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Inter-Decadal Nature of Rainfall Character Over Sudano-Sahel, North-West Nigeria

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Abstract

The study investigated the spatial pattern of decadal variations in annual rainfall amounts in the Sokoto-Rima River Basin, Northwestern Nigeria. Rainfall dataset which is available on high-resolution (0.5 x 0.5 degree) grids resolution from the Climatic Research Unit CRU TS 3.21 of the University of East Anglia, Norwich, United

Kingdom was used for the period 1943-2012 for Bunza, Dakindari southwest of the study area, Gulma, Augi, northwest of the Sokoto-Rima basin, Goronyo, Galadi, northeast Maje and Dan-Dume stations southeast of the basin. Correlation of CRU TS dataset was performed with measured rainfall data (Yelwa climatic station) from Nigerian Meteorological Agency, using the Pearson Product Moment Correlation statistic at 0.05 significant levels. In general, the study found that periods of downward fluctuations in annual rainfall below mean values corresponded with period of rise in global temperature occasioned by anthropogenic greenhouse gases emission. The study revealed a significant decrease in the annual rainfall from late 1980 onwards.

Key Word: Rainfall, decadal departure, River Basin, Rainfall variation. Climate Research Unit

Introduction

The greatest environmental problem faced in the semi-arid belt of Nigeria is aridity, rainfall variability and repeated/prolong drought and flooding, all of which are products of both natural processes and population expansion. The conclusions of the last Intergovernmental Panel on Climate Change (IPCC) report confirmed an increase in world temperature since the beginning of the industrial period and an acceleration of warming since late 70s (IPCC, 2013). Although climate change may have global dimension, there is intra-regional and inter-regional variations in vulnerability and impact depending on location, adaptation capacity and other socioeconomic factors. The Sudano-Sahel Nigeria is one of the vulnerable regions to climate change and variability, given the fact that some of its physical and socio-economic characteristics predispose it adverse effect of climatic extremes. Since 1960, the region has witnessed an increase in the variability of intra-and inter-annual rainfall patterns.

Generally, studies have confirmed increase rate of desertification (IPCC, 2013; Zhoa *et al*., 2005; Huang and Siegert, 2006; Susana and Kelley, 2006; Sonia *et al.*, 2007; Sivakumar, 2007; Hanafi and Sauffret, 2008) and this has implications for agricultural productivity, food security and sustainability of rural population who rely heavily on agriculture for their livelihoods. The Sokoto-Rima river basin which lies in the Sudano-Sahelian belt is generally considered an agricultural region with traditional mode of production predominating and more than 70 percent of the population engaged in subsistence farming. The main crops produced in the study area are millet, guinea corn, maize, rice, beans, wheat, cassava, potatoes, groundnut, cotton, sugar cane, and tobacco (Ita, 1993) which according to Allen *et al*., (2003) whose sensitivity weather extreme event range from medium to high. Rainfed agriculture remains the dominant livelihood and source of income for the population of semi-arid Nigeria with limited opportunities outside of the agricultural sector. Thus, changes in climatic variables/prolong climatic variability in particular rainfall will adversely affect farming operations. Similarly, Adelana *et al*., (2003) found that infrequent and short period of rainfall (<60 raining days) in most part of the basin prevents the development of agriculture, restricting crop production to only one planting season per year. Given the unique character rainfall Basin, there is need to examine the extent of variability on decadal basis and trend. Such information will enhance predictive model building and long-term climate change/variability impacts adaption programmes in the basin. The aim of this study therefore is to investigate the extent of decadal variation in annual rainfall amount in the Sokoto-Rima River Basin, southwest of Nigeria.

Materials and Method

The study area is located in the north-western Nigeria and lies largely in the far north Sudano- Sahel of West Africa in zone of Savanna-type vegetation belt generally classified as semi-arid (Sombroek & Zonneveld, 1971). It lies between latitudes 12° and 14° N and longitudes 5° and 7°E. The Sokoto River joins the Niger about 75 km downstream of the border and extends upstream with a broad floodplain for about 387 km (Hughes and Hughes, 1991). There are an estimated 470,000 ha of seasonal floodplains on the Niger/Sokoto system (Ita, 1993). The Sokoto River has its source near Funtua in the south of Katsina State, some 275 km in straight line from Sokoto. It flows north-west passing Gusau in Zamfara State, where the Gusau Dam forms a reservoir that supplies major towns with water (Fig.1). Further downstream the river enters Sokoto State where it passes by Sokoto and is joined by the Rima River, then turning south and flowing through Birnin Kebbi in Kebbi State. Flood ponds are common within the flood basins of most of the major rivers and are usually cut off from the main river channels during periods of low water.

The Sokoto Basin is underlain by a sequence of inter-bedded semi-consolidated gravels, sands, clays and some limestone and ironstone of Cretaceous to Quartenary age resting on pre-Cambrain Basement Complex rocks which outcrop extensively to the East and South of Zamfara State as well as to the South of Kebbi State (Sombroek and Zonneveld, 1971). The sedimentary sequences are sub-divided from bottom to top into the late Jurassic to early Cretaceous Illo and Gundumi formations, the Maestrichtian Rima Group, the late Paleocene Sokoto Group and the Eocene-Miocene Gwandu Formation. Thick sediments of both marine and continental origins constitute the series of aquifers in the basin with the oldest being the Gundumi formation that uncomformably overlies the basement complex. The Sokoto Basin is a semi-arid region marked by distinct weather conditions-the wet and dry seasons. Rainfall is highly seasonal and controlled by the movement of the Inter Tropical continuity (ITD). Rainy season usually starts from May or June of each year and lasts till September or early October depending on the rainfall pattern for that year. There is a marked seasonal variation in temperature and diurnal range of temperature. Daily maximum temperature of the basin is between 36^{o}C-40^{o}C. During the harmmattan season, daily minimum temperature may fall below 18^{o}C. Between February and April which is the peak of heat, temperature reaches the highest of 44^{o}C.In the extreme north, the shrubby and thorny vegetation of the Sahel zone is dominant vegetation type.

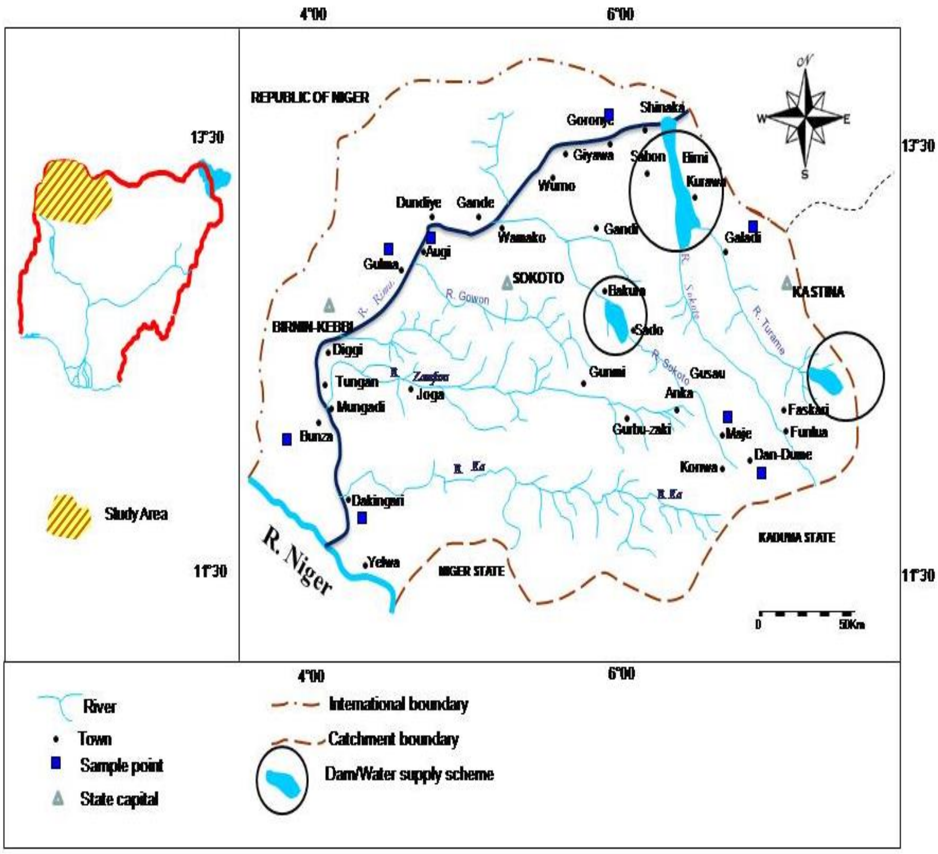

FIG. 1: SOKOTO RIVER BASIN

Source: (Adopted from Ita, 1993)

