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Research Article

Spatio-Temporal Variability Analysis of Rainfall in Kumadugu-Yobe River Basin, Nigeria

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ABSTRACT

Large-scale climatic variability is seriously affecting rainfall and temperature distribution pattern in Sudano-Sahelian parts of Lake Chad Basin. The Kumadugu-gana and Yobe Rivers that drain the south-western part of the Lake Chad Basin now flow for six months only in a year instead of nine, and this has affected the entire ecosystem of the basin. This study examines the spatio-temporal variability of Kumagu-Yobe river basin rainfall. The study used monthly rainfall records for 1981-2017 from five different weather stations that spread across the up-and-downstream parts of the basin. To accomplish the objective of the study descriptive and inferential statistics were used in analyzing the rainfall attributes and temporal distribution pattern for each of the stations during the study period. Linear regression model was used in analyzing the stations rainfall temporal variability trend. The findings of the study revealed a large scale spatio-temporal variability in the distribution of the rainfall attributes during the study period. Generally, the basin recorded increasing trend of rainfall within the study period. Annual increasing trends of 1.1mm, 3.1mm, 17.6mm and 17.2mm were observed at Potiskum, Nguru, Bauchi and Kano stations respectively. Thus, Jos records insignificant decreasing trend of -0.2mm annually. Specifically, a variability of less than 1% was also observed at Jos and Potiskum stations which is statistically insignificant. A variability of 19%, 28% and 44% was observed at Nguru, Kano, Jos, and Bauchi respectively. Overall, throughout the study periods the basin recorded increasing trend of rainfall that is characterised with large scale fluctuations particularly at the upstream section of the basin. However, desertification and upstream water abstraction may have reduced any noticeable increase in stream downstream

Keywords : River Yobe; Kumadugu-Yobe Basin; rainfall; spatio-temporal variability

1. Introduction

According to Alexandrov & Genev (2003), the Earth's climate had been exhibiting marked "natural" variations and changes, with time scales ranging from millions of years down to one or two years. Climatic variability in Africa particularly rainfall and temperature, caused by natural forcing factors is large (Buontempo et al., 2010; Hulme, 1995), the rainfall variability manifest as severe droughts at yearly time-scales or as more prolonged desiccation (Hulme, 1995). A decreasing trend in the amount of rainfall with increasing variability in the West African Sudano-sahelian region, in the last 50 years has been reported, (Anyamba & Tucker, 2005; Bibi et al., 2014; Jury & Isabelli, 2002). Also, International Fund for Agricultural Development, IFAD (2008) also reported a long term decline in West African rainfall of almost 20-40% in 1931-1990.

Moreover, Mertz et al. (2012) reported a significant increase in temperature trend all over African regions. Large scale climatic variability is affecting rainfall and temperature distribution pattern in Sudano-Sahelian parts of Lake Chad Basin (Isiorho et al., 1996). The erratic rainfall and rising temperature is causing shrinking and degradation of water resources in the Lake Chad basin at large, especially dramatic shrinking of the Lake Chad drainage basin (Gao et al., 2011; Science Daily, 2011), migration of aquifer's water table (Geerken et al., 2010; Buma et al., 2016), and decrease in flow of Chari, Logone and Kumadugu rivers and their tributaries (Okonkwo et al., 2014). The drying of lake Chad is largely at the northern pole of the lake where river Kumadugu-Yobe empty its water, which number of studies and reports attributed to upstream dam construction (water obstruction) for large scale irrigation (Finlayson et al., 2006). According to IUCN (2011), River Kumadugu-Gana (one of the major tributaries of River Yobe) which discharges into the main stream at Damasak, was contributing 2% of water inflow into the Lake Chad is no longer reaching river Yobe. According to United Nations Environment Programme (2006), the Kumadugu-gana and Yobe Rivers that drain the south-western part of Lake Chad Basin now flow for six months of the year instead of nine. The two major rivers of the sub-basin are the major sources of aquifers, wetlands and floodplain recharge, especially at the downstream within the sedimentary parts of the basin.

Therefore, it is against this backdrop that this study is focusing on examining the basin rainfall variability pattern. As available studies on rainfall variability focus on the entire eco-climatic region rather than on the hydrological basin for example the works of Adeyeri and others in 2017, 2019 and 2020 (Adeyeri et al., 2020; Pham-Duc et al., 2020). Although, Mahmood et al. (2019) examined the rainfall and temperature variability and trends for the period of 64 years (1951–2015) in Lake Chad basin catchment in contrast this study used rainfall data from 8 stations all from Chari and Lagon sub-basin, and used proxy interpolated data for Kumadugu, Fitri, Yeng sub-basins. This study analyse rainfall data from both up and downstream parts of the basin in order to understand specifically the basin rainfall related to spatio-temporal variability pattern.

2. Methods

2.1 Study Area

Geographically, Kumadugu-Yobe basin is located approximately between latitude 10^{o} to 14^{o}20' north of the Equator and longitudes 7^{o}25' to 13^{o} east of the Greenwich Meridian Line, respectively. The basin has a total area of 145 833 Km^{2}. The Hydrological boundaries of the Basin traverse the States of Kano, Jigawa, Bauchi, and Yobe and to a lesser extent, Plateau, Kaduna, Katsina and Borno in Nigeria and Diffa region in Niger Republic (Umar & Ankidawa, 2016). The map of the basin is shown in Figure 1. The Komadugu-Yobe River Basin has a network of wetlands and pools along its extensive floodplains. A study of recharge trends in the region indicates that the underlying aquifers fundamentally depends on water infiltration from pools that emerge during flood events and continue through drought periods (Desconnets et al., 1997).

In terms of prevailing land cover, seven to eight different land use land cover could be identified and these includes open water body, dense vegetation, sparse vegetation, shrubs, irrigation fields, desiccated and inundated fields and bare lands. North of the wetlands advancing sand dune and weed invasion has partly affected the landscape of the wetland (Oyebande, 2001; Thompson & Polet, 2000; Zemba et al., 2018).

Thompson and Polet (2000) reported that the prevailing climate of the Komadugu-Yobe River area is typically semi-arid in its nature and the rainfall regime depends on the seasonal migration of the Inter-Tropical Convergence Zone known as ITCZ. The spatial distribution of rainfall in the Sahel symbolized the difference between productive areas and desertification-stricken areas. The probability of precipitation in the Sahel strongly depends on the West African monsoon, characterizing a substantial rainfall probability in the southern areas of the Sahel as appropriately highlighted by Lapworth et al. (2013).

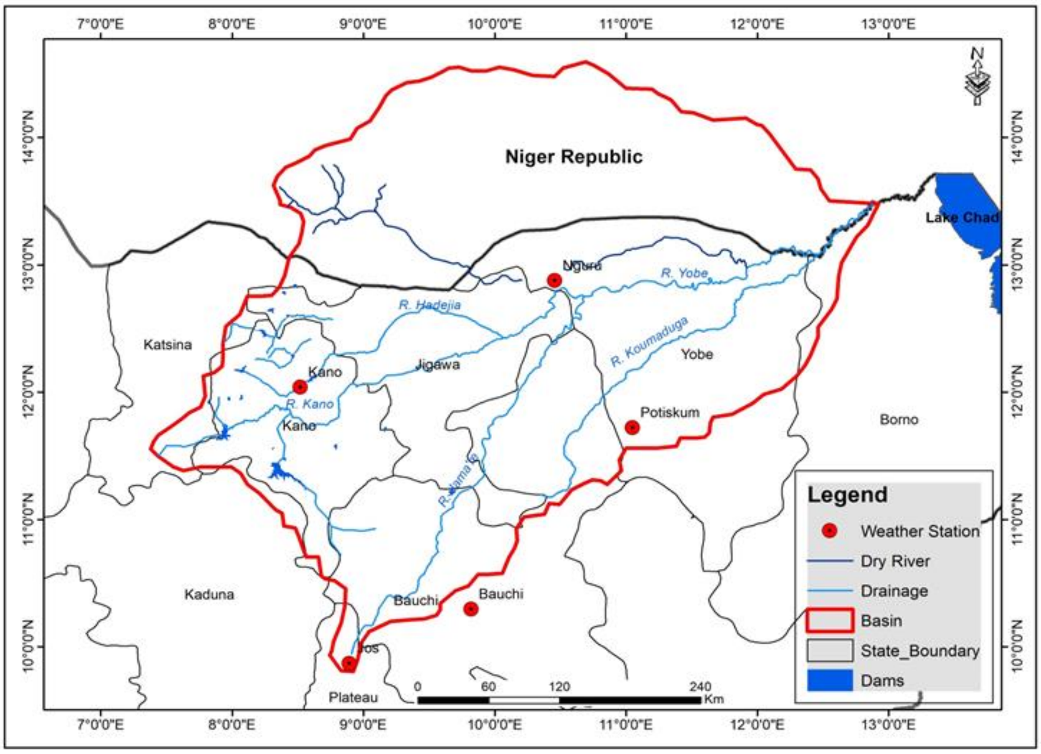

Figure 1. Map of the study area showing the sampled weather stations

2.2 Data Source

In the course of conducting this study, the monthly rainfall amounts and mean monthly temperature of the river basin were used. The source of the data used and the weather stations where the data are generated are presented in Table 1.

