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TREND ANALYSIS OF HYDRO-METEOROLOGICAL VARIABLES USING THE MANN-KENDALL TREND TEST: APPLICATION TO THE NIGER RIVER AND THE BENUE SUB-BASINS IN NIGERIA

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ABSTRACT
This paper presents the outcome of the trend analysis of hydro-meteorological variables in the Niger River and the Benue sub-basins in Nigeria. A non-parametric Mann-Kendall trend test was used to analyse the trends exhibited by the variables. The results revealed that precipitation exhibits insignificant positive trends in five locations, while insignificant negative trends were exhibited in the remaining six locations. This implies that the increase or decrease in precipitation would not be noticeable in all the locations, since the changes are statistically insignificant. The evaporation exhibits a significant positive trend in three locations, while in another three locations it exhibits an insignificant positive trend and also exhibits an insignificant negative trend in the remaining five locations. This is an indication that the incremental change in evaporation would be noticeable in three locations, while the increase or decrease would not be noticed in the remaining eight locations. In the case of minimum and maximum temperature, the trends in almost all the locations, except Ibi, are statistically significant positive. However, the runoff and water level in five locations out of six locations exhibit a significant negative trend. The downward trends exhibited by the runoff and water level in the two sub-basins may be due to the effect of climate variability on the hydro-meteorological variables. The reduction of runoff is an indication of the decrease in water resources in the sub-basins and this can result in low reservoir inflow to the Kainji and Jebba hydropower dams located in the basin.

Keywords: Climate variables; Mann-Kendall; Niger River and Benue; Runoff; Trend detection

1. INTRODUCTION
Water resource management is a major issue in the Niger River and Benue sub-basins in Nigeria. The past and current trend of the hydro-meteorological variables can assist in visualization and characterization of the past, current and future water resource situation within the basins. Reviews of related works include Hirsch et al. (1982), Gleick (1989), Gan (1992), Inter-governmental Panel on Climate Change (IPCC, 1996), Chrysoulakisa et al. (2001), Burn et al. (2002), Yue and Wang (2004), Prashanth (2005), Partal and Kahya (2006), Karabulut et al. (2008), Longobardi and Villani (2009), Karpouzos et al. (2010), Salami et al. (2010), Makanjuola et al. (2010), Gandomkar (2011), Salami et al. (2011), Mondal et al. (2012), Jain and Kumar (2012), Danneberg (2012).

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From the review work a range of potential impacts of climate change and variability on the hydrologic regime for various geographic areas has been hypothesized and the Mann-Kendall non-parametric test was adopted to detect trends observed by most authors.

Mann-Kendall non-parametric test is widely used for the analysis of trends in meteorological and hydrological series. One of the advantages of this method is its applicability for a time series distribution, which does not follow a typical statistical distribution. This method of analysis adopts two parameters such as the Kendall statistic, S and the normalized test statistic Z_s, which are used to determine the nature and level of the significance of trends exhibited by the variables. Generally, a positive value of S is an indication of an upward trend, while a negative value indicates a downward trend. Also the value of Z_s greater than 1.96 at a selected confidence limit of 95% shows that the trends can be interpreted as statistically significant or otherwise.

The purpose of this study is to investigate the variability of hydro-meteorological variables in the Niger River and Benue sub-basins in Nigeria and to deduce the influence of variability on the hydrological and meteorological variables within the basin. In achieving this, the Mann-Kendall non-parametric test was explored to establish trends in the hydro-meteorological variables considered.

1.1. Objectives

The objectives of this study are to analyse the hydro-meteorological variables within the Niger River and Benue sub-basins using the Mann-Kendall trend analysis in order to identify the nature of trend exhibited by the variables and the consequence of variability of climate change on the runoff in the sub-basins.

1.2. Study area

The Niger River is the principal river of western Africa, extending about 4,180 km. Its drainage basin is 2,117,700 km^2 in area. Its source is in the Guinea Highlands in southeastern Guinea. It runs in a crescent through Mali, Niger, on the border with Benin and then through Nigeria, discharging through a massive delta, known as the Niger Delta or the Oil Rivers, into the Gulf of Guinea in the Atlantic Ocean. The Niger is the third-longest river in Africa, exceeded only by the Nile and the Congo River (also known as the Zaïre River). The Niger River was dammed at Kainji and Jebba in Nigeria for electricity generation.