Data Collection and Analysis

Precipitation datasets in millimetres which is available on high-resolution (0.5x0.5 degree) grids resolution from the Climatic Research Unit CRU TS 3.21 of the University of East Anglia, Norwich, United Kingdom (New *et al*., 2000; Mitchell and Jones, 2005) was used in this study. The data is available on http://www.cru.uea.ac.uk/. Rainfall data were collected for a period of 70 years for Bunza and Dakindari, South West of the basin, Gulma and Augi, North West, Goronyo and Galadi, North East and Maje and Dan-Dume South East of the basin for the period 1943-2012. Quality control of CRU datasets is discussed in detail by (New *et al*., 2000) and (Jones, 2005). In addition, the suitability of CRU data sets was verified by correlating rainfall data from this source with measured rainfall data from Yelwa synoptic station, Nigerian Meteorological Agency for the period 1950-2012. Although over 56 data point were initially assembled from CRU dataset only points that yielded positive relation were used in the study (Table 1).

Table 1: Result of correlation of Rainfall data from CRU data set with measured data from NIMET (Yelwa Station)

Data Point	Multiple R	R Square	Adjusted R Square	Standard Error
Bunza	0.97	0.94	0.93	14.8
Dakingari	0.96	0.92	0.91	17.2
Gulma	0.97	0.95	0.95	13.5
Augi	0.98	0.96	0.96	12.1
Goronyo	0.95	0.90	0.89	29.7
Galadi	0.96	0.92	0.92	26.1
Maje	0.97	0.95	0.94	16.7
Dan-dume	0.97	0.94	0.93	18.8

Correlation was performed on monthly basis

Results

In Gulma town annual rainfall distribution showed evdnece of variability. The first five (5) decades starting from late 1940 into the start of 1990 were wet decades. Downward trend appeared to concentrated from the end of 1990s upto the beginning 2000. Rainfall in distribution from the year 2000 was fairly above mean value of 733.5mm. Lowest rainfall was recorded in 1973 with annual rainfall of 389.1mm. Other years of significant low rains are 1982 (392.2mm), 1987 (449mm), 1984 (500.2mm) 1944 (510.4mm), 1947 (529.6mm), while highest rainfall was recorded in 1946 (1038.7mm), followed by 1978 (1031mm), 1952(1020.7mm), 1995 (1004.7mm). A total rainfall of 31146mm was recorded in Gulma station in the wet years (i.e. 37years in which annual rainfall was above mean value of 733.5mm) with an average rainfall of 841.8mm. Minimun and maximun rainfall of the wet rainfall episode were 734.9mm and 1038.7mm respectively, with a range value of 303.8mm. In the dry years episode (33years) in which rainfall amounts were below average, a total of 20198 mm rainfall amount was recorded with an average value of 612.1mm. maximun and minumun amounts during the dry episode were 381.1mm and 725.2mm with a range value of 336.1mm (Fig.2). The regression equation explain relationship between fluctustions in rainfall amount and year. The regression line describes how a response variable y (i.e rainfall amount) changes as an explanatory variable x (i.e. year) changes. R-squared is a statistical measure of how close the data are to the fitted regression line and repersents the fraction of the variation in the values of y that is explained by the least squares regression on x.

In Augi town, lowest rainfall was recorded in 1982 with annual rainfall of 379.3mm. Other years of significantly low rains are 1973 (379.7mm), 1987 (434.4mm), 1997 (500.5mm) 1984 (510.5mm). Highest rainfall was recorded in 1946 (1050.7mm). other years of very high rainfall are 1957 (998.8mm), 1978 (194.2mm), 1952 (993.4mm), 1991 (957.5mm) and 1994 (920.9mm). Continous upward trend in rainfall was concentrated between the start of 1940 and 1980 before a downward trend from the earlier 1990s. A total rainfall of 27631mm was recorded in the wet years (i.e. 33years) in which annual rainfall was above mean value of 711.0mm. Average rainfall of wet years in Augi was 837.3mm. Minimun and maximun rainfall of the wet rainfall episode were 715.8mm and 1050.7mm respectively, with a range value of 334.9mm. In the dry years episode (37years) a total of 22141.5 mm rainfall amount was recorded with an average value of 598.4 mm. Maximun and minumun amounts during this episode were 379.3mm and 707.3mm with a range value of 328mm (Fig. 3).

