | | | | | | - |

TABLE IV SUMMARY OF MANN-KENDALL ANALYSIS AT KAINJI DAM.

| VARIABLE | S | VARIANCE | Z | TREND SIGNIFICANCE |
|---|---|---|---|---|
| Rainfall (mm) | -282 | 14287.7 | -2.351 | ** |
| Temperature ($^0$C) | 631 | 14223.3 | 5.2852 | ** |
| Energy Generation (MW) | -21 | 212.7 | -1.371 | |
| Computed Inflow ($M^3$/SEC) | 9 | 211.7 | 0.5502 | * |
| Average Turbine Discharge($M^3$/SEC) | -24 | 211.7 | -1.5818 | |
| Storage Differential ($Mm^3$) | 13 | 212.7 | 0.8230 | |

(* for 95%, ** for 99%).

TABLE V THE DEVELOPED LINEAR TREND LINE EQUATION.

| VARIABLE | TREND LINE MODEL EQUATION* |
|---|---|
| Rainfall (mm) | $y = -2.2273x + 4870.8$ |
| Temperature ($^0$C) | $y = 0.2857x - 232.68$ |
| Energy Generation (MW) | $y = -10.925x + 349.09$ |
| Computed Inflow ($M^3$/SEC) | $y = 21.431x + 847.36$ |
| Average Turbine Discharge($M^3$/SEC) | $y = -23.043x + 967.08$ |
| Storage Differential ($Mm^3$) | $y = 50.582x - 552.19$ |

*x represents time and y represents the meteorological variable.

TABLE VI DEVELOPED REGRESSION MODEL EQUATIONS OF CORRELATED VARIABLES.

| VARIABLES | REGRESSION EQUATIONS* | ERROR |
|---|---|---|
| Temperature / Rainfall (1961- 2011) | y = -0.0193x + 28.589 | -2.02 ± 0.01 |
| Rainfall / Computed Inflow (2009-2011) | y = 1.37x + 675.6 | 1.4 ± 3.5 |
| Temperature / Storage (2009-2011) | y = -100.7x + 2647.9 | -101 ± 43 |
| Computed Inflow / Energy Generated (2009- 2011) | y = 0.0751x + 203.9 | 0.08 ± 0.05 |

*Where x and y represents meteorological variable.

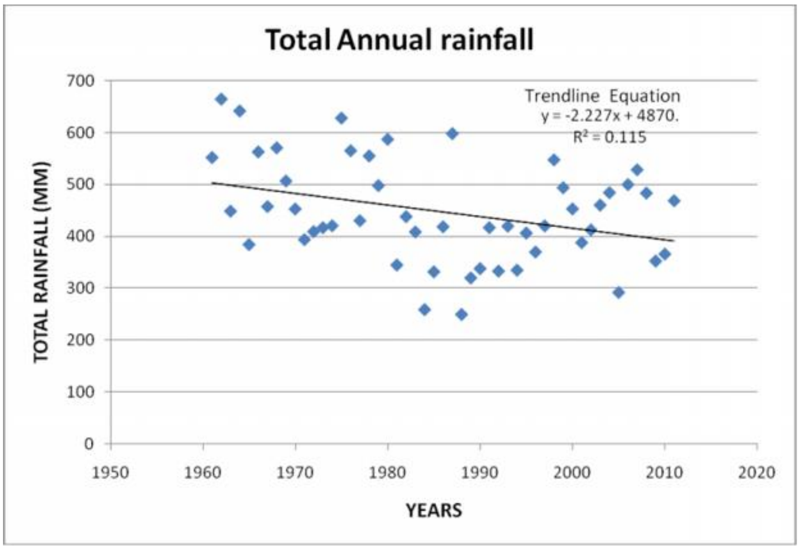


Figure 1. Kainji rainfall trend during 1961-2011.

The total annual rainfall graph representing rainfall frequency (see Figure 1) that contributes water into the Kainji reservoir has been on a decadal decrease even though some traces of increase could be noticed from 1975 to 1980. However, since then, the volume and frequency of rainfall has been on a decreasing side. The graph clearly shows a decrease from an average of 510mm to 390mm in 2011, which shows a decrease of about 24% in 50 years. This further indicates and annual decrease of 0.48%. There is also less pressure from the rivers and tributaries that contribute to the reservoir which some of, have travelled thousands of kilometres from the North, Northwest and Western sides of the reservoir. This could be attributed to steady unravelling effects of climate changed which is predicted to change rainfall pattern, which potentially could shrink the size of the reservoir capacity thus affect electricity generation from the reservoir.