Table 1. Nature and source of the data used in the study

Data Used	Source
Mean Monthly rainfall and temperature records (see Fig 4.1)	
Potiskum	NEAZDP office Gashua
Nguru	NEAZDP office Gashua
Kano	Aminu Kano International airport, Kano
Bauchi	Nimet office
Jos	National Tuber Crop Research Institution Jos

2.3 Data Analysis

To accomplish the fundamental objective of this study, we used descriptive statistical tools such as mean, minimum, maximum, standard deviation, skewness, kurtosis and coefficient of variance in analyzing the rainfall attributes temporal distribution pattern for each of the stations during the study period. Linear regression statistical tool was used in analyzing the temporal variability of rainfall attributes for each station. While correlation statistical tool was used in determining, the relationship of rainfall attributes between the stations.

3. Results and Discussion

3.1 Kumadugu-Yobe River Basin (KYRB) Downstream Rainfall Variability (1981-2017)

3.1.1 Rainfall variability pattern of Potiskum (1981-2017)

The results of analysis presented in Table 2 revealed that there is significant year-to-year variability in rainfall characteristics within these 37 years (1981-2017). The total annual rainfall and rainy days has large variability with a standard deviation of 142mm from the average of 641mm and 9 days from the average 49 days respectively. The coefficient of variance results reveals that the variability in duration of rainy season is larger than total annual rainfall and number of rainy days. On monthly basis, the onset and cessation months of June and September respectively show large variability with a standard deviation of 43mm from the average of 80.3mm and standard deviation of 59 mm from the average of 99mm respectively. The total annual rainfall and rainy days fluctuate between the maximum of 966.1mm to minimum of 374.6mm and maximum of 69 days to minimum of 30 days respectively. The station records precipitation from March to November thus the threshold of 51mm was recorded from April to October within the study period. With the exception of the month of July, the Minimum rainfall below 51mm was recorded in all of the months within the period. The Month of August, which recorded the peak of season, shows a dramatic variability trend with maximum of 535mm and minimum of 35.2 mm, which is below 51mm threshold with a variance coefficient of 42%. Therefore, July rainfall shows high level of stability with a variance coefficient of 32% as shown. As it can be seen in Figure 2 the station records, nine rainy months with only four months with rainfall threshold of 51mm. The result of annual variability trend analysis is presented in Figure 3.

Table 2. Potiskum Monthly Rainfall Descriptive Statistics (1981-2017)

	Mean	Max	Min	Stdv	Skwn	Kurtosis	Coefficient of Variance	Count of rain>51mm (%)
Jan	0	0	0	0	0	0	0	0
Feb	0	0	0	0	0	0	0	0
Mch	0.6	13	0	2.5	4.5	20.6	400	0
Apr	8.3	53	0	15	1.7	1.9	181	0
May	29	16	0	32	2.2	6.4	111	19
Jun	80	195	16.9	43	0.7	0.02	52	76
Jul	184	361	60.9	65	0.9	1.3	35	100
Aug	217	535	35.2	91.5	0.9	2.9	42	97
Sep	100	210	1.6	58.7	0.1	-0.8	59	78
Oct	24	84	0	25	0.9	0.2	105	14
Nov	0.8	27	0	4.5	5.9	36.0	550	0
Dec	0	0	0	0	-	-	0	0
Rdy	49	69	30	9.2	0.1	-0.1	19	-
Arf	641	966	375	142	0.1	-0.1	21	-
Drs	96	135	47	23	-0.3	-0.6	23	-

Note: Rdy (rainy days); Arf (annual rainfall); Drt (Duration of rainy seassion)

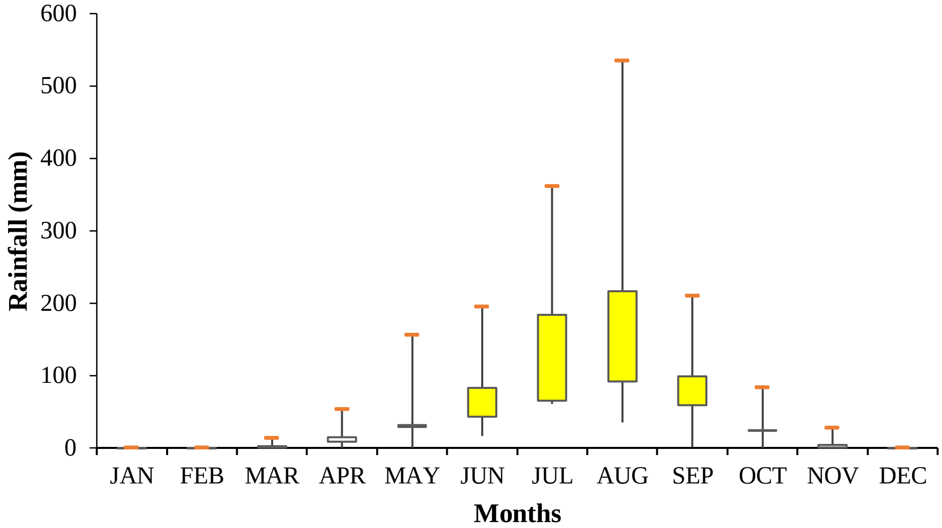

Figure 2. Potiskum Monthly Rainfall Distribution (1981-2017)

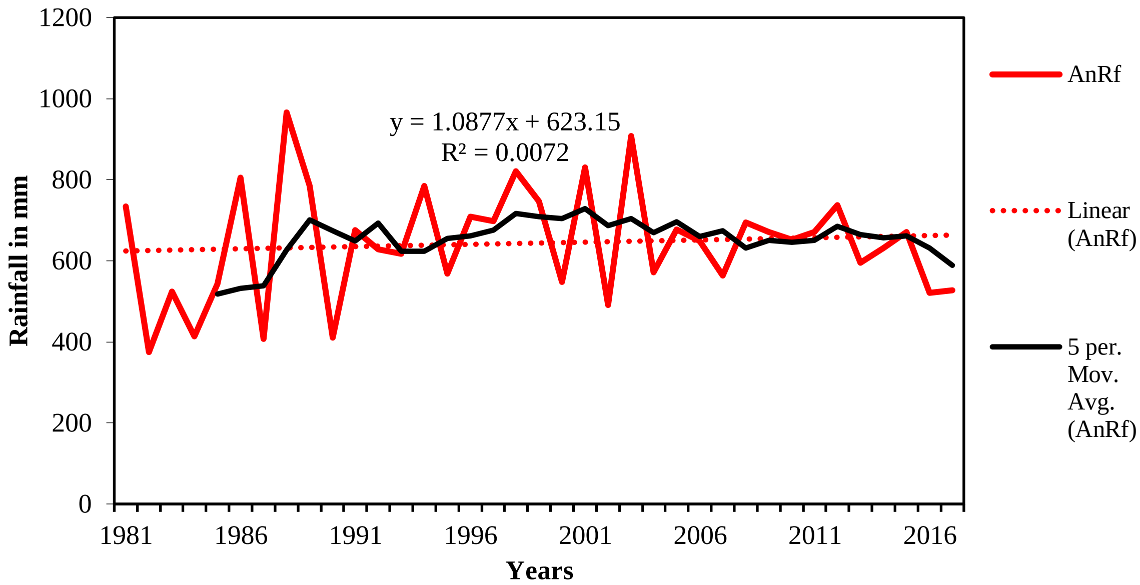

Figure 3. Potiskum Station Annual Rainfall Variability Trend (1981-2017)

The variability in rainfall attributes was large in 1980s up until 1990s and lower between 2000 and 2018, as in Figure 3. The annual rainfall variability trend shows an increasing trend of 1.1mm, which is statistically insignificant at 0.001 R^2. The findings of the study contradict the projection of Adakayi (2012) who projected a rainfall decline until 2019 and from 2020; rainfall begins to increase until 2030, mean annual number of rain days decreased from 6.5 days per month in 2007 to 5.2 days per month in 2030. Therefore, rainfall trend prediction using statistical models is far from reality, as rainfall variability driver's behaviours are irregular. The decadal drought hypothesis after the Sahelian drought of 1973, 1983 and 1993 is disproved by wetness recorded in 2003, during which Potiskum and Nguru recorded a wetness index of 1.9 and 1.1 respectively. The results of Standardized precipitation index (SPI) for Potiskum is given in Table 3.

