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Investigating the Effects of Climatic Variability on Reservoir Inflows to Kainji Hydropower Station, Nigeria

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Abstract

The present study investigated the effects of key climatic variables such as rainfall, temperature, and relative humidity on inflows to Kainji hydropower station. Monthly climatic data were collected in part from the Nigerian Meteorological Agency (NIMET) and the meteorological unit, Kainji Dam hydropower station, Niger State. Data were collected for the period 1985-2017.Reservoir inflow (1985-2017) data were collected from the hydrological unit at the Kainji station. These climatic data were investigated for variability using time series statistics. The study found that annual rainfall over Kainji hydropower station did not show any evidence of statistical significant change at a = 0.1, even though annual rainfall varied around mean value. Annual temperature over the Kainji hydropower station showed very strong evidence of significant change at a <0.01. Trend results were 3.41 (Mann-Kendal, z-score), 3.22 (spearman's rho, z-score) and 4.30 (Linear regression, t-test). Similarly, there was very strong to strong evidence of significant step jump in annual temperature distribution at a <0.01 and a <0.05. CUSUM test showed strong evidence of step jump of 8 maximum deviation, while cumulative deviation and Worsley tests results were of 1.68 and 4.37 respectively. Results of Pearson's Product Moment correlation revealed that Lake level is positively related with temperature and rainfall with coefficient values of 0.69 and 0.45with r^2 values of 45% (temperature) and Rainfall (35%) at 0.05 statistical threshold. This implies that Lake level of Kainji dam is sensitive to temperature by 45% and 35% sensitivity to changes in rainfall pattern.

Keywords: Climate variability, dams, rainfall, Temperature, reservoir inflows

INTRODUCTION

In the tropics, hydropower generation rely mainly on water supply from rainfall, which is an important component of the hydrological cycle. Unfortunately, since climate is a primary input for a hydrological system, its change holds significant effects on hydrological regime

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sas shown by authors such as Payne *et al*., (2004); Barnett *et al*., (2005); Vicuna *et al*., (2008); Fenner, (2009); Viviroli *et al*., (2011); Beniston, (2012); Mukheibir, (2013); Georgakakos *et al*., (2014); Cherry *et al*., (2017).The spatial change in amount, intensity and frequency of the rainfall is expected to affect the magnitude and frequency of river flows and consequently the water resources available for any meaningful water resources development projects including hydropower projects. Over the years, Nigeria has witnessed tremendous changes in both climatic and hydrological systems in the form of climatic/hydrological droughts in the semi-arid and arid parts of the country and floods in the southern and coastal parts. In the northern part of the country which is the focus of the present study, there are evidence of decreasing rainfall since 1980s with corresponding rise in temperatures and evapotranspiration (Odjugo 2005, 2007; Odjugo & Ikhuoria 2003; Yaqub, 2007, Emeribe *et al.,* 2017). Decreased runoffs are therefore expected in part due to reduced flows as a result of decreasing rainfall, and these trends are expected to accelerate throughout the 21st century, reducing water availability and hydropower potential.

Infact it has been reported that, many rivers in northern Nigeria have dried up or are becoming more seasonally navigable while Lake Chad shrunk in area from 22,902 km^2 in 1963 to a mere 1304 km^2 in 2000. This shows that what is left of Lake Chad in the year 2000 is just 5.7% of 1963 (Odjugo, 2007). Awake (2009) also confirms the fact that Lake Chad has shrunk by 95% since the 1960s and Aral Sea in Central Asia was the fourth largest lake in the planet in 1960, but by 2007 it had shrunk to 10% of its original size. Similarly, Mohammad (2009) reports that desert, which now covers about 35%of Nigeria's land mass, is advancing at an estimated 0.6 km per annum while deforestation is taking place at 3.5% per annum. The desert belt has moved from Kebbi, Kano, Maiduguri to New Bussa, Kaduna, Jos, Sheleng while Savannah now interface between desert and forest along Oyo, Osun, Kogi and Benue states (Mohammad, 2009).

In Nigeria Hydropower generation which accounts for a substantial part of the total electricity generation mix of the country representing about 32% of the installed grid-connected electricity generation capacity (Energy Commission of Nigeria, 2003) is greatly affected by climatic variability and change. To compound this problem, are the issues of prohibitive cost of operations, environmental problems, flooding of upstream ecosystems and the general uncertainties related to fluctuation and intermittency of energy sources. Study has shown that hydroelectricity in Nigeria, has decreased from its peak of 8.2 billion kWh since 2009, while a fraction of power generated in the country is exported to Niger through an agreement under the West African Power Pool (Adebayo, 2014).Even on the whole, the consumption of electricity including from thermal power plants is reported to have declined by 13.4% between 2002 and 2006 and this has been attributed mainly due to a decline in hydroelectric power (Adebayo, 2014).

