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Spatial patterns of climatic variability and water budget over Sudan Savannah Region of Nigeria

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The study examined the effect of climatic variability on climatic water balance over Sudan Savannah, Nigeria. Temperature and Rainfall data were collected for the period 1943-2012 from the Nigerian Meteorological Agency. The data were divided into two climatic years 1943-1977 and 1978-2012. On the whole, rainfall amount decreased from a very high mean value of 981.5 mm in Yelwa (Lat. 10.88 N; Long. 4.75 E) to a very low value of 656.1mm in Katsina (Lat. 13.02 N; Long.7.68 E). This pattern reveals gradual/potential extension of dryness from the Lake Chad area in Nigeria in northeast, towards the Sudan savannah, northwest of Nigeria. Annual temperature, PET, moisture deficit distributions revealed very strong evidence of upward trend at $\alpha<0.01$ with corresponding decrease in rainfall in the second climatic period, an indication of changing climate. However, in Yelwa, Sokoto and Gusau, there was little evidences of significant downward trend in annual rainfall distribution at $\alpha = 0.10$, but rather a quasi–periodic pattern, even though there were signs of statistical rise in temperature. The general pattern of deviation in PET from the first climate period were 1.4, 3.7, 2.7, 1.9% for Yelwa, Sokoto, Gusau and Katsina respectively, while moisture deficits were 5.0, 4.2, 4.0 and 7.9% for Yelwa, Sokoto, Gusau and Katsina respectively. This general observation may suggest that water balance parameters during the second climatic period deviated from patterns Observed in the first climatic period (1943-1977). Repetition of drought within the present climate regime could be expected and should be planned for. For temperature, there is strong evidence of increasing trends for all the stations in the region which agrees with global trend. This has implications for socio-economic development of the study area especially coupled with the attendant consequences of increasing population and economic activities in the region. There is thus need to plan for and design sustainable water resources management techniques in different sectors-agriculture, irrigation and dams, water supply to adapt to the quasi-periodic patterns of rainfall fluctuation.

Key words: Thornthwaite, Sudan Savannah, water balance, climate change, rainfall and temperature.

INTRODUCTION

The hydrological cycle is one of the main components of the earth's system, regulating life in the ecosystem. As a

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result, the sustainability of the hydrological cycle is key toward the continued existence of man, animals and plants. Regrettably, over the past decades beginning from the 18th century, the stability of the hydrological cycle has come under threat essentially due to global warming. The Intergovernmental Panel on Climate Change (IPCC) reported in 2001 that the global climate is changing, largely because of human activities (IPCC, 2007). Exponential increase in demography now puts pressure on land use/ water resources, fossil fuels utilization and natural resources (Van Asselen et al., 2013; Avis et al., 2011; Romero et al., 2014).

The resultant effects of these actions have been drastic changes in the natural environment, including climate change with noticeable implications on the climatic water distribution. These changes can be seen from the frequency of water crises (UNGC, 2009, IPCC, 2017), repeated drought (Vicente-Serrano et al*.,* 2010; Koutroulis et al., 2011; Kwak et al., 2013), water pollution (Jutla et al., 2011; Reyburn et al., 2011) and other hydrological extremes with far reaching effects on the economy, social, political and cultural wellbeing of mankind. Studies have shown that while one consequence of global warming is an increase in temperature, and thus the water holding capacity of the atmosphere, other consequence is an increase in evaporation over the ocean or evapotranspiration on land. This will speed up the hydrological cycle. Finding from all climatic models as they relate to climate change predict an increased evapotranspiration in the presence of water. However, in the absence of precipitation, this will results in increased risk of drought due to enhanced surface dryness (Westerling and Swetnam, 2003), heat wave (Lyon, 2009; Lau and Nath, 2012) and wild fires (Whitman, et al., 2015).

This is true of the Sudan the Savannah Region of Nigeria, which is characterized by acute rainfall variability and in the last 40 years has witnessed dramatic reductions in mean annual rainfall throughout the region (Dai et al., 2004; Ekpoh and Nsa, 2011). Note that this is not new in this region as the region is a significant portion of the Sudan-Sahel ecological zone of West Africa. However, since the early 1970s, climatic anomalies in the form of recurrent droughts, frightening dust storms and rampaging floods have overprinted their rhythms, creating short-duration climatic oscillations as against the normal cycles of larger amplitudes (Camberlin and Diop, 2003; Ekpoh and Nsa, 2011). The persistence of drought in parts in the Sudano-Sahel Nigeria has been attributed to the prevalence of a stagnated anti-cyclonic circulation of the tropical atmosphere over areas that normally should be exposed to the rising arm of the tropical Hadley Cell circulation by mid-summer (Kalu, 1987; Kamara, 1986). These conditions are themselves related to the tropical component of the global general circulation system. Tropical circulation patterns are particularly influenced by heat inputs from such sources as warm ocean surfaces acting through latent heat released in deep cumulus convection (Lockwood, 1979). Related heat sources which also have an important bearing on tropical circulations are high plateaus and equatorial rainforests (Nicholson and Tucker, 1998). These heat sources display visible latitudinal and longitudinal variations, and also a marked tendency to vary on both annual and, in the case of oceans, non-annual scales. One of the consequences of these circulation patterns is that rainfall patterns in West Africa, including northern Nigeria, show both annual and greater than annual variations and also marked tele-connections with distant locations (Nicholson, 1993). Ikhatua (2010) shows that in Nigeria and by extension globally, climate change will affect all four dimensions of food security, namely food availability (production and trade), access to food, stability of food supplies, and food utilization.

The Sudan Savanah region of Nigeria is considered most suitable for the cultivation of grain crops such as millet, sorghum, *acha* and rice, and grain legumes such as beans, cowpea etc. It is also important to mention that the main concentration of cattle production in the country occurs in the zone primarily because it is relatively free from tsetse fly infestation (Oguntoyinbo et al., 1983). Consequently, agricultural production in this region will be affected by moisture deficiency as water is required for photosynthesis and transpiration. In an attempt to attain sustainable food production, there is need to develop adaptation measures. One step towards achieving this however is to gain an understanding of the changes in water balance indices and effects on climatological drought over the region. This is the main focus of this study.

