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Trend Analysis of Hydro-meteorological Data for River Kaduna at Shiroro Dam Site, Niger State Nigeria

Kuti I. Abayomi[1*], Animashaun I. Murtala[2], Olawale Babatunde[2] and Abdullahi Suleiman[1]

[1]Centre for Disaster Risk Management and Development Studies, Federal University of Technology, Minna, Nigeria.
[2]Department of Agricultural and Bioresources Engineering, Federal University of Technology, Minna, Nigeria.

Authors' contributions

This work was carried out in collaboration between all authors. Author KIA designed the study, wrote the protocol, and performed the trend analysis. Author AIM managed the literature searches while authors OB and AS wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

Variation in the hydro-climatic variables of River Kaduna at Shiroro Dam site, Nigeria is linked to a number of climate change activities around the river. In view of this, the paper aims at examining the trend of stream flow, rainfall, temperature and evaporation. Monthly discharge, rainfall, temperature and evaporation records were obtained for a period of Thirty Three (33) years (1980-2012). These variables were used to examine the trend of the area. Incremental/Reductional analysis was used to determine a positive and negative change with percentage hydro-climatic variables difference. Mann- Kendall test, Turning point test and Kendall's Rank Correlation were also used to estimate the significance of the trend. The result of the Mann –Kendall shows that the

**Corresponding author: Email: abykuti6@futminna.edu.ng;*

month of September had a value of Zs equals -2.09 (greater than $Z_{0.025}$) which makes it statistically significant; the rainfall value has no trend on a long term basis; the month of February and October had values of Zs equal to -2.2 (greater than $Z_{0.025}$) which made it statistically significant; the month of October had a value of Zs equal to 2.2 (greater than $Z_{0.025}$) which makes it statistically significant. Turning Point and Kendall's Rank correlation Tests indicated that the variables have negative trends. The incremental/reduction analysis indicated that the discharge, rainfall and evaporation have significant trend (10%, 90% and 35%) on the seasonal than the long term basis while the trend of temperature was significant on long term than the seasonal which has little or no trend (0.37%) in the area. The study shows that the trend pattern of stream flow, rainfall, temperature and evaporation from 2002 - 2012 was extremely high compared to 1980 - 1990 and 1991 – 2001. It is thus recommended that River Kaduna should be dredged and channelised so as to reduce depth of runoff during the full wet seasons. Also, deforestation and bush burning activities around the river at Shiroro Dam site should be prohibited.

Keywords: Climate change; Mann-Kendall Test; turning point test and Kendall's rank correlation test; trend analysis; Shiroro River.

1. INTRODUCTION

Every year, human activities result in heightening atmospheric concentration of greenhouse gases. These gases have observable impacts on the global climate. Regardless of uncertainty in future climate, there are manifestations/features that there would be significant result on the water cycle and its environs [1]. Water cycle rises when there is increasing evaporation which in turn causes excessive rainfall [2,3]. Rainfall intensity and amount vary with time and space [4,3] and these changes have either positive or negative significance on the water resource management [3], thereby causing hydrological response in term of flooding and drought risk. According to [5] analysed rainfall and temperature variability over Nigeria. Their analyses show that there is significant increases in rainfall and temperature in Nigeria.

In line with [6], hydro-climatic variable are modified by human activities which in turn change the trend pattern in the variables. According to [7] opined that rainfall fluctuation is the major factor causing impact of climate change but the prediction of rainfall is different from that of temperature and evaporation. The rainfall trend pattern in Northern-Nigeria varied between 15% and 20% in spatial and temporal dimensions which led to either flooding or drought [8]. According to [5] examined rainfall and temperature variability over Nigeria between the year 1971 and 2000 using statistical approach and their result shown that there is significant positive trend in rainfall and temperature within the stipulated years.

The essence of the trend analysis in Rivers give general idea of changes in rainfall, temperature and evaporation and this result will be compared with the 2020 predicted General Circulation Models (GCMs) so as to establish whether the current trend in the study area matches the projections of future conditions [2], the trends were more prominent for shorter time intervals.

Globally, parametric and non- parametric methods are used to analyze trend. The non-parametric method (Mann-Kendall) assesses the significance of trends in hydro-meteorological time series like rainfall, temperature and evaporation because it is more suitable for non-normally distributed data and censored data, which are frequently encountered in hydro-meteorological time series [9]. While the parametric method is used to determine the main periods and oscillation strength of the series and also expresses the energy of fluctuations with distribution of time scales. In order to overcome the gap in work of [2], the study would use percentage change in variation, Mann-Kendall statistics and Turning point test on the historical rainfall, temperature and evaporation dataset of River Shiroro to detect the short and long term trend of the area so as to improve the hydro infrastructure of Shiroro Dam. In view of this, this study aim to examine the trend of discharge, rainfall, temperature and evaporation and this was achieved through the determination of trends in the hydro-climatic attributes of the River.

