ASSESSMENT OF TREND AND DETECTION OF MUTATION OF RAINFALL OVER SOKOTO - RIMA RIVER BASIN, NIGERIA

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Abstract

Time-based characteristics of hydro meteorological processes are of great significance in the planning, designing and operation of water systems. In view of this, attempt was made to assess general trend characteristics and change point (mutation) of rainfall over the Sokoto -Rima River Basin, in Nigeria. Investigations were carried out by using rainfall data from selected gauging stations across the basin; Three statistical tests: (i) Pettit's Test, (ii) Robust Mann-Kendall Test, and (iii) Sequential Mann–Kendall test (SQ-MK test) were employed for the analysis. The results obtained indicated that few stations showed insignificant trends in annual and seasonal series. However, Pettit's' test showed that 100% of the station exhibited significant trend. Mann- Kendall test on annual rainfall series for some stations showed a mixture of varying contrast in negative and positive trend; for instance, Katsina, Gusau and Sokoto showed increasing positive trend (48.86% of the stations) while for Goronyo, there were indications of decreasing trend (14.28% of the stations). On the other hand, Jibiya, Bakalori and Zobe do not indicate discernible trend pattern. Generally, the seasonal Mann-Kendall revealed that the sum percentage of the negative significant trend far outweighed that of the positive trend at the ratio of 4:1 while for SQ- MK, it is of 11:1; i.e., ratio of significant negative trend to positive significant trend. The consequence is that for every 1% increase in rainfall amount, there is a 4% or 11% decrease in trend signature. The results showed that most of the significant mutation points began in 1990s. Considering the results obtained, there is need to examine other hydrometeorology variables in addition to rainfall in order to have a thorough understanding of the time-space dependent behaviour of the hydro-meteorological processes and their correlating aggregate effects. It is pertinent therefore that several statistical approaches should be used to capture trend and mutations; as one approach may not truly give a snapshot of hydrological variability in a particular basin; for the purposes of drawing effective conclusions.

Keywords: Stochastic, rainfall, mutation, trend, variability, climate change

1. Introduction

In recent years, rainfall variability is now accepted as a serious environmental issue because it is a threat to sustainable development and food security (Olaniran, 1999). As reported by Hulum (2001), rainfall variability is a major characteristic of the Sokoto Rima Basin climate; to be precise, the last 40 years (since 1969) have witnessed dramatic changes in terms of mean annual rainfall throughout the region. Rainfall is a complex atmospheric processes, which is space and time dependent and basically not easily predictable (Lu *et al*.,2004). In this regard, the assessment of the dynamics and regime of a particular hydrological phenomenon such as rainfall is imperative; especially the time-based characteristics (Otache *et al*., 2011).Against this backdrop therefore, as noted by Kottegode (1990), the lack of complete understanding of the physical processes involved and the consequent uncertainties in the magnitudes and frequencies of future events highlight the importance of time series analysis. Within this general context, assessment of trend and change point detection of time series can enhance our understanding of the underlying hydrometeorological dynamics of these process, especially in a changing climate.

Generally, trend is a steady and regular movement in a time series through which the values are, on average, either increasing or decreasing (Otache *et al*., 2011).This type of behaviour can be local, in which case the nature of the trend is subject to change over short intervals of time, or, on the other hand, a global trend that is long lasting. In contrast to long-term trends usually appropriate for steady growth in economics, if a trend in a hydrological time series appears, it is, in effect, part of a low-frequency oscillatory movement induced by climatic factors or through changes in land use and catchment characteristics (Otache *et al*., 2011).Over the years there have different methods (e.g. Robust Mann-Kendall, Sen's slope estimator, Turning point, etc) have been employed for trend analysis with their associated attributes. On the other hand, statistical change point (Mutation) detection have been done by using, for instance, the Pettit's Test, a nonparametric test, is useful for evaluating the occurrence of abrupt changes in climatic records (Sneyers, 1990). One of the attribute of this test is that it is more sensitive to breaks in the middle of the time series (Wijngaard *et al.,*2003). In addition, others like the Sequential Mann-Kendall (SQ-MK) can also be used. It has the power to indicate the beginning and ending of trend, and its intensity, respectively.

It suffices to note that quantitative estimation of the temporal characteristics of rainfall and perhaps its modelling are important considering the fact that it is a critical weather parameter in the estimation of crop water requirement, and development of long lead time flood and flash -

flood warning systems. However, it is interesting to note that despite substantial progress, several issues still remained unresolved. For instance, the best appropriate approach to be adopted in evaluating trend analysis and statistical change point (Rammana *et al.,* 1980) Most of the researches focused on singular approach to quantify hydrological time series variability which could be misleading in terms of accuracy and prediction. For example (Boroujerdy, 2008) used Mann–Kendall test to define trend in annual and seasonal precipitation for the period 1960–2001, (Modarres *et al*., 2017) analysed the time series of annual rainfall, number of rainy-days per year and monthly rainfall of 20 stations using the Mann–Kendall test to assess climate variability in the arid and semi-arid regions of Iran and Hess *et al*., (1995), examined trends in the dates of onset, termination and duration of the rainy season in north-eastern Nigeria based on the standard climatic normal periods using Sequential Mann-Kendall test; the findings are different to some degrees and interpretations. Therefore, it is important to note that single approach may not give exact snapshot of hydrologic variability signatures of a given basin. Considering this therefore, the central thesis of this paper is the evaluation of the effects of different approaches in trend and mutation or statistical change point (SCP) analysis.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Study Location and Data Assembly