The implication of this is that the electrification rate in Nigeria is below 50 percent as a whole – leaving approximately 80 million people without access to electricity in Nigeria (IEA, 2013). As at August 2010, the peak generation supplied was just 3,804MW for a population of 150 million people. Similarly, production activities in the manufacturing sub-sectors are reported to be on the decline. The situation in the rural areas of the country is even worst resulting in over dependence on fuelwood. Report of the Inter-Ministerial Committee on Combating Deforestation and Desertification (2000) indicates that the rate of deforestation is about 350,000 hectares per year, which is equivalent to 3.6% of the present area of forests and woodlands, whereas reforestation is only at about 10% of the deforestation rate. This trend is expected to have risen with attendant environmental consequences. Managing electricity inadequacy and uncertainties in climatic variability, as it affects water resources development is a huge challenge facing the government of Nigeria, and by extension economic development and meaningful improvement in livelihood given the importance of energy, coupled with the fact that beside thermal plants, hydropower is second largest source of energy in country.

The Kainji hydropower station with installed capacity of 760MWwhich is the focus of the present study and as we argue, the operations of the station is vulnerable to climatic and decline in inflows partly due to the geographical location of the facility and the threat of reduced water volume following plans by Niger Republic to dam the upstream section of river Niger for the proposed Kandadji dam. In the last few years, there is renewed interest to increase the generation capacities of the three major hydropower stations in Nigeria- Kainji, Jebba and Shioro hydropower stations in addition to policy approvals for feasibility studies of rivers across the country for Small Hydropower (SHP) potential. Interest in the sustainability of hydropower in the country relative to other sources of energy some of which are undeveloped, not economically viable or environmentally injurious is justifying the need for more researches and developments in this area. One of such area includes understanding the linkages between variabilities in climatic inputs and inflows to power station. The present study is aimed at evaluating the effects of key climatic variables such as rainfall, temperature, and relative humidity on inflows to Kainji hydropower station.

MATERIALS AND METHODS

The Kainji hydropower station is located in Kainji town about 15km to new Bussa, Bargu Local Government Area of Niger State. Geographically, the area lies at the intersect of latitude 09^0 55´N and longitude 04^0 33´E (Fig. 1). The Kainji Lake has a total area coverage of 1250km^2, with maximum depth and length of 55m and 136km respectively. The length of the width (Widest part), is 10,000km^2. The climate is governed by the annual cycle of humid air masses penetrating from the ocean, the monsoon, followed by a southern movement of dry air from the Sahara Desert, the harmattan. The year therefore has two distinct seasons, the wet season which begins in June and lasts until October and the dry season which lasts for the rest of the year. During the wet season, the air temperature rises to a mean maximum of about 35° C, while mean minimum is about 24°C. The average annual rainfall is about 1018 mm. Strong winds occur normally only during the beginning and end of the wet season when the inter-tropical front passes over the area.

The regime of the Niger River is determined by its peculiar geographical situation. The run-off from the rains in the Fouta Djallon Mountains travels 2700km before reaching Nigeria six months later. The water from the upper catchment area is comparatively clear when it reaches Nigeria, having deposited its silt in the swampy areas (for this reason it is known as the "Black Flood"). The second drainage area contributing to the run-off starts downstream of Niamey, where tributaries in Dahomey flow north into the Niger. In Nigeria the rivers Sokoto and Malendo and a few smaller streams contribute to the local flood above Kainji Lake (Figure, 1).

The local flood water has a milky appearance due to the silt it carries, and is therefore called the "White Flood". The peak of the Black Flood reaches Kainji in January-February with a discharge of about 2000m^3/s falling to less than a hundred m^3/s in May-June. The White Flood starts rising in July and it reaches its peak inflow in late September with a maximum discharge of about 2500 m^3/s. The lake level starts to rise in late August with the incoming White Flood and reaches the maximum level in December during a normal year. This level is maintained until March, when it starts to fall, reaching normal minimum in August. The drawdown is about 10m during a normal year. A large proportion of the rocks in the area consist of ancient crystalline types. A major unconformity separates these crystalline rocks from sandstones, conglomerates and gravels found overlying them in certain areas upstream of Shagunu. The sediments form part of the Nupe sandstone group that was deposited in a shallow area during an earlier geological period. Limestone and other soluble sedimentary rocks are absent in the reservoir site (Kogbe 1989; Oteze, 1989). The study area lies on the border of the Sudan and northern Guinea savanna. The typical vegetation of this area is characterized by grasses and fire tolerant trees and shrubs. Bush fires are common in the area during the dry season, with early fires starting in November. Before inundation, part of the Foge Island (about 4,000ha) was cleared of vegetation to provide fishermen with a fishing ground where nets could be set without being entangled in the vegetation (Abdulla 1994).