Its main tributary is the Benue River (Gleick, 2000). The Benue River is one of the longest tributaries of the Niger River. The Benue River is approximately 1,400 km long and is almost entirely navigable during the rainy season. The origin of the Benue River can be traced to the Adamawa Plateau of Northern Cameroon from where it flows west and through the town of Garoua and Lagdo Reservoir, into Nigeria, south of the Mandara mountains and through Jimeta, Ibi and Makurdi, before meeting the Niger River at Lokoja (Nwilo et al., 2012). The Benue River's largest tributary is the Mayo Kébbi, which connects it with the Logone River (part of the Lake Chad system) during floods. Other tributaries are the Taraba River and the Katsina Ala River located between Lokoja and the Niger Delta. The only significant tributary is the Anambra River, which has its source from the Ayangba and Ankpa Highlands. The Benue main tributary passes the Garua alluvial plain before joining the Faro River running along the border between Nigeria and Cameroon. The Benue River flows through seven states in the northeast and north-central geopolitical zones of Nigeria namely Adamawa, Taraba, Gombe, Plateau, Nasarawa, Benue and Kogi states. Figure 1 is the map of Nigeria showing the Niger River and Benue sub-basin hatched.

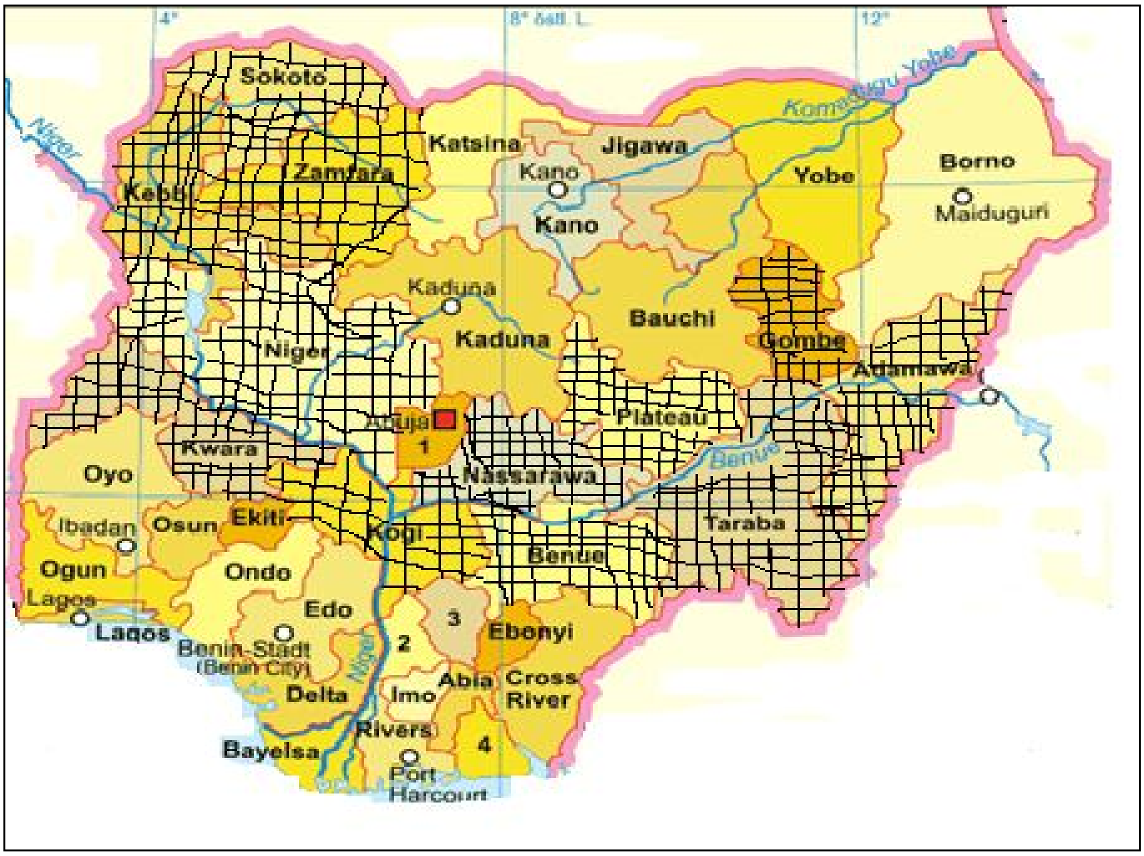

Figure 1 Map of Nigeria showing the Niger River and the Benue sub-basin hatched

2. METHODOLOGY

2.1. Data collection

The hydro-meteorological data such as temperature, evaporation, precipitation, water level and runoff were collected from thirteen (13) gauging stations in the sub-basins of the Niger and Benue Rivers. The geographical location of the sources of data and the available data is presented in Table 1. The available data vary from one location to the other depending on the gauging instrument installed. Some locations captured only meteorological data such as temperature, evaporation and precipitation, while some captured additional data such as water level and runoff. The data was available for a period of 53 years (1960–2012) in most of the locations except at Kainji which only was available for a period of 43 years (1970–2012) (Mohammed, 2013; Abdulmalik, 2013).

Table 1 Geographical location and hydro-meteorological variables