MATERIALS AND METHODS

The study area is Sudan Savannah region of Nigeria. Five synoptic stations in the region were selected for the study; Kano (12.05 N; 8.20 E; 472.5 m), Katsina (13.02 N; 7.68 E; 517.6 m), Yelwa (10.88 N; 4.75 E; 244.0 m), Gusau (12.17 N; 6.70 E; 463.9 m) and Sokoto (13.02 N; 5.25 E; 350.8 m). The region runs east to west of the North occupying an over 250 km band width. Mean annual rainfall is between 510 - 1,140 mm and the dry season lasts between 5 - 7 months (Figure 1). The vegetation is made up of tall grasses and trees which vary in density from place to place. Most of these have umbrella-shaped canopies which become smaller as one move northwards. Cultivation is intense in this region, coupled with heavy grazing, bush burning and cutting trees for fuel and building has promoted desertification in this zone (Agabi, 1995).

Data collection

Monthly temperature and rainfall data were collected for the period 1943-2012 from the Nigerian Meteorological Agency (NIMET), Lagos State. Climatic data were divided into two climatic periods 1943-1977 and 1978-2012 for ease of discussion. The Thornthwaite water balance computer software version 1.10, developed by the United States Geological Survey Department was used to estimate potential evapotranspiration based on Hamon equation (Hamon,

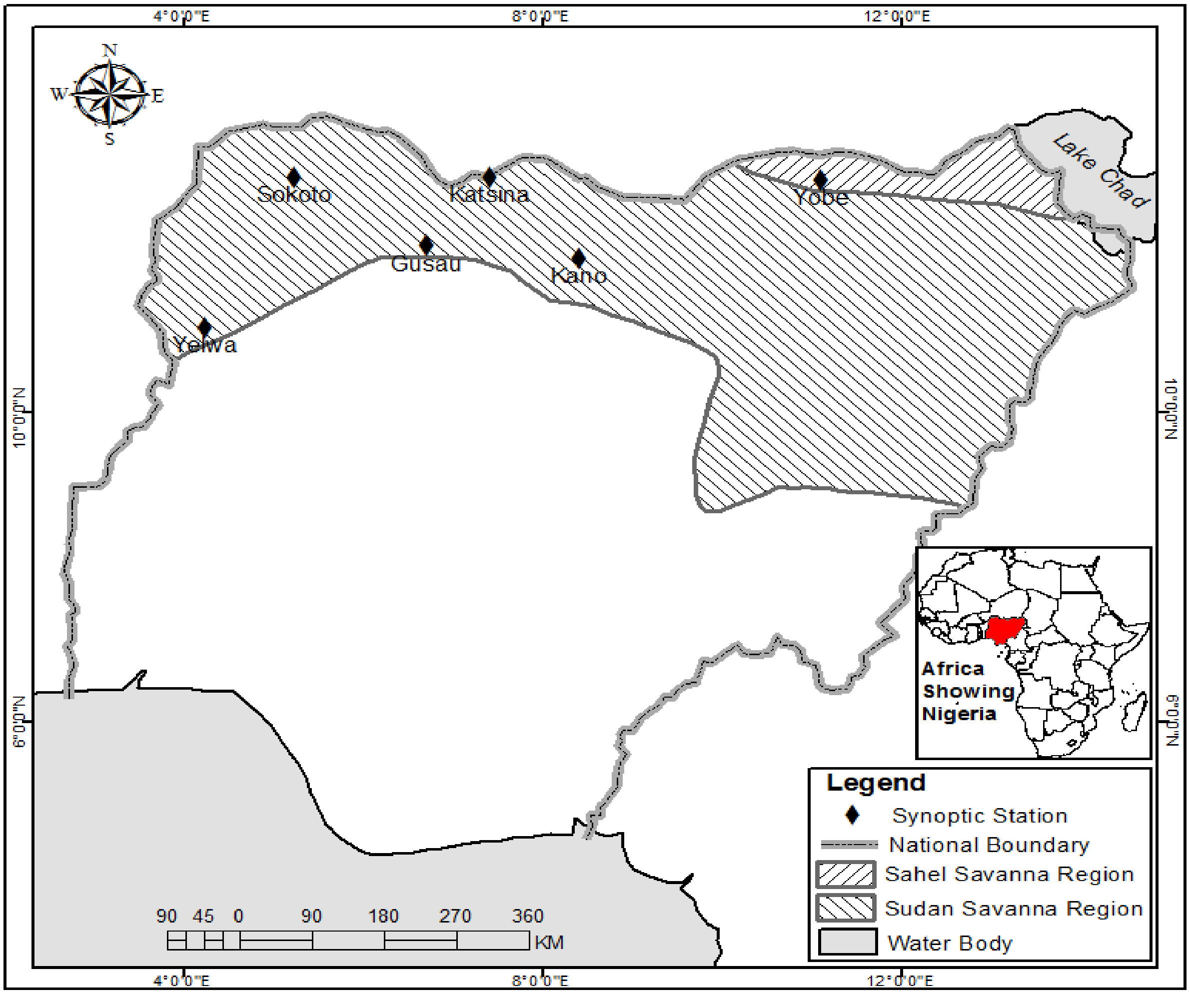

Figure 1. Sudan-Sahelian Region of Nigeria.

1961). The equation estimates monthly *PET* from mean monthly temperature (*T*).

The choice of this model is based on the nature of physical processes that interact to produce the phenomena under investigation (that is, temperature rainfall relationship), availability of the required model components/data and wide applicability of the model for hydrological impact of climate change assessment. Although studies have shown the Penman (1948) equation is considered to be the most accurate and has widespread application (Ayoade, 1983; Anyadike, 1987), unfortunately, the model demands a great deal of data which may not be readily available particularly in most developing countries for example where net radiation data and soil heat flux are important. Like the FAO Penman model, the Thornthwaite software version 1.10 also takes into account the geographical location of the area of concern, assumed soil moisture capacity. But more importantly, the authors preferred the Thornthwaite software version 1.10 mainly due to availability of input data such as temperature, rainfall, longitude and latitudes, available moisture capacity, unlike Penman model most of whose inputs data are not available for the country.