2. MATERIALS AND METHODS

2.1 Climate and Hydrology of the Study

The study area is characterised by wet and dry season with rainfall occurring in the rainy season months of May to October. Temperature is high in the period of dry season and less in full wet raining season between 27°C and 35°C [10]. Shiroro is located on 9° 58' 00" N and 9° 65' 25'' N latitude and longitude 6° 51' 00" E and 6° 75' 10'' E. River Kaduna is the only river feeding Shiroro dam. Shiroro River has fifteen drainage tributaries among its watershed and these tributaries are rivers Dinya, SarkinPawa, Guni, Erena, and Muyi as shown in Fig. 1. The tributaries flow in the North-South direction and then meander in the Northwest to Southeast direction. This river has a low base flow problem and the volume of the rivers swell in volume with ranging torrent while in the dry season they dry up.

2.2 Data Collection/Assembly

Monthly discharge, rainfall, Temperature, evaporation records were obtained for a period of Thirty Three (33) years (1980-2012) [11]. These variables were used to examine the trend.

2.3 Data Quality Test

The monthly stream flow, rainfall, temperature and evaporation data were pre-tested using Runs Test to establish the significance of the dataset.

2.4 Increment/Reduction Pattern Analysis

The hydro-climatic data were divided into three segments and the average of each segment was computed , this denotes Discharge (Di), Rainfall (Ri), Temperature (Ti), and Evaporation (Ei) while the average of the three segments was computed as which denotes Discharge (Dm), Rainfall (Rm), Temperature (Tm), and Evaporation (Em). The percentage change in variation was computed for the hydro-climatic variables as follows [12]:

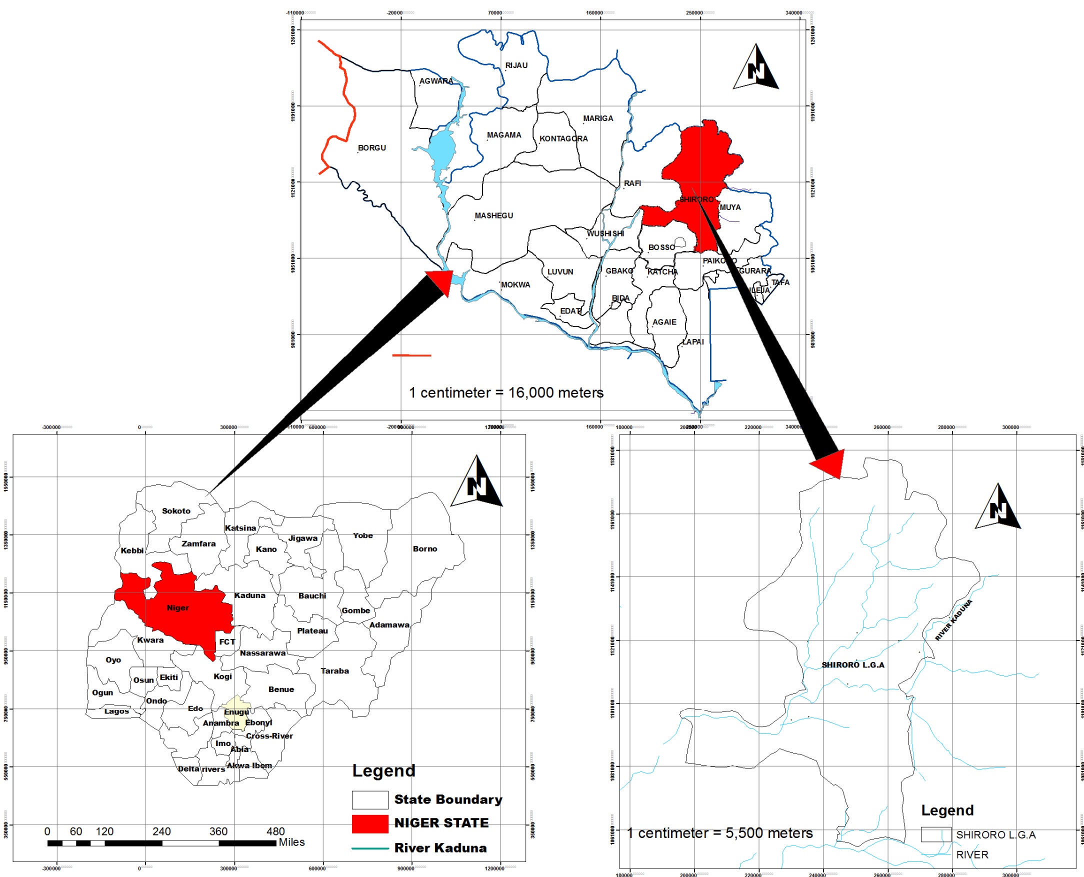

Fig. 1. Location of Niger State with the projected extracts (top and right) of Niger State with Shiroro dam inset and the River Kaduna drainage basin, respectively

Source: Olaxxy consult (2014)

$$Percentage\ Change\ in\ Variation = \frac{(X_i - X_m)}{X_m} \times 10 \quad (1)$$

Where, $x_{i-}\, x_m$ equal to deviation of the hydro-climatic variables.

