SPATIAL AND TEMPORAL PATTERNS OF CLIMATIC CHANGE IN THE SOKOTO-RIMA RIVER BASIN, SUDANO-SAHEL REGION, NIGERIA

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Abstract

The Sokoto-Rima drainage basin is important for food and agricultural production in the country as well as has a sizeable number of irrigation and other river basin development projects that requires the knowledge of response patterns of climatic variables to changing climate in terms of the magnitude of change, rate of change, spatial and temporal trends of the changing climate both annual and seasonal, when the change became significant. Such information is very useful in designing measures and formulating policy for appropriate response and adaptation to climate change. The study therefore attempts to investigate the response of rainfall and temperature to climatic change. To achieve this aim, data from the Nigerian Meteorological Agency, NIMET and the global Climatic Research Unit CRU for the period 1943-2012 were obtained and utilizing various statistical methods such as Mann-Kendel, Spearman’s Rho, Linear regression, free distribution CUSUM, cumulative deviation and Worsley Likelihood tests the data were tested for trends and step jumps. The Pearson’s Product correction was performed to ascertain the reliability of CRU data used in the study. The results revealed evidence of decreasing tend in the time series of annual rainfall, while evidence of rising trend was detected in the time series of temperature. There was evidence of statistical difference between the two climatic periods; 1943-1977 and 1978-2012. These were detected at statistical thresholds of $\alpha<0.05$ for rainfall and $\alpha<0.01$ for temperature. Average percentages of change in annual rainfall and temperature which is the magnitude of deviation from annual rainfall and temperature of the first climatic period during the second climatic period were determined as 5.7% (rainfall) and 0.95% (temperature) in the northwest part of the study area, 3.2% (rainfall) and 0.88 (temperature) in southwest of the study area, 5.99% (rainfall) and 1.02% (temperature) in northeast of the study area , 2.3% (rainfall) and 0.87% (temperature) southeast of the study area. On a seasonal scale, average percentages of change in rainfall northwest of the study area were observed as 8.5%, 6.6% in southwest, 13.0% in northeast and 3.2% southeast of the study area. The study showed that annual temperature change in the Sokoto-Rima River basin was observed to be higher than the observed 0.74 ± 0.18°C increase in average global temperature of the Earth during the past 100 years. Change points in the long-term rainfall annual distributions occurred in1970, while change point in long-term annual temperature pattern in the basin was observed in 1981.

Keywords: Climate change, Rainfall, Temperature, Agricultural Production, River Basin

Introduction

The study area delineated for this study is the Sokoto-Rima River basin, located in north western Nigeria and thus lies within the semi-arid region or the transition zone between Sahel savanna in the north and sub humid Sudan savanna in the south and which according to IPCC (2007), is highly vulnerable to climate change. The greatest food insecurity concerns in Nigeria remain in the extreme north of which the Sokoto-Rima River basin is a part. This area according to the United States Agency for International Development (USIAD, 2012) is already classified as "stressed" under the 2012 estimated food security conditions in Nigeria and will have serious implications on the population of the study area which dependent heavily on agriculture with limited opportunities outside of the agricultural sector. The report attributed this water-stress to the prolonged dry spells during the 2011 growing season with significant shortfalls in cereal production. Similarly, for any meaningful water resources project in the region, understanding the response patterns of climatic variables to global warming is fundament and prerequisite. Such knowledge is necessary for modelling the basin behaviour to climatic variability as well as for building predictive models. Again, given the threats due to climate change on water resources, the need to understand how change in global climate could affect regional water supplies becomes very necessary. The study therefore attempts to investigate the response of rainfall and temperature to climatic change.

Materials and Method

The study area is located in the northwestern 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 and 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.