The Hamon equation is given as:

$$PET_{Hamon} = 13.97 \times d \times D_2 \times W_t \qquad (1)$$

where PET_{Hamon} is *PET* in millimeters per month, *d* is the number of days in a month, *D* is the mean monthly hours of daylight in units of 12 h, and W_t is the saturated water vapor density term, in grams per cubic meter, calculated using Equation 2:

$$W_t = \frac{4.95 \times e^{0.062 \times T}}{100} \qquad (2)$$

Where *T* is the mean monthly temperature in degrees Celsius (Hamon, 1961).

With the knowledge of the monthly precipitation, potential evapotranspiration values and soil moisture holding capacity of the study area, other water budget elements such as actual evapotranspiration, change in storage, soil moisture deficit and surplus were calculated as arithmetical differences, either positive or negative, between precipitation and potential evapotranspiration values.

Analysis for trend

Mann-Kendall, Spearman's Rho and Linear Regression were carried out using TREND software and were determined using a

Trend/change detection software (TREND) version 1.0.2 developed by the Cooperative Research Centre for Catchment Hydrology's (CRCCH) Climate Variability Program, in Australia.

Mann-Kendall test

This tool is used test whether there is a significant trend in the time series data. The n time series values (X1, X2, X3, ….., Xn) were first replaced by their relative ranks (R1, R2, R3,….., Rn) (starting at 1 for the lowest up to n). The test statistic S is:

$$s=\sum_{i=1}^{n-1}\ \left[\ \sum_{j=i+1}^{n}\operatorname{sgn}\left(R_i-R_i\right)\ \right] \tag{3}$$

Where Sgn(x) = 1 for x > 0
Sgn(x) =0 for x = 0
Sgn(x) = -1 for x <0
If the null hypothesis Ho is true, then S is approximately normally distributed with:µ = 0

$$\sigma = n\,(n-1)\,(2n+5)\,/\,18 \tag{4}$$

The z-statistic is therefore (critical test statistic values for various significance levels may be obtained from normal probability tables):

$$Z=\left|\ s\ \right|/\,\sigma^{0.5} \tag{5}$$

A positive value of S indicates that there is an increasing trend and vice versa.

Spearman's Rho test

This was used to determine whether the correlation between two variables is significant. One variable was taken as the time itself (years) and the other as the corresponding time series data. Like the Mann-Kendall Test, the n time series values were replaced by their ranks. The test statistic *ρs* is the correlation coefficient, which is obtained in the same way as the usual sample correlation coefficient, but using ranks. The equation is expressed as-:

$$\rho_S\ S_{xy}\,/\left(S_xS_y\right)^{0.5} \tag{6}$$

$$where\quad S_x=\sum_{i=1}^{n}\left(x_i-\overline{X}\right)^2 \tag{7}$$

$$S_y=\sum_{i=1}^{n}\left(y_i-\overline{Y}\right)^2 \tag{8}$$

$$S_{xy}=\sum^{n}\left(x_i-\overline{X}\right)^2\left(y_i-\overline{Y}\right) \tag{9}$$

and x_i (time), y_i (variable of interest), $\bar{x}$ and $\bar{y}$ refer to the ranks ($\bar{x}$, $\bar{y}$, S_x and S_y have the same value in a trend analysis).

Linear regression test

It tests whether there is a linear trend by examining the relationship between time (x) and the variable of interest (y). The regression gradient is estimated by:

$$b=\frac{\sum_{i=1}^{n}\left(x_i-\overline{x}\right)\left(y_i-\overline{y}\right)}{\sum_{i=1}^{n}\left(x_i-\overline{x}\right)^2} \tag{10}$$

and the intercept is estimated as:

$$a=y-bx \tag{11}$$

The test statistic S is:

$$where\ \ \sigma=\sqrt{\frac{12\sum_{i=1}^{n}\left(y_i-a-bx_i\right)}{n\left(n-2\right)\left(n^2-1\right)}}. \tag{12}$$

The test statistic S follows a Student-t distribution with n-2 degrees of freedom under the null hypothesis (critical test statistic values for various significance levels was obtained from Student's t statistic tables).

Analysis of moisture index

Moisture index was determined using the Thornthwaite (1953) method as follows:

$$\text{Im} = \frac{100S-100D}{PET}$$

Where, Im is the moisture index, S is the sum of monthly surpluses, D is the sum of monthly moisture deficit and PET is evapotranspiration.

$$\text{Ia} = \frac{100D}{PET}$$

Where Ia is the Index of aridity, D is the sum of monthly moisture deficit and PET is evapotranspiration.

$$\text{Ih} = \frac{100S}{PET}$$

Where Ih is the index of humidity, S is the sum of monthly surpluses and PET is evapotranspiration.

RESULTS AND DISCUSSION

In Figures 2 to 10, the long-term annual rainfall and temperature patterns are presented. Annual rainfall was generally random. However, for locations such as Yelwa and Sokoto there was evidence of a gentle decrease in rainfall amount first between 1940s and 1950 and between 1970 and 1990 (Figures 2 and 4). For Gusau, annual rainfall was generally low with a sign of a sharp increase towards the end of the 1990s. In Katsina and Kano annual rainfall revealed decreasing trend from 1980