The study location is Sokoto-Rima Basin; it is located between 10^{o}N - 14^{o}N and 4^{o}E - 9^{o}5$^'$E. It belongs to the semi-arid region of the country, precisely of a predominantly Sudan vegetation. It is characterised by a distinct bi-seasonal weather pattern; i.e., wet and dry. The wet season starts in April and ends in October, while the dry season starts in November and ends in March (Sombroek *et al.,* 1971). **Figure 1** shows the map of Sokoto-Rima Basin. For this study, historical rainfall time series of the Basin was used. To do this, mean monthly rain gauge rainfall values (i.e., point rainfall) for substantial decadal time period were collected from NIMET and Sokoto- Rima River Basin Development Authority Zonal offices across the catchment States of Katsina, Zamfara, Sokoto and Kebbi, respectively. (i.e., the gauging stations of Katsina, Sokoto, Zobe, Goronyo, Gusau Jibiya and Bakalori, respectively). The available data for the seven gauging stations were for these respective periods: Bakalori (1953 - 1970), Goronyo (1961 - 2015), Gusau (1953 - 2010), Katsina (1931 -2011), Sokoto (1910 -2015), Zobe (1950 - 1975). and Jibiya (1950 - 1968).The segmentation was based on the available time series, which was unequal in length. Therefore, it is important to note, that the objective here is to bring to fore significant variability in hydrometeorological phenomenon in the basin not inter- stationary comparison, that is often based on equal assessment parameters or dimensions**.**

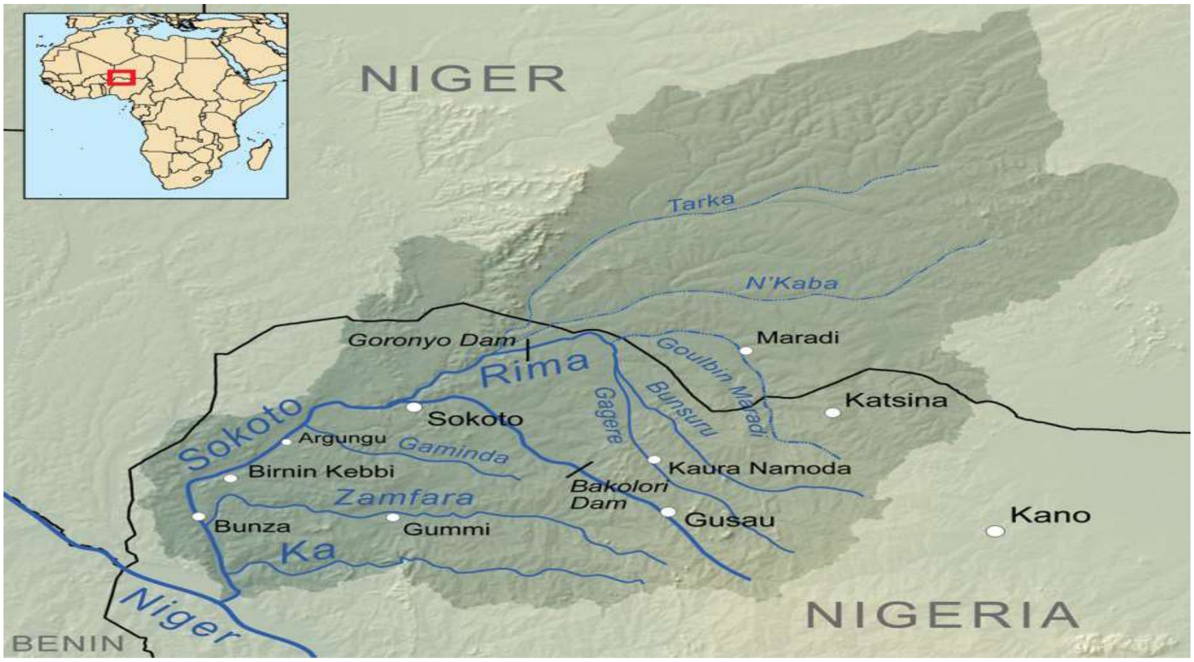


Figure 1: Map of Sokoto Rima River Basin.
Source: (Danmagaji, 2017)

2.2. Methodology

(a) General Trend Analysis

In this regard, Time series plot was examined to establish whether it does exhibit intermittency or otherwise as well as seasonal characteristics like trends. Three statistical techniques were used for the study: (i) Pettit's Test, (ii) SQ-MK Test and (iii) MK Test. To examine the time series appropriately, the data for each station was divided within a given range in order to give a snapshot of the variability, especially with respect to climate change implications.

(i) Mann-Kendall Test

The Mann-Kendall test was implemented for both annual and monthly rainfall series. To do this, the annual time series was pre-processed via a pre-whitening strategy Wang (2006), as in equation (1).

$$m_i = x_i - \phi x_{i-1} \quad (1)$$

where, m_i is the pre-whiten series value, x_i is the original series value, and ϕ is the estimated lag 1 serial correlation. The entire Mann-Kendall approach was done by evaluating the following test statistics as in equations (2 - 4).

$$S = \sum_{i=1}^{N-1} \sum_{k=i+1}^{N} \operatorname{sgn}(x_k - x_i) \quad (2)$$

where

$$\operatorname{sgn}(x) = \begin{cases} +1 & x > 0 \\ 0 & x = 0 \\ -1 & x < 0 \end{cases}$$

$$\tau = \frac{2S}{N(N-1)} \qquad (3)$$

and

$$\sigma_s^2 = \frac{1}{18}\left[\begin{matrix} N(N-1)(2N+5) - \\ \sum_{i=1}^{m} p_i(p_i-1)(2p_i+5) \end{matrix}\right] \qquad (4)$$

Where, m is the number of tied groups in the data set and p_i, the number of data points in the i^{th} tied group. Similarly too, under the null hypothesis, the quantity z is taken to be standard normally distributed. Based on this,

$$z' = \begin{cases} \left(S' - 1\right)/\sigma_{s'} & S' > 0 \\ 0 & S' = 0 \\ \left(S' + 1\right)/\sigma_{s'} & S' < 0 \end{cases} \qquad (5)$$

Though the tradition most often times is to use annual time series for trend analysis, it is necessary to examine what is happening at lower time scale; here at a monthly temporal scale. The essence is to be able to critically bring to fore probable changes at this level due to the implications of seasonality. Thus, the seasonal Mann-Kendall test was employed. The implementation of this approach is according as in equations (6-11).