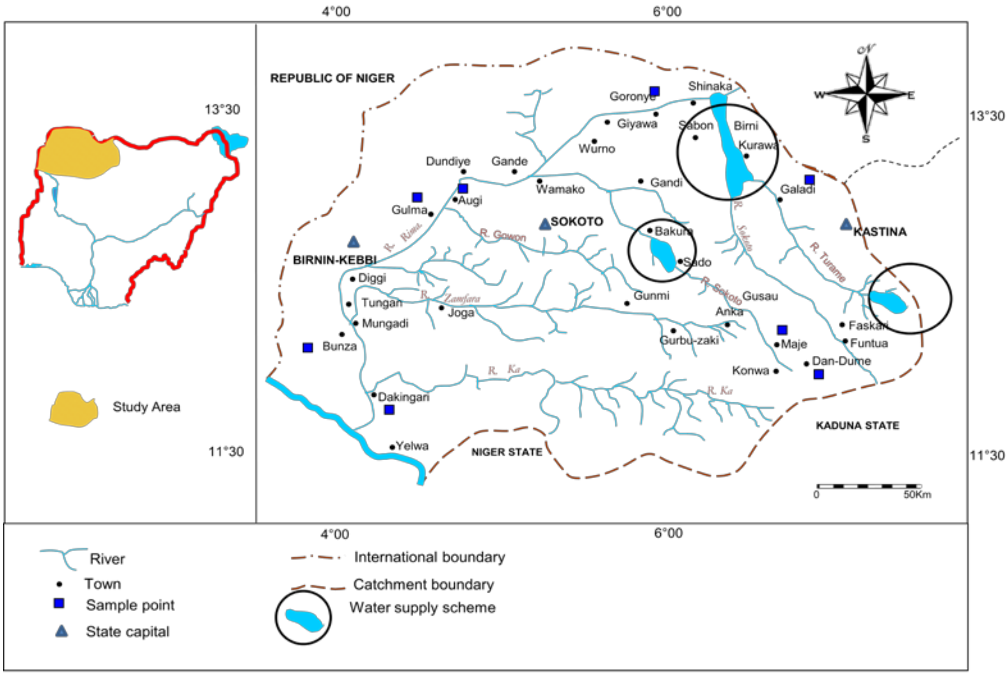

FIG. 1: SOKOTO RIVER BASIN

Source: (Adopted from Ita, 1993)

Data collection and Analysis

High-resolution precipitation datasets in millimeter 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 covers the entire globe for the period 1901-2012 is available on http://www.cru.uea.ac.uk/ Rainfall and temperature data were assembled on monthly basis for a period of 70 years for Bunza and Dakindari, SW of the basin, Gulma and Augi, NW, Goronye and Galadi, NE and Maje and Dan-Dume SE of the basin. This climatic period was chosen to enable the comparison between two climatic period (1943-1977 and 1987-2012). This first climatic period as used in the study is represented as 1943-1977 (first climatic scenario) while 1987-2012 represents the second climatic period (second climatic scenario). Quality control of CRU datasets is discussed in detail by New et al (2000) and Mitchel and Jones (2005). In addition the CRU data sets were verified by correlating data from this source with measured data from the Nigerian Meteorological Agency. Data analysis involved comparisons using the standard meteorological procedure of means of the selected parameters. Test for trend and step jump in long-term annual rainfall and temperature distributions were analyzed, using Mann-Kendel, Spearman's Rho, and Linear regression. The free distribution CUSUM, cumulative deviation and Worsley likelihood tests were used to test for trends, step jumps/change, while statistical differences in time series of hydro-meteorological indices were analyzed using the student t test and Rank sum test. These analyses were carried out using the TREND analytical software version 1.1.2 which is developed by Cooperative Research Centre for Catchment Hydrology, Australia.

Results and Discussion

Rainfall pattern of Sokoto-Rima River Basin, showed decreasing trend towards the northeast. Highest rainfall amounts are concentrated in the southeast. Northwest of the basin, Gulma town, recorded an average rainfall amount of 761.7mm was recorded during the first climatic period. This value however, dropped to 705.2mm in the second climatic period. Augi town recorded an average rainfall amount of 749.3mm during the first climatic period, with standard deviation value of 147.2. Rainfall was generally more variable in the second climatic period that pattern observed in the first climatic period (Table 1). In Table 2, there was evidence of rising temperature during the second climatic period. Lowest temperatures were found southeast of the basin. Temperature was generally variable in the second climatic period than pattern observed in the first climatic period. Coefficient of variability was however highest northeast of the basin which corresponds with rainfall variability coefficient in northeast of the basin. The fact that rainfall and temperature patterns became more irregular in the second climatic period is an indication of pronounced anomaly and change in the basin and which can be linked to global and regional large-scale sea-surface temperature anomaly (SSTA) which began in 1950s. Other model studies have shown that the increased Sahelian rainfall variability which became pronounced since 1970 onward is associated with SST anomaly patterns, including changes in the tropical Atlantic (e.g., Lamb, 1978a, 1978b; Hastenrath, 1990; Vizy and Cook, 2001, 2002), in the Pacific (e.g., Janicot *et al*., 1996; Rowell, 2001), in the Indian Ocean (Palmer, 1986; Shinoda and Kawamura, 1994), and in the Mediterranean (Rowell, 2003). Lucas *et al* (2014) on the other hand also attributed this change to global warming caused by anthropogenic emission of greenhouse gasses and the gradual expansion of the tropics. Results of trend and step jump analysis are presented in tables 3 and 4.