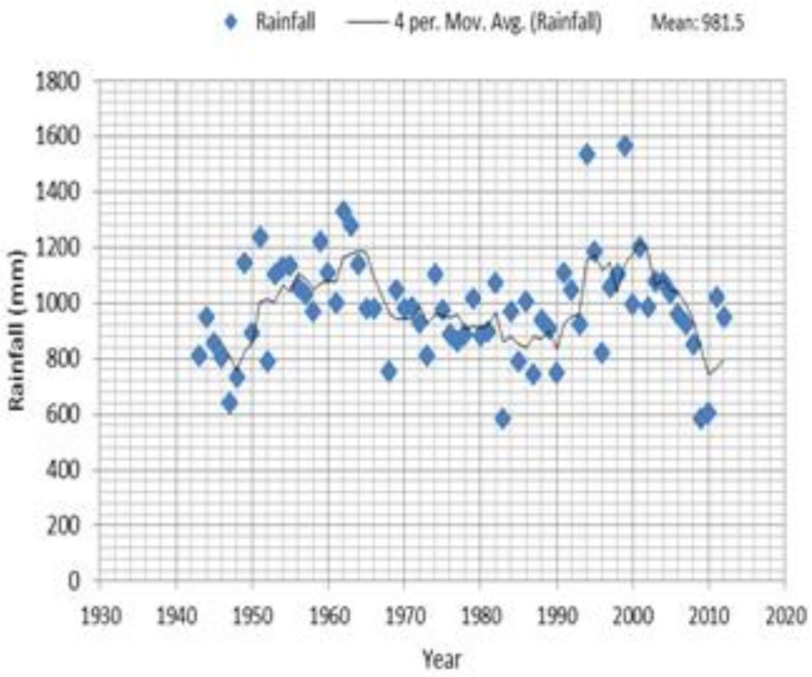

Figure 2. Annual rainfall distribution over Yelwa.

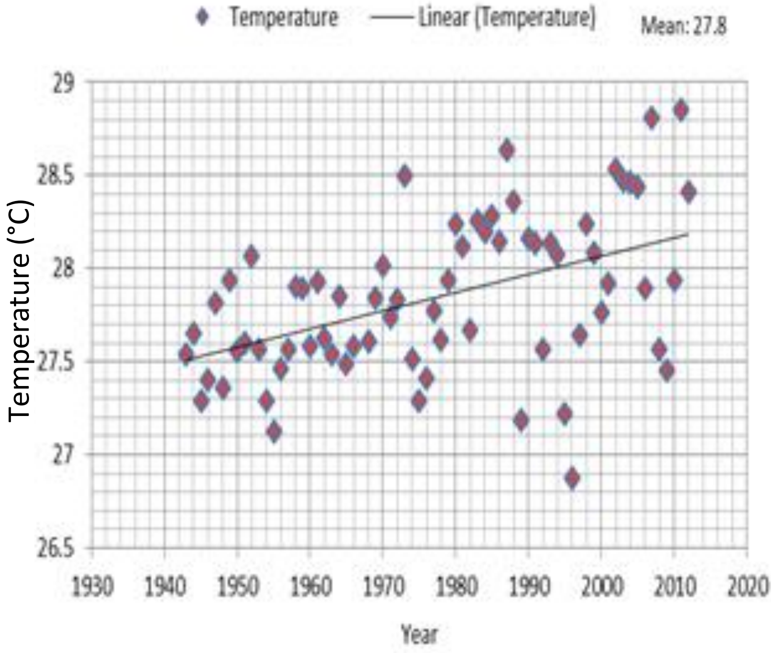

Figure 3. Annual temperature distribution over Yelwa.

for Katsina and 1990 for Kano station. Annual temperature distribution on the other hand revealed very strong evidence of an upward trend at α<0.01 for all the synoptic stations (Figures, 3, 4, 6, 8, 10 and Table 1). The observed decreasing trends in the 1940s and 1950 and between 1970 and 1990 coincides with the Sahel droughts of the 1940s, 1960-1973 and 1980-1987 (Amissah-Arthur, 1999); it is attributed to the prevalence of a stagnated anti-cyclonic circulation of the tropical atmosphere over areas that normally should be exposed

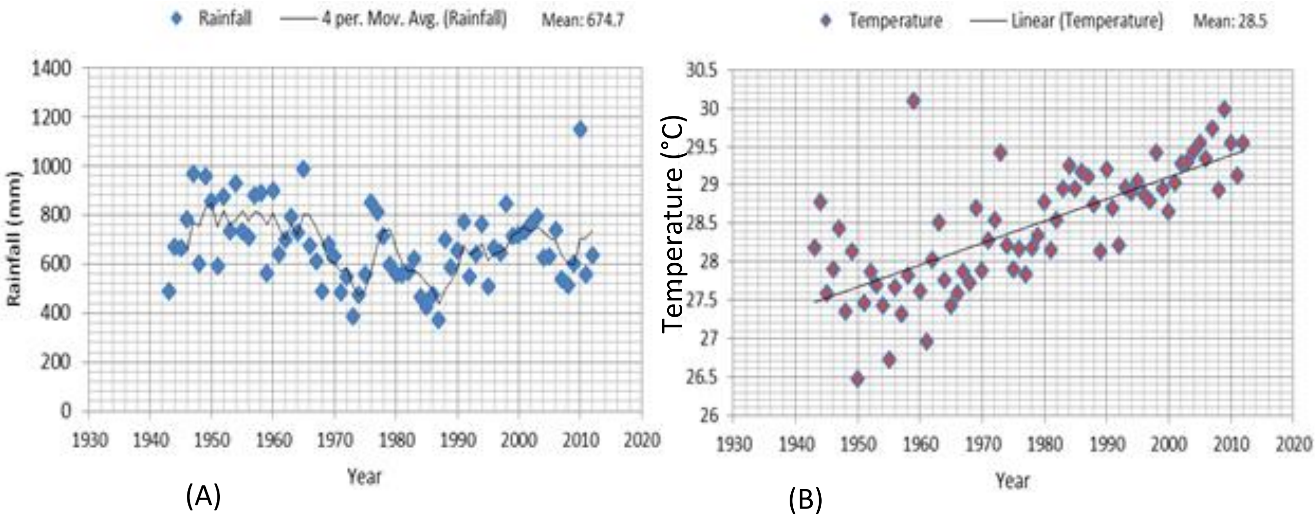

Figure 4. (a) Annual rainfall distribution over Sokoto, (b) Annual temperature distribution over Sokoto.