Table 3. Descriptive Summary of Potiskum Station SPI (1981-2017)

Drought Intensity Categories	SPI Values	Number of Years	Percentage
Extremely wet	>2	1	3
Very wet	1.5 to 1.99	1	3
Moderately wet	1 to 1.50	5	14
Near normal	-0.99 to 0.99	25	68
Moderately dry	-1 to -1.49	1	3
Severe dry	-1.5 to -1.99	4	11
Extremely dry	-2<	0	0

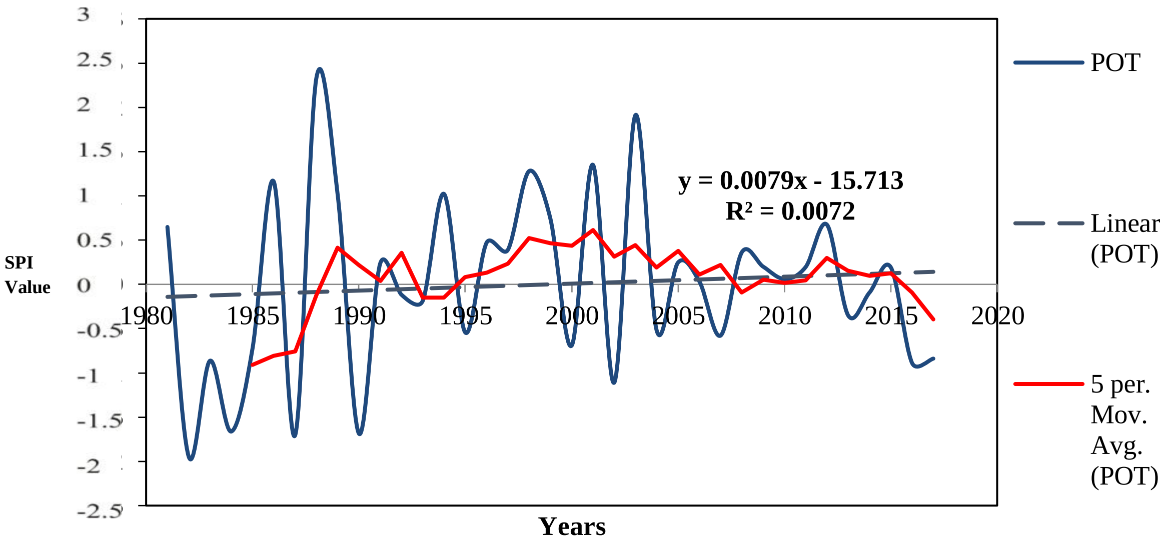

Figure 4. Potiskum Station SPI Variability Trend (1981-2017)

The SPI variability trend for Potiskum station during the study period shows a positive trend by 0.01 value per season. As it could be seen from Figure 4, the variability was larger in 1980s, the regression R^2 revealed 10 % variability.

3.1.2 Rainfall variability pattern of Nguru (1981-2017)

The results of descriptive statistics of Nguru monthly rainfall (1981-2017) are presented in Table 3 and Figure 5. While results of decadal standardize precipitation index and annual rainfall, variability trend is presented in Table 3 and Figure 6.

Table 3. Nguru Monthly Rainfall Descriptive Statistics (1981-2017)

	Mean	Max	Min	Stdv	Skwns	Kurtosis	Coefficient of Variance	Count of rain>51mm (%)
Jan	0	0	0	0	-	-	0	0
Feb	0	0	0	0	-	-	0	0
Mch	0.4	14	0	2.4	-	34	536	0
Apr	3	38	0	8.4	2.9	8.8	248	0
May	8.8	49	0	12	1.9	3.9	131	0
Jun	33	110	4	24	1.2	1.3	73	30
Jul	135	314	29	62	0.5	0.3	42	92
Aug	161	281	74	49	0.6	0.7	29	100
Sep	62	186	5	35	1.1	3.1	57	0
Oct	5	39	0	8	2.7	8.1	186	0
Nov	0	0	0	0	-	-	-	0
Dec	0	0	0	0	-	-	-	0
RDY	31	53	17	8	0.5	0.7	25	-
ARF	408	616	237	85	-0.5	-0.3	19	-
DRT	63	95	35	15	-	-	24	-

The results of the monthly descriptive statistics in Table 3 revealed that Nguru station records precipitation from March to October thus the threshold of 51mm was recorded from July to September within the study period. With the exception of the month of August, the minimum rainfall below 51mm was recorded in all of the months within the period. The month of August, which records the peak of the rainy season, shows a dramatic variability trend with maximum of 161mm and minimum of 74mm, which is slightly above 51mm, threshold.

Annual rainfall and rainy days fluctuate between the maximum of 616mm to minimum of 237mm and maximum of 53 days to minimum of 17 days respectively. The annual rainfall and rainy has large variability with a standard deviation of 85mm from the average of 408mm and 8 days from the average 31 days respectively. On monthly basis, the onset and cessation months of July and September showed large variability with a standard deviation of 62 mm from the average of 135 mm and 35 mm from the average of 62mm respectively. The monthly rainfall distribution is presented in Figure 5.

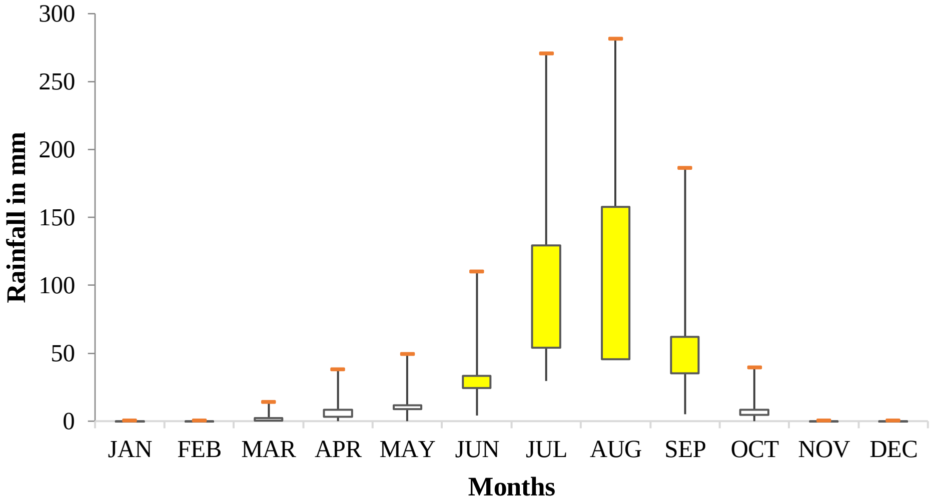

Figure 5. Nguru Monthly Rainfall Distribution (1981-2017)

The monthly rainfall distribution in Figure 5 revealed that the rainfall of Nguru station records, eight rainy months with only three months with mean rainfall threshold of 51mm. The rainfall is largely concentrated in two months (July and August). Although September rainfall mean is slightly above the 51 mm monthly threshold, but the month minimum within study period is almost near 00mm reading. The annual rainfall trend is presented in Figure 6.

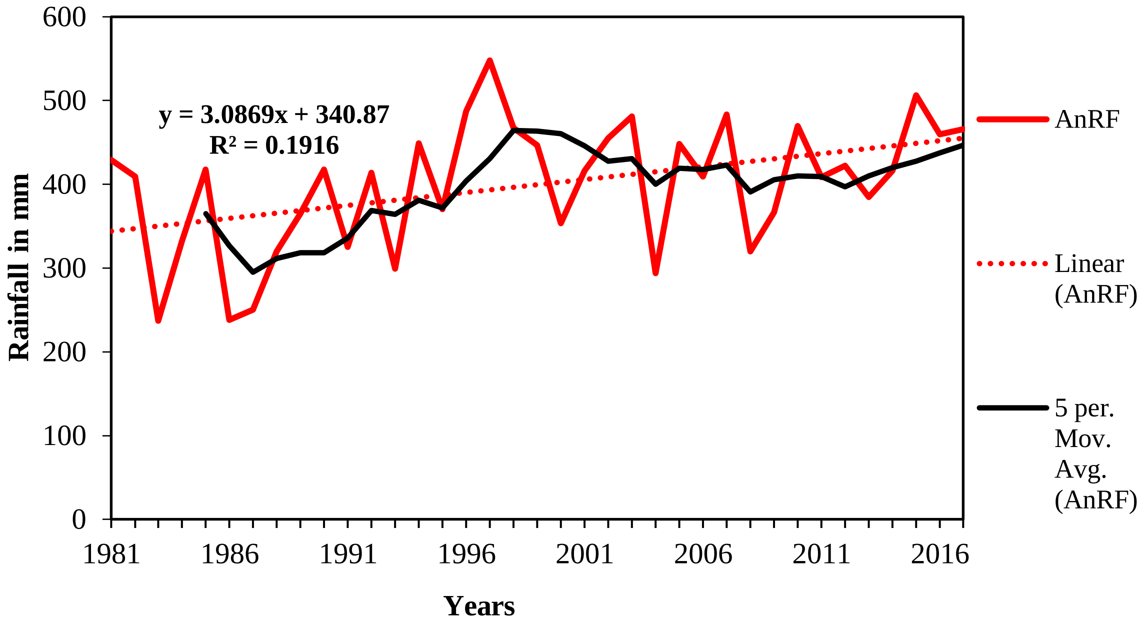

Figure 6. Nguru Annual Rainfall Variability Trend (1981-2017)

The results of the analysis revealed a significant year-to-year variability in rainfall characteristics within these 37 years (1981-2017), much more than Potiskum station. Although the variability pattern is similar between the stations, the rainfall fluctuation trend of Nguru is dramatic. Similar to Potiskum station the variability in rainfall attributes of Nguru station was also large in 1980s until 1990s and lower between 2000 and 2018, as it can be seen in Figure 6. This confirms the results of empirical studies on Sudano-Sahelian savanah ecological zone rainfall variability in the Sudano-Sahelian ecological zone of Nigeria, over the period of fifty years such as Bibi et al. (2014), Hulme (2001), and Anyamba & Tucker (2005). They reported a downward trend in rainfall amount in the 1970s and 1980s and an upward trend for rainfall between 1990 and 2000 with increasing variability in the West African Sudano-sahelian region, in the last 50 years.