Also, equation 1 above was used to calculate the seasonal percentage change in variation. The year was divided into two, the average of the incipient drying and full wet season was computed as while the average of both incipient dry and full wet season was computed as x_m.

2.5 Trend Analysis

The study explored Mann-Kendall statistic for monthly stream flow, rainfall, temperature and evaporation records. The study explored Kendall tau statistic, τ, to test for randomness against trend in hydro- climatic time series [13]. In this test, the null hypothesis Ho states that the deseasonalised data (x_1. . . xn) are a sample of *n* independent and identically distributed random variables. The alternative hypothesis H_1 of a two-sided test is that the distribution of and is not identical for all *k*, *j* ≤ *n* with *k*≠ *j*. The test statistic (S) was calculated with equation 2 and 3 below has mean zero and variance of S, computed by:

$$Var(S) = [n(n-1)(2n+5) - \sum_t t\,(t-1)(2t+5)]/18 \quad (2)$$

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} Sgn(\, x_j - x_k) \quad (3)$$

$$(x_j - x_k) = \begin{cases} +1 \quad if\ (x_j - x_k) > 0 \\ 0 \quad if\ (x_j - x_k) = 0 \\ -1\ \ if\ (x_j - x_k) = 0 \end{cases} \quad (4)$$

and is asymptotically normal, where *t* is the extent of any given tie, and *t* denotes the summation over all ties. For the cases in which *n* is larger than 10, the standard normal variate Z is computed by using equation 4 and 5 [13]:

$$Z = [\begin{cases} \frac{S-1}{\sqrt{Var(S)}} \\ \frac{S+1}{\sqrt{Var(S)}} \end{cases} \begin{cases} if\ \ S > 0 \\ if\ \ S = 0] \\ if\ \ S < 0 \end{cases} \quad (5)$$

The test statistic Zs was used as a measure of significance for trend. In fact, this test statistic was also used to test the null hypothesis, $H0$: There is no monotonic trend in the data. If Zs is greater than $Z\propto\ 2$, where $\propto$ represents the chosen significance level (usually 5%, with = 1.96), then the null hypothesis is invalid, meaning that the trend is significant.

For the purpose of this study, after testing the monthly discharge, rainfall, Temperature and evaporation data using Mann-Kendall test the steady increase or decrease of the time series was done for detecting the presence of trend via Turning Point and Kendall's Rank correlation test. Also, the Turning Point test and Kendall's Rank correlation test were used to detect the long term annual temperature, and rainfall and evaporation data. The Turning Point was done when x_i is either greater than both preceding and succeeding values or less than both, this follows any conditions for a variate $x_{i-1}<x_i>x_{i+1}$ or $x_{i-1}>x_i<x_{i+1}$ gives a turning point while the Kendal's Rank Correlation test was done by picking the first value of the series x_i and comparing it with the rest of series and sum all the expected values.

3. RESULTS AND DISCUSSION

The results of the incremental /Reduction pattern were shown in the Table 1.

The discharge records of 1980 to 1990, 1991 to 2012 and 2002 to 2012 had the average annual flow (Dm) of 279 m^3/s as shown in Table 1. The average river flow (Di) of the year 1980 – 1990 decreased to 276 m^3/s showing a negative change with percentage river flow difference of -1.1%. Also, the average flow of the year 1991 - 2001 reduced to 278 m^3/s with a percentage flow difference of -0.36% showing a negative flow. The average river flow (Di) of the year 2002 - 2012 increased to 282 m^3/s showing a positive change with percentage river flow difference of 1.1%. In general, the total average river flow was 279 m^3/s and it decreases between the year 1980 and 1990 as well as the year 1991 -2000 while the year (2002 - 2012) have the average river flow more than the total average river flow. The study revealed that the year (2002 - 2012) has high River flow which causes flooding in the area.

Fig. 2 shows the variation of discharge over thirty – three years. The fluctuation of discharge began in the year 1983 and stabilized in the year 2000 while the increase in the fluctuation occurred between 2001 and 2012. On long term basis, the discharge had an increasing trend over the period. The study revealed that the trend of the discharge commenced from the year 2000 and above.

Apart from the annual discharge deviation, the Mann-Kendall test carried out on the monthly discharge records show that the month of September had a value of Zs equals -2.09 (greater than Z 0.025) which makes it statistically significant while the remaining months were insignificant because their Zs have less values (less than Z 0.025) as shown in the Fig. 3. This study denotes that the increase in discharge was highly noticeable in the month of September.

Between 1980 and 2012, the highest discharge (stream flow) was 615 m^3/s and it came in August. The minimum discharge equals Zero (0 m^3/s) and it occurred from October to December. Runs test carried out on the discharge records show that the month of September was significant with p-value of 0.05 which is equal to the alpha level 0.05 while the remaining months were insignificant as shown in Table 2.