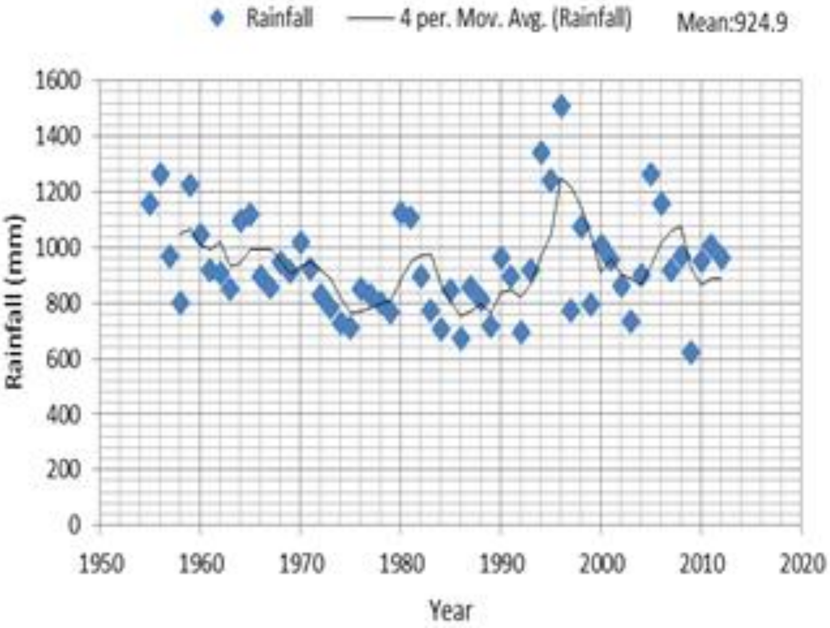

Figure 5. Annual rainfall distribution over Gusau.

to the rising arm of the tropical Hadley Cell circulation by mid-summer (Kamara, 1986). More so the abnormally high rainfall at the end of 80s, and within the decade 90s attest to the study area is characterized by unstable annual rainfall character. In Table 1, results of long-term trend patterns of rainfall and temperature over Sudan savannah (1943-2012) are presented. In locations such as Yelwa, Sokoto and Gusau, there is little or no evidence of statistical downward trends in annual rainfall distribution at α =0.10, but rather quasi –periodic patterns in nature. However for Katsina and Kano there is strong evidence of statistical downward trends in annual rainfall patterns at α<0.05.

In Table 2, descriptive statistics of long-term annual rainfall and temperature are presented. Rainfall amount decreased from a very high value of 981.5 mm in Yelwa (Lat. 10.88 N; Long. 4.75 E) to a very low value of 656.1 mm in Katsina (Lat. 13.02 N; Long.7.68 E), followed by Sokoto (Lat. 13.02 N; Long. 5.25 E). Kano also recorded a low annual value of 841.9 mm compared to stations in the extreme northwest. This pattern also reveals gradual outward spread of dryness from the Lake Chad basin in

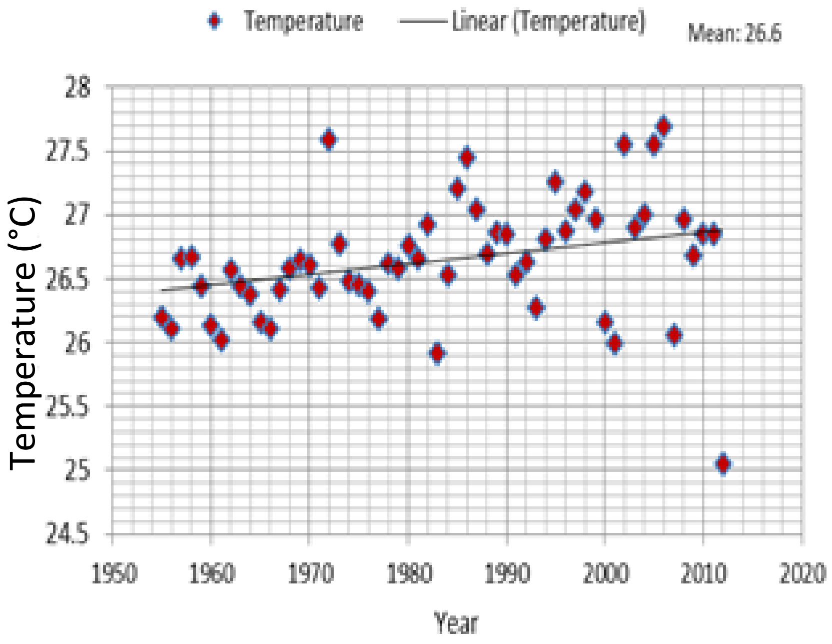

Figure 6. Annual temperature distribution over Gusau.

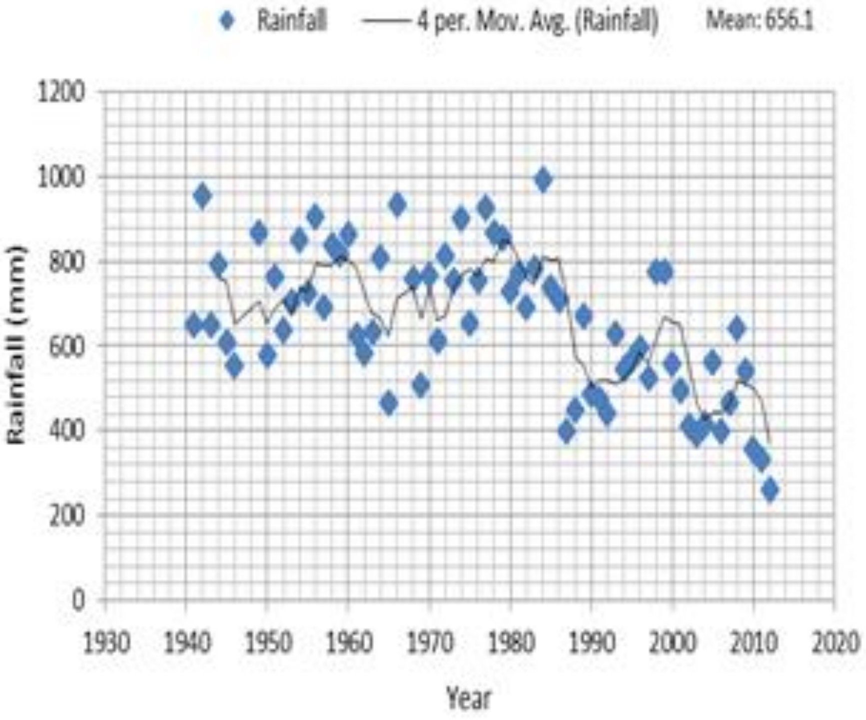

Figure 7. Annual rainfall distribution over Katsina.