State	Gauge Location	Latitude (°N)	Longitude (°E)	Available Data
Sokoto	Sokoto	13° 03' 46"	5° 14' 46"	Temperature, Evaporation & Precipitation
Zamfara	Gusau	12° 08' 43.4"	6° 42' 45.5"	Temperature, Evaporation & Precipitation
Kebbi	Yelwa	12° 27' 40.5"	4° 11' 38.5"	Temperature, Evaporation & Precipitation
Niger	Minna	9° 36' 17.3"	6° 34' 01.5"	Temperature, Evaporation & Precipitation
Kogi	Lokoja	7° 48' 30.7"	6° 44' 14.5"	Temperature, Evaporation, Precipitation, Runoff & Water level
Kogi	Idah	7 ° 05 ' 00"	6 ° 45 ' 00"	Runoff & Water level
Kwara	Ilorin	8° 29' 42.6"	4 ° 32' 54"	Temperature, Evaporation & Precipitation
Niger	Kainji	9° 50' 00"	4° 40' 00"	Temperature, Evaporation Precipitation, & Runoff
Niger	Baro	8 ° 35 ' 27"	6 ° 27 ' 41"	Runoff & Water level
Adamawa	Yola	9.33	12.5	Temperature, Evaporation, Precipitation, Runoff & Water level
Benue	Makurdi	6.25	8.80	Temperature, Evaporation &Precipitation, Runoff & Water level
Plateau	Jos	9.52	8.50	Temperature, Evaporation & Precipitation
Taraba	Ibi	4.16	13.52	Temperature, Evaporation & Precipitation

Source: Mohammed (2013) and Abdulmalik (2013)

2.2. Data analysis

The Mann-Kendall non-parametric test was adopted in identifying trends in time series data. It compares the relative magnitudes of sample data rather than the data values. The major benefit of this test is that the data need not conform to any particular distribution. Moreover data reported as non-detects can be included by assigning them a common value that is smaller than the smallest measured value in the data set. The procedure for the trend analysis assumes that there exists only one data value per time period. When multiple data points exist for a single time period the median value is used. The data values are evaluated as an ordered time series and each data value is compared to all subsequent data values. The initial value of the Mann-Kendall statistic (S) is assumed to be 0, if there is no trend. If a data value from a later period is higher than a data value from an earlier time period, then S is incremented by 1. Conversely, if the data value from a later period is lower than a data value sampled earlier, then S is decremented by 1. The net result of all the increments and decrements yield the final value of S. The expressions for the Mann-Kendall trend analysis are given in Equations 1 to 4.