Table 1. Increment/Reduction Pattern of Annual Discharge

Period	Di	Dm	Di-Dm	%Change
1980- 1990	276	279	-3	-1.1
1991- 2001	278	279	-1	-0.36
2002- 2012	282	279	3	1.1

Table 2. Statistics of discharge data

Month	Mean	Runs test
January	244.32	0.11
February	248.46	0.21
March	251.74	0.01
April	227.52	0.217
May	211.33	0.75
June	238.73	0.03
July	340.00	0.22
August	357.64	0.11
September	349.88	0.05
October	348.30	0.07
November	279.01	0.28
December	247.68	0.80

Table 3 shows the average river discharge (Dm) from incipient drying season to full wet period was estimated to be 279 m^3/s. It was observed from incipient drying season that the river discharge (Di) decreased to 250 m^3/s showing a negative change with Percentage River difference of -10.39% as shown in Table 3. The pattern of the river changed during raining season when the river discharge (Di) increased to 308 m/s^3 showing percentage river difference of 10.39%. Thus, the change in river discharge began from the month of July to October. The study revealed that the river swell up in the full wet season by 10 percent which causes flooding in the area.

The rainfall records of 1980 - 1990, 1991 - 2012 and 2002 - 2012 have the average rainfall (Rm) of 111.5 mm as shown in Table 4. The average rainfall (Ri) of the year (1980 – 1990) increased to 112 mm showing a positive change with percentage rainfall difference of 0.45%.This pattern changed from 1991-2001 by showing a negative rainfall and the average rainfall (Ri) reduced to 111mm with a percentage rainfall difference of -0.45%. The average rainfall (Ri) of the year (2002 -2 012) increased to 112 mm showing a positive change with percentage rainfall difference of 0.45%. The study shows that the decadal percentage value between 1980 and 1990 was equaled to that of 2002 - 2012 while that of 1991 - 2001 experienced reduction over the last ten (10) years. This implies that there was excessive rainfall in the year 1980 -1990 and 2002 - 2012 while the 1991 -2001 had less rainfall over ten (10) years.

The rainfall deviation increased in the year 1984, 1990, 1996 but declined in the year 2006 as shown in Fig. 4. In the year 2010, the rainfall fluctuated till 2012. The trend of rainfall increased after six years interval which shows that the rainfall records have increasing trends between 1980 and 2012. The study shows that the rainfall increased sporadically at interval of six years with increasing trend between 1980 and 2010.

Fig. 5 attested that the monthly rainfall record had values of Zs (less than Z0.025) with a positive and negative trend. It implies that the rainfall value was statistically insignificant on a long term basis. On annual basis, the rainfall records had increasing trend between 1980 and 2012. The trend of the rainfall record was significant on annual basis.

Runs test carried out on the rainfall records revealed that the months of June and September were significant with p-values of 0.03 and 0.04 were smaller than the alpha level 0.05 while the remaining months were insignificant as shown in Table 5. This implies that the month of June and September had excessive rainfall causes flooding annually in the area.

The average rainfall (Rm) from incipient drying season period to full wet period was 111.8 mm. It was observed from dry season that the rainfall decreased (Ri) to 11 mm showing a negative change with percentage rainfall difference of -90%. Concurrently, the pattern changed during raining season and the average rainfall (Ri) increased to 212.5 mm with percentage rainfall difference of 90% as shown in Table 6. The change in rainfall commenced from the month of May to October. This implies that the negative value had reduction while the positive had the increment. The study indicated that the rainfall reduced drastically in the drying season and increases during the full wet season.