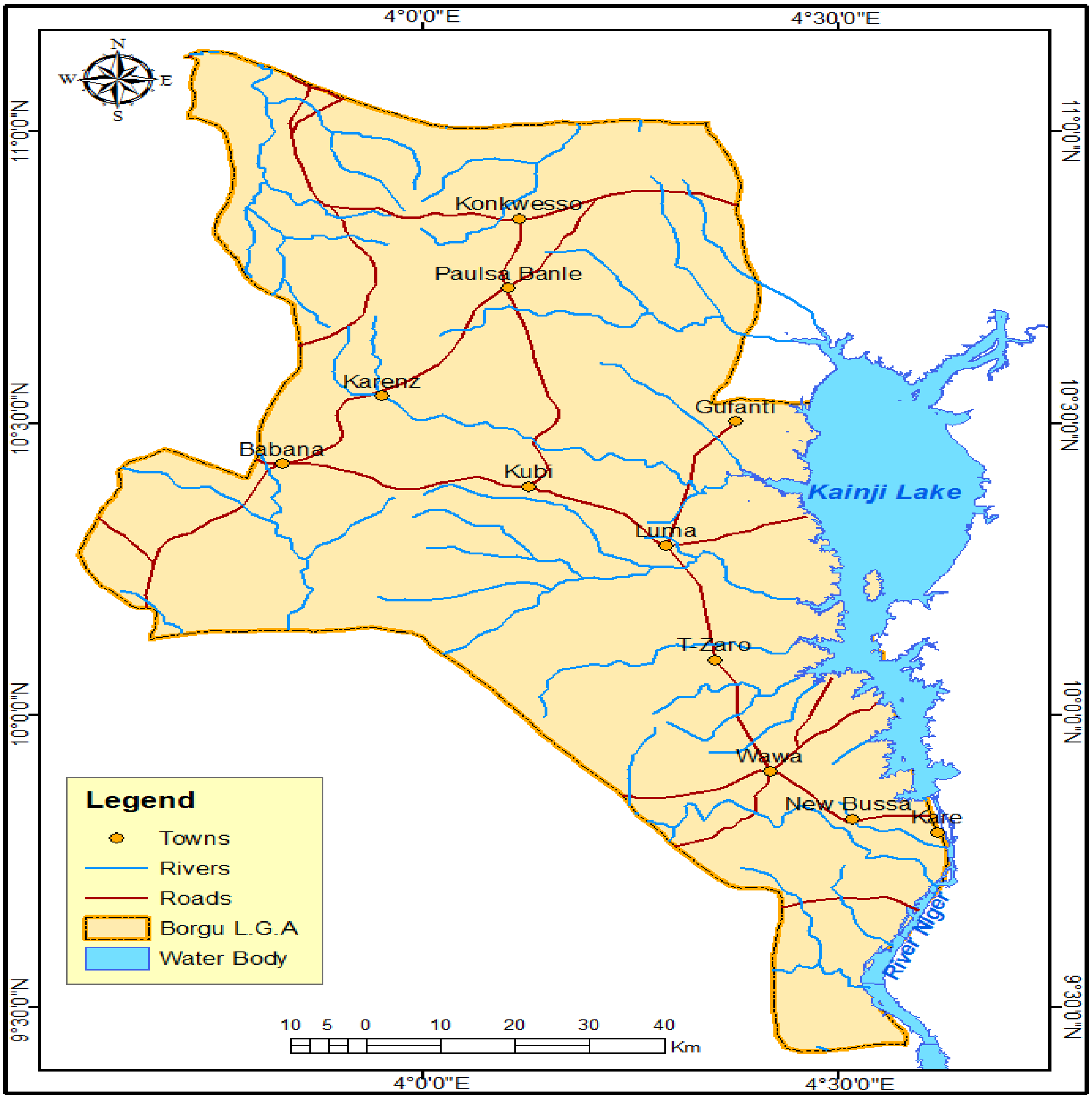

Fig. 1: Bargu LGA, showing Kainji Lake

Data Type and Sources

Monthly climatic data (temperature, rainfall, and Relative humidity) were collected in part from the Nigerian Meteorological Agency (NIMET) and the Meteorological unit, Kainji Dam hydropower station, Niger State. Data were collected for the period 1985-2017. In the absence of stream flow data, reservoir inflow (1985-2017)data were collected from the Hydrological Unit at the Kainji station.Annual Data on lake level was collected for the period in which data was available, 1990-2004. Lake level data was collected on annual basis.These data were investigated for variability using time series including linear regression analyses and Mann-Kendall, Rank-sum, Spearman's Rho, Distribution-Free CUSUM, Cumulative Deviation, Worsley Likelihood Ratio and Students' Statistics. TREND analytical software version 1.0.2 which is developed by Cooperative Research Centre for Catchment Hydrology, Australia was used to test for trend in the annual characters of climatic-hydrological variables. Trends were tested at significance levels of $\alpha = 0.1$, <0.1; $\alpha<0.05$ and $\alpha<0.01$, i.e no evidence against H_0, possible evidence against H_0,strong evidence against H_0 and very strong evidence against H_0 respectively. Descriptive statistics, regression statistical tools were adopted for comparison of means and for investigating the extent to which change in climatic rainfall distribution will affect reservoir inflow into the Kainji Dam. For easy of discussion, these data were further broken into decades, 1985-1994, 1995-2004 and 2005-2014.