Monthly rainfall series was represented by the matrix

$$\mathbf{X} = \begin{pmatrix} x_{11} & \cdots & x_{1p} \\ \vdots & \ddots & \vdots \\ x_{n1} & \cdots & x_{np} \end{pmatrix} \qquad (6)$$

Here, p is the number of seasons for n years under consideration.

$$\mathbf{R} = \begin{pmatrix} R_{11} & R_{12} \cdots & R_{1p} \\ R_{21} & R_{22} \cdots & R_{2p} \\ \vdots & \vdots & \vdots \\ R_{n1} & R_{n2} \cdots & R_{np} \end{pmatrix}, \qquad (7)$$

Equation (7) denotes the ranks corresponding to the observations in x where the n observations for each season are ranked among themselves. Thus each column of **R** is a permutation of (1, 2, . . ., n); specifically, the rank matrix $\mathbf{R_{ij}}$ was computed as

$$R_{ij} = \frac{1}{2}\left[n + 1 + \sum_{k=1}^{n} \operatorname{sgn}\left(x_{ij} - x_{kj} \right) \right] \qquad (8)$$

The Mann-Kendall test statistic (z) for each season was computed by employing equations (9 - 11); i.e, based on (6 and 8).

$$S_i = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_{ji} - x_{ki} \right) \qquad (9)$$

where, n is water year, i = number of seasons (12) and a season is defined as one calendar month, and S_i is the S-statistic in the MK test for season i (i = 1, 2, …, 12)

$$S' = \sum_{i=1}^{p} S_i \text{ , p = seasons; } \sigma^2_{s'} = \sum_{i=1}^{p} Var\left(S_i \right) \qquad (10)$$

In the presence of serial correlation, as in the monthly rainfall series, the variance of S'
is defined as

$$\sigma^2_{s'} = \sum_{i=1}^{p} Var\left(S_i \right) + \sum_{g=1}^{p-1} \sum_{h=g+1}^{p} \sigma_{gh} \qquad (11)$$

where, the covariance matrix σ_{gh} is expressed according as equation (12- 13)

$$\hat{\sigma}_{gh} = \frac{1}{3}\left[K_{gh} + 4\sum_{i=1}^{n} R_{ig} R_{ih} - n\left(n+1 \right)^2 \right] \qquad (12)$$

$$K_{gh} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left[\left(x_{jg} - x_{ig} \right)\left(x_{jh} - x_{ih} \right) \right] \qquad (13)$$

This is for a ***no missing data*** situation, and g and h are different seasons respectively with the test statistic z' which is standard normally distributed, and evaluated as in equation (14).

$$z' = \begin{cases} \left(S' - 1 \right) / \sigma_{s'} & S' > 0 \\ 0 & S' = 0 \\ \left(S' + 1 \right) / \sigma_{s'} & S' < 0 \end{cases} \qquad (14)$$

(b) Detection of Statistical Change Point (Mutation)

The detection of Statistical Change Point in the probable trend of the rainfall series was done by employing: (i) Pettit's and Sequential Mann- Kendall (SQ-MK) tests as in equations (14 - 15)

i. Pettit's Test

The Pettit's test for change point detection was implemented by following the steps according as:

1. Compute U_k statistic by using the formula

$$U_k = 2\sum_{i=0}^{n} m_i - k(n+1) \qquad (15)$$

where,

m_i is the rank of the i^{th} observation when the values $x_1, x_2, \ldots, x_n$ in the series are arranged in ascending order and k takes values from 1, 2, ..., n.

2. Define the Statistical Change Point test (SCP) as follows:

$$K = \max|U_K| \qquad (16)$$

where, $1 \le k \le n$

when U_k attains maximum value of K in a series, then a change point will occur in the series. The critical value according Zarenistanank *et al.* (2014), as reported in Danmagaji (2017), is

$$K_\alpha = \left[-\frac{\text{In}\alpha(n^3+n^2)}{6}\right]^{\frac{1}{2}} \qquad (17)$$

where, n is the number of observations and α is the level of significance which determines the critical value. For this study, α = 0.05 was adopted; that is 95% significance level.

ii. Sequential Mann–Kendall (SQ - MK) Test

The Sequential Mann- Kendall (SQ-Mk) test as proposed by Sneyers (1990),was employed based on the following steps, viz:-

1. The magnitudes of x_j annual series (j=1, 2, . . ., n) were compared with x_k,(k=1, . . .,j-1).
2. At each comparison, the number of cases $x_j > x_k$ shall be counted and denoted by n_j.
3. The test statistic t was computed according as