the northeast part of the region towards the Sudan savannah, northwest of Nigeria. Mean annual temperature also followed a pattern similar to rainfall. Sokoto recorded the highest temperature in the region in the period under consideration. Coefficient of variation values for Katsina, Sokoto and Kano also confirm that rainfall amounts and temperatures were very erratic in these stations. This observations confirm the report of USAID (2012), that the

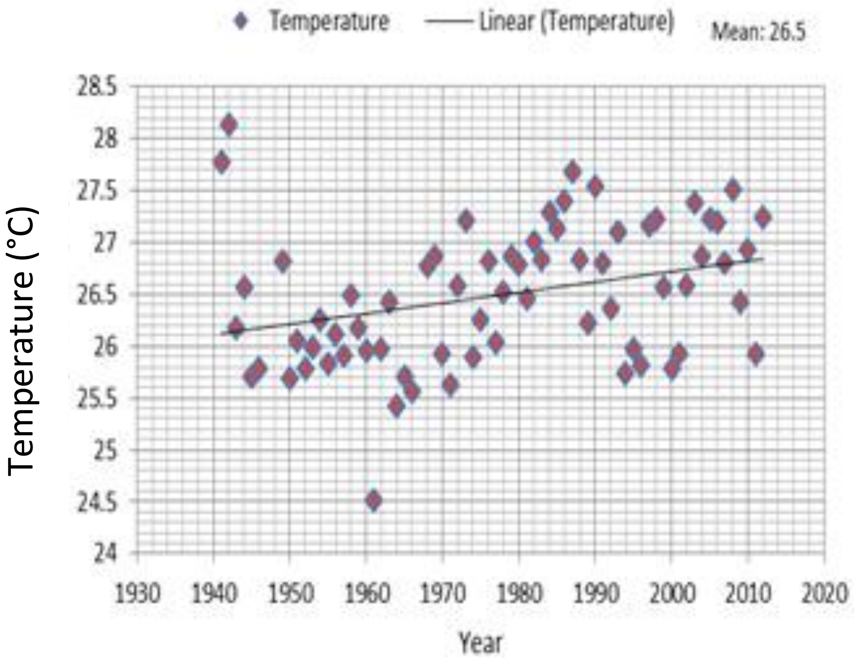

Figure 8. Annual temperature distribution over Gusau.

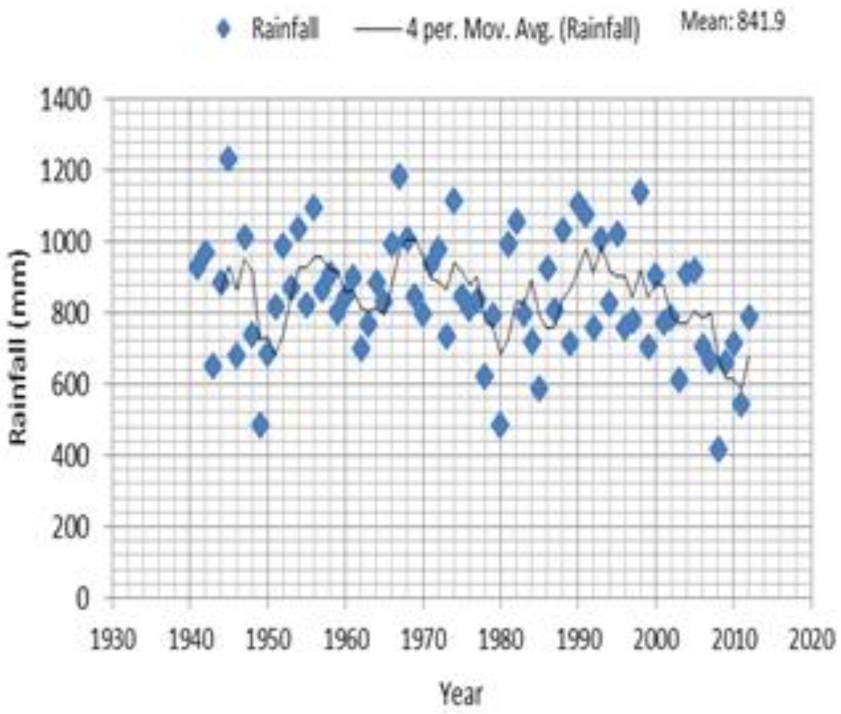

Figure 9. Annual rainfall distribution over Kano.

greatest food insecurity concerns in Nigeria remains in the extreme north, particularly in the northern most parts of Borno, Yobe and Jigawa states in the northeast, and the northern most parts of Kano, Katsina and Sokoto in the northwest. Similarly the National Action Programme to Combat Desertification in Nigeria estimates, about 50

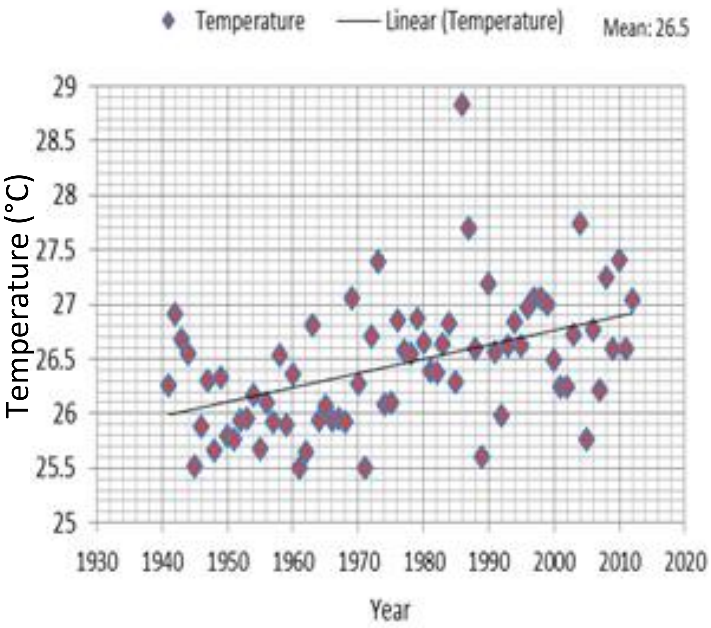

Figure 10. Annual temperature distribution over Kano.