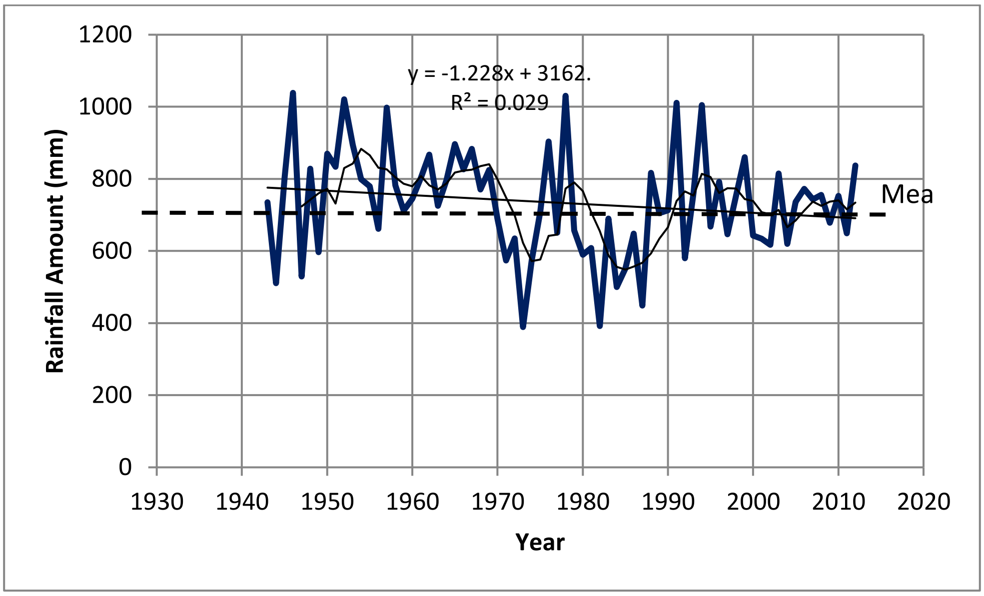

Figure 2: Annual trend of rainfall in Gulma, NW, Sokoto-Rima River basin

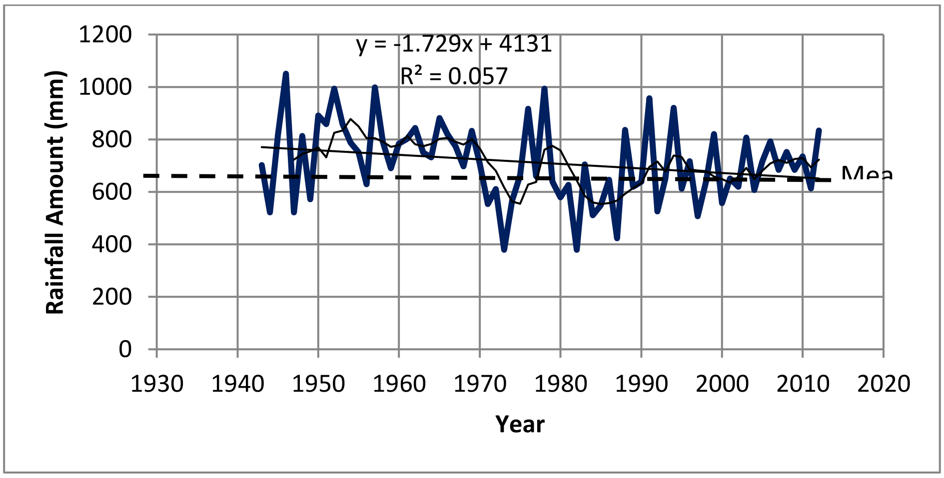

Figure 3: Annual trend of rainfall in Augi, NW, Sokoto-Rima River basin

An extended uninterupted rise in rainfall above mean value was observed in Bunza town from mid 1940 upto late 1980s . This was followed by a prolonged/continous downward movement in rainfall was which lasted from early 1990 into the 21st centuries. Annual rainfall in Bunza was lowest in 1973 with annual rainfall of 423.2mm. Other years of significantly low rains are 1982 (453.2mm), 1987 (515.7mm) and 1992 (579.9mm). Highest rainfall was recorded in 1978 (1100.2mm), followed by 1957 (1074.9mm), 1946 (1065.1mm), 1991 (1010.9mm) and 1953 (1000.5mm). For the wet years, a total rainfall of 32583.8mm was recorded (i.e. 36years in which annual rainfall was above mean value of 796.1mm). A mean rainfall of 905.1mm was calculated for wet years. Minimun and maximun rainfall of the wet rainfall episode were 797.7mm and 1100.2mm respectively, with a range value of 302.5mm. In the dry years episode (34years) in which rainfall amounts were below average, a total of 23146.4mm rainfall amount was recorded with an average value of 680.8mm. Maximun and minumun amounts of the episode were 423.2mm and 792mm with a range value of 338.2mm (Fig 4).

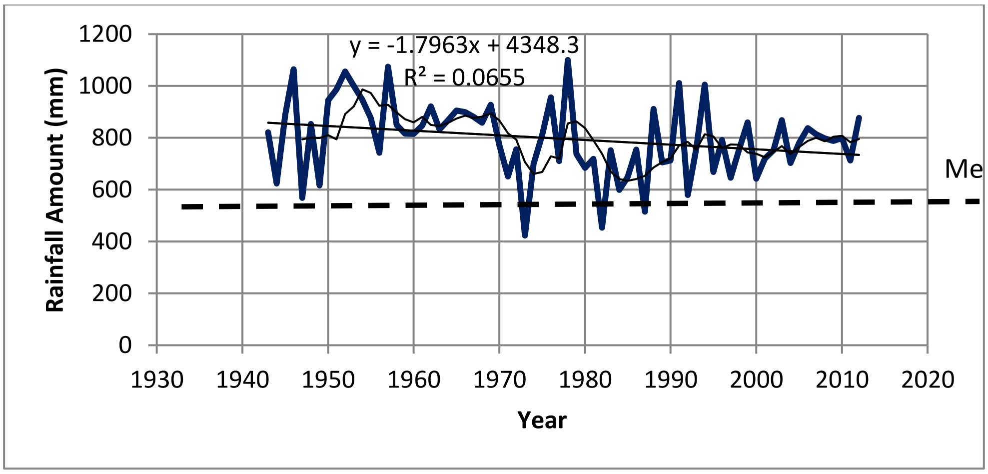

Fig. 4: Annual trend of rainfall in Bunza, SW, Sokoto-Rima River basin

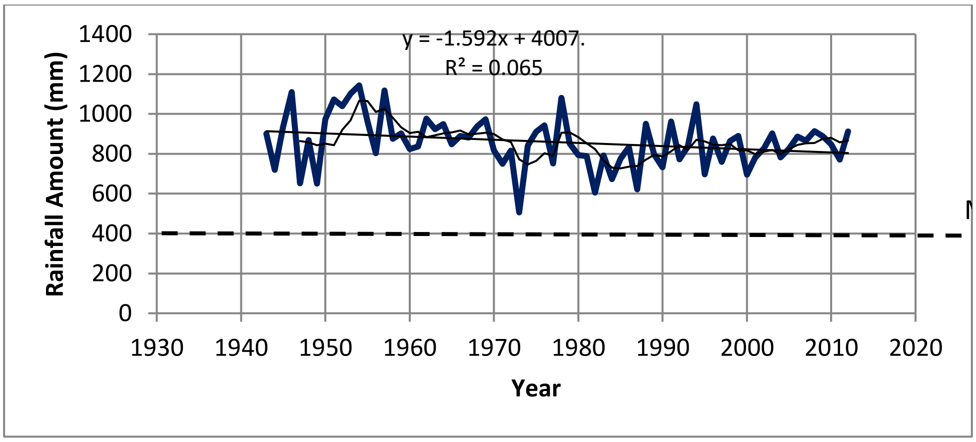

Fig.5: Annual pattern of rainfall in Dakingari, SW, Sokoto-Rima River basin

There was continous downward trend in rainfall pattern in Dakingari town beginning from late 1980, which continued into 21st century. The decades 1950, 1960, 1970 and the start of 1980 are wet decades as their rainfall values exceeded mean value of 858.5mm (Fig.5). Lowest annual rainfall of 506mm was recorded in Dakingari in 1973. In 1982, 1987, 1949, 1947 and 1984, very low rainfall amounts of 605.1mm, 621.4mm, 650.7mm, 652.6mm and 672.8mm respectively were recorded. In 1954, highest rainfall amount of 1143.1mm was recorded. This was followed by 1946 (1109.2mm), 1953 (1102.2mm), 1978 (1081mm) ,1951 (1073.4mm), 1994 (1048.6mm) and 1952 (1038.8mm). In the wet years episode, a total rainfall of 33423.1mm was recorded (i.e. 35years) in which annual rainfall was above mean value of 858.5mm. An average rainfall of 954mm was calculated for wet years. Minimun and maximun rainfall of the wet rainfall years were 863.4mm and 1143.1mm respectively, with a range value of 279.7mm. In the dry years episode (35years) a total of 26672.6 mm rainfall amount was recorded with an average value of 762.1mm. Maximun and minumun amounts during this episode were 506mm and 850.9mm with a range value of 344.9mm (Fig.5).