$$t_j = \sum_{1}^{j} n_j \qquad (18)$$

4. The mean and variance of the statistic:

$$e(t_j) = j(j-1)/4 \qquad (19)$$

and

$$\text{Var}\, t_j = \frac{j(j-1)(2j+5)}{72} \qquad (20)$$

5. The sequential values of statistic U was then calculated as

$$U(t_j) = \frac{t_i - e(t)}{[Var(t_j)]^{\frac{1}{2}}} \qquad (21)$$

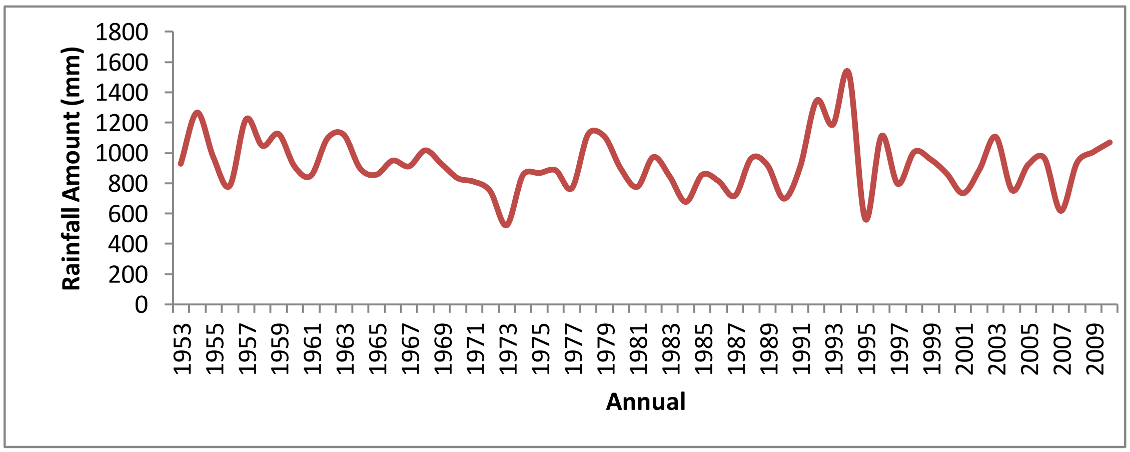
6. Similarly, the values of u' (t), the retrograde was computed backward, starting from the end of series. The approaches were applied to annual rainfall series for the selected gauging stations.

3. Results and Discussion

3.1 General stochastic characteristics of the rainfall series

Hydrologic processes such as rainfall evolve on continuous time scale. The implication(s) of this is simple; as shown by **Figure 2**, the rainfall time series for selected stations exhibit typical stochastic or random characteristics. This phenomenon translates into statistical characteristics which vary within an annual cycle. **Figure 2** shows clearly a discernible random nature of the rainfall; precisely periodic over an annual cycle.

(a)



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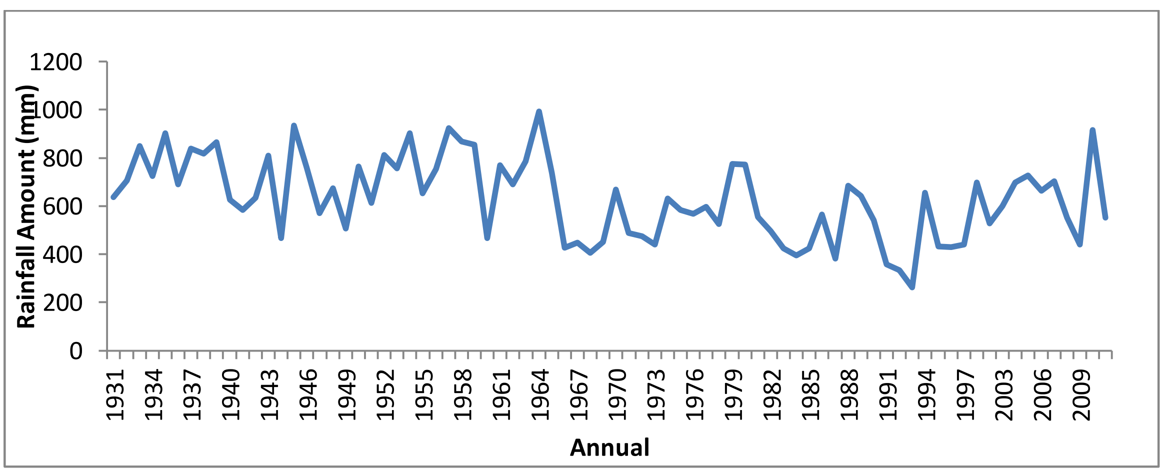

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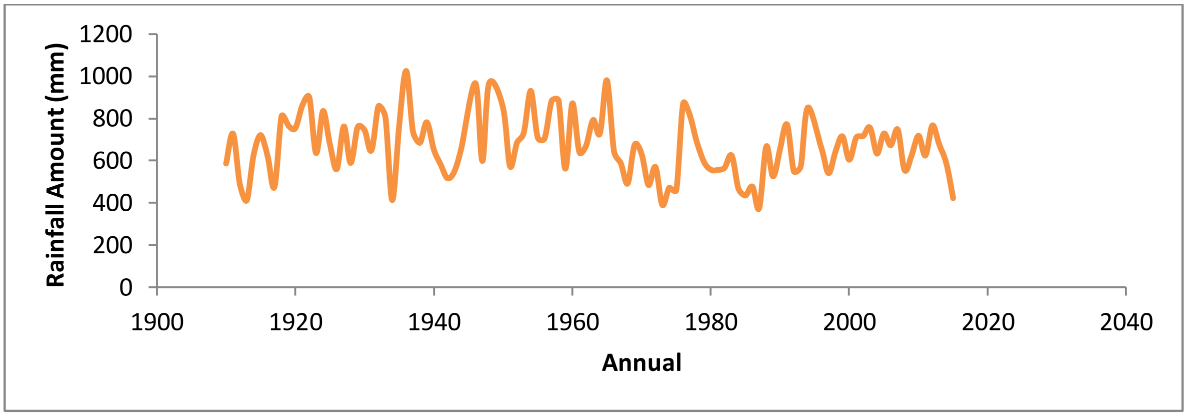


Figure 2: Annual rainfall hydrograph for selected stations (a) Gusau (b) Katsina (c) Sokoto

1. Statistics of Rainfall over the Basin

Table 1 shows the values of moment statistics for annual series. The values indicate significant dispersion or deviation from normality though over the entire basin, on the average, the characteristics of Table 1 portend a probable contiguous transition, especially values of the Skewness coefficient

Table 1: Stochastic Characteristic of the Basin

Stations	Means	Standard Deviation	Skewness
Katsina	629.84	168.5	-0.293
Sokoto	668.78	141.035	0.20
Gusau	926.04	**180.93**	0.586
Jibyia	719.27	174.47	-0.04
Bakalori	771.529	168.478	-0.31683
Zobe	837.87	**186.36**	-0.626
Goronyo	60.68	122.70	-0.44

Figure 3 below shows periodic nature of the rainfall series. As is usually typical of monthly time series, the extent of persistence is not strong though serial dependence decreases with temporal lag; the lack of strong dependence in the autocorrelation structure connotes a seeming short-term memory. Perhaps, this could be explained against the backdrop of heteroscedasticity, a form of volatility; it is imperative to state that this phenomenon may suggest that rainfall series cannot be treated as purely stochastic but with traces of nonlinear determinism at best.