However, Mahmood et al. (2019), reported a contradicting result. They reported a statistically significant rainfall-decreasing trend of 1.5mm per annum. This may not be unconnected with the fact that their study period covered (1951-2015), which included two pre-drought decades. Therefore, what could be explored from this contraption is that, the observed rainfall recovery by this study and several related study is not up to pre-drought period rainfall pattern. Rainfall trend empirical studies between 1950s and 1990s reported a decreasing trend. Dramatic rainfall recovery of West African Sudano-Sahelian ecosystem is a game changer in annual rainfall trend pattern. Statistically insignificant annual rainfall variability trend result showed an annual increasing trend of 3.1 mm, as revealed in linear trend result presented in Figure 6. The result of the Nguru station SPI descriptive statistics and variability trend are presented in Table 4 and Figure 7 respectively.

Table 4. Descriptive Summary of Nguru Station SPI (1981-2017)

Drought Intensity Categories	SPI Values	Number of Years	Percentage
Extremely wet	>2	0	0
Very wet	1.5 to 1.99	1	3
Moderately wet	1 to 1.50	4	11
Near normal	-0.99 to 0.99	25	68
Moderately drought	-1 to -1.49	4	11
Severally drought	-1.5 to -1.99	1	3
Extremely drought	-2 <	2	5

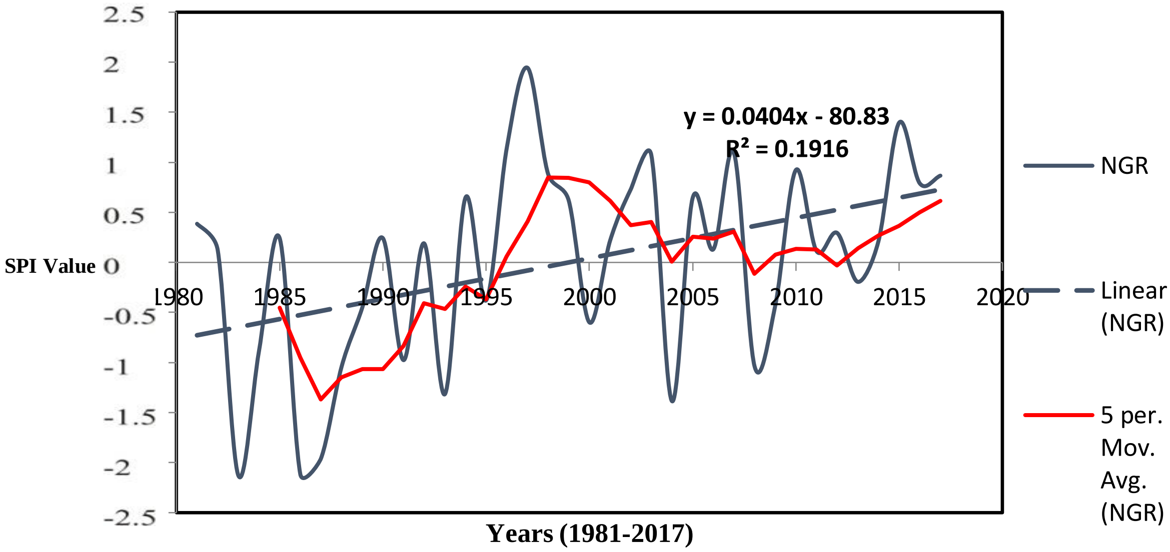

Figure 7. Nguru Station SPI Variability Trend (1981-2017)

The results of descriptive statistics analysis presented in Table 4 revealed that, within the study period the rainfall pattern at Nguru recorded 25 years of near normal wetness at Nguru similar to that of Potiskum station. The station recorded seven (7) years of dryness; extreme drought in 1983 and 1986, severe drought in 1986 moderate drought in 1988, 1993, 2004 and 2008. Five (5) years of wetness were also recorded with very wet season in 1997 and moderate wetness in 1996, 2003, 2007 and 2015, as can be seen from Table 4. SPI trends vary between Nguru and Potiskum despite their altitudinal and longitudinal location similarities. These differences may not be unconnected to latitudinal difference, which is believed to be a major driver of rainfall spatial distribution.

Therefore, it can be concluded that Nguru and Potiskum rainfall temporal pattern may be having different drivers. The findings of this study confirmed the findings of Usman et al.(2015) that reported shift toward wetter condition. Similarly, it agrees with the study by Ogungbenro & Morikanyo (2014) in their study of 90 years rainfall distribution across all climatic zones of Nigeria. Table 5 presents the decadal rainfall seasonality indices in KYRB. Similarly, Abaje et al., (2013) also, reported that Sudano-sahelian ecological zone of Nigeria recorded larger extent of severe drought beginning from 1968 through the early 1970s. The series of 1980s drought was the most severe of the study period. The late 1990s and the 2000s witnessed a decrease in the number of drought occurrences.As confirmed by Jajere et-al (2021), argue that although there is a positive shift towards a wetter condition, but statistically insignificant comparing the decadal mean. They reported a break and decline in magnitude and frequency of occurrence of the drought in the area.

Table 5. Decadal Rainfall Seasonality Indices in KYRB Downstream (1981-2017)

Period	**Nguru**		**Potiskum**	
	Seasonality Index	**Remark**	**Seasonality Index**	**Remark**
1981-1990	1.3	Most rain in three months or less	1.1	Most rain in three months or less
1991-2000	1.2	Most rain in three months or less	1.1	Most rain in three months or less
2001-2010	1.2	Most rain in three months or less	1.1	Most rain in three months or less
2011-2017	1.4	Most rain in three months or less	1.1	Most rain in three months or less

The result of seasonality index analysis from 1981 to 2017 at downstream of KYRB revealed that the rainfall seasonal spread is largely concentrated within 3 months at both Nguru and Potiskum. Thus, the higher values observed at Nguru in 1980s and 2011-2017 revealed that the rainfall spread during the periods occurs in less than three months.

3.2 Upstream Rainfall Pattern During the Study Period

In analysing Spatio-temporal rainfall pattern of the upstream, records of Jos, Bauchi and Kano weather stations were considered to depict the climatic pattern of the upstream part of the KYRB.

3.2.1 Rainfall variability pattern of Jos (1981-2017)

The results of descriptive statistics of Jos monthly rainfall (1981-2017) are presented in Table 6 and Figure 8.

Table 6. Descriptive Summary of Jos Annual Rainfall (1981-2017)

	Mean	Max	Min	Stdv	Skew	Kurt	Coefficient of Variance	Count of rain>51mm (%)
Jan	1.5	34	0	6.5	4.5	20.5	425	0
Feb	2.9	38	0	8.3	3.4	11.4	288	0
Mch	21	148	0	31	2.4	7	148	5
Apr	90	247	0	56	0.6	0.5	63	29
May	167	346	48	61	0.5	0.9	37	36
Jun	221	402	94	77	0.6	-0.4	35	37
Jul	269	431	101	73.2	-0.04	0.02	27.2	37
Aug	285	485	74.6	73.3	-0,4	1.8	25.7	37
Sep	195	316	85	55.9	-0.04	-0.06	28.6	37
Oct	56	267	0.4	52.5	2.3	7.3	94	16
Nov	0.5	13.4	0	2.4	5.2	27.8	454	0
Dec	0	0	0	0	0	0	0	0
RDY	103	128	75	9.1	-0.14	2.9	8.8	-
ARF	1317	1612	1018	35	-0.14	0.07	10.2	-

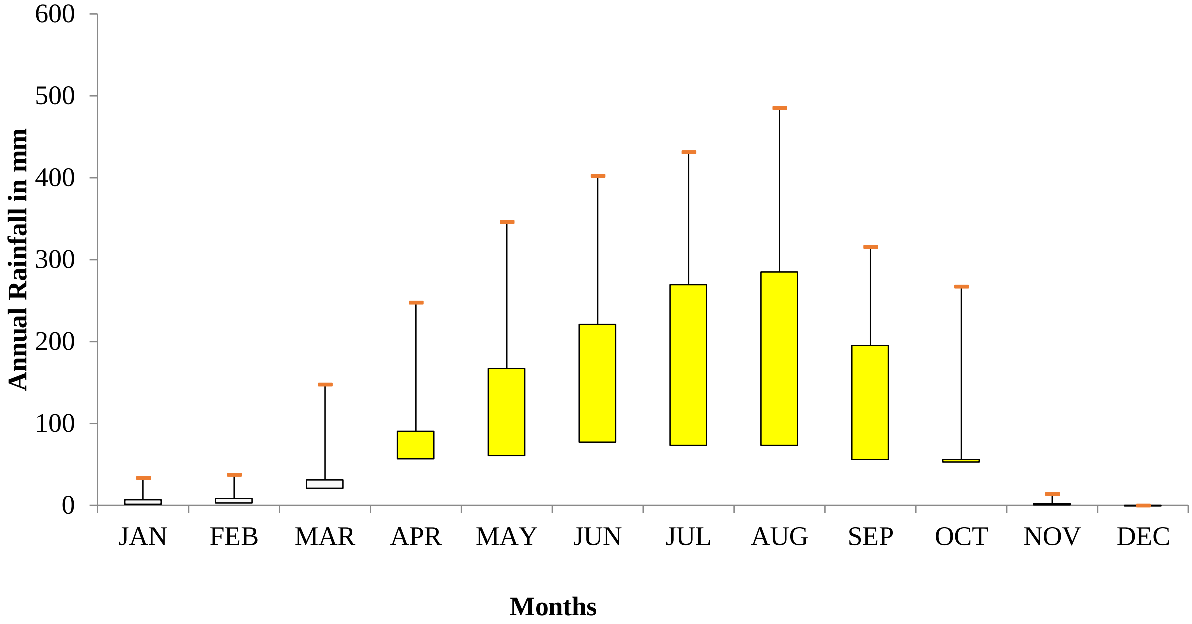

Figure 8. Jos Monthly Rainfall Distribution Rainfall (1981-2017)