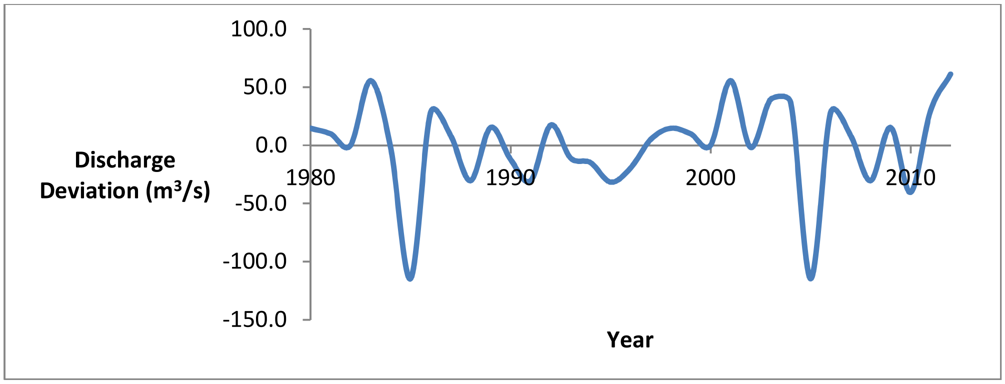

Fig. 2. Discharge deviation

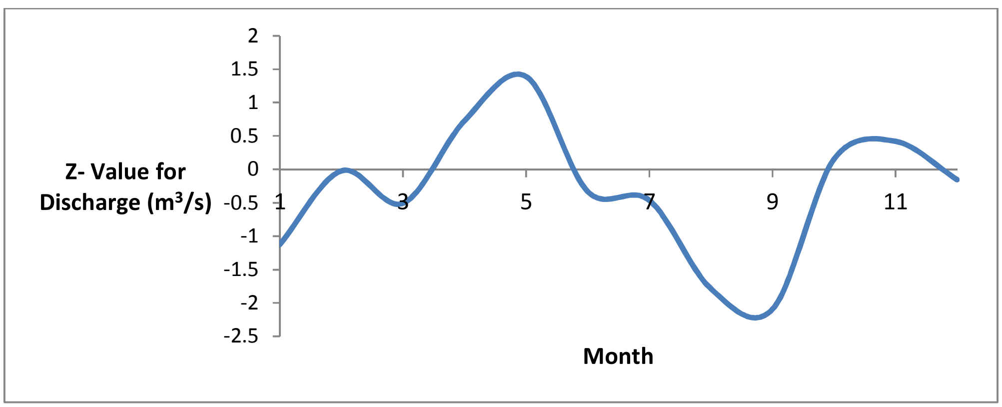

Fig. 3. Plot of Z-value using Mann-Kendall test

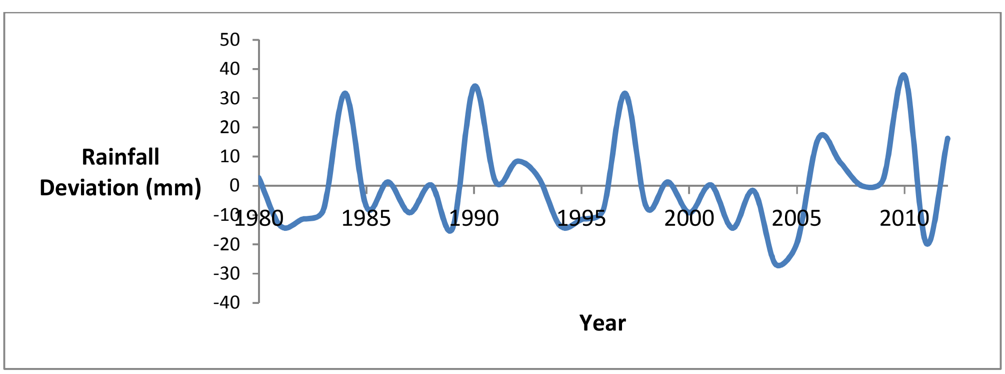

Fig. 4. Rainfall Deviation

The average temperature records of 1980 - 1990, 1991 - 2012 and 2002 - 2012 were shown in Table 7. The average temperature of the year (Ti) 1980 – 1990 equal to the entire average temperature (Tm) showing no change with zero (0) percentage temperature difference. The temperature of the year 1991-2001 decreased to 26°C showing a negative change with percentage temperature difference of -3.7%.The average temperature of 2002- 2012 increased to 28°C with a percentage temperature difference of 3.7 % showing a positive temperature. The study indicated that the temperature of the third decade (2002 -2012) was high compared with two other decades (1980 -1990) and (1991 – 2001).

Table 3. Increment/reduction pattern of mean discharge

Period	Di	Dm	Di-Dm	%Change
Incipient drying season	250	279	-29	-10.39%
Full wet season	308	279	29	10.39%

Table 4. Increment/reduction pattern of annual rainfall

Period	Ri	Rm	Ri-Rm	%Change
1980 - 1990	112	111.5	0.5	0.45%
1991 -2001	111	111.5	-0.5	-0.45%
2002 -2012	112	111.5	0.5	0.45%

Table 5. Statistics of rainfall data

Month	Mean	Runs test
January	0	*
February	0	*
March	4.39	0.72
April	61.46	0.78
May	127.26	0.29
June	185.79	0.03
July	259.18	0.5
August	275.94	0.07
September	300.23	0.04
October	127	0.37
November	0.32	0.28
December	0.03	0.79

Fig. 6 shows the temperature deviation between 1980 and 2012. The temperature deviation decreased between the year 1980 and 1983 and it also increased from 1984 to 1988. Temperature deviation decreased in the year 1989 and increased in the year from the 1995 to 1997. The temperature deviation reduced in the year 1999 to 2001 and it fluctuated from 2002 to 2012. Between 1980 and 2012, the study revealed that the temperature fall and rise.