Table 1: Descriptive statistics of annual rainfall over Sokoto-Rima River basin for different climatic Periods

		Rainfall (mm)						
Climatic Station	Period	Mean	SD	Min	Max	Range	Sum	CV
NW								
Gulma	First Climatic period	761.7	145.8	389.1	1038.7	649.6	26660.4	19.14
	Second Climatic period	705.2	142	392.2	1031	638.8	24643.6	20.14
Augi	First Climatic period	749.3	147.2	379.7	1050.7	671	26224.2	19.7
	Second Climatic period	672.8	138.7	379.3	994.2	614.9	23548.3	20.6
SW								
Bunza	First Climatic period	836.2	143.9	423.2	1074.9	651.7	29267.0	17.2
	Second Climatic period	756.1	131.8	453.2	1100.2	647	26463.2	17.4
Dakindari	First Climatic period	891.1	139.7	506	1143.1	637.1	31200.4	15.7
	Second Climatic period	825.6	103.7	605.1	1081	475.9	28895.9	12.5
NE								
Goyonye	First Climatic period	584.1	120.6	325.5	788.7	463.2	20442.6	20.6
	Second Climatic period	484.9	109.3	294.2	740.4	446.2	16969.8	22.5
Galadi	First Climatic period	681.9	137.9	351.1	885.3	534.2	23865.7	20.2
	Second Climatic period	571.4	121.6	326.9	746.8	419.9	19998.6	21.2
SE								
Maje	First Climatic period	933.3	145.1	701.4	1327.5	626.1	32666.1	15.5
	Second Climatic period	890.9	136.5	693.2	1209	510.7	31183.2	15.3
Dan-Dume	First Climatic period	1029.9	160.7	763.4	1412.2	648.8	36049.7	15.7
	Second Climatic period	967.0	164.1	579.6	1288.7	709.1	33846.7	16.9

Table 2: Descriptive statistics of annual rainfall over Sokoto-Rima River basin for different climatic Periods

		Rainfall (mm)						
Climatic Station	Period	Mean	SD	Min	Max	Range	Sum	CV
NW								
Gulma	First Climatic Period	342.9	4.8	333.5	355	21.5	0.81	1.3
	Second Climatic Period	349.3	5.3	340.7	360.2	19.5	0.89	1.51
Augi	First Climatic Period	342.4	4.9	333	354.7	21.7	0.82	1.43
	Second Climatic Period							
SW								
Bunza	First Climatic Period	342.4	4.8	333.7	355.8	22.1	0.81	1.4
	Second Climatic Period	348.9	5.3	338.9	359.5	20.6	0.89	1.52
Dakindari	First Climatic Period	339.8	4.7	331.5	353.4	21.9	0.78	1.35
	Second Climatic Period	346.6	5.1	336.9	356.5	19.6	0.86	1.47
NE								
Goyonye	First Climatic Period	338.8	6.2	320.9	354.6	33.7	1.0	1.82
	Second Climatic Period	347.1	5.6	335.7	357.6	21.9	0.9	1.64
Galadi	First Climatic Period	335.7	9.6	313.1	351.1	38.2	1.6	2.9