The results of Jos station rainfall descriptive statistics between 1981 and 2017 in Table 6 revealed that within the study period rainfall in Jos plateau is concentrated between April and October. Although rainfall was recorded in all the months of year with exception of December within the period, 100% monthly rainfall above the 51 mm threshold was recorded between June to September, thus April and May counts 78% and 97%, also 14% and 43% counts was recorded in March and October. Therefore, April and October are the mean onset and cession months, having mean rainfall greater than 51 mm. High rainfall variability between months of the years was observed as shown by the coefficient of variance.

However, the wettest month of the year (June, July August and Sept) have the least variability with coefficients values of 34.9%, 27.2%, 25.7%, 28.6% respectively. July, August and Sept records are negatively skewed with July and Sept records showing near normal distribution pattern than August peak. The mean annual rainfall of the area within the period was 1317 mm, and maximum and minimum values were 1612 mm and 1018 mm respectively. The annual rainfall values were positively skewed indicating that most rainfall values are above the mean. The variability of annual rainfall and rainy days is low within the study period with coefficient value of 10% and 9% respectively. A positive shift in Jos rainfall was observed and agreed with the study of Mustapha et al., (2018), who reported that the mean rainfall of Jos was 1263.2mm, during 1971-2012 climatic periodand maximum and minimum values were 1646.6 mm and 814.7 mm respectively. A slight decrease in variability was observed from 12% during 1971-2012 period to 10% during 1981-2017 period. The annual rainfall variability linear trend pattern is presented in Figure 9.

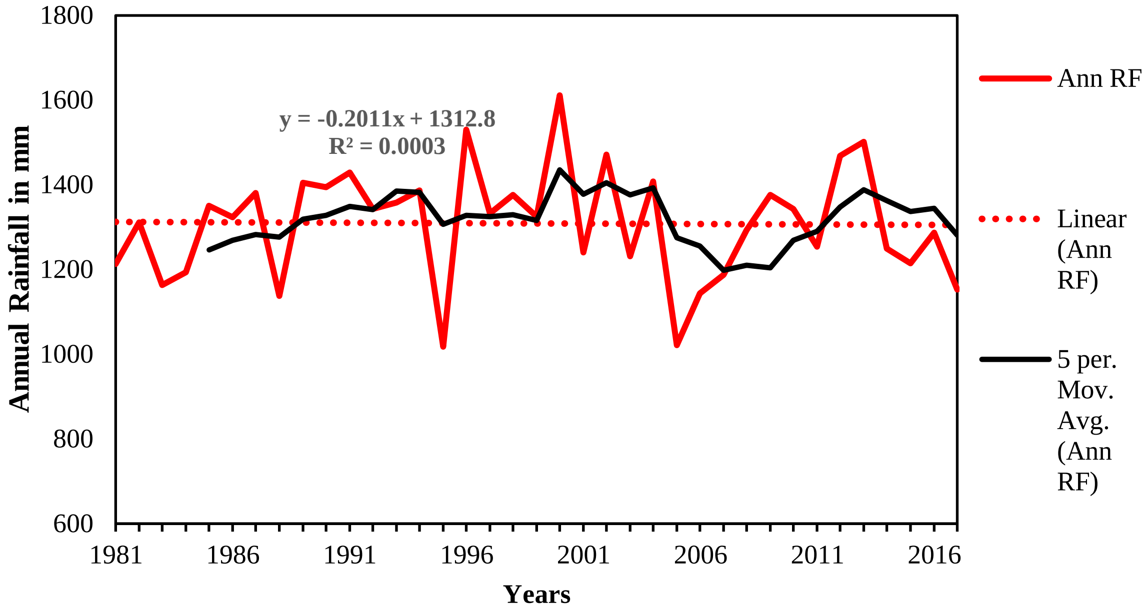

Figure 9. Jos Annual Rainfall Distribution Trend (1981-2017)

The results of the Jos annual rainfall linear trend in Figure 9 revealed that the variability of Jos annual rainfall trend was almost stable during the study period. The R^2 value revealed a statistically insignificant variability. Insignificant annual decreasing trend of 0.2mm was observed. The decadal rainfall seasonality indices of Jos and Standardize precipitation index of Jos is depicted in Table 7 and Table 8 respectively.

Table 7. Decadal Rainfall Seasonality Indices of Jos (1981-2017)

	1981-1990	1991-2000	2001-2010	2011-2017
JOS Seasonality index	**0.9**	**0.9**	**0.9**	**0.9**
Remark	Markedly seasonal with a long drier season	Markedly seasonal with a long drier season	Markedly seasonal with a long drier season	Markedly seasonal with a long drier season

Table 8. Descriptive Summary of Jos SPI (1981-2017)

Drought Intensity Categories	SPI Values	No. of Years	Percentage
Extremely wet	>2	1	3
Very wet	1.5 to 1.99	1	3
Moderately wet	1 to 1.50	3	8
Near normal	-0.99 to 0.99	27	73
Moderately dry	-1 to -1.49	3	8
Severe dry	-1.5 to -1.99	0	0
Extremely dry	-2<	2	5

From Table 8 the rainfall pattern at Jos within the 37 years period records extremely wet period of 2.19 in the year 2000, the rainfall distribution was largely near normal with two years of extreme (1995 and 2005) and moderate drought (1983 and 2006). Seventy-three percentage (73%) of the study seasons recorded normal wetness. Standardised precipitation index trend analysis results is presented Figure 10.

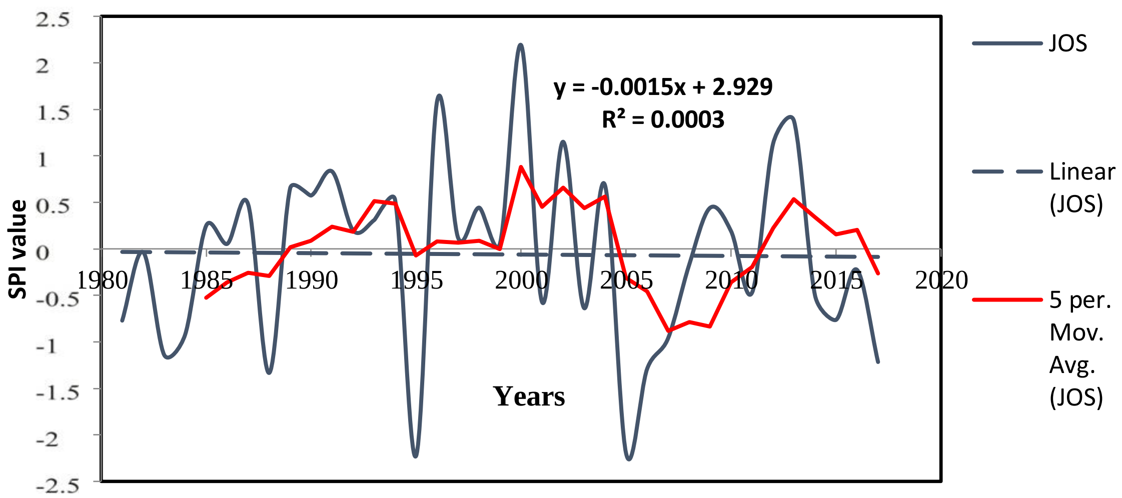

Figure 10. SPI trend and moving averages of Jos (1981-2017)

The results presented in Table 7 and Figure 10 revealed that, the decadal seasonality index of Jos shows a more stable trend during the study period. The decades record a markedly seasonal rainfall with longer drier season. It could be established from seasonality index results that the climate of Jos is a dry land type in terms of rainfall duration, than humid type as 100% monthly rainfall threshold count, was recorded in only four (July to September) months during the study period.

3.2.2 Rainfall variability pattern of Bauchi (1981-2017)

The results of descriptive statistics of Bauchi monthly rainfall from the year (1981-2017) as presented in Table 9 and Figure 11 respectively.