Table 6. Increment/reduction pattern of mean rainfall

Period	Ri	Rm	Ri-Rm	%Change
Incipient drying season	11	111.8	-100.8	-90%
Full wet season	212.5	111.8	100.7	90%

Table 7. Increment/reduction pattern of annual temperature

Period	Ti	Tm	Ti-Tm	%Change
1980 - 1990	27	27	0	0%
1991 -2001	26	27	-1	-3.70%
2002 -2012	28	27	1	3.70%

The results of Mann-Kendall test show that February and October had values of Zs equal to-2.2 (greater than Z0.025) which made it statistically significant as presented in Fig. 7 while the remaining months were insignificant because their Zs have less Zs values (less than Z0.025) with positive and negative natures. This shows that temperature has significant trend in the month of February and October.

The maximum temperature between the year 1980 and 2012 was 33°C and it took place in April and June. The minimum temperature was 18°C and it occurred in January and December. Runs test carried out on the rainfall records revealed that the month of March, April and August were significant with p-values of 0.05, 0.01 and 0.01 which were equal to and smaller than the alpha level 0.05 while the remaining months were insignificant as shown in Table 8.

The average temperature (Tm) from incipient drying season period to wet period was 26.9°C. It was observed in the dry season that the temperature increased to 27°C with percentage temperature difference of 0.37%. The temperature of raining period reduced (Ti) to 26.8°C showing a negative change with percentage temperature of 0.37°C as shown in Table 9. The temperature records of the area reduced drastically in the raining season. The study shows that the temperature of the full wet season experienced negative trend pattern.