Definition of TREND statistics

Mann-Kendall Test

This tool was used to test whether there is a significant trend in the time series data or not. The n time series values (X1, X2, X3, ….., Xn) were first replaced by their relative ranks (R1, R2, R3,….., Rn) (starting at 1 for the lowest up to n). The test statistic S is:

$\sum_{i=1}^{n-1}[\sum_{j=i+1}^{n} sgn(R_{i-}R_{i-})]$ ……………………………………………………………………………..…………(1)

Where Sgn(x) = 1 for x > 0
Sgn(x) =0 for x = 0
Sgn(x) = -1 for x <0
S is approximately normally distributed with:
$\mu = 0$
$\sigma = n (n - 1) (2n + 5) / 18$………………………………………………………………..(2)

The z-statistic is which is the critical test statistic values for various significance levels was obtained from normal probability tables:
$Z = |s|/\sigma^{0.5}$………………………………………………………………..……………(3)

A positive value of S indicates that there is an increasing trend and vice versa.

Spearman's Rho Test

This was used to determine whether the correlation between two variables is significant. One variable was taken as the time itself (years) and the other as the corresponding time series data. Like the Mann-Kendall Test, the n time series values were replaced by their ranks. The test statistic ρs is the correlation coefficient, which is obtained in the same way as the usual sample correlation coefficient, but using ranks. The equation is expressed as;
$P_s S_{xy/}(S_X S_Y)^{0.5}$…………………………………………………………………..…(4)

$where\ S_x = \sum_{i=1}^{n}(x_i - \bar{X})^2$ ……………………………………………………..…….(5)

$S_y = \sum_{i=1}^{n}(y_{i-}\bar{Y})^2$ ………………………………………………………………………..(6)

$S_{xy} = \sum_{i=1}^{n}(x_{i-}\bar{X})^2(y_i - \bar{Y})$……………………………………………………………(7)

and x_i (time), y_i (variable of interest), $\bar{x}$ and $\bar{y}$ refer to the ranks ($\bar{x}$, $\bar{y}$, S_x and S_y have the same value in a trend analysis).

Linear Regression Test

It tests whether there is a linear trend by examining the relationship between time (x) and the variable of interest (y). The regression gradient is estimated by:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})2} \quad (8)$$

and the intercept is estimated as:

$$a = y - bx \quad (9)$$

The test statistic S is:

$$where \quad \sigma = \sqrt{\frac{12\sum_{i=1}^{n}(y_i - a - bx_i)}{n(n-2)(n^2-1)}} \quad (10)$$

The test statistic S follows a Student-t distribution with n-2 degrees of freedom (critical test statistic values for various significance levels was obtained from Student's t statistic tables).

Distribution Free CUSUM Test

This method tests whether the means in two parts of a record are different (for an unknown time of change). It is a non-parametric test (distribution free). Given a time series data (x_1, x_2, x_3, …..,x_n), the test statistic is defined as:

$$V_k = \sum_{i=1}^{k} sgn(x_i - x_{mean})k = 1,2,3, \ldots, n \quad (11)$$

Where sgn(x) = 1 for x > 0

sgn(x) = 0 for x = 0

sgn(x) = -1 for x < 0

$x_{medium}$is the median value of the x_i data set.

The distribution of V_k follows the Kolmogorov-Smirnov two-sample statistic (KS=(2/n) max |V_k|) given by:

$\alpha = 0.10$ $1.22\sqrt{n}$

$\alpha = 0.05$ $1.36\sqrt{n}$

$\alpha = 0.00$ $1.63\sqrt{n}$

A negative value of Vk indicates that the latter part of the record has a higher mean than the earlier part and vice versa.

Cumulative Deviation Test

This method tests whether the means in two parts of a record are significantly different (for an unknown time of change). The test assumes that the data are normally distributed. The purpose of this test is to detect a change in the mean of a time series after m observations. It is expressed as follows;

$E(x_i) = \mu$ $\quad i = 1,2,3,\ldots,m$

$E(x_i) = \mu + \Delta$ $\quad i = m+1, m+2, \ldots, n$

Where μ is the mean prior to the change and Δ is the change in the mean. The cumulative deviations from the means are calculated as:

$$S_0 = 0 S_k = \sum_{i=1}^{k}(x_i - X)k = 1,2,3, \ldots \ldots, n \quad (12)$$

and the rescaled adjusted partial sums are obtained by dividing the S_k* values by the standard deviation:

$S_k ** = S_k */D$ ……………………………………………………………………………..(13)

$D_x^2 = \sum_{i=1}^{n} \frac{(x_i - x)^2}{n}$ ……………………………………………………………………………(14)

The test statistic Q is:
$Q = max|S_k **|$ ……………………………………………………………………………(15)

and was calculated for each year, with the highest value indicating the change point. A negative value of S_k * indicates that the latter part of the record has a higher mean than the earlier part and vice versa.