Table 9. Descriptive Statistics of Bauchi Rainfall Characteristics 1981-2017

Months	Mean	Max	Min	Stdv	Skwness	Kurt	Count%	CV
Jan	0	0	0	0	0	0	0	0
Feb	0.1	1.9	0	0.34	4.8	25	0	402
March	4.7	33.8	0	9.5	2.2	3.9	0	202
April	34.5	163	0	36	1.7	3.4	21.6	105
May	99	278	13.4	53	1.1	2.1	83.8	54
June	160	290	33.7	61	-0.02	-0.5	97.3	38
July	272	638	123	122	1.3	1.5	100	45
August	326	668	54.9	128	0.99	1.7	100	39
Sept	190	489	4.1	94	0.8	2.0	91.9	50
Oct	39	186	0	45	2.2	4.4	18.9	116
Nov	0.07	3	0	0.4	6.1	37	0	608
Dec	0	0	0	0	0	0	0	0
AnRF	1127	1871	726	284	0.8	-0.1	45.9	25

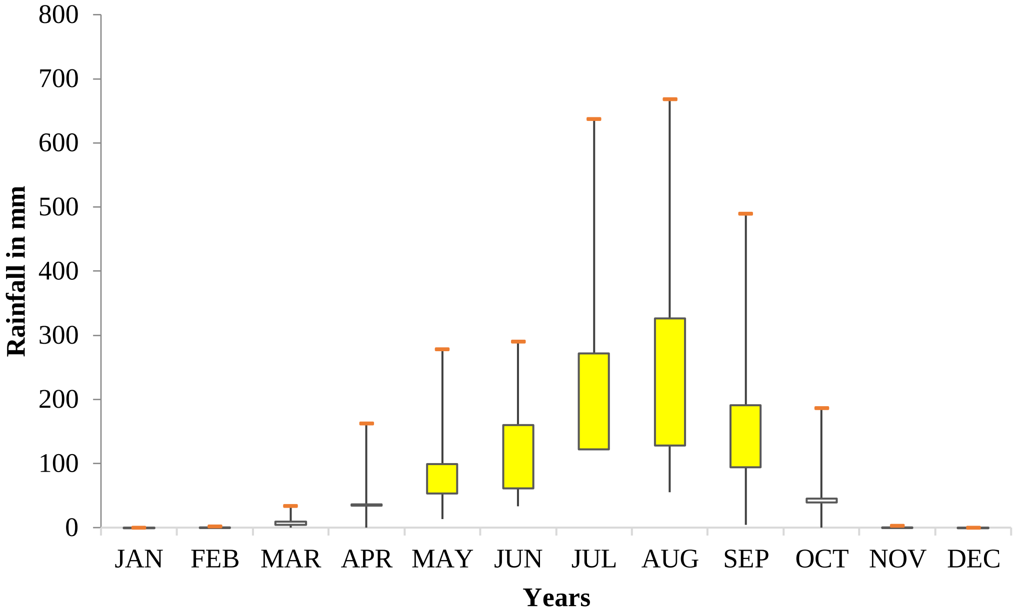

Figure. 11 Bauchi Monthly Rainfall Distribution Rainfall (1981-2017)

The results of descriptive statistics in Table 9 revealed that within the study period rainfall in Bauchi was concentrated between May and September. Hundred percent monthly rainfall above the 51mm threshold was only recorded in July and August. Thus, 83.8%, 97.3 and 92% of the season recorded 51mm monthly threshold in May, June and September respectively also 22% and 19% counts was recorded in April and October. Therefore, May and September were the mean onset and cession months, having mean rainfall greater than 51 mm. High rainfall variability between months of the years was observed as shown by the coefficient of variance.

However, the wettest months of the year (June, July and August) have the least variability with coefficient values of 38%, 45% and 39% respectively. Almost all the months' records are positively skewed with June records showing near normal distribution pattern than August peak. The mean annual rainfall of the area within the period is 1127 mm, and maximum and minimum values are 1871 mm and 726 mm respectively. The annual rainfall values are positively skewed indicating that most rainfall values are above the mean. This result is strongly supported by the findings of Mustaphaet al., (2018) in their study on rainfall variation in some parts of northern Nigeria. The annual rainfall linear regression results of Bauchi station is presented in Figure 12.

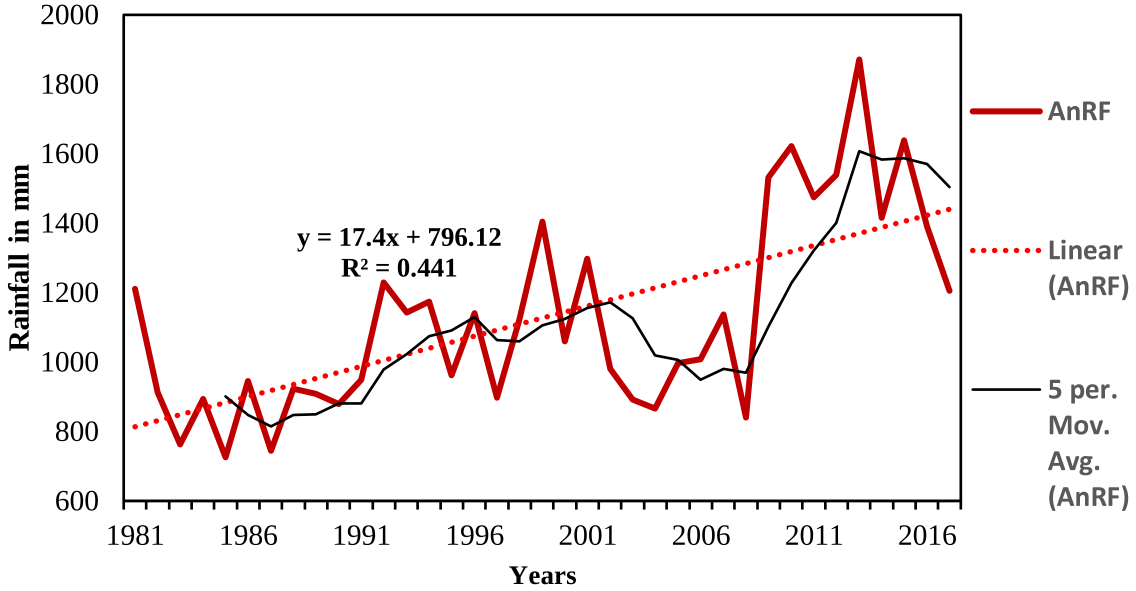

Figure 12. Bauchi Annual Rainfall Distribution Trend (1981-2017)

The results of the annual rainfall variability trend in Figure 12 revealed that the variability is significant within the study period with coefficient value of 44%. An annual increase of 17.4 mm was observed during study period. This contradicts the findings of Taiwo et al, (n.d.) in their studies on monthly variation and annual trends of rainfall across major climatic zones in Nigeria. Their findings of revealed that 1.873mm/year for Bauchi during 1985-2015. In addition, Odiana and Ibrahim (2915), in their studies on evidence of climate change in Bauchi (1978 to 2008), reported an annual increase of only 0.2mm. This may not be unconnected with the large-scale dryness of 1981-1985 and wetness of 2016 and 2017, which the study did not cover. The result of the Standardized Seasonality Index annual and decadal descriptive statistics and variability trend is presented in Table 9, 10 and Table 11, respectively.

Table 10. Descriptive Summary of Bauchi SPI (1981-2017)

Drought Intensity Categories	SPI Values	No of Years	percentage
Extremely wet	>2	1	3
Very wet	1.5 to 1.99	2	5
Moderately wet	1 to 1.50	3	8
Near normal	-0.99 to 0.99	27	73
Moderately drought	-1 to -1.49	4	10
Severally drought	-1.5 to -1.99	0	0
Extremely drought	-2<	0	0

Table 10 shows that Bauchi station recorded 6 years of wetness within the study period with only 4 years of moderate drought and 27 years of normal distributions. Bauchi recorded its extreme wet season in 2013 and moderate drought in 1983, 1987, 1985 and 2009. The decadal Standardised Precipitation Index of Bauchi is presented in Table 11.

Table 11. Decadal Rainfall Seasonality Indices of Bauchi (1981-2017)

	1981-1990	1991-2000	2001-2010	2011-2017
Bauchi Seasonality	1.0	1.0	0.9	1.1
Index Remark	Most rain in 3 months or less	Most rain in 3 months or less	Markedly seasonal with a long drier season	Most rain in 3 months or less

The decadal seasonality index of Bauchi shows a more Stable trend during the study period. The 1991-2000 decade recorded a markedly seasonal rainfall with longer drier season; the decade is the wettest decade in 1981-2017 climatic calendar. It can be concluded from seasonality index results that the climate of Bauchi is a dry land type in terms of rainfall duration, than humid type as 100% monthly rainfall threshold count was recorded in only two (July andSeptember) during the study period. The result of Bauchi station standardized precipitation index linear regression trend is presented in Figure 13.