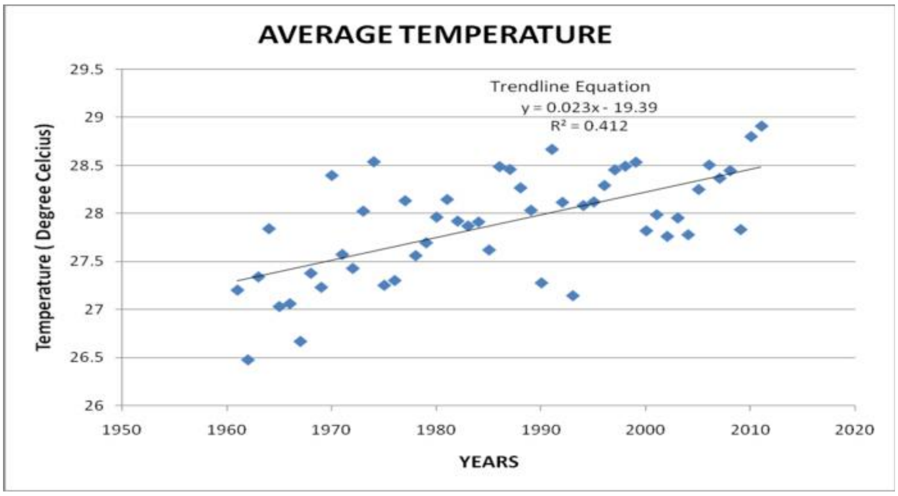


Figure 2 Average temperature trend of Kainji (1961-2011).

As seen from the graph above, temperature of Kainji Dam area is shown (see Figure 2) to be on a steady increase over the years as there has been an average of 16% in 50 years, which gives an average increase of 0.32% annually. This clearly confirms that there is increase in temperature over the years with decrease in rainfall. This further indicates the evidence of change in climate which is predicted that power dam across the world and indeed Nigeria is currently under severe problems of climate change resulting to reduced reservoir balance caused by low rainfall intensity as the direct impact of drought causes the storage in dams to be negatively affected, because the duration of droughts cannot be predicted with any certainty, it may be necessary to impose restrictions on the use of water; there is also evaporation of stored water due to temperature intensity over the year that lowers the hydraulics head, which has been observed in Nigeria.

Rainfall and temperature for the last 50 years shows unfavourable condition to operate a hydro station as the decreasing rainfall means decrease in the inflow and the increasing temperature enhances evaporation of already stored water in the reservoir, however, the last 3 years witnesses a more favourable condition as the rain fall trend has picked up, therefore encouraging more inflow to the dam while the temperature is witnessing a decreasing trend. The graph below (see Figure 3) shows the positive relationship between the rainfall and computed inflow of the dam. It can be observed from the graph that there is a very strong relationship between the rainfall and inflow of the dam, showing clearly that hydrogenation relies solely on availability of rainfall, in which any variation might affect the overall reliability of the station. The graph also shows a two (2) months lapse between the peak rainfall and the inflow, this is as a result of the time it takes all the tributaries contributing to the inflow of the dam, as some of the tributaries travel thousands of miles from either direction. There is also suppose to be a relationship between the inflow and the energy generation but this can be attributed to the aging infrastructure and the lack proper of maintenance. However, facts and figures established that the causes and effect are more aligned to environmental issues.

## VI. CONCLUSIONS

From the results of the analyses, rainfall in the vicinity of Kainji dam has been in a significant downtrend while temperature has been in uptrend over the years. Thus it may be concluded there is enough evidence of climate change in the region. Climate change has produced unfavourable climate conditions around Kainji dam as revealed by the significant rise in temperature and a downtrend in the rainfall of the region, this can lead to decrease in inflow to the dam and increase in turbine release from the dam which results in a significant drop in the storage which could affect the operation of the dam in the future, as the dam may be invariably drying up. The slight increase in rainfall and decrease in temperature over the last 3 years (2009-2011) however, increases the amount of inflow, which gives a favourable climatic condition that favours increased energy generation from the station and decreased evaporation from the reservoir. If this trend continues to increase, it may lead to over flooding of the reservoir causing damage to the station. Therefore, recommendation is hereby made to the operators of the dam to optimize the release of water from the dam so as to ensure optimal operation of the dam and sustain power generation under the prevailing climate condition. It is also necessary to note that in order to achieve stability and sustain hydroelectric power generated from Kainji dam; some measures have to be taken. Climatic factors should be given consideration in water resources planning; also flood/run-off water should be stored during period of excess for use during period of scarcity, to stand as alternative sources. Also, before the construction of any dam in the country, adequate attention should be given to the climatic conditions of the region in which the dam is to be constructed. Based on this initial assessment, a further investigation is required on a case by case basis to assess the potential impact of a change in climate on the catchment sites for future planned large hydroelectric installations.

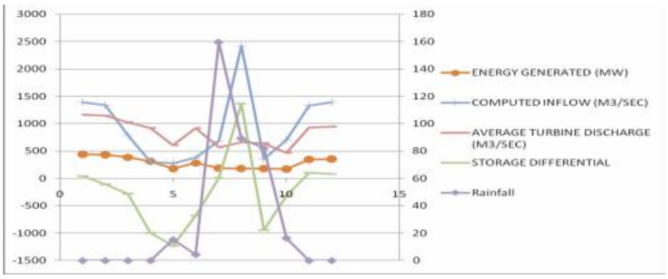


Figure 3 Average three years meteorological variables (2009-2011).