	Second Climatic Period	334.6	5.4	322.9	345	22.1	0.9	1.63
SE								
Maje	First Climatic Period	317.2	3.9	308.7	326.4	17.7	0.67	1.25
	Second Climatic Period	222.6	4.6	312.2	331.1	19.1	0.78	1.43
Dan-Dume	First Climatic Period	305.5	3.6	296.7	314.3	17.6	0.6	1.2
	Second Climatic Period	310.8	4.5	300.7	320	19.6	0.76	1.5

Rainfall in northwest of the basin showed evidence of decreasing rainfall trend. Trend results of rainfall was calculated as -1.98 (Mann-Kendall), -1.954 (Spearman's Rho) and -2.03 (Linear regression) at $\alpha < 0.05$ for all the three tests which suggest strong evidence against our null hypothesis of non existence of trend. Temperature distribution northwest showed evidence of increasing trend. Results of temperature trend were calculated as 4.94 (Mann-Kendall), 4.65 (Spearman's Rho) and 5.71 (Linear regression). Trend in time series of temperature distribution was detected at $\alpha < 0.01$ for all the three tests (Table 3).

There was evidence of decreasing rainfall trend southwest of the basin. Trend results of rainfall was calculated as -2.25 (Mann-Kendall), -2.41 (Spearman's Rho) and -2.18 (Linear regression). Trend was detected in rainfall of southwest at $\alpha < 0.05$ for all the three tests which suggest strong evidence. Temperature distribution southwest of the basin showed evidence of increasing trend. Results of trends were calculated as 5.17 (Mann-Kendall), 4.84 (Spearman's Rho) and 6.03 (Linear regression). Trend were detected at $\alpha < 0.01$ for all the three tests.

Table 3: Results of trend analysis for climatic variables in the Sokoto-Rima River Basin (1943-2012)

Station	Time series	Mann-Kendal	Significance level (F)	Spearman's Rho	Significance level (F)	Linear Regression	Significance level (F)
	Annual Mm/^{0}C	z-test		z-test		t-test	
NW	Rainfall	-1.98	$\alpha<0.05$	-1.954	$\alpha<0.10$	-2.03	$\alpha<0.05$
	Temp	4.94	$\alpha<0.01$	4.65	$\alpha<0.01$	5.71	$\alpha<0.01$
SW	Rainfall	-2.25	$\alpha<0.05$	-2.41	$\alpha<0.05$	-2.18	$\alpha<0.05$
	Temp	5.17	$\alpha<0.01$	4.84	$\alpha<0.01$	6.03	$\alpha<0.01$
NE	Rainfall	-3.01	$\alpha<0.01$	-3.08	$\alpha<0.01$	-3.56	$\alpha<0.01$
	Temp	5.74	$\alpha<0.01$	5.31	$\alpha<0.01$	6.68	$\alpha<0.01$
SE	Rainfall	-1.60	$\alpha=0.10$	-1.53	$\alpha=0.10$	-1.81	$\alpha<0.10$
	Temp	4.73	$\alpha<0.01$	4.6	$\alpha<0.01$	5.48	$\alpha<0.01$

$\alpha = 0.1$: No evidence against H_0

$\alpha < 0.1$: Possible evidence against H_0

$\alpha < 0.05$: Strong evidence against $H_{0\alpha}$

$\alpha < 0.01$: Very strong evidence against H_0

Locations northeast of the basin presented evidence of decreasing rainfall trend (Table 3). Trend results of rainfall was calculated as -3.01 (Mann-Kendall), -3.08 (Spearman's Rho) and -3.56 (Linear regression). Trend was detected in rainfall time series at $\alpha<0.01$ for all the three tests which suggest very strong evidence. Temperature distribution in northeast of the basin showed evidence of increasing trend. Results of temperature trend were calculated as 5.74 (Mann-Kendall), 5.31 (Spearman's Rho) and 6.68 (Linear regression). Trend in time series of temperature distribution over northeast of the basin was detected at $\alpha<0.01$ for all the three tests. In southeast of the basin, trend in rainfall distribution was calculated as -1.60 (Mann-Kendall), -1.53 (Spearman's Rho) and -1.81 (Linear regression) (Table 3). Although trend was not detected in rainfall time series at $\alpha=0.10$ for Mann-Kendall and Spearman's rho tests result of linear regression presented possible evidence against our null hypothesis. Temperature distribution southeast of the basin showed evidence of increasing trend. Results of temperature trend were calculated as 4.73 (Mann-Kendall), 4.6 (Spearman's Rho) and 5.48 (Linear regression). Trend in time series of temperature distribution was detected at $\alpha<0.01$.