Table 1. Long-term trend patterns of rainfall and temperature over Sudan Savannah (1943-2012).

Climatic station	Time series	Mann-Kendal	Significance level	Spearman's Rho	Significance level	Linear regression	Significance level
	Annual	z-test		z-test		t-test	
Yelwa	Rainfall (mm)	-0.269	α =0.10	-0.085	α =0.10	0.046	α =0.10
	Temp (°C)	4.113	α <0.01	3.95	α <0.01	4.422	α <0.01
Sokoto	Rainfall (mm)	-1.774	α =0.10	-1.787	α =0.10	-1.631	α =0.10
	Temp (°C)	7.148	α <0.01	6.36	α <0.01	8.982	α <0.01
Gusau	Rainfall (mm)	-0.51	α =0.10	-0.226	α =0.10	-0.256	α =0.10
	Temp (°C)	3.481	α <0.01	3.242	α <0.01	2.34	α <0.05
Katsina	Rainfall (mm)	-4.563	α <0.01	-4.463	α <0.01	-5.461	α <0.01
	Temp (°C)	3..279	α <0.01	α <0.01	3.029	2.782	α <0.01
Kano	Rainfall (mm)	-2.047	α <0.05	-1.977	α <0.05	-1.95	α =0.10
	Temp (°C)	4.244	α <0.01	4.171	α <0.01	4.339	α <0.01

α =0.10, no evidence of statistical sig trend, α <0.1, possible evidence of statistical sig trend; α<0.05, strong evidence of statistical sign trend; α<0.01, very strong evidence of statistical sig trend.

percent and 75 percent of Adamawa, Bauchi, Borno, Gombe, Jigawa, Kano, Katsina, Yobe, Sokoto, and Zamfara states are seriously affected by desertification (Olawumi, 2009).

In Tables 3a-7b, the results of climatic water distributions over the Sudan savannah are presented. It can be seen that with the exception of Kano State, potential evapotranspiration and moisture demand increased during the second climate period (1978-2012) both seasonally and annually. This pattern also corresponds with a general decrease in rainfall and actual evapotranspiration during the first the climate period. In this study, the first climatic period (1945-1979) is considered as stable period before reports of confirmation

Table 2. Descriptive statistics of annual rainfall and temperature.

Climatic station	Climatic Indices	Mean	SD	SE	Min	Max	Range	Sum	CV
Yelwa Town	Rainfall (mm)	981.5	187.4	22.6	584	1566.2	982.2	67724.9	19.09
	Temperature (°C)	27.8	0.42	0.05	26.87	28.87	1.98		1.51
Sokoto Town	Rainfall (mm)	675.3	154.7	18.6	373.2	1146.7	773.5	46596.6	22.9
	Temperature (°C)	28.5	0.78	0.09	26.46	30.1	3.6		2.74
Gusau Town	Rainfall (mm)	924.8	215.2	28.2	624	1507.1	883.1	53642.6	23.4
	Temperature (°C)	26.6	0.47	0.06	25.05	27.69	2.64		1.76
Katsina Town	Rainfall (mm)	656.1	171.1	20.5	262	993.6	731.6	45267.4	26.07
	Temperature (°C)	26.49	0.67	0.08	24.5	28.1	3.6		2.53
Kano State	Rainfall (mm)	841.9	168.7	19.8	416.1	1234.1	818	60621.2	20.0
	Temperature (°C)	26.45	0.59	0.07	25.5	28.8	3.32		2.23

Table 3a. Seasonal water distribution over Yelwa Town 1943-1977.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.2	1.8	3.1	22.8	97.2	139.1	192.2	242.1	225.0	66.2	0.4	0.2	990.3
PET	135	148	164	170	161	150	143	140	141	146	140	133	1771
ST	0	0	0	0	0	0	49.2	125	125	45.2	0	0	344.4
∆ST	0	0	0	0	0	0	+49.2	0	0	-79.8	-139.6	-132.8	
AET	0.2	1.8	3.1	22.8	97.2	150	143	140	141	66.2	0.4	0.2	765.9
DEF	134.8	146.2	160.9	147.2	63.8	109	0	0	0	-79.8	139.6	132.8	954.5
SUR	0	0	0	0	0	0	0	102.1	84	0	0	0	186.1

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 3b. Seasonal water distribution over Yelwa Town 1978-2010.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.0	15.9	43.1	105.6	150.0	211.8	256.1	173.7	47.6	0.3	0.1	1004.2
PET	137	150	165	171	161	151	144	143	144	149	144	137	1796
ST	0	0	0	0	0	0	67.8	125	125	23.6	0	0	341.4
∆ST	0	0	0	0	0	0	+67.8	0	0	-101.4	-143.7	-136.9	-314.2
AET	0	0	15.9	43.1	105.6	150	144	143	144	47.6	0.3	0.1	793.6
DEF	137	150	149.1	127.9	55.4	1.0	0	0	0	101.4	143.7	136.9	1002.4
SUR	0	0	0	0	0	0	0	113.1	29	0	0	0	142.1

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

of increase in world temperature which began in the beginning of the industrial period and an acceleration of warming since late 70s (IPCC, 2013). This period also corresponds with the period of temperature increase in Sahel region which has been traced to the anomalous large-scale sea-surface temperature (SST) warming over the Indian Ocean, tropical Atlantic SSTA, gulf of guinea and the Mediterranean Sea. It started in 1950 and became pronounced in the 1970 and has influenced the climate of Sahel region (Rowell, 2003; Bader and Latif, 2003; Archibong et al*.*, 2007; Obodo, 2008). Thus, rates of deviation were estimated by multiplying the difference