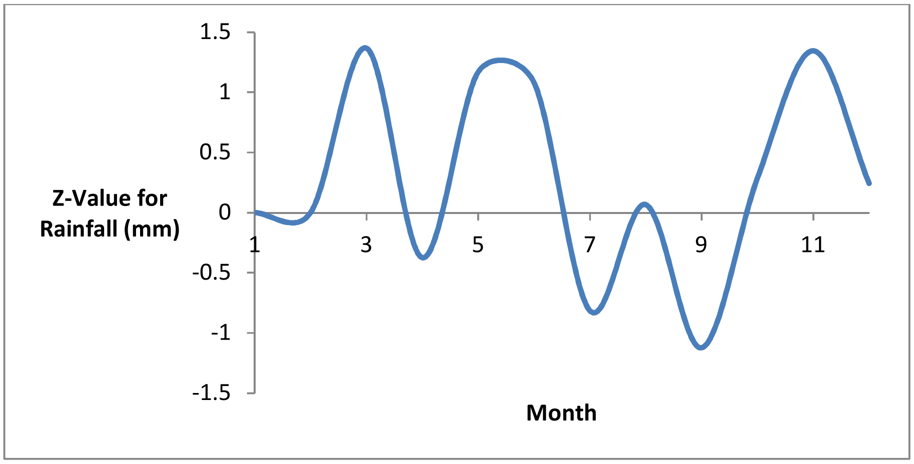

Fig. 5. Plot of Z-value using Mann-Kendall test

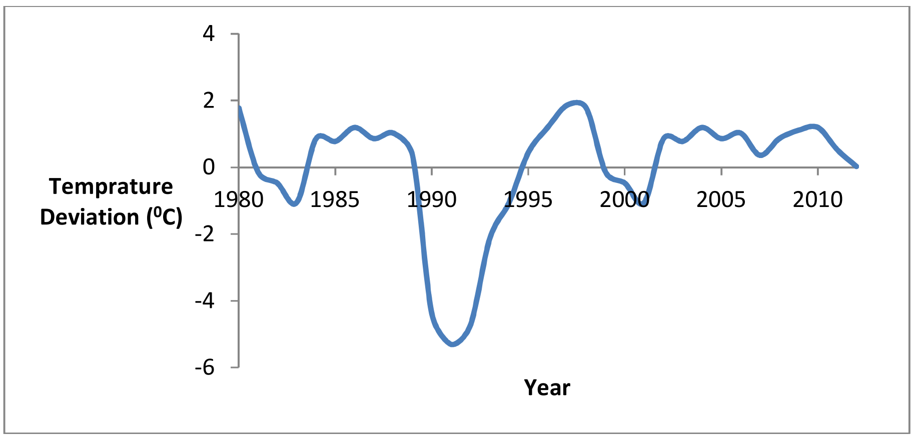

Fig. 6. Temperature deviation

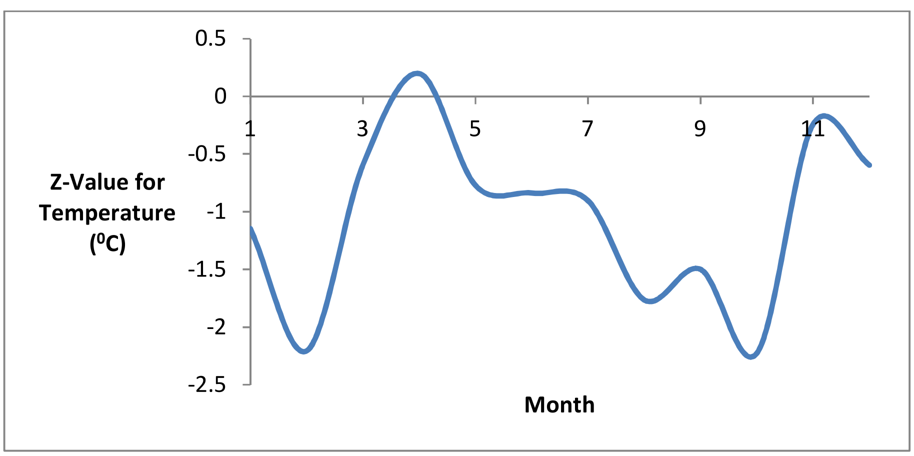

Fig. 7. Plot of Z-value using Mann-Kendall test

The average evaporation (Em) records of 1980 - 1990, 1991 - 2012 and 2002 - 2012 was 11.0 mm/day as shown in Table 10. The evaporation values (Ei) of 1980 – 1990 increased to 11.1 mm/day with percentage evaporation difference of 0.9%. Also, the evaporation values (Ei) increased in the 1991-2001 to 12 mm/day with percentage evaporation difference of 9.1%. The evaporation values (Ei) of 2002-2012 decreased to 10 mm/day showing a negative change with percentage evaporation difference of -9.1%. This indicated that the evaporation value between 1980 and 1990 was less than that of 1991 – 2001 and 2002 - 2012 respectively. In the area, the evaporation pattern changed in the year 2001 and decreased in the year 2012.

Table 8. Statistics of temperature data

Month	Mean	Runs test
January	24.27	0.75
February	26.09	0.37
March	29.09	0.05
April	30.21	0.01
May	28.82	0.69
June	27.61	0.59
July	26.3	0.51
August	25.45	0.01
September	25.94	0.16
October	26.76	0.06
November	26.97	0.79
December	25.15	0.22

Table 9. Increment/reduction pattern of mean temperature

Period	Ti	Tm	Ti-Tm	%Change
Incipient drying season	27	26.9	0.1	0.37%
Full wet season	26.8	26.9	-0.1	-0.37%

Table 10. Increment/reduction pattern of annual evaporation

Period	Ei	Em	Ei-Em	%Change
1980 -1990	11.1	11	0.1	0.90%
1991 -2001	12	11	1	9.10%
2002 -2012	10	11	-1	-9.10%

Fig. 8 shows that the evaporation deviation decreased in 1980, 1981, 1987, 1991, 1992, 1993, 1994 till 2012 and increased in 1986, 1990, 1995, 1998, 2000, 2006 and 2010 respectively. The records of evaporation exhibits decreasing trend from the year 1990. This implies that the evaporation deviation fluctuated throughout the years.

The results of Mann-Kendall test shows that the month of October had a value of Zs equal to 2.2 (greater than Z0.025) which makes it statistically significant as presented in Fig. 9 while the remaining months were insignificant because their Zs have less Zs values (less than Z0.025) with positive and negative natures. Over the 30 years, the evaporation records had significant trend with positive nature in the month of October.

The highest evaporation was 25.21 mm/day between 1980 and 2012 and it occurred in the month of February. The minimum evaporation was 3.1 mm/day and it occurred in the month of June. Runs test carried out on the evaporation records revealed that the month of May, November and December were highly significant with p-values of 0.05, 0.04 and 0.009 were equaled and smaller than the alpha level 0.05 while the remaining months were insignificant as shown in Table 11.

Table 11. Statistics of evaporation data

Month	Mean	Runs test
January	16.62	0.63
February	16.67	0.92
March	14.82	0.19
April	10.03	0.78
May	6.84	0.05
June	5.08	0.55
July	4.37	0.59
August	5.61	0.22
September	10.03	0.39
October	10.5	0.21
November	14.45	0.04
December	16.82	0.009

The average mean evaporation (Em) for incipient drying and full wet season was 11 mm/day. It was observed from dry season that the evaporation increased to 14.9 mm/day with percentage evaporation difference of 35.5%. The evaporation values of the raining period decreased (Ei) to 7.1 mm/day showing a negative change with percentage evaporation of 35.5%. The study shows that the evaporation value was high during the drying season than the full wet season as shown in Table 12.

Table 12. Increment/reduction pattern of mean evaporation

Period	Ei	Em	Ei-Em	%Change
Incipient drying season	14.9	11	3.9	35.50%
Full wet season	7.1	11	-3.9	35.50%