Table 4: Results of change detection analysis for variables in the Sokoto-Rima River Basin (1943-2012)

Station	Time series	**CUSUM**	**Significance level (F)**	**Cumulative deviation**	**Significance level (F)**	**Worsley Likelihood**	**Significance level (F)**
	Annual Mm/^{0}C	Max. Deviation		Q/Sqrt(n)		W	
NW	Rainfall	13	α<0.05	1.43	α<0.05	3.09	α<0.1
	Temp	21	α<0.01	2.38	α<0.01	6.15	α<0.01
SW	Rainfall	19	α<0.05	1.68	α<0.01	3.73	α<0.05
	Temp	21	α<0.01	2.41	α<0.01	6.01	α<0.01
NE	Rainfall	19	α<0.01	2.44	α<0.01	6.30	α<0.01
	Temp	23	α<0.01	2.55	α<0.01	6.42	α<0.01
SE	Rainfall	11	α = 0.1	1.38	α <0.05	3.17	α <0.05
	Temp	19	α <0.01	2.47	α <0.01	6.10	α <0.01

$\alpha = 0.1$: No evidence against H_0
$\alpha < 0.1$: Possible evidence against H_0
$\alpha < 0.05$: Strong evidence against $H_{0\alpha}$
$\alpha < 0.01$: Very strong evidence against H_0

Change detection results in time series of rainfall in northwest of the basin was calculated as 13 (Free distribution CUSUM), 1.43(Cumulative deviation) and 3.09 (Worsley likelihood ratio). Change in the time series of rainfall was detected at $\alpha<0.05$ for Free distribution CUSUM and cumulative deviation tests which suggest strong evidence against our null hypothesis of non existence of change, while Worsley likelihood test result showed possible evidence of step jump at $\alpha<0.10$. Temperature distribution in northwest of the basin showed evidence of change. Results of change in the time series of temperature were calculated as 21 (Free distribution CUSUM), 2.38 (cumulative deviation) and 6.15 (Worsley Likelihood ratio). Change in the time series of temperature distribution was detected at $\alpha<0.01$ for all the three tests (Table 4).

Locations southwest of the basin presented evidence of step jump/change (Table 4). Change detection results in time series of rainfall in Bunza town was calculated as 18 (Free distribution CUSUM), 1.68(Cumulative deviation) and 3.73 (Worsley likelihood ratio). Change in the time series of rainfall over southwest of the basin was detected at $\alpha<0.05$ for CUSUM and Worsley likelihood tests, while cumulative deviation test detected step jump at $\alpha<0.01$ which is a very strong evidence against our null hypothesis on non existence of change in annual time series of rainfall in Bunza town. Temperature distribution over southwest of the basin showed evidence of step jump. Results of change/step jump in the time series of temperature were calculated as 21 (Free distribution CUSUM), 2.41 (cumulative deviation) and 6.01 (Worsley Likelihood ratio). Change in the time series of temperature distribution was detected at $\alpha<0.01$ for all the three tests. Change detection results in time series of rainfall over northeast of the basin was calculated as 19 (Free distribution CUSUM), 2.44 (Cumulative deviation) and 6.30 (Worsley likelihood ratio). Change in the time series of rainfall was detected at $\alpha<0.01$ for the three tests. Temperature distribution northeast of the basin showed evidence of step jump. Results of change/step jump in the time series of temperature were calculated as 23 (Free distribution CUSUM), 2.55 (cumulative deviation) and 6.42 (Worsley Likelihood ratio). Change in the time series of temperature distribution was detected at $\alpha<0.01$ for all the three tests (Table 4).