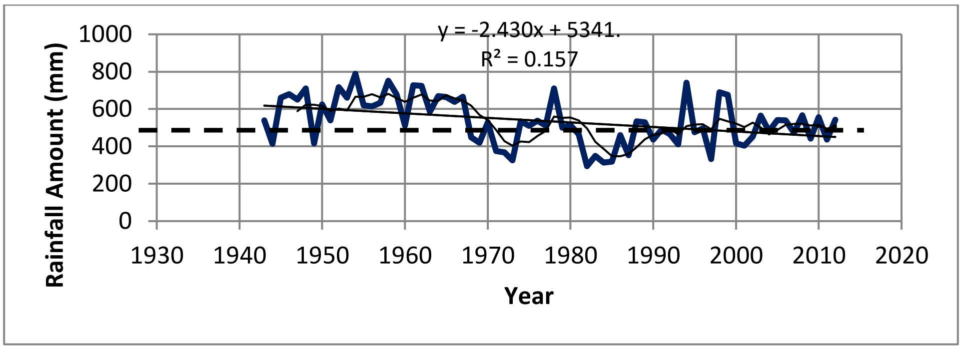

Fig. 6: Annual trend of rainfall in Goronye, NE, Sokoto-Rima River basin

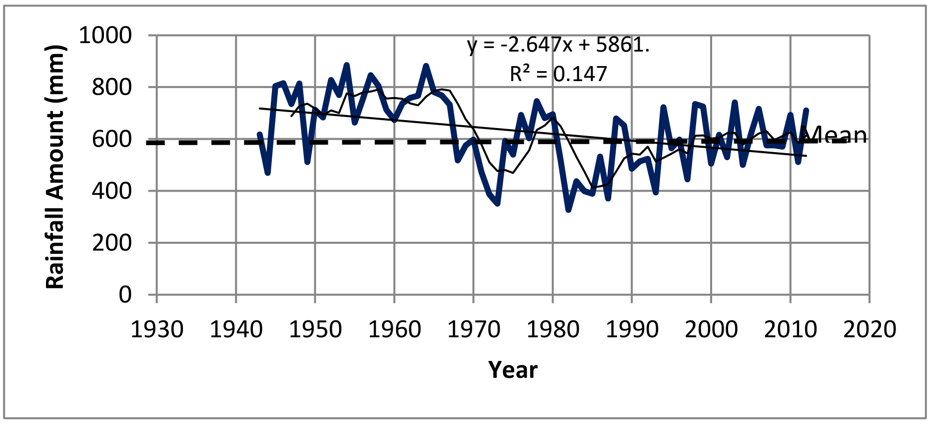

Fig. 7: Annual trend of rainfall in Galadi, NE, Sokoto-Rima River basin

Annual rainfall trend in Goronye town is presented in Fig. 6. The first five (5) decades beginning from mid 1940 down to late 1980 were wet decades. Sharo downward fluctuation in rainfall however set in from early1990 which continued into the 21st century. From 1990, rainfall distribution became very irregular with few wet years.

Lowest rainfall was recorded in 1982 with annual rainfall of 294.2mm. Other years of significantly low rains are 1984 (314.1mm), 1985 (317.9mm), 1973 (325.5mm) 1997 (331.9mm), 1983 (348.9mm), 1987(352.7mm) and 1972 (367.9mm). Highest rainfall in Goronye town was recorded in 1954 (788.7mm). This was followed by 1958 (751.5mm), 1952(892.2mm), 1994 (740.4mm), 1961 (726.8mm) and 1962 (724.7mm) and 1952 (718mm).

A total rainfall of 21737.6mm was recorded in the wet years (i.e. 34years) in which annual rainfall was above mean value of 534.5mm. During the wet years an average rainfall of 639.34mm was observed. Minimun and maximun rainfall of the wet rainfall episode were 534.6mm and 788.7mm respectively, with a range value of 254.1mm. In the dry years episode (36years) in which rainfall amounts were below average, a total of 15674.8mm rainfall amount was recorded with an average value of 435.4mm. Maximun and minumun amounts in Goronye during the dry episode were 294.2mm and 533.3mm with a range value of 239.1mm (Fig. 6). Similar to character observed in Goronye, the first five decades in Galadi stating from mid 1940, to late 1980s were the wet decades (Fig.7). Lowest rainfall was recorded in 1982 with annual rainfall of 366.9mm. Significant low rainfall years were recorded in 1973 (351.1mm), 1987 (370.1mm), 1972 (387.3mm) 1985 (389.2mm), 1993 (394.1mm) and 1983 (399.3mm). Highest rainfall in Galadi was recorded in 1954 with an annual value of 885.3mm. This value was followed by values recoreded for 1964 (882.6mm), 1957 (846mm), 1952 (828mm), 1946 (815.9mm) , 1948 (814.2mm) and 1958 (805.4mm).

A total rainfall of 26124.5mm was recorded in the wet years (i.e. 35years) in which annual rainfall was above mean value of 626.6mm. Mean value of wet years was 746.4mm Minimun and maximun rainfall of the wet rainfall episode were 652.7mm and 885.3mm respectively, with a range value of 232.6mm. There are 35years in which rainfall amounts were below average (626.6mm). In the dry years a total of 17739.8mm rainfall amount was recorded with an average value of 506.9mm. Maximun and minumun amounts in Galadi during the dry episode were 326.9mm and 618.3mm with a range value of 291.4mm (Fig. 7).

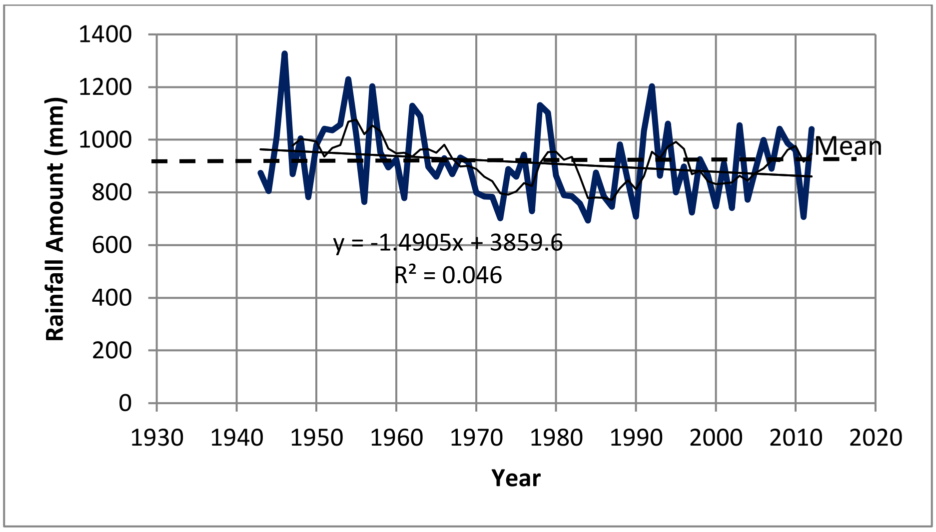

Fig. 8: Annual pattern of Rainfall in Maje, SE, Sokoto-Rima River basin

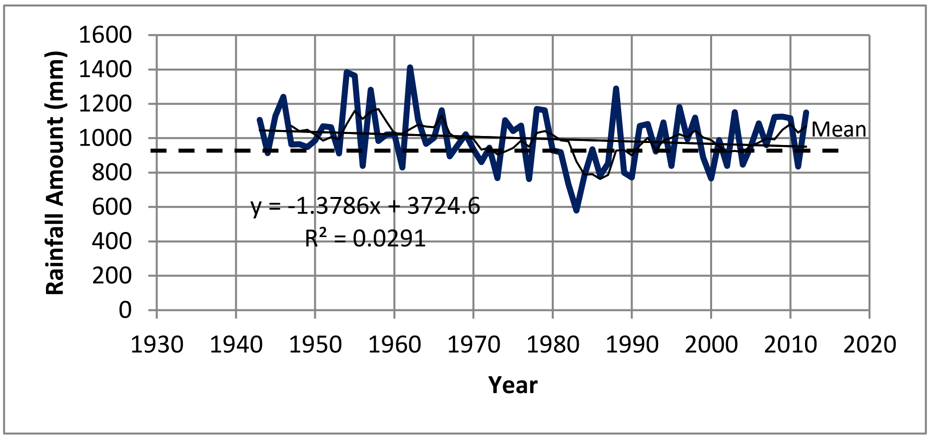

Fig. 9: Annual Trend of Rainfall in Dan-Dume, SE, Sokoto-Rima River basin

Maje town recorded more years in which rainfall amount were below an average of 915.2mm during the 70 years under investigation. Lowest rainfall was recorded in 1984 with annual rainfall of 693.2mm. Years of noticeable low rainfall includes 1973 (701.4mm), 2011 (707.3mm), 1990 (708mm) 1997 (729.2mm) and 2002 (740.6mm). Highest rainfall in Maje town was recorded in 1946 with an annual value of 1327.5mm (4.34). Other years in which rainfall amounts were signficantly high are 1954 (1229.9mm), 1992 (1203.9mm), 1957 (1203.9mm), 1978 (1132.1mm), 1962 (1129.1mm) and 1979 (1102.4mm). A total rainfall of 32250.1mm was recorded in the wet years (i.e. 31years) in which annual rainfall was above mean value of 912.1mm. A mean rainfall value of 1040.4mm was recorded for wet years. Minimun and maximun rainfall of the wet rainfall episode were 915.1mm and 1327.5mm respectively, with a range value of 412.4mm. In the dry (39years) a total of 31598.6mm rainfall amount was recorded with an average value of 810.2mm. Maximun and minumun amounts in the dry episode were 693.2mm and 911mm respectively. Rainfall range value of 287.6mm was observed in the dry years episode (Fig. 8).