Let $X_1, X_2, \ldots, X_n$ represents n data points where X_j represents the data point at time j. Then the Mann-Kendall statistic (S) is given (Hirsch et al., 1982 and Gan, 1992) as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sgn\left(X_j - X_i\right) \tag{1}$$

$$Sgn\left(X_j - X_i\right) = \begin{cases} +1, & X_j \rangle X_i \\ 0, & X_j = X_i \\ -1, & X_j \langle X_i \end{cases} \tag{2}$$

A very high positive value of S is an indication of an increasing trend while a very low, negative value indicates a decreasing trend. However, it is important to compute the probability associated with S and the sample size n in order to statistically quantify the significance of the trend (Prashanth, 2005). Calculation of the variance of S, $\boldsymbol{\sigma^2}$ is given by using Equation 3,

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{g}(t_p - 1)(2t+5)\right] \tag{3}$$

where n is the number of data points, g is the number of tied groups (a tied group is a set of sample data having the same value) and t_p is the number of data points in the p^{th} group. Computation of a normalized test statistic $\mathbf{Z_s}$ is shown in Equation 4.

$$Z_s = \begin{cases} (S-1)/\sigma & for \quad S \rangle 0 \\ 0 & for \quad S = 0 \\ (S+1)/\sigma & for \quad S \langle 0 \end{cases} \tag{4}$$

The test statistic $\mathbf{Z_s}$ is used as a measure of trend significance. In fact this analysis is used to test the null hypothesis, $\mathbf{H_0}$: There is no monotonic trend in the data if $|\mathbf{Z_s}|$ is greater than $\mathbf{Z}_{\propto/2}$ where $\propto$ represents the chosen significance level (usually 5% with $\mathbf{Z_{0.025} = 1.96}$) then the null hypothesis is invalid, meaning that the trend is significant. Being significant implies that the trend has a causative factor and did not occur by chance. The Mann-Kendall statistical analysis has been found to be an excellent tool for trend detection in different applications (Prashanth, 2005). The Mann-Kendall non-parametric test was applied to the hydro-meteorological variables in the Niger River and the Benue sub-basins (Mohameed, 2013; Abdulmalik, 2013).

3. RESULTS AND DISCUSSION

3.1. Results

The results of the Mann-Kendall analyses for all the hydro-meteorological variables at the selected locations in the two sub-basins are summarized in the Tables 2–14.

Table 2 Mann-Kendall results for Yelwa

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	98	0.79	Positive	No
Max Temp	376	3.06	Positive	Yes
Evaporation	419	3.40	Positive	Yes
Precipitation	14	0.11	Positive	No

Table 3 Mann-Kendall results for Sokoto

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	782	6.35	Positive	Yes
Max Temp	536	4.35	Positive	Yes
Evaporation	120	0.97	Positive	No
Precipitation	101	0.81	Positive	No

Table 4 Mann-Kendall results for Gusau

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	304	2.47	Positive	Yes
Max Temp	299	2.43	Positive	Yes
Evaporation	521	4.23	Positive	Yes
Precipitation	185	1.49	Positive	No

Table 5 Mann-Kendall results for Minna

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	286	2.32	Positive	Yes
Max Temp	462	3.76	Positive	Yes
Evaporation	139	1.12	Positive	No
Precipitation	53	0.42	Positive	No

Table 6 Mann-Kendall results for Lokoja

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	331	2.69	Positive	Yes
Max Temp	171	1.38	Positive	No
Evaporation	-199	1.61	Negative	No
Precipitation	-5	0.03	Negative	No
Runoff	-327	2.65	Negative	Yes
Water level	-307	2.49	Negative	Yes

Table 7 Mann-Kendall results for Kainji

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	398	4.81	Positive	Yes
Max Temp	114	4.31	Positive	Yes
Evaporation	-12	0.15	Negative	No
Precipitation	65	1.14	Positive	No
Runoff	-240	2.79	Negative	Yes

Table 8 Mann-Kendall results for Ilorin

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	553	4.49	Positive	Yes
Max Temp	-213	1.73	Negative	No
Evaporation	315	2.55	Positive	Yes
Precipitation	-57	0.46	Negative	No

Table 9 Mann-Kendall results for Baro

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Runoff	-225	3.18	Negative	Yes
Water level	-372	5.27	Negative	Yes

Table 10 Mann-Kendall results for Idah

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Runoff	-380	5.16	Negative	Yes
Water level	-338	4.59	Negative	Yes