Change detection results in time series of rainfall over southeast of the basin was calculated as 11 (Free distribution CUSUM), 1.38 (Cumulative deviation) and 3.17 (Worsley likelihood ratio). Change in the time series of rainfall was detected at $\alpha<0.05$ for cumulative and Worsley likelihood tests. However, CUSUM test did not detect significant step jump at $\alpha=0.10$. This character further buttressed our earlier observations that even though climate during the second climatic Period changed in the study area, the rate of change for locations in the southern most part of the basin has been gradual when compared to magnitude of change northward. Time series of annual temperature distribution in the southeastern part of the basin showed evidence of step jump. Results of change/step jump in the time series of temperature were calculated as 19 (Free distribution CUSUM), 2.47 (cumulative deviation) and 6.10 (Worsley Likelihood ratio) (Table 4). For the entire basin, change points in rainfall and temperature occurred in 1970 and 1981 respectively Figs. 2a,b.

Table 5: Percentage variations in climatic variables in the Sokoto-Rima River Basin during the 2 climatic Periods

	Gulma	Augi	Bunza	Dakingari	Goronye	Galadi	Maje	Dan-dume	Ave%
				Rainfall					
First Climatic Period	761.7	749.3	836.2	891.4	584.1	681.9	933.3	1029.9	
Second Climatic Period	705.2	672.80	756.1	825.6	484.90	571.4	890.9	967	
Diff	56.5	76.5	80.1	65.8	99.2	110.5	42.4	62.9	
% Change	3.9	5.4	5.0	3.7	9.2	8.8	2.3	3.2	5.2
				Temperature					
First Climatic Period	342.9	342.4	342.4	339.8	338.8	335.7	322.6	305.5	
Second Climatic Period	349.3	348.6	348.9	346.8	347.1	334.6	317.2	310.8	
diff	6.4	6.2	6.5	7	8.3	1.1	5.4	5.3	
% Change	0.92	0.89	0.94	1.0	1.2	0.16	0.84	0.85	0.85

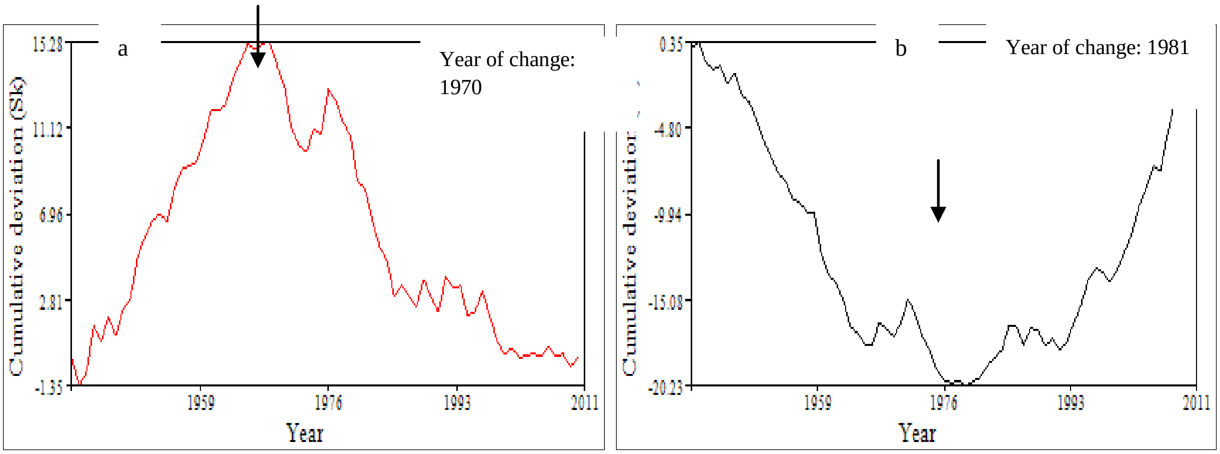

Fig. 2a,b: Change points in annual time series of (a)Rainfall and (b) Temperature in the SokotoRima River Basin

Deviations in annual rainfall and temperature distributions during the second climatic periods were higher in Goronye and Galadi northeast of the study area, followed by values determined for locations in the northwest of the study of the study. Locations in the southeast of the basin recorded the less deviation values. Average temperature deviation in the second climatic period shows that the southernmost part of the study area was characterized by little to moderate deviation from temperature character of the first climatic period (Table 5). Average percentage change in rainfall of the

Sokoto-Rima River basin of 0.85% is found to be higher than the observed 0.74 ± 0.18°C (1.33oF ± 0.32°F) increase in average global temperature of the Earth surface during the past 100 periods which implies that Sokoto-Rima River Basin is changing faster that observed global warming trend.