Worsley Likelihood Ratio Test
This method tests whether the means in two parts of a record are significantly different (for an unknown time of change). The equation is expressed as follows;
$Z._k\, [k(n - k)]^{-0.5} S *_k$ ……………………………………………………………………………..(16)

$Z_k" = Z_k'/D_x$ ……………………………………………………………………………(17)

The test statistic W is;
$w = \frac{(n-2)^{0.5} V}{(1-V^2)^{0.5}}$ ……………………………………………………………………..(18)

A negative value of W indicates that the latter part of the record has a higher mean than the earlier part and vice versa.

Rank-Sum Test
This method tests whether the medians in two different periods are significantly different. It is a nonparametric test. To compute the rank-sum test statistic:
We ranked all the data, from 1 (smallest) to N (largest). In the case of ties (equal data values), we used the average of ranks. The relationship is expressed as follows;

$\mu = n (N+1)/2$ ……………………………………………………………………………(19)

$\sigma = [n\, m\, (N + 1) / 12^{0.5}$ ……………………………………………………………………..(20)

Where n is the number of observations in the smaller group and
m is the number of observations in the larger group
The standardized form of the test statistic Z_{rs} is computed as:
$Z_{rs} = (S - 0.5 - \mu)/\sigma$ if $S > \mu$ ……………………………………………………………..(21)

$Z_{rs} = 0$ if $S = \mu$ ……………………………………………………………………(22)

$Z_{rs} = |S + 0.5 - \mu| / \sigma$ if $S < \mu$ …………………………………………………………(23)

Zrs is approximately normally distributed, and the critical test statistic values for various significance levels was obtained from normal probability tables.

Student's t Test
This method tests whether the means in two different periods are different. The test assumes that the data are normally distributed. The relationship is expressed as follows;

$$t = \frac{(xy)}{s\sqrt{\frac{1}{n}+\frac{1}{m}}} \quad (24)$$

where $\bar{x}$ and $\bar{y}$ are the means of the first and second periods respectively, and m and n are the number of observations in the first and second periods respectively, and S is the sample standard deviation (of the entire m and n observations).
The Student's t test statistic t is (critical test statistic values for various significance levels was obtained from Student's t statistic Tables).

RESULTS AND DISCUSSION
Annual rainfall over Kainji hydropower station did not show any evidence of statistical significant change at α = 0.1. Trend results were 1.069 (Mann-Kendal, z-score), 1.004 (spearman's rho, z-score) and 1.213 (Linear regression, t-test) (Table 1). Similarly, there was no evidence of significant step jump in annual rainfall distribution at α = 0.1. Step jump test results were calculated as 6 (maximum deviation) for CUSUM and 0.68 (cumulative deviation). Nevertheless, Worsley test for step jump showed possible evidence of significant step jump at α <0.1 (Table 2). Although results of CUSUM and cumulative deviation test tend to show no evidence of significant step jumps during the period under study, there were indications of significant break in annual rainfall distribution between 2007 and 2008, though this was a weak sign of decrease. Results of rank sum (277) and student t tests (-0.08) showed that the median value of rainfall from 1985-2000 is not significantly different from median value from 2001-2017 (Table 3).

In Table 1, annual temperature over the Kainji hydropower station showed very strong evidence of significant change at α <0.01. Trend results were 3.41 (Mann-Kendal, z-score), 3.22 (spearman's rho, z-score) and 4.30 (Linear regression, t-test) (Table 1). Similarly, there was very strong to strong evidence of significant step jump in annual temperature distribution at α <0.01 and α <0.05. CUSUM test showed strong evidence of step jump of 8 maximum deviations, while cumulative deviation and Worsley tests results were of 1.68 and 4.37 respectively. Step jump tests indicate significant jumps in temperature data between 2001 and 2002. Both CUMSUM and cumulative deviation test revealed that mean temperature of 1985-2001 is smaller than observation from 2001-2017 while CUMSUM test shows that data in the later years was higher. Results of rank sum (-3.11) and student t tests (-4.21) showed that the median value of temperature from 1985-2000 is significantly different from median value from 2001-2017 α <0.01. Means and median of temperature distribution of 1985-2001 were smaller than distributions from 2001-2017 (Table 3).