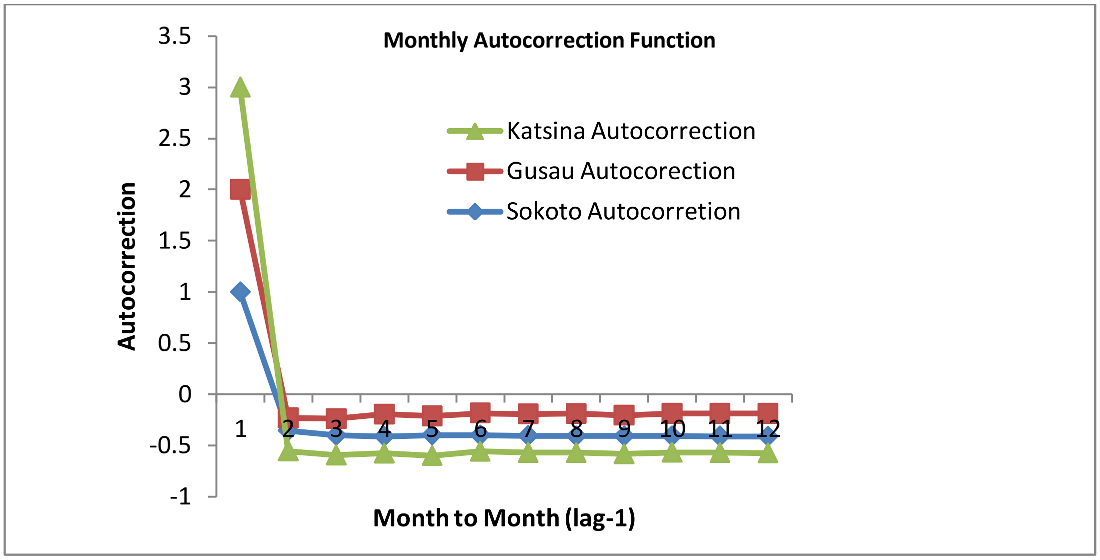


Figure 3: Monthly autocorrelation function for selected stations in the basin

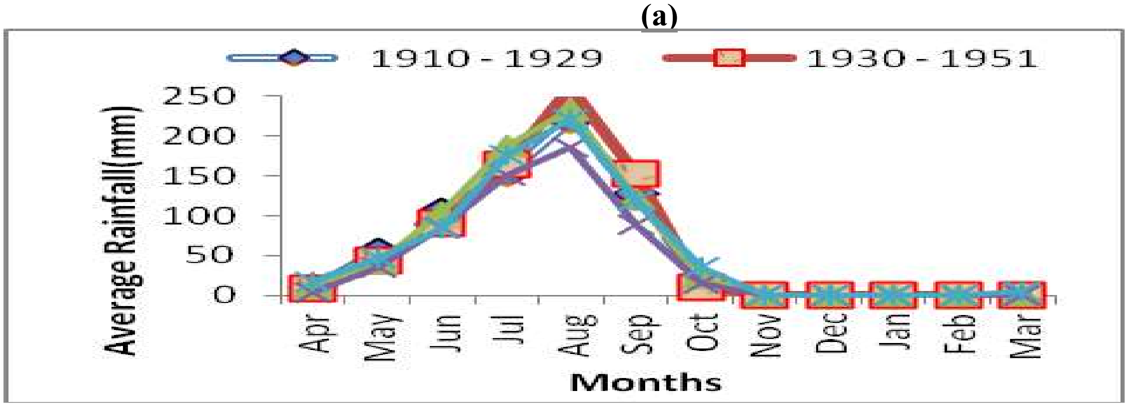
3.2 Trend Analysis

I. Annual trend behaviour

a) Inter-annual Rainfall Variation

Figure 4 shows inter-annual variation in the rainfall series. From the figure, inter-annual variability is copiously discernible in all the stations; in all instances, the trend pattern is characterised by sharp rises and sudden recession in the hydrographs with uni-modal peaks. From figure, the segmentation was based on the available time series, which was unequal in length. Therefore, it is important to note, that the objective here is to bring to fore significant variability in hydrometeorological phenomenon in the basin not inter- stationary comparison, that is often based on equal assessment parameters or dimensions .

(a)



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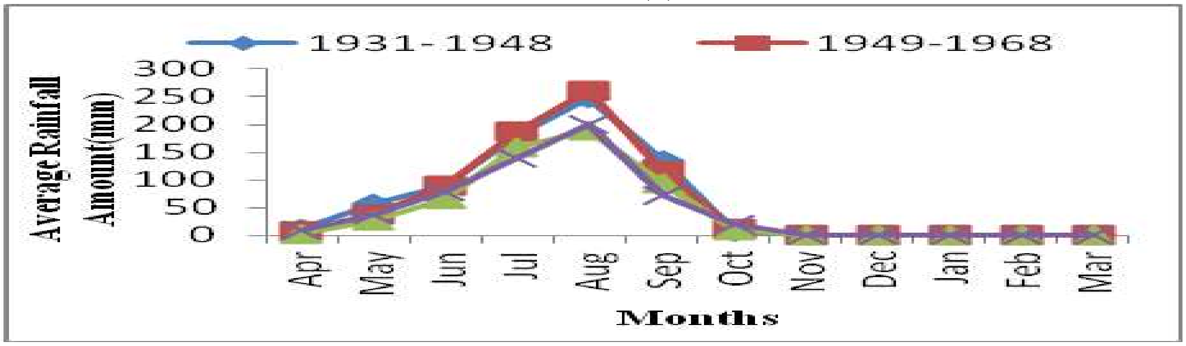