Table 11 Mann-Kendall results for Makurdi

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	506	4.12	Positive	Yes
Max Temp	377	3.06	Positive	Yes
Evaporation	-13	0.10	Negative	No
Precipitation	-121	0.97	Negative	No
Runoff	-369	5.38	Negative	Yes
Water level	-389	5.67	Negative	Yes

Table 12 Mann-Kendall result for Jos

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	331	2.69	Positive	Yes
Max Temp	422	3.44	Positive	Yes
Evaporation	180	1.46	Positive	No
Precipitation	-67	0.5308	Negative	No

Table 13 Mann-Kendall result for Ibi

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	225	3.22	Negative	Yes
Max Temp	-499	4.05	Negative	Yes
Evaporation	-177	1.42	Negative	No
Precipitation	-81	0.64	Negative	No

Table 14 Mann-Kendall result for Yola

Variables	Kendall's S	Z_s	Trend nature	Trend significance
Min Temp	723	5.88	Positive	Yes
Max Temp	171	1.38	Positive	Yes
Evaporation	-19	1.60	Negative	No
Precipitation	5	0.03	Negative	No
Runoff	10	1.11	Positive	No
Water level	64	1.13	Positive	No

3.2. Discussion

In the Niger River sub-basin, the precipitation, evaporation, minimum and maximum temperature for Yelwa have positive Kendall's (S) values, which indicate that all the variables have positive trend. Minimum temperature and precipitation have test statistic (Z_s) values of 0.79 and 0.11 respectively which are less than 1.96 (test statistic for a significant level of 5% i.e. $Z_{0.025}$). This implies that an insignificant positive trend is demonstrated by minimum temperature and precipitation. The maximum temperature and evaporation for Yelwa have Z_s values of 3.05 and 3.40 respectively, which are greater than 1.96, thus indicating that a statistically significant positive trend is demonstrated by maximum temperature and evaporation. The two parameters have been increasing over time and the trend is likely to continue.

The evaporation, precipitation, minimum and maximum temperature for Sokoto have positive S values, which imply a positive trend for the variables. Evaporation and precipitation have Z_s values of 0.97 and 0.81 respectively, which are less than 1.96, thus these indicate that the increase in evaporation and precipitation are not significant. Minimum and maximum temperatures have Z_s values of 6.35 and 4.35 respectively that are greater than 1.96, thus these show a statistically significant positive trend. This is an indication that the increase in evaporation and precipitation would not be noticed, while those of temperature variation would be noticed.

The evaporation, precipitation, minimum and maximum temperature for Gusau have positive S values, which show that all of the variables indicate a positive trend that can increase over time. Precipitation has a Z_s value of 1.50, which is less than 1.96, thus this reveals an insignificant positive trend (the increment) that would not be noticed. Evaporation, minimum and maximum temperature have Z_s values of 4.23, 2.47 and 2.43 respectively, which are greater than 1.96, thus these show that there is a statistically significant positive trend for the variables. The variables have been increasing over time and the trend is likely to continue.

The evaporation, precipitation, minimum and maximum temperature for Minna have positive S values which indicate a positive trend. Evaporation and precipitation have Z_s values of 1.12 and 0.42 respectively, which are less than 1.96, thus these imply a statistically insignificant trend for the evaporation and precipitation. Minimum and maximum temperature has Z_s values of 2.32 and 3.76 respectively, which are greater than 1.96, thus there is a statistically significant positive trend for the minimum and maximum temperature. The variables have been increasing over time and the trend will continue.

The variables at Lokoja such as minimum and maximum temperature have positive S values, which show a positive trend, while the evaporation, precipitation, runoff and water level have negative S values, which show a negative trend. Maximum temperature, evaporation and precipitation have Z_s values of 1.38, 1.61 and 0.03 respectively, which are less than 1.96, thus these imply a statistically insignificant positive trend. However, the minimum temperature, runoff and water level have Z_s values of 2.69, 2.65 and 2.49 respectively that are greater than 1.96, thus these indicate a statistically significant positive trend for the minimum temperature, while the runoff and water level have a statistically insignificant negative trend and the trend may continue in future.