Annual rainfall trend of Dan-Dume town is presented in (Fig.9). Like rainfall pattern in Maje, there was more years of downward fluctuations below mean value which began from 1980s with few upward rise above mean value. Lowest rainfall was recorded in 1983 with annual rainfall of 579.8mm. Other years with very low rainfall are 1982 (733.4mm), 1977 (763.4mm), 2000 (766mm) 1973 (768.4mm), 1990 (772.2mm), 1984 (783.2mm). Highest rainfall was recorded in 1962 with an annual value of 1412.2mm. Other years of high rainfall in Dan-Dume include 1954 (1384.1mm), 1955 (1364.1mm), 1988 (1288.7mm), 1957 (1281.3mm) and 1946 (1241.2mm). In the wet years episode (32years), a total rainfall of 36540.1mm was recorded. A mean value of 1141.9mm was recodered in the wet years. Minimun and maximun rainfall of the wet rainfall episode were 1001.9mm and 1412.2mm respectively. A rainfall range value of 410.3mm was observed in wet years. In the dry years a total of 33356.3mm rainfall amount was recorded with an average value of 877.8mm. Maximun and minumun amounts during this episode were 579.6mm and 993.1mm with a range value of 413.5mm (Fig. 9). Detailed descriptive statistics of annual rainfall patterns in the study area is presented in Table 2.

Table 2: Descriptive statistics of long term annual rainfall (mm) character in southeast, Sokoto-Rima river Basin

	Location	Duration of wet years	Duration of dry years (mm)	Lowest amount in dry years (mm)	Highest amount in wet years (mm)	Mean of wet Years (mm)	Mean of dry years (mm)	Total rainfall of wet years (mm)	Total rainfall of dry years (mm)
NW	Gulma	37	33	389.1	1038.7	841.8	612.1	31146	2019.8
	Augi	33	37	379.3	1050.7	837.3	598.4	27631	22141.5
SW	Bunza	36	34	423	1102.5	905.1	680.8	32583.8	23146.4
	Dakingari	35	35	506	1143.1	954	762.1	33423.1	26672.6
NE	Goronye	34	36	294	788.7	534.5	435.4	21737.6	15674.8
	Galadi	35	35	366.9	885.3	746.4	506	26124	17739.8
SE	Maje	31	39	693.2	1327.5	1040.4	810.2	32250	31598.6
	Dan-Dume	32	38	579.8	1412.2	1141.9	877.8	36540.1	33356.3

Rainfall was generally highest south of the Sokoto-Rima River Basin. This is expected given the general rainfall trend in Nigeria. Highest rainfall amounts were however found, southeast of the Basin with Dan-Dume recorded the highest rainfall amount. This pattern is followed by rainfall values of stations, southwest of the basin. Lowest annual rainfall amount was recorded north east of the basin (Table 3). The spatial pattern of rainfall distribution can be explained in the light of movement of The Inter-Tropical Discontinuity (ITD which is most popularly accepted medium that influence rainfall distribution in Nigeria (Lamb 1983; Adejuwon *et al*.1990). Studies have shown that to the southern part of ITD, varying degrees of convective activity and precipitation takes place, whereas, little or no cloud development or precipitation occur to the northern most part. In other words, rain falls mostly when an area is over-lain by the Tropical maritime (mT) air mass and ceases when the area is over-lain by the Continental Tropical (cT) air mass. This makes the position of ITD a great determinant of most rainfall attributes in the region.

Table 3: Descriptive statistics of annual rainfall in Sokoto-Rima River basin (1943-2012)

Rainfall (mm)

	Climatic Station	Mean	SD	Min	Max	Range	SE
NW	Gulma	733.5	145.7	389.1	1038.7	649.6	17.4
	Augi	711.0	147.4	379.3	1050.7	671.4	17.6
SW	Bunza	796.14	142.8	432.2	1100.2	677	17.1
	Dakingari	858.5	126.5	506	1143.1	637.1	15.12
NE	Goronyo	534.5	124.7	294.2	788.7	494.5	14.9
	Galadi	626.6	140.4	326.9	885.3	558.4	16.7
SE	Maje	912.13	141.4	693.2	1327.5	634.3	16.9
	Dan-Dume	998.5	164.3	579.6	1412.2	832.6	19.6

Average percentage rates of deviations from mean annual rainfall amounts are presented in Figs 10-17). In Gulma town, average departure rates of 9.6%, 9.5%, 9.6%, 9.8%, 9.8% and 2.4% were recorded in 1950s, 1960s, 1970s, 1980s, 1990s and 21st

century (Fig 10). This is the rate of deviation from annual mean for the period 1943-2012.Lowest departure from average rainfall was recorded in the start of 21st century while highest deviation was recorded in 1980s and 1990s. In the 1950, there were more years with rainfall above annual mean line. The annual percent departures were established as follows, 11%, 32%, 17%, 7%, 5%, -8%, 29%, 5%, -2% and 1% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was 9% (1960), 17% (1961), -1% (1962), 8% (1963), 21% (1964), 12% (1965), 19% (1966), 4% (1967), 12% (1968), -5% (1969). For the decade 1970 annual rainfall departure were 25%, 15%, 55%, 25%, 3%, -27%, 13%, -47%, 12% and 23% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 9% (1980), 27% (1981), 3% (1982), 18% (1983), 14% (1984), 6% (1985), 22% (1986), -6% (1987), 2% (1988), 1% (1989). The 1990-decade deviation was recorded as follows, 1990 (71%), 1991 (-39%), 1992 (7%), 1993 (70%). 1994 (-17%), 1995 (15%), 1996 (-22%), 1997 (5%), 1998 (32%) and 1999 (23%). Between 2000 to 2010, year-year deviation was 47%, 55%, -38% 54% -1% -18% -4% -10% 26% and -9% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

In Augi town decadal departure rates of 9.7%, 9.7%, 9.8%, 9.7%, 11.2% and 10% were recorded in 1950s, 1960s, 1970s, 1980s, 1990s and the start of 21st century. Lowest departure was recorded in 1950s and 1960s (Fig. 11). In the 1950, there were more years with rainfall above annual mean line. The annual percent departures were established as follows, 14%, 27%, 14%, 7%, 3%, -7%, 27%, 7%, -2% and 7% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was 12% (1960), 18% (1961), 5% (1962), 2% (1963), 23% (1964) , 14% (1965), 8% (1966), -1% (1967), 16% (1968). For the decade 1970 annual rainfall departure were 28%, 18%, 60%, 26%, 8%, -37%, 9%, -51%, 13% and 24% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 7% (1980), 28% (1981), 0% (1982), 17% (1983), 13% (1984), 5% (1985), 24% (1986), -10% (1987), 7% (1988), 6% (1989). The 1990-decade deviation was recorded as follows, 1990 (-97%), 1991 (91%), 1992 (29%), 1993 (-93%), 1994 (48%), 1995 (-2%), 1996 (79%), 1997 (35%), 1998 (-53%) and 1999 (75%). Between 2000 to 2010, year-year deviation was 96%, 46%, -54%, 66%, -7% -30%, 43% -65%, 43% and -38% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