Conclusion and Recommendation

River basins provide a host of hydrologic, economic and social benefit. They play fundamental roles in supporting significant size of human population in terms water supply to man and animals, flood plains and irrigation water supply for dry season farming, dams and reservoirs have been developed in the study Sokoto-Rima river basin as part of the objectives of the River Basin Development Authorities in Nigeria. Flood plains abound in the Sokoto River which are being utilized for agricultural and fishing purposes. The links and inter-connection between the basin hydrology, land-use and human activities demands that water dependent projects in the basin should not be undertaken without proper knowledge of responses patterns of the basin hydrology to changing climatic variables some of which control to a very large extent the discharge pattern in the study area. This study has offered quantitative analysis of the rainfall and temperature response patterns to global warming in the Sokoto-Rima drainage basin, the result of which will relevant in the future design and implementation of water resource project as well as taking steps to prevent the effects of having too much or too little water in the basin as a results of climate change. The study showed strong evidence of climate change in the study area. However what is of note is the fact that the magnitude of change in climate variables differed from one section of the basin to another. There is urgent need to build response capacity of the inhabitants of the basin including adopting technologies and practices that will reduce water loss, provide insurance for most vulnerable persons as well as increase community awareness. There is also need to develop alternative water supply sources in particular community water harvesting approach while at the same time protect the source of available water supply in the basin.

References:

Hastenrath S (1990): Decadal-scale changes of the circulation in the tropical Atlantic sector associated with Sahel drought. *Int J Climatol* 10:459–472.

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

IPCC: (2007)*: The Physical Science Basis*. *Contribution of working group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. [Solomon, S., QIN, D., Manning, M., Chen, Z., Marquis, M., Averyt, K. B., Tignor, M. and Miller, H. L. (eds)] Cambridge University Press, Cambridge, United Kingdom and New York NY, USA, pp. 996

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

Janicot S, Moron V, Fontaine B (1996) Sahel drought and ENSO dynamics. *Geophys Res Lett* 23(5):515–518

Lamb, P. J. (1978a), Case studies of tropical Atlantic surface circulation patterns during recent sub-Saharan weather anomalies: 1967 and 1968, *Mon. Wea. Rev.*, 106, 482– 491,

Lamb, P. J. (1978b), Large-scale tropical Atlantic surface circulation patterns associated with sub-Saharan weather anomalies, *Tellus*, 30, 240 – 251,

Lucas, C.; Timbal, B.; Nguyen, H (2014): The expanding tropics: A critical assessment of the observational and modeling studies. *Wiley Interdiscip. Rev. Clim. Chang.*, *5*, 89–112

Mitchell T. D and. 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., and. Jones, P.D (2000): Representing twentiethcentury space–time climate variability. Part 2: Development of 1901–96 monthly grids of terrestrial surface climate. *J. Climate*, 13, 2217–2238

Palmer TN (1986): Influence of the Atlantic, Pacific and Indian Oceans on Sahel rainfall. *Nature* 320:251–253

Rowell D.P (2001): Teleconnection between the tropical Pacific and the Sahel. *Q J R Meteorol Soc* 127:1683–1706

Rowell D.P (2003): The impact of Mediterranean SSTs on the Sahelian rainfall season. *J Clim* 16:849–862

Shinoda M, Kawamura R (1994) Tropical rainbelt, circulation, and sea surface temperatures associated with the Sahelian rainfall trend. *J Metab Soc Jpn* 72:341–357

Sombroek, W. G., and 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, pp109

USAID (2012): Famine Early warning systems Network: Nigerian security outlook, www.fews.net/west-africa/Nigeria

Vizy E.K, Cook K.H (2001) Mechanisms by which Gulf of Guinea and eastern North Atlantic Sea surface temperature anomalies can influence African rainfall. *J Clim* 14:795–821

Vizy E.K, Cook KH (2002) Development and application of a mesoscale climate model for the tropics: influence of sea surface temperature anomalies on the West African monsoon. *J Geophys Res* 107(D3):4023