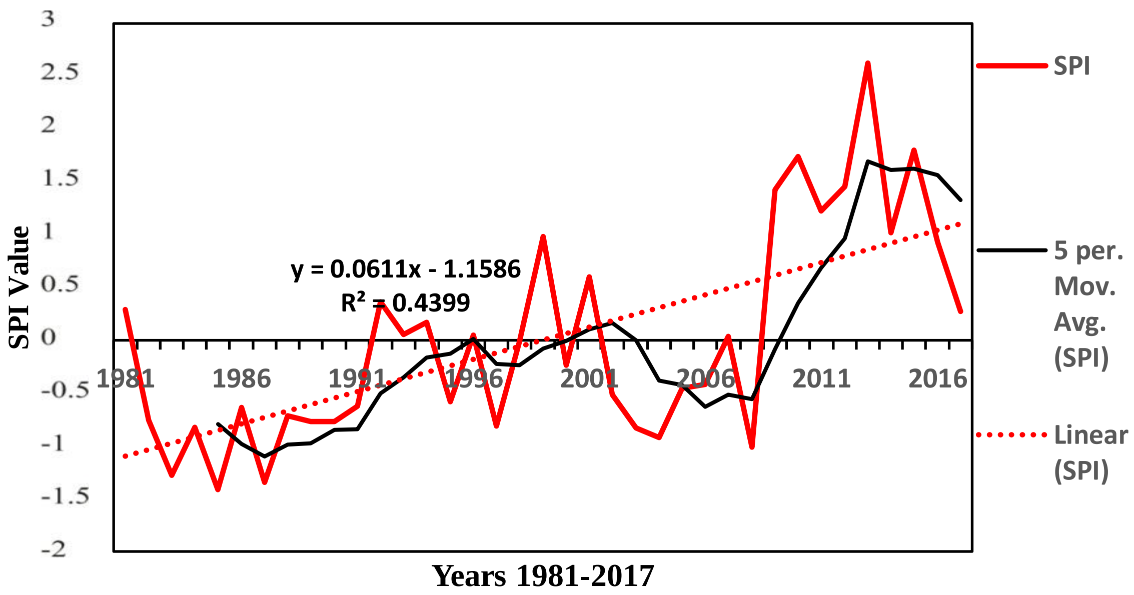

Figure 13. Bauchi SPI trend and moving averages (1981-2017)

From Figure 13, it could be seen that the climate of Bauchi is changing to wetter climate. The R^2 value of 0.44, revealed a variability of 44%. The 1980s, and 1990s season were drier, a significant wetness was recorded in 2000s.

3.2.3 Rainfall variability pattern of Kano (1981-2017)

The results of descriptive statistics of Kano monthly rainfall (1981-2017) are presented in Table 12 and Figure 14.

Table 12. Descriptive Summary of Rainfall in Kano (1981-2017)

Months	Mean	Max	Min	Stdv	Skewn Eess	Kurtosis	Coefficient of Variance	Count of rain>51mm (%)
Jan	0	0	0	0	0	0	0	0
Feb	0.25	8.1	0	1.3	5.9	36	539	0
Mar	0.84	21.5	0	3.7	5.4	30.5	434	0
Apr	13.1	65.7	0	18.7	1.5	1.4	143	5
May	60	186	0	48.8	0.88	0.3	81.3	46
Jun	145	433	36	84.0	1.40	2.8	58	92
Jul	268	604.7	91.4	130.1	0.99	0.33	48.5	100
Aug	357	739	45.5	146	0.15	0.39	40.9	97
Spt	159	346	26.9	69.6	0.25	0.03	44	95
Oct	18.7	102.3	0	23.6	1.69	3.19	126	11
Nov	0.02	0.7	0	0.12	6.08	37	608	0
Dec	0	0	0	0	-	-	-	0
ARF	1022	1789	473.7	352.5	0.27	-0.66	34.5	-

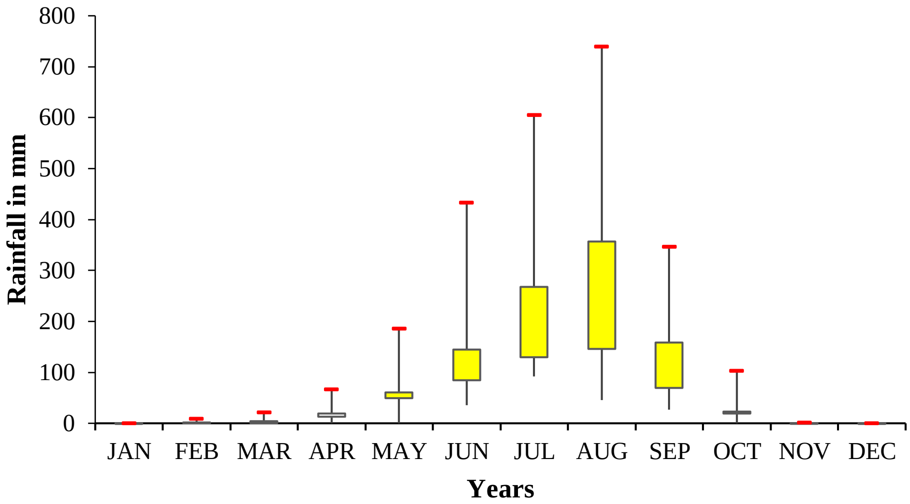

Figure 14. Kano Monthly Rainfall Distribution (1981-2017)

From the results in Table 12 and Figure 14, it could be seen that within the study period rainfall in Kano was concentrated between May to September. Although rainfall was recorded in all the months of year with exception of December and January within the period. Hundred percent (100%), 92%, 97% and 95% of the study years recorded monthly rainfall above 51mm in June, July, August and September respectively. High rainfall variability between months of the years was observed as shown by the coefficient of variance.

However, the wettest months of the year (June, July August and Sept) have the least variability with coefficient values of 58%, 48.5%, 40.9%, 44% respectively. September rainfall distribution records show near normal distribution pattern than August. The mean annual rainfall of the station within the period is 1022 mm, maximum and minimum values are 1789 mm and 473.7 mm respectively. The annual rainfall values are positively skewed indicating that most rainfall values were above the mean. The result of the Kano station annual rainfall variability is presented in Figure 15.

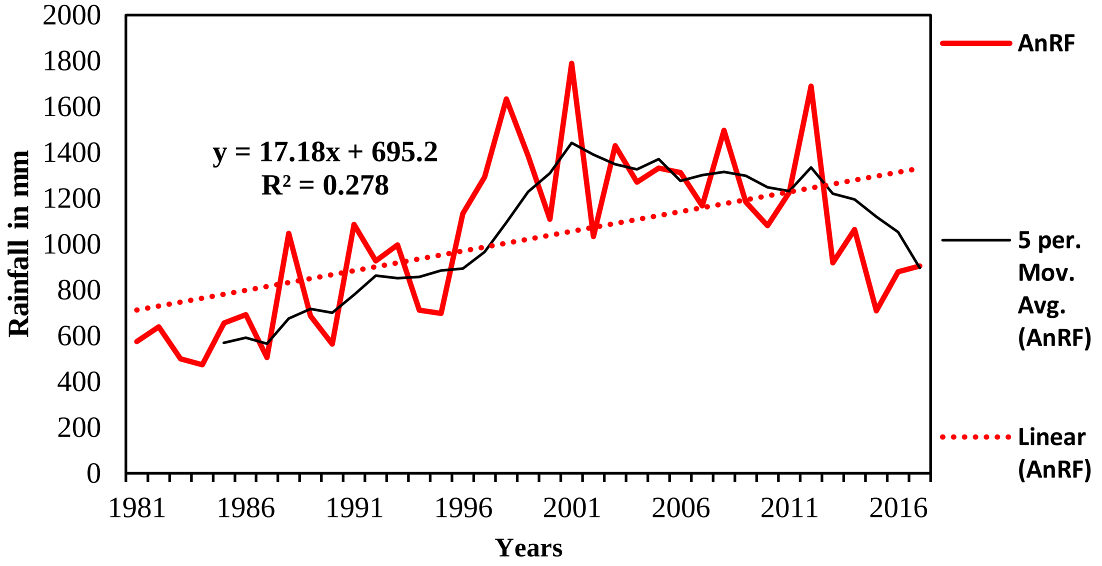

Figure 15. Kano Annual Rainfall Distribution Trend (1981-2017)

The results of annual rainfall variability trend for Kano revealed a positive trend in annual amount during the study period. An annual increasing trend of 17mm was observed, which revealed a shift in Kano rainfall to a wetter climate. The result of variability trend revealed a larger annual variability of 28%. Similar results findings was made by Murtala et al., (2015) in their study on Kano rainfall dynamics and climate change. Results of descriptive statistics of the annual decadal standardized precipitation index and annual rainfall variability trend is presented in Table 13 and Table 14, respectively.

Table 13. Descriptive Summary of Kano SPI (1981-2017)

Drought Intensity Categories	SPI Values	No of Years	percentage
Extremely wet	>2	1	3
Very wet	1.5 to 1.99	2	5
Moderately wet	1 to 1.50	3	8
Near normal	-0.99 to 0.99	24	65
Moderately drought	-1 to -1.49	6	16
Severally drought	-1.5 to -1.99	1	3
Extremely drought	-2<	0	0

Similarly, Kano rainfall within the period records extreme wetness in the year 2001 and very wet in 1998 and moderate wetness in 2012, as it can be seen in appendix 9. The results in table 5.13, revealed that almost $^3/_4$ of the study seasons recorded near normal wetness. The rainfall distribution was largely near normal with severe drought in 1985. The results in six (6) years of moderate drought was recorded 1981 to 1986, with break in 1985. Therefore, it can be concluded that the recorded drought of 1980s in Kano was not extreme but largely moderate with the exception of that of 1985.