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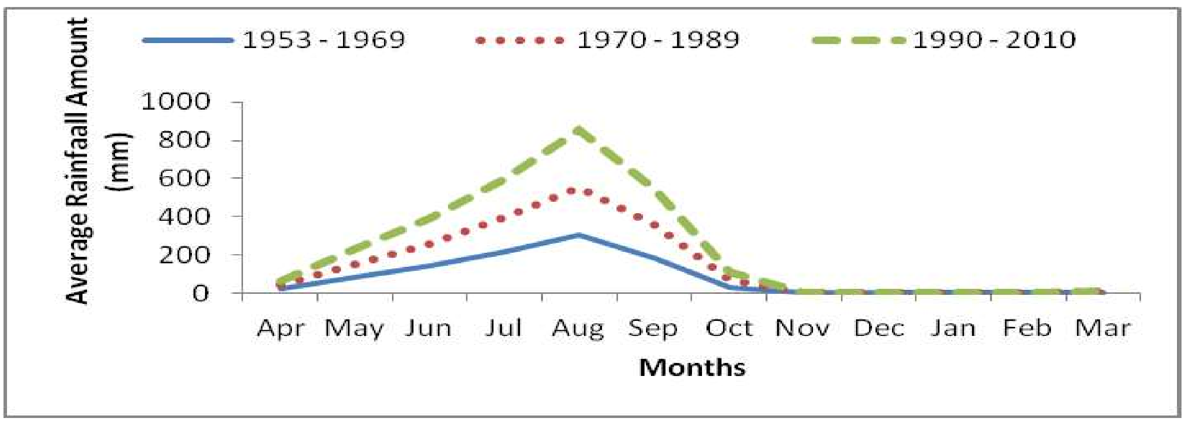


Figure 4:Inter-annual mean monthly rainfall variation pattern for selected stations (a) Sokoto (b) Katsina and (c) Gusau

II. Seasonal Mann-Kendall Trend Test

The Mann-Kendall test results as shown below in **Table 2**, indicate that at 5% level of significance, i.e., ± 1.96, the computed value of the test statistic z, (i.e., two-tailed) for monthly rainfall for each stations is not within the range of ± 1.96 except Bakalori and Jibiyia. Notable of interest, Katsina experienced significant decrease in rainfall at the peak of raining season with the most severe months being September, May and August, with respective Z statistic of **-22.28, -13.11** and **-11.9**. The total decreasing trend value amounts to **41.7%** of the total months of the water year. Similarly, **Sokoto** exhibited significant decreasing trend throughout the period of the raining season, with the most acute month being May amounting to **-25.87** of Z-statistic value. In Sokoto station about **41.7%** of total months of the water year suffered deceasing trend and **8.3%** experienced increasing positive trend. On the other hand, **Gusau** also experience a similar pattern with the months of April, July September, November, January, February and March constituting **58.3%** and **8.3%** of positive and negative trends respectively for the period under discourse.

Goronyo experienced positive trend at the months of September and October indicating significant positive change in the behaviour in the rainfall pattern; obviously skewed towards the end of the year with **25%** positive trend and **8.3%** negative trend. **Zobe** station on the other hand, showed negative trend at the month of October, which is normal because there is often decreases in the amount of rainfall towards later part of the year; the negative trend accounts for **8.3%**. **Jibiyia** and **Bakalori** showed a contrasting situation; there is no significant change in the rainfall. Out of seven stations considered, 71% of the stations exhibit negative trend, 42% positive trend and 28%, no significant trend at all. **Table 3** shows Mann- Kendall test results for annual series; the results depict an admixture of trend regime based on the Z statistic. The variability in both the seasonal and annual trend pattern derives directly from the deleterious implications of climate change.

Table 2: Seasonal Mann-Kendall Trend Test

					Z							
Months	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Station												
Katsina	0.33	**-13.1**	-1.8	**-9.7**	**-12**	**-22.3**	-1.1	**-2.2**	0.0	-0.4	-1.9	0.9
Bakalori	0.13	-0.8	-0.4	0.02	-0.5	-0.6	-0.0	0.0	0.0	0.0	-0.2	0.2
Sokoto	**-7.6**	**-25.9**	**-8.8**	**9.5**	**-15.**	**-12.5**	**12.5**	0.7	0.0	-0.6	1.2	-1.0
Goronyo	**2.2**	**-2.8**	1.08	1.87	1.21	**4.6**	**4.7**	0.0	0.0	0.0	-0.2	-0.5
Zobe	0.3	0.2	-0.1	-1.1	0.0	-1.4	**-2.6**	0.13	0.0	-0.13	0.0	0.0
Gusau	**-2.5**	-0.82	-0.4	**-2.7**	0.1	**-3.6**	**2.9**	**-2.0**	0.0	**-3.0**	**-4.7**	**-4.7**
Jibiyia	-0.1	-0.1	0.4	0.7	-0.3	-1.5	-0.71	0.0	0.0	0.0	-0.1	0.0

Table 3: Mann-Kendall Tests on annual rainfall series

Stations	Statistics		
	τ	z	S
Katsina	0.2434	**16.0903**	731.00
Jibyia	0.3333	0.7494	35.00
Goronyo	-0.1039	**-1.6752**	-77.00
Sokoto	0.1148	**13.2690**	603.00
Gusau	0.0926	**3.3503**	153.00
Zobe	0.3247	1.6311	75.00
Bakalori	0.3676	1.0800	50.00