Annual reservoir inflow in Kainji hydropower station showed very strong evidence of significant change at α <0.01. Trend results were 4.63 (Mann-Kendal, z-score), 4.35 (spearman's rho, z-score) and 7.38 (Linear regression, t-test) (Table 1). There was also very evidence of significant step jump in annual reservoir inflow distribution at α <0.01. Step jump test results were calculated as 13 (maximum deviation) for CUSUM, 2.26 (cumulative deviation) and 7.88 (Worsley test) at α <0.01 (Table 2). Both cumulative deviation and Worsley Tests for step jumps indicates significant jumps in inflow data in 1993 and 1997 while CUMSUM test shows that data in the later years was higher. The tests revealed that mean inflow data of 1985-1993 is smaller than 1997-2017. Results of rank sum (-3.51) and student t tests (-3.67) showed that the median value of reservoir inflow from 1985-2000 is significantly different from median value from 2001-2017 α <0.01. Means and median of reservoir inflow distribution of 1985-2001 were smaller than distributions from 2001-2017 (Table 3).

Annual distribution of Relative humidity over Kainji hydropower station revealed very strong evidence of statistical significant change at α <0.01. Mann-Kendal, spearman's rho and Linear regression trend test were 4.98(z-score), 4.63 (z-score) and 9.58 (t-test) respectively (Table 1). Also, there was very strong evidence of significant step jump in annual Relative humidity distribution at α <0.01. Results of CUSUM, cumulative deviation and Worsley tests were 16 (maximum deviation) 2.54 and 10.8 respectively. These tests revealed that distributions in the later years were higher that later years. Specifically, cumulative deviation and Worsley tests results showed that the mean Relative humidity distribution of 1985-2002 was smaller than observation from 2002-2017 at α <0.01. Significant step jump was observed in 2002. Results of rank sum (-4.8) and student t tests (-4.52) showed that the median value of Relative humidity from 1985-2000 is significantly different from median value from 2001-2017 α <0.01. Means and median of Relative humidity distribution of 1985-2000 were smaller than distributions from 2001-2017 (Table 3).

In table 4, there is a general increase in the annual decadal distributions of rainfall, temperature, Relative humidity and inflows. This patterns are similar to recent observed statistically significant increases in precipitation and air temperature in vast majority of the country (Egbinola & Amobichukwu, 2013; Akinsanola & Ogunjobi 2014; Yaya *et al.,* 2015) For example, Obot *et al.* (2010) considered rainfall series in each of the six geopolitical zones in Nigeria by examining the trend over the period between 1978 and 2011 and found Maiduguri in the Northeast zone to show an increasing trend among other rainfall towns in other zones. Furthermore, Nnaji (2011) applied the Rescaled Statistic (R/S) and other long memory detecting approaches to obtain evidence of long range dependency in rainfall series in Nigeria. Similarly, Akinsanola & Ogunjobi (2014) studied the rainfall variability in Nigeria using observations from 25 stations from 1971 to 2000, analyzing temporal and spatial trends. They found evidence of significant increase in rainfall anomaly in most of the stations and these stations include Lokoja, Kaduna, Bida, Bauchi and Warri, Delta State.

On seasonal basis however, there seems to be evidence of seasonal decadal increase in temperature distribution, corresponding to decreasing rainfall and reservoir inflow distributions (Table 5). Results of Pearson's Product Moment correlation revealed that lake level is positively related with rainfall and temperature at 0.05 statistical threshold. Thus, further increase in temperature or decrease in rainfall amount will affect lake level, and hydropower operations. Temperature affects inflow through rapid evaporation while declining rainfall amount affects the amount of water available for power generation.

Table 1: Trend Analysis for hydro-climatological variables over Kainji Dam hydropower station (1985-2017)

Time series Annual	Mann-Kendal z-test	Significance level	Spearman's Rho z-test	Significance level	Linear Regression t-test	Significance level

Rainfall (mm)	1.069	α =0.10	1.004	α =0.10	1.213	α =0.10
Temp (^{0}C)	3.409	α <0.01	3.24	α <0.01	4.33	α <0.01
Reservoir Inflow m^3/sec	4.63	α <0.01	4.36	α <0.01	7.38	α <0.01
Relative Humidity (%)	4.99	α <0.01	4.63	α <0.01	9.57	α <0.01

α =0.10, no evidence of statistical sig trend, α <0.1, possible evidence of statistical sig trend; α<0.05, strong evidence of statistical sign trend; α<0.01, very strong evidence of statistical sig trend

Table 2:Change detection for hydro- climatological variables Over Kainji Dam hydropower station (1985-2017)

Time series Annual	CUSUM Max. Deviation	Significance level	Cumulative deviation Q/Sqrt(n)	Significance level	Worsley Likelihood W	Significance level
Rainfall (mm)	6	α =0.10	0.69	α =0.10	2.92	α =0.10
Temp (^{0}C)	8	α <0.05	1.68	α <0.01	4.37	α <0.01
Reservoir Inflow m^3/sec	13	α <0.01	2.26	α <0.01	7.88	α <0.01
Relative Humidity (%)	16	α <0.01	2.54	α <0.01	10.8	α <0.01