Table 14. Decadal Rainfall Seasonality Indices of Kano (1981-2017)

Variables	1981-1990	1991-2000	2001-2010	2011-2017
KANO Seasonality index	1.2	1.1	1.1	1.2
Remark	Most rain in 3 months or less	Most rain in 3 months or less	Most rain in 3 months or less	Most rain in 3 months or less

The decadal seasonality index of Kano fluctuates during the study period. The decades record a 3-month seasonal rainfall. Therefore, it can be concluded from seasonality index results that the climate of Kano is a dry land type in terms of rainfall duration, than humid type as only July records 100% monthly rainfall threshold count, during the study period. Results of the standardized precipitation index variability trend are presented in Figure 16.

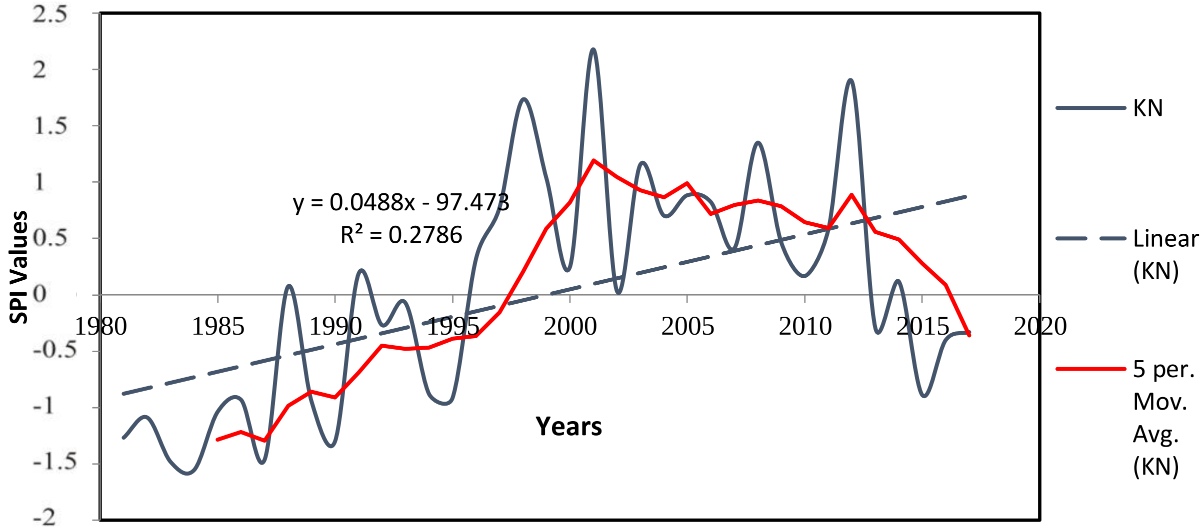

Figure 16. SPI trend and moving averages in Kano (1981-2017)

The linear trend line in Figure 16 cross positive line in year 2000, the line reaches the moderate wet value in 2017. Variability of 28% was observed during the study period. The SPI trend line was negative from 1981 up to 1996. It crossed the positive line in 1996, and dropped to negative in 2013. Therefore, what can be explored from the results in Figure 16 is that the Kano rainfall regime recovered from dedecal dryness in the mid-1990s. The 2000 to 2010 decade is most wet decade during the study period.

3.3 Rainfall Spatial Variability Within The Basin

Table 15 present the correlation coefficient result for relationship between annual rainfalls of KYRB meteorological station. While the mean annual rainfall spatial distribution pattern is presented in figure 16.

Table 15. Annual rainfall spatial distribution relationship correlation coefficient

	Kano	Jos	Potiskum	Nguru	Bauchi
Kano	1	0.085	0.53**	0.32	0.258
Jos	0.085	1	-0.08	-0.04	0.164
Potiskum	0.53**	-0.08	1	0.15	0.174
Nguru	0.32*	-0.04	0.15	1	0.38*
Bauchi	0.258	0.164	0.174	0.38	1

Note : **. Correlation is significant at the 0.01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed).

With this, the rainfall pattern of Jos has no significant relationship with the rainfall of the downstream. The relationship between Jos rainfall and that of Kano is statistically insignificant. The results of 1981-2017 annual rainfall correlation analysis revealed a positive relationship between rainfall of Kano and that of the downstream (Potiskum and Nguru). A strong positive correlation coefficient of 0.53 significant at 99% confidence level reveals that Kano and Potiskum rainfall pattern have same drivers, as they are located on almost same latitude, and this could be observed on the spatial distribution map of the rainfall across the entire basin as depicted in Figure 17.

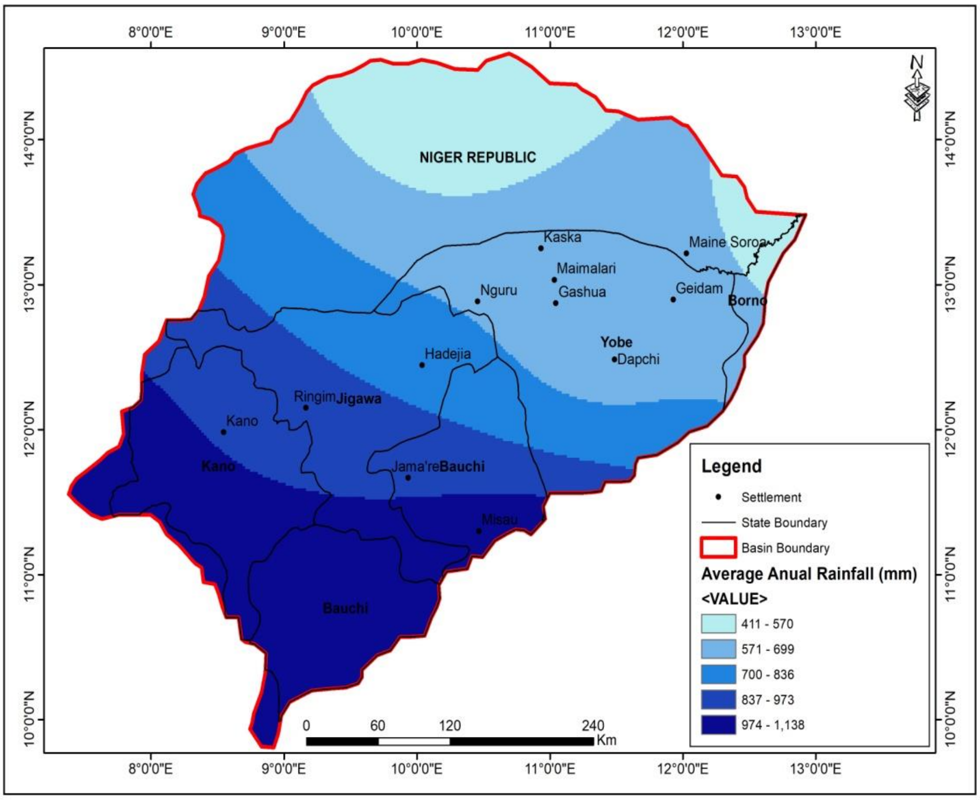

Figure 17. KYRB Annual Rainfall Spatial Variability Patterns

Thus, in terms of rainfall received, Kano receives more than Potiskum example within the period, 1100mm of mean annual rainfall was recorded at Kano as against 641mm at Potiskum. In addition, the results revealed a positive significant relationship between Kano and Nguru rainfall pattern at 95% confidence level. The results revealed week positive relationship between downstream (Nguru and Potiskum) stations as well as between the upstream stations (Jos and Kano).The result of the rainfall spatial variability analysis in Figure16 reveals that the annual rainfall decrease north eastwards from the watershed head at the north central high lands of Nigeria to desert margin drylands of Niger republic. Within the basin the rainfall amount decreases from 1200mm to less than 400mm. The spatial variability is large and follows the monsoon wind direction pattern.

4. Conclusion

KYRB recorded a large scale rainfall spatio-temporal variability during the study period (1981-2017). Generally the basin recorded increasing trend of rainfall within the study period. Annual increasing trends of 1.1mm, 3.1mm, 17.6mm and 17.2mm was observed at Potiskum, Nguru, Bauchi and Kano stations respectively, although Jos recorded insignificant decreasing trend of -0.2mm annually. The major findings of this study consolidate existing empirical studies on rainfall variability in West African Sahel. The rainfall variability within the basin was large in 1980s and 1990s during the study period, what looks like a recovery was observed in 2000s, and 2010s. The findings of this study revealed a break in decadal series of Sahelian drought and decline in frequency and magnitude of drought in 2000s and 2010s compared to what is observed in 1980s and 1990s. Therefore this study concludes that the basin rainfall is recovering from the drought of 1970s and 1980s. The spatial variability pattern of the basin rainfall is also large, as the rainfall amount decrease from 1200mm at the basin watershed head to less than 400mm at the desert margin. The spatial variability is large and follows the Monsoon southwest wind direction pattern. Thus, Agriculture and hydrological planning, policies and programmes of the basin should adjust to reflect the shift in rainfall pattern especially those designed in response to Sahelian drought. Following the findings of this paper future study should specifically focus on temperature spatio-temporal variability and its associated impact on the wetlands as well as its relationship with rainfall. Moreover, as the current study focused on rainfall spatio-temporal variability, subsequent study should explore the river discharge and the entire ecosystem response to rainfall recovery.

Conflict of Interest

The authors declare that there is no conflict of interest with any financial, personal, other people or organizations related to the material in this article.

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