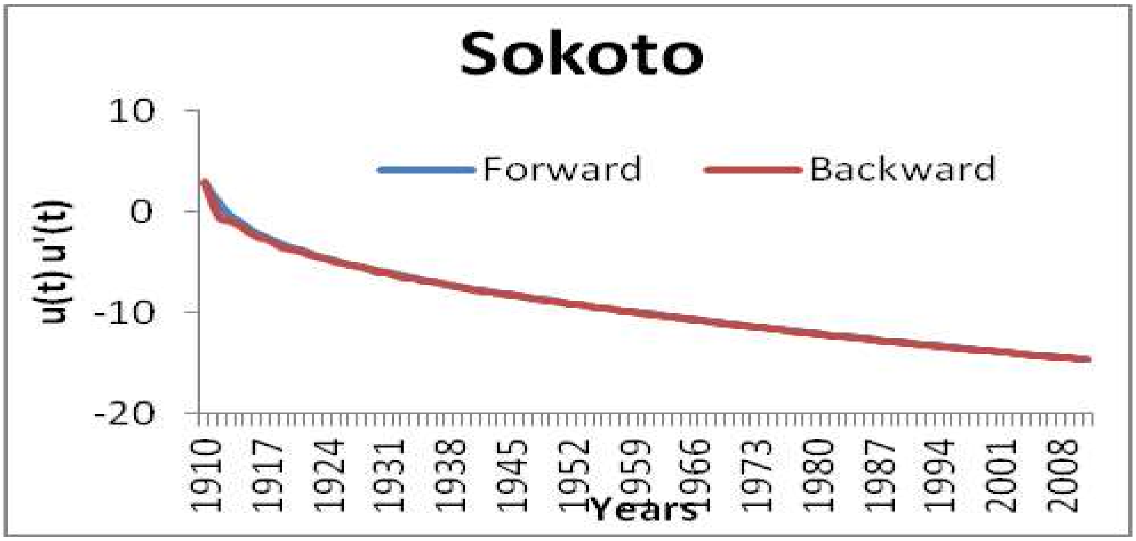
3.3 Detection of Statistical Change Point (SCP)

I. Pettit's Test

Pettit's test was applied to detect statistical change point of annual seasonal trend in the basin. The results revealed the existence of significant change point in all the stations with 100% in the stations.

II. Sequential Mann- Kendall Test

The results obtained by applying SQ-MK test to annual rainfall series are as shown in **Figure 5**. For instance, **Zobe** has a mutation point at 1954 which amounts to 5.9% of the total years observed; precisely, 1955 to 1971 exhibited downward trend which accounts for 94.1% of the mutation period while 1953 specifically showed upward positive trend corresponding to 5.9% of the observation time period. **Bakalori** has several mutation points; i.e., 1954, 1955, 1957, 1960, 1962 and 1963. This amounts to 27.27%. **Jibyia** experienced mutations in 1951, 1955, 1956, 1957, 1958, which accounts for 33.3% of the mutation period while **Sokoto** had mutation in 1913 which led to 0.9% of the total number of years observed and downward trend of 97.1% and positive trend of 2.91% of the total year, **Katsina** has no mutation point and **Goronyo** experienced mutation in 1963,1962,1963,1965 and 1963 amounting to 13.15% of the total number of years observed. On the other hand, **Gusau** experienced mutation in 1963 corresponding to 1.75% and downward trend from 1963 to 2010 and upward trend from 1963 to 1953 corresponding to 82.75% and 17.24% of the total years observed respectively. In the overall 85% of the total stations observed exhibited significant trend and percentage sum of the negative and Positive significant trend in the stations were **275.85** and **26.05** respectively. As reported in the findings of Raziei (2008) and Shifteh (2012), the probable reason for insignificant trends in some of the stations could be non-availability of century scale data; this could be possible because of variability as short data length may not give room repetitiveness as espoused in the concept of recurrence interval and consistency. **Figure 6 and Table 4** attest to this variability in terms of general trend and mutation, though not starkly discernible. In addition, it is pertinent to bring to bear from **figure 5** that there is no staggering different in mutations and change of point characteristics in the basin and that account for seemly similarity in the appearance of the plots illustrated in the figure*s* .In Anyadike (1993), theoretical explanation for the varying incidence of statistical change points (Mutations) is high seasonal variability and probable influence of Inter-tropical Discontinuity which usually migrates across West Africa in response to the relative intensities of the Azores-Libyan and St. Helena sub-tropical pressure systems. The Inter-tropical Discontinuity is entrenched to the north of the country and thus placing Sokoto-Rima Basin under the influence of the tropical maritime.