In Bunza town, departure rates of 9.7%, 9.4%, 0.8%, 9.7%, 19.8%, 9.8% were recorded in 1950s, 1960s, 1970s, 1980s, 1990s and at the start of 21st century. Lowest departure from average rainfall was recorded in 9.4% with the highest departure rate being witnessed in the 1990s and 2000s (Fig. 12). In the 1950, there were more years with rainfall above annual mean line. The annual percent departures were established as follows, 11%, 14%, 19%, 15%, 11%, 6%, -4%, 20%, 4% and 1% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was 2% (1960), 6% (1961), 15% (1962), 4% (1963),9% (1964), 13% (1965),12% (1966), 10% (1967), 7% (1968) and 16%(1969). For the decade 1970 annual rainfall departure were 6%, 42%, 11%, 18%, 28%, -4%, -46%, 24%, -88% and 17% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 9% (1980), 6% (1981),28% (1982), 3% (1983), 16% (1984), 12% (1985), 3% (1986), 22% (1987), -

9% (1988), 7% (1989). The 1990-decade deviation was recorded as follows, 1990 (48%), 1991 (-25%), 1992 (26%), 1993 (20%), 1994 (-21%), 1995 (74%), 1996 (2%), 1997 (87%), 1998 (24%) and 1999 (-37%). Between 2000 to 2010, year-year deviation was 56%, 29%, 17%, -28%, 36%, 5%, -16%, -6%, 0% and 2% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

In Dakingari town average percentage departure of 9.8% was recorded in 1950s and 1960s, 2.9% in 1970s, 9.6% in 1980s, 19.0% in 1990s and -0.4% in 2000s (Fig. 13). In the 1950, there were more years with rainfall above annual mean line. The annual percent departures were established as follows, 17%, 14%, 19%, 22%, 8%, -4%, 20%, 1%,34% and -2% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was -4% (1960), 26% (1961), 14% (1962), 20% (1963), -2% (1964), 6% (1965),5% (1966), 17% (1967), 25% (1968) and -9%(1969). For the decade 1970 annual rainfall departure were 0%, 1%, 0%, 0%, 0%, -1%, 0%, 17%, 8% and 4% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 6% (1980), 24% (1981), 6% (1982), 18% (1983), 8% (1984), 2% (1985), 23% (1986), -9% (1987), 6% (1988) and 12% (1989). The 1990-decade deviation was recorded as follows, 1990 (-55%), 1991 (46%), 1992 (11%), 1993 (-12%), 1994 (87%), 1995 (-9%), 1996 (53%), 1997 (-2%), 1998 (-16%) and 1999 (87%). Between 2000 to 2010, year-year deviation was -2%, 3%, -5%, -2%, 2%, 0%, 4%, 2%, 0% and -6% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

Goronyo town recorded average departure rates of 9.6% in 1950s, 9.8% in 1960s, 9.9% in 1970s, 9.6% in 1980s, 18.8% and 10.1% in 1990 and 2000s respectively (Fig. 14). The annual percent departures were established as follows 15%, 10%, 21%, 7%, 6%, 8%, 18%,12% and -1% for, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. There was no evidence of deviation in 1950. For the 1960 decade, the annual percent deviation was 26% (1960), 26% (1961), 6% (1962), 18% (1963), 17% (1964), 14% (1965),17% (1966), -11% (1967), -15% (1968) and -1%(1969). For the decade 1970 annual rainfall departure were 34%, 36%,45%, 0%, 5%, 0%, 5%, -37%,78% and 4% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 5% (1980), 18% (1981), 14% (1982), 17% (1983), 16% (1984), 5% (1985), 14% (1986), 0% (1987), 0% (1988) and 7% (1989). The 1990-decade deviation was recorded as follows, 1990 (29%), 1991 (45%), 1992 (81%), 1993 (-35%), 1994 (35%), 1995 (24%), 1996 (33%), 1997 (-12%), 1998 (-93%) and 1999 (78%). Between 2000 to 2010, year-year deviations were 40%, 25%, -9%, 16%, -1%, -1%, 18%, -9%. 28% and -6% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

Galadi town recorded average percent departure rates of 12.7%, 8.4%, -0.5%, -12.5%, -2.0% and -0.3% in 1950s, 1960s, 1970s, 1980s, 1990s and at the start of 21st century respectively (Fig. 15). The annual percent departures were established as follows 4%, 19%, 14%, 25%, 3%, 12%, 21%,17%, 8% and 4% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was 12% (1960), 12% (1961), 13% (1962), 25% (1963), 15% (1964), 13% (1965), 10% (1966), -10% (1967), 4% (1968) and -2% (1969). For the decade 1970 annual rainfall departure were 30%, -23%, -27%, -3%, -8%, 6%, -2%, 11%,5% and 6% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 7% (1980), 29% (1981), 18% (1982), -22% (1983), -23% (1984), -95% (1985), -25% (1986), 5% (1987), 2% (1988) and -13% (1989). The 1990-decade deviation was recorded as follows, 1990 (20%), 1991 (-10%), 1992 (-22%), 1993 (9%), 1994 (-6%), 1995 (-2%), 1996 (-17%), 1997 (12%), 1998 (9%) and 1999 (-11%). Between 2000 to 2010, year-year deviation was 8%, -9%, 11%, -12%, 0%, 8%, -4%, -4%, -5%, and 6% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively

In Maje Town, average rainfall departure rates of 9.8%, -5%, 9.7%, -7.5%, -3.7%, and 10% were recorded in 1950, 1960, 1970, 1980, 1990 and the start of the 21st century (Fig. 16). The annual percent departures were established as follows 13%, 12%, 14%, 31%, 10%, -14%, 29%, 3%, -1% and 1% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was -18% (1960), 72% (1961), 22% (1962), -17% (1963), -65% (1964), 23% (1965), -53% (1966), 25% (1967), 3% (1968) and -42% (1969). For the decade 1970 annual rainfall departures were 38%,38%, 63%, 6%, 15%, -9%, 55%,66%, -57% and 14% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 10% (1980), -10% (1981), -13% (1982), -18% (1983), -3% (1984), -11% (1985), -14% (1986), 6% (1987), -5% (1988) and -17% (1989). The 1990-decade deviation was recorded as follows, 1990 (59%), 1991 (89%), 1992 (-31%), 1993 (79%), 1994 (-51%), 1995 (-64%), 1996 (-85%), 1997 (66%), 1998 (-25%) and 1999 (-74%). Between 2000 to 2010, year-year deviations were, -35%, 12%, -19%, -17%, 68%, -17%, 12%, 58%, and 28% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, and 2008 respectively. There was no evidence of deviation in 2009.

Dan-dume recorded departure rate of 9.3% in 1950, -0.8% in 1960, 7.8% in 1970, -13.7% in 1980, 3.0% in 1990 and 1.8% in 2000s (Fig. 17). The annual percent departures were established as follows 7%, 6%, -8%, 37%, 36%, -15%, 27%, -1%, 2% and 2% for, 1950, 1951, 1952, 1953, 1954,1955, 1956, 1957, 1958 and 1959 respectively. For the 1960 decade, the annual percent deviation was -54% (1960), 40% (1961), 10% (1962), -3% (1963), 0% (1964), 16% (1965), -10% (1966), -3% (1967), 2% (1968) and 6% (1969). For the decade 1970 annual rainfall departures were 81%, -5%, -22%, 10%, 4%, 7%, -23%, 16%, 167% and -6% for 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977, 1978 and 1979 respectively. In the decade 1980 year-year deviation was 5% (1980), -26% (1981), -41% (1982), -21% (1983), -6% (1984), -21% (1985), -14% (1986), 28% (1987), -19% (1988) and -22% (1989). The 1990-decade deviation was recorded as follows, 1990 (-21%), 1991 (8%), 1992 (-7%), 1993 (-15%), 1994 (17%), 1995 (0%), 1996 (11%), 1997 (-10%), 1998 (-25%) and 1999 (-3%). Between 2000 to 2010, year-year deviations were, -4%, -15%, 15%, -14%, -4%, -8%, -3%, 12%, 12% and 11% for 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008 and 2009 respectively.