α =0.10, no evidence of statistical sig change, α <0.1, possible evidence of statistical sig change; α<0.05, strong evidence of statistical sign change; α<0.01, very strong evidence of statistical sig change

Table 3: Differences between means of hydro- climatological variables over Kainji Dam hydropower station (1985-2000 and 2001-2017)

Time series Annual	Rank-sum z-statistics	Significance level	Student 't' t-test	Significance level
Rainfall (mm)	0.162	α =0.10	-0.02	α =0.10
Temp (^{0}C)	-3.12	α <0.01	-4.21	α <0.01
Reservoir Inflow m^3/sec	-3.51	α <0.01	-3.67	α <0.01
Relative Humidity (%)	-4.85	α <0.01	-4.52	α <0.01

α =0.10, no evidence of statistical sig difference in mean value, α <0.1, possible evidence of statistical sig difference in mean value; α<0.05, strong evidence of statistical difference in mean value; α<0.01, very strong evidence of statistical sig difference in mean value

Table 4:Descriptive statistics of Decadal Mean Annual hydro-climatic indices over Kainji Hydropower station

Decade Annual	Mean	SD	SR	Variance	Min	Max	Range	Sum	%CV
				Rainfall (mm)					
1985-1994	1038.33	175.3	55	30728.0	753.7	1285.4	531.7	10383.3	16.9
1995-2004	1029.0	200.6	63.3	40026.9	735.3	1349.4	614.03	10290.6	19.5
2005-2014	1078.9	144.6	45.7	20900.9	783.7	1323.5	539.8	10789	13.4
				Temperature ^{0}C					
1985-1994	27.0	0.20	0.06	0.04	26.7	27.3	0.55	270.1	0.74
1995-2004	27.1	022	007	0.05	26.6	27.3	0.76	271.2	0.81
2005-2014	27.3	0.17	0.05	0.03	27.1	27.7	0.56	272.8	0.62
				Reservoir Inflow m^3/sec					
1985-1994	800.7	136.2	43.1	18536.9	641	1075.9	434.9	8007	17.0
1995-2004	1128.4	127.3	40.1	16200.6	906	1290	384	11284	11.3

2005-2014	1200.8	142.1	44.9	20189.7	1024	1431.5	407.5	12008.6	11.8
				Relative Humidity (%)					
1985-1994	61.8	1.6	0.5	2.7	59.4	64.5	5.1	617.8	2.6
1995-2004	64.2	4.3	1.3	18.1	59.8	71.4	11.6	641.9	6.7
2005-2014	73.5	3.6	1.2	13.3	68.8	79.8	11.1	735.3	4.5
				Lake level (m)					
1990-2004	138.0	0.6	0.1	0.3	136.9	139.2	2.3	2069.5	0.43

Table 5: Descriptive statistics of Decadal Mean Seasonal hydro-climatic indices over Kainji Hydropower station

				Rainfall (mm)					
Decade seasonal	Mean	SD	SR	Variance	Min	Max	Range	Sum	%CV
1985-1994	102.9	101.3	29.3	10270.0	0	256.8	256.8	1234.7	98.4
1995-2004	101.2	97.7	28.2	9551.3	0	261.6	261.6	1214.5	96.5
2005-2014	87.8	89.2	25.7	7952.4	0	224.6	224.6	1053.9	101.6
				Temperature ^{0}C					
1985-1994	26.92	1.64	0.47	2.68	24.90	30.13	5.23	323.09	6.09
1995-2004	27.1	1.7	0.5	2.9	24.8	29.9	5.1	325.4	6.3
2005-2014	27.4	1.9	0.6	3.6	25.0	30.6	5.6	329.3	6.9
				Reservoir Inflow m^3/sec					
1985-1994	1231.75	725.9	209.6	527003.1	151.0	2052.0	1901.0	14781.0	58.9
1995-2004	1137.58	674.7	194.8	455198.1	153.0	1892.0	1739.0	13651.0	59.3
2005-2014	947.41	688.3	198.7	473742.8	55.0	1762.0	1707.0	11369.0	72.7
				Relative Humidity (%)					
1985-1994	61.8	21.6	6.2	466.5	33.1	87.1	54.0	741.4	34.9
1995-2004	64.2	19.4	5.6	375.8	35.9	86.2	50.3	770.3	30.2
2005-2014	73.5	9.3	2.7	86.4	55.9	84.6	28.7	882.3	12.7

Table 6: Result of Correlation of correlation with Lake Level (1990-2004**)**

Parameter	Multiple R	R Square	Adjusted R Square	Standard Error
Temperature ^{0}C	0.65	0.42	0.37	0.45
Rainfall mm	0.59	0.35	0.30	0.48
Relative humidity %	0.27	0.07	0.003	0.57
Inflows m^3/sec	0.41	0.16	0.102	187