Sokoto
Forward
Backward
u(t) u'(t)
10
0
-10
-20
1910
1917
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1931
1938
1945
1952
1959
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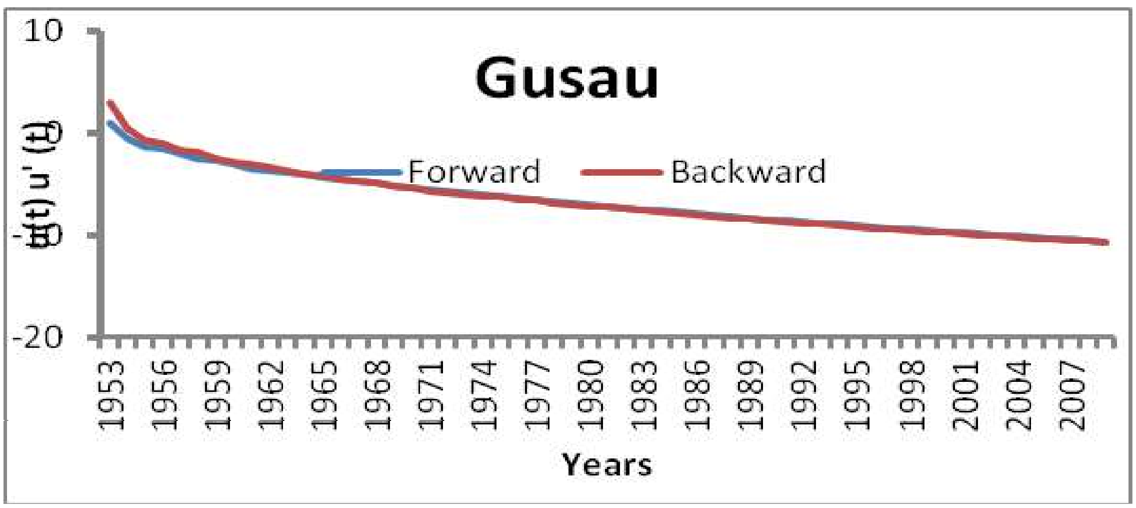
Gusau
Forward
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u(t) u' (t)
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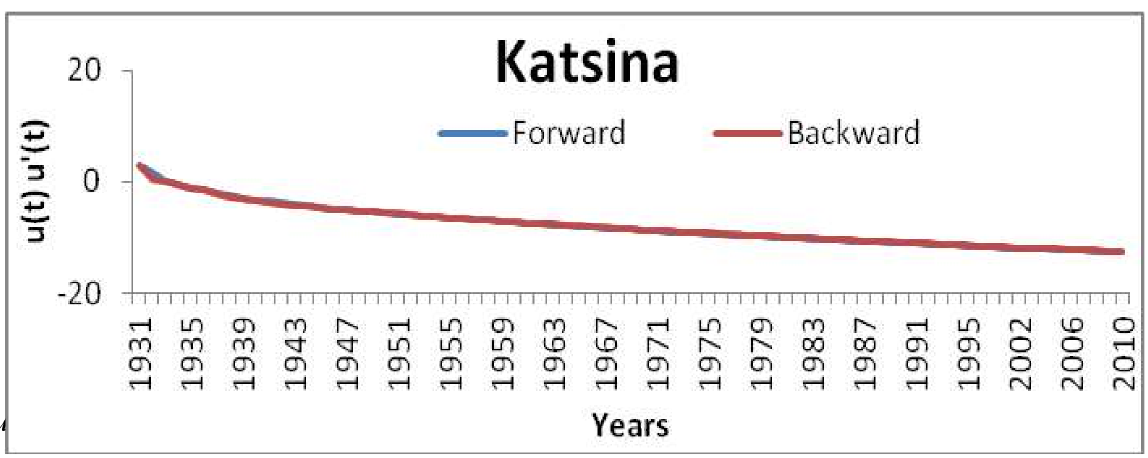
Katsina
Forward
Backward
u(t) u'(t)
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Figu

Table 4: Analysis of SQ-MK Statistics Result

Stations	**Positive Trend (%)**	**Negative Trend (%)**	**Mutation Points (%)**
Bakalori	0.0	0.0	27.3
Zobe	5.9	94.1	5.9
Jibyia	0.0	0.0	33.3
Sokoto	2.1	97.1	0.9
Katsina	0.0	0.0	0.0
Goronyo	17.2	82.75	1.75
Total	**26.05**	**275.85**	**69.15**

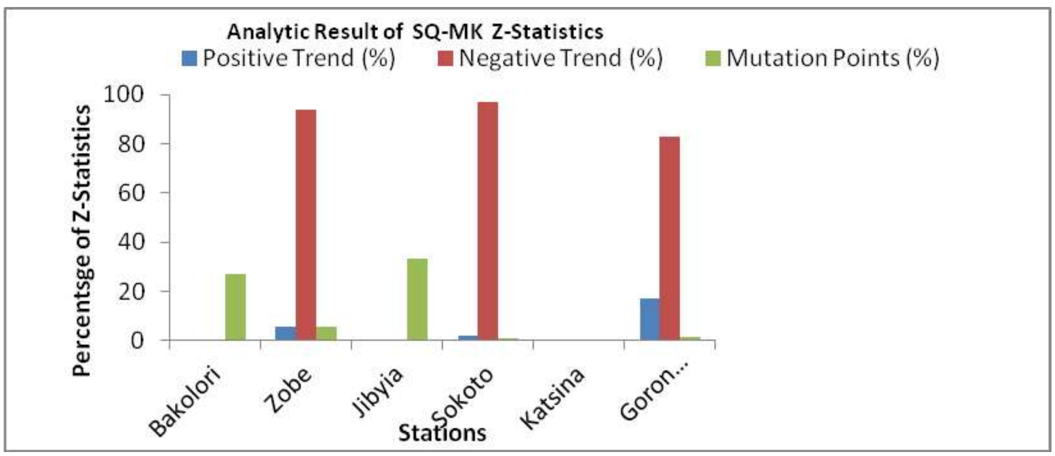

Figure 6: Trend Pattern across the Basin

4. Conclusions

The results of trend analysis and change point detection in rainfall series are important for policy makers, especially for water resources management and agriculture. It was observed that most of the stations showed significant trend in annual and monthly rainfall series using annual and seasonal Mann-Kendall test. The highest number of stations with significant negative trends occurred in the raining season with few significant positive trends. To be precise, Mann- Kendall test on annual rainfall series indicated that **Katsina, Gusau and Sokoto** stations have increasing positive trend; this accounts for 48.86% of the stations while Goronyo station showed a decreasing trend (14.28% of the stations). In contrast, **Jibiyia, Bakalori and Zobe,** respectively have no significant trend. However, traces detected correspond to 48.86% of the stations. In the overall, the seasonal Mann-Kendall test revealed that the sum percentage of the negative significant trend far outweighed the positive trend at the ratio of 4:1 while SQ- MK gave a picture of 11:1; that is, significant negative trend to significant positive trend. The physical implication of this scenario is that for every 1% increase in rainfall amount, there is a 4% or 11% decrease in trend signature.

Generally it can be inferred that, there is evidence of significant change in rainfall regime in the basin for the period (1931–2016). This varying degree in the trend pattern across the basin has the potential of leading to extreme hydro-meteorological conditions of flood and drought. It suffices to note that the variability as epitomised in the mutation results became critical from the 1990s. Significant trends were detected can largely be attributed to global warming caused by anthropogenic emission of greenhouse gasses and the gradual expansion of the tropics during the last 30 years. Based on the results, for effective generalisation in the long-term, it is strongly recommended that extensive data should be employed for analysis. In the same context, a plurality of analytical approaches should be deployed in the assessment while considering admixture of hydro-meteorological variables in the context of the aggregate effects of the interactions of same on the variability evolution of the associated extremes.

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