The precipitation, minimum and maximum temperature for Kainji have positive S values, which indicate a positive trend, while the evaporation and runoff have negative S values, which imply a negative trend. Evaporation and precipitation have Z_s values of 0.14 and 1.14 respectively, which are less than 1.96, thus there is a statistically insignificant positive trend for the precipitation and evaporation. Runoff, minimum and maximum temperature have Z_s values of 2.79, 4.81 and 4.31 respectively, which are greater than 1.96 and thus these reveal a statistically significant positive trend for the minimum and maximum temperature that may increase over time, while the runoff demonstrates a statistically significant negative trend that is likely to continue over time.

The minimum temperature and evaporation for Ilorin have positive S values, which indicate a positive trend, while the maximum temperature and precipitation have negative S values. Maximum temperature and precipitation have Z_s values of 1.73 and 0.46 respectively, which are less than 1.96, thus these reveal a statistically significant negative trend for the maximum temperature and precipitation. Minimum temperature and evaporation have Z_s values of 4.49 and 2.55 respectively, which are greater than 1.96, thus these imply a statistically significant positive trend for both minimum temperature and evaporation.

The water level and runoff for Baro have negative S values and Z_s values of 3.18 and 5.27 respectively, which are greater than 1.96, thus these indicate that a statistically significant negative trend is demonstrated by both water level and runoff. The trend may continue to decrease over time for the two variables.

The water level and runoff for Idah have negative S values and Z_s values of 5.16 and 4.59 respectively, which are greater than 1.96, thus these show that a statistically significant negative trend is demonstrated for both water level and runoff. The trend may continue to decrease over time for two variables.

However, in the Benue River sub-basin, the results of the Mann-Kendall statistics carried out on the climatic and hydrologic data of the Makurdi, Jos, Ibi and Yola presented in Tables 11-14 show that three of the stations exhibit a positive trend in temperature. The only exception is Ibi station, which gave a negative trend for the temperature. Similarly precipitation and evaporation trends for four stations showed a negative trend and these were of no statistical significance. The Mann-Kendall trend analysis for the runoff and water level at Makurdi shows a statistically significant negative trend, thus implies that the decrease in runoff and water level in Makurdi has a tendency to continue. The Yola station, however, exhibits a positive trend in both runoff and water level with no statistical significance, thus the increase in the two variables in Yola might not be noticed

4. CONCLUSION

The trends in hydro-meteorological variables at annual time scale were examined for the Niger River and Benue sub-basins in Nigeria. The non-parametric Mann-Kendall test was adopted to analyze trends exhibited by the variables.

The study revealed that the average precipitation level at Yelwa, Sokoto, Gusau, Minna and Kainji exhibit a statistically insignificant positive trend, while those at Lokoja, Ilorin, Makurdi, Jos, Ibi and Yola exhibit a statistically insignificant negative trend. The evaporation levels at Yelwa, Gusau, and Ilorin exhibits a statistically significant positive trend, while those at Sokoto, Minna and Jos exhibit a statistically insignificant positive trend. However, the evaporation level at Lokoja, Kainji, Makurdi, Ibi and Yola exhibit a statistically insignificant negative trend. The minimum and maximum temperature exhibits a statistically significant positive trend in most of the locations except at Ibi in which both minimum and maximum temperature exhibit a statistically significant negative trend. The runoff and water level in Lokoja, Baro, Makurdi, Idah and Kainji exhibit a statistically significant negative trend, while those of Yola exhibit an insignificant positive trend.

The behavior of the parameters might be due to variability in the climatic variables over the period considered. It can be concluded that the variables that exhibit a statistically significant positive trend have a tendency to increase with time and their increment will be noticeable, while those that are statistically insignificant, their increment will not be noticeable. Conversely, the variables that exhibit statistically significant negative trend have a tendency to decrease and their reduction will be noticeable, while those that are statistically insignificant, their reduction would not be noticeable.

The significant outcome of the analysis in relation to Kainji sub-basin where the major hydropower dams in Nigeria are situated is that there is a tendency for a reduction in the stream flow to the reservoirs. These could be as a result of an increase in temperature, which could lead to an increase in evaporation and cause a reduction in runoff.

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