**ACKNOWLEDGEMENT**

We are grateful to Professor Yakubu Mukhtar, Vice Chancellor, Yobe State University, Damaturu, Nigeria for providing the facilities for the research work. One of us (MBM) is grateful to Dr. Wolf G. Fruh for his support and encouragement. We also like to thankful to the Nigerian Meteorological Agency and Kainji Hydro Electric plc for readily available data. MBM also thanks to Reza Mohammadi for his encouragement and words of wisdom.

## REFERENCES

[1] Harrison G. P. et al (1998). Climate Change Impacts on Hydroelectric Power. *Proceedings of the 33rd University Power Engineering Conference,* (UPEC' 98), Edinburgh, September, 1998. pp 391-394.
[2] Guo S. and Ying A. (1997). Uncertainty analysis of impact of climate change on hydrology and water resources. *Proceedings of the Rabat Symposium*, pp. 331 – 338.
[3] Ononiwu N. U. (1994). Managing the effects of global climate changes in geographic information systems (GIS) environment from a river basin perspective; the case of drought. *Proceedings the Int. Workshop on Impact of Global Climate Change on Energy Development*, March 28-30, held at the Eng. Building of the Nigerian Society of Eng. in Lagos, Nigeria.
[4] Mehra T. S., Alvi N. I. and Rajasekhar A. (2007), Performance of Tawa Hydroelectric Power Plant-A Case Study, *International Conference on Small Hydropower-Hydro,* Sri Lanka. Pamphlets: Operations of Shiroro, Kainji & Jebba Hydropower Stations.
[5] Energy Digest (2008). Climate change, Low water levels threatens Kainji power plant. *Nigerian Energy Digest* 8(223/224): 1-2.
[6] EPA (2009). Climate change. United States Environmental Protection Agency. www.epa.gov. Date accessed: 15/05/2012
[7] Madueme T. C. (1999). The Need for Long-Term Studies on Regional Climate Change to Ensure Adequate Electric Power Production. *Global Climate Change*.
[8] IPCC (2001) Climate Change 2001. *Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge. University Press, Cambridge
[9] McBean E. and Motiee H. (2008). Assessment of Impact of Climate Change on Water Resources: A Long Term Analysis of the Great Lakes of North America. *Hydrol. Earth Syst. Sci*. Vol. 12, pp 239-255.
[10] Kavvas M. L., Chen Z. Q., Ohara N., A. J. and Amin M. Z. M. (2006). Impact of Climate Change on the Hydrology and Water resources of Peninsular Malaysia. *International Congress on River Basin Management*, 529-537
[11] Ruti P. M. et al., 2011. The West African climate system: a review of the AMMA model inter-comparison initiatives. *Atmospheric Science Letters*, 12(1), pp.116–122
[12] Easterling D. R., Amin M. Z. M. and Bray T. (2010). Observed variability and trends in Nigerian extreme climate events: a brief review. *Bulletin-Nigerian Meteorological Agency*, 81(3), pp.417–426.
[13] Omotosho, B. J. (2011). The separate contributions of line squalls, thunderstorms and the monsoon to the total rainfall in Nigeria. *Journal of Climatology*, 5(5), pp.543–552.
[14] Nigerian climate change review bulletin 2010, Nigerian Meteorological Agency. http://nimetng.org/uploads/publication/2010%20Climate%20Review.pdf. Date accessed: 15/05/2012
[15] David O. and Adebayo W. S. (2009). *Assessment of Impact of Hydropower Dams Reservoir Outflow on the Downstream River Flood Regime Nigeria's Experience***.** Department of Civil Engineering, Covenant University, Ota, Ogun State, Department of Civil Engineering, University of Ilorin, Ilorin, Nigeria. pp. 210-213
[16] Nigerian Meteorological agency official website: http://www.nimetng.org/. Date accessed 14/05/2012
[17] Paulin C. and Xiaogang S. (2005). Identification of the Effect of Climate Change on Future Design Standards of Drainage Infrastructure in Ontario. Department of Civil Engineering, 1280 Main Street West Hamilton, Ontario, Canada.
[18] Kendall M. (1975). *Rank correlation methods*, 4th ed. Charles Griffin & Company, London.
[19] Gilbert R. O., 1987. *Statistical methods for environmental pollution monitoring.* Van Nostrand Reinhold, New York.
[20] Khambhammettu P. (2005). Mann-Kendall Analysis. *Annual Groundwater Monitoring Report of Hydro Geologic Inc*, pp. 1-6.
[21] Walpole R. E. (1974). *Introduction to Statistics*, Macmillan Publishing Co. Inc. New York. Second Edition. pp. 257-258.
[22] Adamu S. O. and Johnson T. L. (1975). *Statistics for Beginners*. Onibonoje Press and Book Industries (Nig.) Ltd. Ibadan, Nigeria. First Edition. Pp 182 – 195.