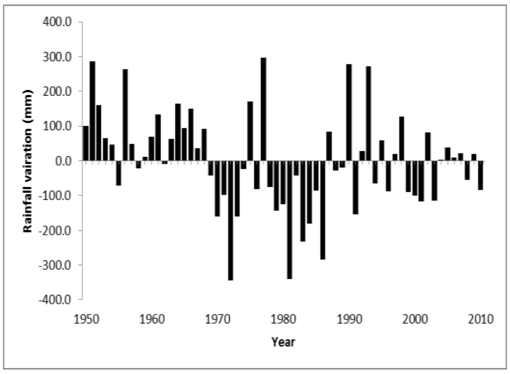

Fig. 10: Annual departures from Long-term average rainfall in Gulma, NW, Sokoto-Rima River basin

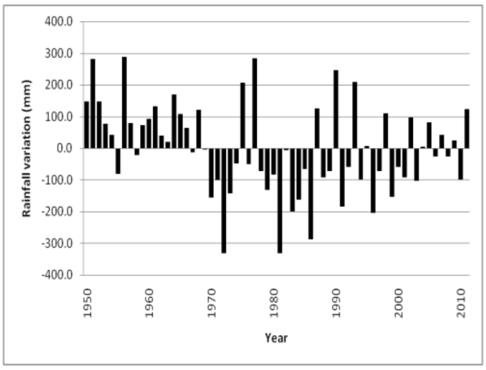

Fig. 11: Annual departures from Long-term average rainfall in Augi, NW, Sokoto-Rima River basin

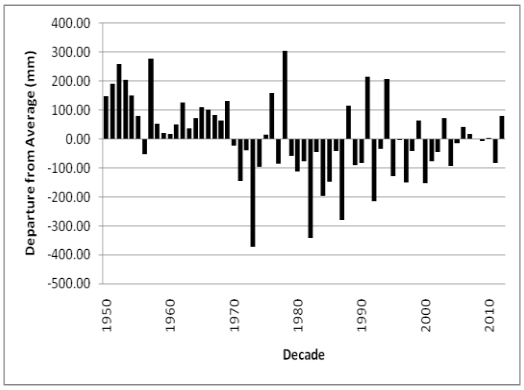

Fig. 12: Annual departures from Long-term average rainfall in Bunza, SW, Sokoto-Rima River basin

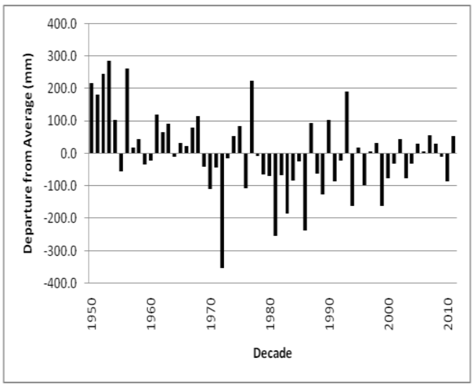

Fig. 13: Annual departures from Long-term average rainfall in Dakingari, SW, Sokoto-Rima River basin

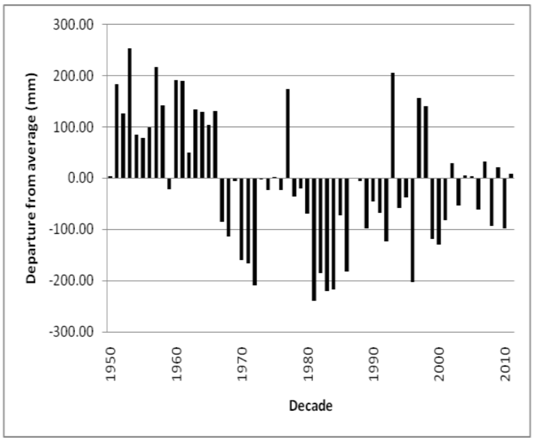

Fig. 14: Annual departures from Long-term average rainfall in Goronyo, NE, Sokoto-Rima River basin

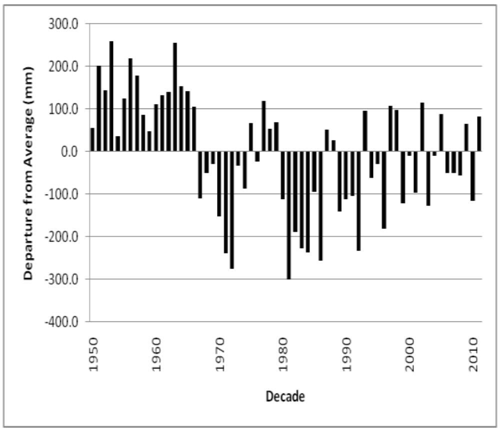

Fig. 15: Annual departures from Long-term average rainfall in Galadi, NE, Sokoto-Rima River basin

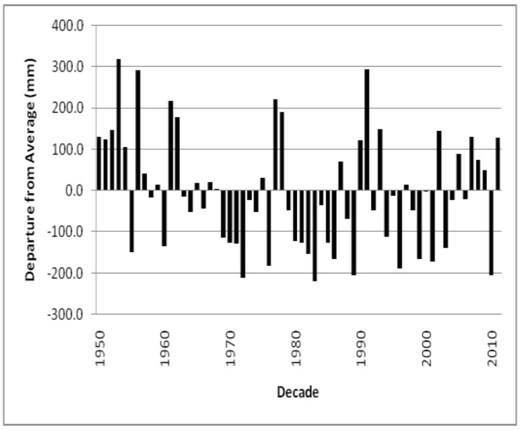

Fig. 16: Annual departures from Long-term average rainfall in Maje, SE, Sokoto-Rima River basin

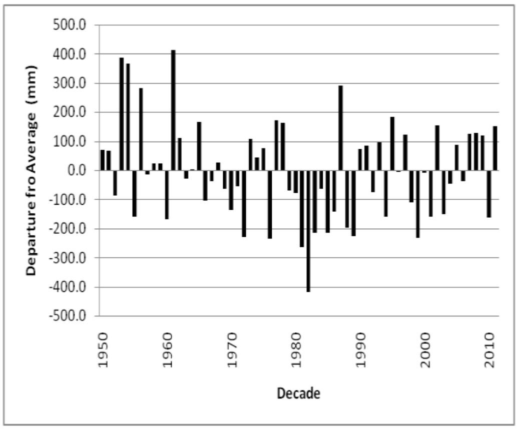

Fig. 17: Annual departures from Long-term average rainfall in Dan-Dume, SE, Sokoto-Rima River basin