Table: 7: Analysis for Variation between climatic variables and Lake Level

	df	*SS*	*MS*	*F*	*Significance F*
ANOVA Result for statistical variation between temperature and Lake level over Kainji hydropower dam					
Regression	1	1.943441	1.943441	9.28537	0.00935

Residual	13	2.720919	0.209301		
Total	14	4.66436			
ANOVA Result for statistical variation between Rainfall and Lake level over Kainji hydropower dam					
Regression	1	1.640252	1.640252	7.051094	0.019808
Residual	13	3.024108	0.232624		
Total	14	4.66436			
Regression	1	1.640252	1.640252	7.051094	0.019808
ANOVA Result for statistical variation between RH and Lake level over Kainji hydropower dam					
Regression	1	0.348124	0.348124	1.048509	0.324528
Residual	13	4.316236	0.332018		
Total	14	4.66436			

In tables 6 & 7, the results of the effects of sampled climatic variables on lake levels are presented (Table 6), while Table 7 illustrate the results of analysis of variance between lake level and climatic variables. In Table 6, it can be seen that temperature recorded a coefficient value of 0.65. This implies 65% degree of association between changes in temperature and variation in lake level. The 0.42 (r^2) recorded for temperature represent percentage of variation in lake level which can be explained by changes in atmospheric temperature. This implies that any variation in temperature with the lake accounts for 45% variation in lake level. Rainfall on the other hand recorded coefficient value of 0.59 and 0.35 (r square) respectively implies 59% degree of association between lake level and rainfall and the fact that 35% of variation changes in Lake level is explained by variation in rainfall over the lake. On the whole, the observation can be used to represent sensitivity of Lake Level to temperature and rainfall changes. Thus, lake level of Kainji dam is sensitive to temperature by 45% and 35% sensitivity to changes in rainfall pattern. Changes in any of these variables will induce 45% and 35% changes in Lake Level respectively. Annual temperature increase and declining rainfall pattern as revealed from this study, are evidence of changing climate. This confirms findings from other researchers that since the last century, an increase in average global temperature has been observed, and it is expected to increase further in future Brunett, *et al*., (2009); Stocker *et al*.,(2013). The intensity and frequency of precipitation are also expected to change, despite the trend differing with the season and the region (Gobiet, *et al.,* 2014). This will alter river-flow conditions, and in turn hydropower, which has been investigated from single catchments to a global scale (Schaefli *et al.,* 2007; Koch, *et al.,* 2011; Majone, *et al.,* 2016). In Table 7, the results of the one way analysis of variance showed there is statistical significant relationship between lake level and temperature and with rainfall. This buttresses the results of Pearson's product Moment Correlation, confirming some degrees of sensitivity of Lake Level at the Kainji to temperature and rainfall patterns.

CONCLUSION AND RECOMMENDATIONS

Nigeria dependence on hydropower as a source of electricity needs today cannot be overemphasize going by the contribution of hydro to the power generation pool. Using the trend analysis and regression models, the results of this study in the absence of any adaptation measure shows evidence of significant change in annual temperature, annual distribution of relative humidity, and reservoir inflows over Kainji dam, a pattern which is similar to recent observed statistically significant increases. Although climatic indices trends do not conclusively indicate impact of climate variability on reservoir inflows to Kainji dam, however, the possibility of high significant change of such variability cannot be underestimated, especially as the results of correlation show positive relationships between lake level and climatic variables (temperature and rainfall).

In an attempt to mitigate climate change impacts, several solutions have been proposed to reduce greenhouse gas emissions, including modern efficient energy alternatives and enhancing the use of sustainable energy sources. Among alternative options for power generation, hydropower is considered to be most lucrative due to renewability, lower emissions, and longevity of infrastructure. In Nigeria, while the hydropower sector is making a significant effort to cope with rising national energy demands, this effort will be difficult due to climate change effects. Climate change will have a variety of effects on streamflow, involving quantity and timing, temperature, sediment load, and ecosystem changes. Temperature fluctuations, rainfall patterns, floods, and droughts are all major signs of climate change that have strong effects on river systems, which will consequently affect hydropower generation (Mohammad & Guido, 2018). The possible recession of river flow may lead to decreased hydropower generation, which in turn will have certain influences on the economic viability of the hydropower plant schemes. Already, an important finding of this study indicate increasing temperature which will lead to increased evaporation and evapotranspiration over the lake. There is also evidence of decreasing rainfall.

There is need for further assessments on the lake, which will address some of the limitations identified in this study (such as unavailability of streamflow data). Such data should be based on long term (e.g. 50-100 years) to provide a much higher evidence of significant climatic variability and change on the Kainji dam as well as effects on hydropower operations. This study shows that there is a need to improve the collection of hydro-climatic data, and also that the use of other watershed hydrological models for accessing sensitivity of water resources of Kainji Dam to climate variability and change.

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