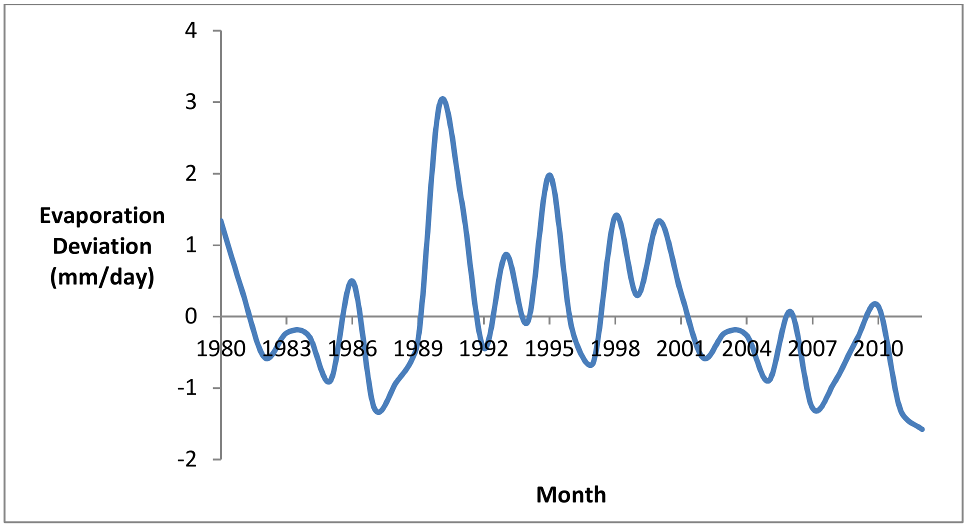

Fig. 8. Evaporation deviation

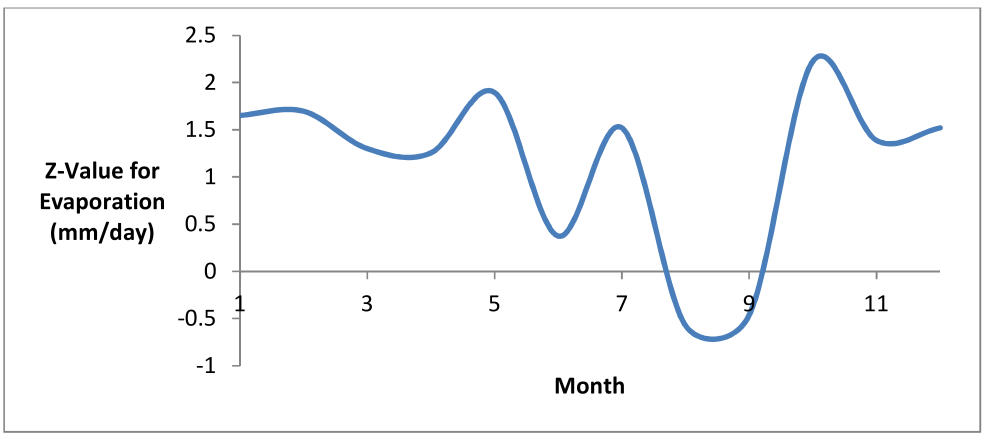

Fig. 9. Plot of Z-value using Mann-Kendall test

Table 13. Turning point and Kendall's rank correlation tests

Variable	Turning point test (Z)	Kendall's rank correlation	Variance (T)	Z (T)	Interpretation
Stream flow	5.3	-0.68	0.032	-3.8	Negative Trend
Rainfall	5.3	-0.65	0.033	-3.57	Negative Trend
Temperature	2.31	-0.65	0.033	-3.57	Negative Trend
Evaporation	4.8	-0.065	0.033	-3.57	Negative Trend

The parametric test conducted on the hydro meteorological data was shown in the Table 13. The yearly historical rainfall, temperature and evaporation were significant when compared with Z= ± 1.96 and these variables have negative trend. This means that an increase in temperature, evaporation and relative humidity in the dry season reduced hydrologic response of the river. In the raining season, river exhibits high hydrologic response because the temperature and evaporation records have fewer values.

4. CONCLUSIONS

Globally, climate change caused increased heavy rainfall, high temperature and evaporation that required effective planning of water resources so as to estimate the trend pattern of the hydro meteorological records. In view of this, the study assessed the trend pattern of stream flow, rainfall, temperature and evaporation in River Kaduna. The study established that there was a slight difference in the historical rainfall records since there was a change in percentage rainfall difference. The total annual discharge was 11, 0372.3 m^3/s. The difference between the year 1980 - 1990 and 1991 - 2001 had a slight increase (262 m^3/s) while that of 1980 - 1990 and 1991 – 2012 had high difference value of 734.1 m^3/s. This implies that the excess runoff accrued on the hydrologic response was not only responsible for the discharge from the river but also for the whole catchment area. The study revealed that the difference in rainfall amount between 1980 - 1990 and 1991 - 2001 was 116 mm which showed a slight difference within the year. Also, the difference in rainfall amount between 1980 -1990 and 1991 – 2012 was 14, 619 mm. This implies that there are lots of climate change activities in the whole catchment area. The total evaporation data within thirty three (33) was 4343 mm/day. The difference in evaporation amount between 1980 - 1990 and 1991 – 2001 was 81 mm/day; this implies that there exists slight evaporation within the catchment area. Also, the difference in evaporation amount between 1980 – 1990 and 1991 - 2012 was 709 mm/day. This implies that there are climate change activities around the hydrologic response of the area. Thus, the study confirmed that the increase in temperature causes more intense evaporation via relative humidity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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