Discussion

In general, the study found that periods of downward fluctuations in annual rainfall below mean values corresponded with period of rise in global temperature occasioned by anthropogenic greenhouse gases emission, a relationship which is an evidence of changing climate in the study area. This pattern is in line with the Third Assessment Report of the Intergovernmental Panel on Climate Change IPCC, (2001), which provided evidence of decreasing rainfall for locations between latitudes 10 °S and 0°N of the globe as a direct response to rising global mean temperature surface temperature by about 0.6+/- 0.2°C over the 20th century. Karmalka et *al.*, (2010) have also shown that mean temperature annual in temperature in Nigeria has increased by around 0.8°C between 1960 and 2006 and average rate of 0.18°C per decade. This increase has been accompanied by statistically decreasing trend of 3.5mm in rainfall per month (1.8%) per decade between1960-2006. Odjugo (2010) also showed that the period of drastic rainfall decline in Nigeria corresponds with the period of sharp temperature rise. The author found that temperature increase in Nigeria has been gradual until the late 1960s and this gave way to a sharp rise in air temperatures from the early 1970s, which continued till date. The mean air temperature in Nigeria between 1901 and 2005 was 26.6°C while the temperature increase for the 105 years was 1.1°C. Similarly, the observed variability patterns of rainfall around mean values in the study area reflect observations in several studies which have analyzed rainfall trends and characteristics in Northeastern Nigeria. Hess *et al* (1995); Tarhule and Woo (2002) and Bibi (2014) for example identified a negative trend in yearly rainfall totals in the region from 1961–1990 with an increase in dry spells (dry episodes) during the wet season. Hess *et al* (1995) found a reduction of 8 $mm \cdot yr^{-1}$ over the period. The occasionally observed downward trends in annual rainfall amounts 1950, 1960 and in the late 70s/early 80s in the Sokoto-Rima River Basin may be attributed to the large inter-annual variations in rainfall amounts as well as the effects of the repeated and prolonged Sahel droughts of 1940s, 1960-1973 and 1980-1987 (Amissah-Arthur, 1999).

The marked variations in positive and negative departures from mean annual amounts maybe attributed to the large inter-annual variations in rainfall amounts as well as the effects of the repeated and prolonged Sahel droughts of 1940s, 1960-1973 and 1980-19871950, 1960 and in the late 70s/early 80s in the Sokoto-Rima River Basin (Amissah-Arthur and Jagtap, 1999). Similarly, studies have shown that the Sahelian drought is believed to have tele-connections with El Nino Southern Oscillation (ENSO), a phenomenon that is associated with periodic fluctuation in the intensity of the inter-tropical atmospheric and oceanic circulations that is usually coincident with an anomalous warming of the Eastern Tropical Pacific Ocean (Nicholson and Tucker, 1998; Akonga, 2001; Giannini et al., 2005) further identified SST as the principal driver of Sahelian rainfall variability, which they modeled successfully for the period 1930-2000, using a model that also represent the land-atmosphere interaction, via moisture feedbacks. The study found total annual rainfall in the Sahel was above average during the 1950s and early 1960s, and then steadily decreased from the late 1960s through the 1970s and 1980s. The decline was punctuated by major widespread episodes of drought and famine, e.g., in 1972–1973 and 1982–1984. This finding is similar to patterns observed for the climatic stations in the study area and may confirm the strong correlation between tropical ocean's surface temperature and precipitation in the Sahel and suggest a gradual encroachment of the Sahelian anomalous rainfall conditions into the Sudano region of the Sokoto-Rima River Basin. Notwithstanding, variation was observed to be more pronounced northeast of the study area and confirms the tele-communications of the Sokoto-Rima River basin with El Nino Southern Oscillation effect. The gradual extension of Sahel rainfall character into the Sudano area of the study area will induce changes in the basin in the form of human-induced desertification, e.g., loss of vegetative cover caused by the farming and overgrazing of marginal lands to satisfy the needs of an ever-increasing population, increasing demand on declining surface water resources for irrigation/agricultural purposes, loss of agricultural output.

References

Adelana, S. M. A., Olasehinde, P. I. & Vrbka, P. (2003). Isotope and geochemical characterization of surface and subsurface waters in the semi-arid Sokoto Basin, Nigeria. *African Journal of Science and Technology*, 4(*2*). 76–89

Adejuwon, J. O., Balogun, E. E., Adejuwon S. A. (1990). On the annual and seasonal pattern of rainfall fluctuations in Sub-Saharan West Africa. *International Journal of Climatology*, 10: 810-848

Akonga, A. Z. (2001). The causes and impacts of drought. *ANIS Monograph*, 3. 1-6

Allen, R.G., Pereira, L.S., Raes, D. & Smith, M. (1998). Crop evapotranspiration – Guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper*, No. 56, FAO, Rome

Amissah-Arthur, A. & Jagtap, S. S. (1999). Geographic variation in growing season rainfall during three decades in Nigeria using principal component and cluster analyses. *Theor. Appl. Climatol.* 63. 107–116

Giannini A., Saravanan R., Chang P. (2005). Dynamics of the boreal summer African monsoon in the NSIPP1 atmospheric model. *Clim Dyn.* 25. 517–535

Hanafi, A. & Jauffret, S.A. (2008): Long-term vegetation dynamics useful in monitoring and assessing desertification processes in the arid steppe, southern Tunisia", *Journal of Arid Environments*, 72 (*4*).557–572.

Hess, T. M., Stephens, W., Maryah, U. M., (1995). Rainfall trends in the North East Arid Zone of Nigeria 1961–1990. Agric. For. Meteorol., 74. 87–97.

Huang, S. & Siegert, F. (2006). Land cover classification optimized to detect areas at risk of desertification in North China based on Spot Vegetation imager", *Journal of Arid Environments*, 67(*2*). 308 – 327.

Hughes, R. H. & Hughes, J. S. (1991). *A directory of African wetlands*, IUCN, Gland, Switzerland.

IPCC, (2001). *Climate change 2001: Synthesis report. Contribution of working groups i, ii, and iii to the third assessment report of the intergovernmental panel on climate change* [Watson, R.T. and the Core Writing Team (eds.)]. Cambridge: Cambridge University Press. 398.

IPCC: Climate Change (2013). *The physical science basis. Contribution of working group I to the fifth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, USA: Cambridge University Press. 2013.

Ita, E. O. (1993). Inland Fishery Resources of Nigeria *CIFA Occasional Paper* No 20. Rome, FAO. 1993. 120p

Karmalkar A., McSweeney, C., New, M. & Lizcano, G. (2010). UNDP climate change country profiles: Nigeria http://country-profiles.geog.ox.ac.uk

Lamb P. J. (1983). Sub-Saharan rainfall update for 1982 continuous drought. *Journal of climatology*. 3. 419-422

Mitchell T. D. &. Jones P. D. (2005): An improved method of constructing a database of monthly climate observations and associated high-resolution grids *Int. J. Climatol*. 25. 693–712

New, M., Hulme M. & Jones, P.D. (2000). Representing twentieth century space–time climate variability. Part 2: Development of 1901–96 monthly grids of terrestrial surface climate. *J. Climate*. 13. 2217–2238

Nicholson, S. E. & Tucker, C. J. (1998). Desertification, drought, and surface vegetation: an example from the West African Sahel. *Bulletin of the American Meteorological Society*, 79(*5*). 815-829

Odjugo P.A.O. (2010). Regional evidence of climate change in Nigeria, J. Geogr. Reg. Plann., 3(*6*). 142-150.

Sivakumar, M. V. K. (2007). Interactions between climate and desertification". *Agricultural and Forest Meteorology*, 142 (*2&4*). 143–155.

Sombroek, W. G., & Zonneveld, I. S. (1971): *Ancient dunes fields and fluviatile deposits in the Rima Sokoto River Basin*, soil survey paper No.5, Netherland Soil Survey Institute, Wageningen. 109

Sonia, K., Max, R., Minus, V.B. & Michel, L. (2007). Local facilitation, bistability and transitions in arid ecosystems. *Theoretical population biology*, 71(*3*). 367–379.

Susana, B. A. & Kelley, A. C. (2006). Aridity and desertification: Exploring environmental hazards in Jáchal, Argentina. *Applied Geography*. 26 (*1*). 61 – 85

Zhao, H. L., Zhao, X.Y., Zhou, R. L., Zhang, T. H., & Drake, S. (2005). Desertification processes due to heavy grazing in sandy rangeland, Inner Mongolia. *Journal of arid environments*. 62 (*2*). 309–319