Table 4a. Seasonal water distribution over Sokoto Town 1943-1977.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.1	0.0	0.9	11.0	46.5	95.6	167.4	240.1	137.1	16.5	0.0	0.0	715.2
PET	131	144	166	175	174	161	150	143	148	154	145	133	1824
ST	0	0	0	0	0	0	17.4	114.5	125	0	0	0	256.9
∆ST	0	0	0	0	0	0	+17.4	+97.1	0	-137.5	-145	-133	
AET	0.1	0	0.9	11.0	46.5	95.6	150	143	148	16.5	0	0	611.6
DEF	130.9	144	165.1	164	127.5	65.4	0	0	0	137.5	145	133	1212.4
SUR	0	0	0	0	0	0	0	0	11.1	0	0	0	11.1

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus

Table 4b. Seasonal Water Distribution over Sokoto Town 1978-2012.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.1	2.9	6.3	51.3	95.9	181.4	195.6	100.1	13.6	0.3	0.0	647.5
PET	138	151	169	181	178	166	154	150	154	161	152	138	1892
ST	0	0	0	0	0	0	27.4	72.4	78.5	0	0	0	178.3
∆ST	0	0	0	0	0	0	+27.4	+45	+6.1	-147.4	-151.7	-138	
AET	0	0.1	2.9	6.3	51.3	95.9	154	150	154	13.6	0.3	0	628.4
DEF	138	150.9	166.1	174.7	126.7	70.1	0	0	0	147.1	151.7	138	1263.3
SUR	0	0	0	0	0	0	0	0	0	0	0	0	0

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 5a. Seasonal Water Distribution over Gusau Town 1943-1977.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.2	0.5	4.0	22.6	71.8	139.6	202.3	279.1	179.6	29.5	0.6	0.8	930.6
PET	131	141	157	166	163	153	146	142	145	146	136	131	1757
ST	0	0	0	0	0	0	56.3	125	125	8.5	0	0	314.8
∆ST	0	0	0	0	0	0	+56.3	0	0	-116.5	-135.4	-130.2	-325.8
AET	0.2	0.5	4.0	22.6	71.8	139.6	146	142	145	29.5	0.6	0.8	702.6
DEF	130.2	140.5	153	143.4	91.2	13.4	0	0	0	116.5	135.4	130.2	1053.8
SUR	0	0	0	0	0	0	0	137.1	34.6	0	0	0	171.7

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 5b. Seasonal Water Distribution over Gusau Town 1978-2012.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.6	3.6	17.6	83.8	135.0	205.4	287.6	187.6	29.0	0.3	0.0	950.5
PET	132	146	163	174	171	157	147	143	147	150	141	133	1804
ST	0	0	0	0	0	0	58.4	125	125	4.0	0	0	312.4
∆ST	0	0	0	0	0	0	+58.4	0	0	-121	-140.7	-133	-336.3
AET	0	0.6	3.6	17.6	83.8	135	147	143	147	29	0.3	0	706.9
DEF	132	145.4	159.4	156.4	87.2	22	0	0	0	121	140.7	133	1097.1
SUR	0	0	0	0	0	0	0	144.6	40.6	0	0	0	185.2

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 6a. Seasonal Water Distribution over Katsina Town 1943-1977.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.1	0.0	0.1	7.2	51.5	85.3	182.2	268.9	123.1	9.7	0.3	0.0	728.4
PET	123	135	156	172	173	164	150	143	149	153	138	124	1780
ST	0	0	0	0	0	0	32.2	125	99.1	0	0	0	256.3
∆ST	0	0	0	0	0	0	+32.2	0	-25.9	-143.3	-137.7	-124	
AET	0.1	0	0.1	7.2	51.5	85.3	150	143	149	9.7	0.3	0	596.2
DEF	122.9	135	155.9	164.8	121.5	78.7	0	0	0	143.3	137.7	124	1183.8
SUR	0	0	0	0	0	0	0	125.9	0	0	0	0	125.9

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 6b. Seasonal Water Distribution over Katsina Town 1978-2012.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.0	1.1	20.4	34.5	74.1	154.2	161.8	90.8	14.2	0.0	0.0	551.1
PET	124	136	160	175	176	166	153	149	155	156	140	125	1815
ST	0	0	0	0	0	0	1.2	14	0	0	0	0	15.2
∆ST	0	0	0	0	0	0	+1.2	+12.8	-64.2	-141.8	-140	125	-207
AET	0	0	1.1	20.4	34.5	74.1	154	149	90.8	14.2	0	0	538.1
DEF	124	136	158.9	154.6	141.5	91.9	0	0	64.2	141.8	140	125	1277.9
SUR	0	0	0	0	0	0	0	0	0	0	0	0	0

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 7a. Seasonal Water Distribution over Kano Town 1943-1977.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.2	1.7	8.8	69.0	116.9	207.1	313.7	139.2	13.0	0.1	0.0	869.7
PET	125	138	158	173	173	167	158	159	162	167	156	145	1881
ST	0	0	0	0	0	0	49.1	125	102.2	0	0	0	276.3
∆ST	0	0	0	0	0	0	+49.1	0	-22.8	-154	-155.9	-145	-428.6
AET	0	137.8	156.3	8.8	69	116.9	158	159	139.2	13.0	0.1	0	958.1
DEF	125	137.8	156.3	164.2	104	50.1	0	0	22.8	154	155.9	145	1215.1
SUR	0	0	0	0	0	0	0	154.7	0	0	0	0	154.7

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

in the indices of annual climatic value between the first and second climatic periods, and then dividing the result with annual value of the first climatic period which is considered as stable period. The percentage of deviation in this study is used to denote the extent to which distributions in the second climatic period differed from events in the first climatic period.

General patterns of deviation in PET from the first climate period were 1.4, 3.7, 2.7, 1.9% for Yelwa, Sokoto, Gusau and Katsina respectively. Deviations in climatic moisture demand (soil moisture deficit) in the second climatic period were 5.0, 4.2, 4.1 and 7.9% for Yelwa, Sokoto, Gusau and Katsina respectively. Moisture storage also decreased in the second climatic period with deviation rates of 0.87, 30.6, 0.76 and 94.1% for Yelwa, Sokoto, Gusau and Katsina respectively. Rainfall was also seen to have decreased in Sokoto and Katsina during the second climatic period with deviation rates of 9.5% (Sokoto) and 24.3% (Katsina).

In Table 8a-d, the difference and rates of deviations in climatic indices are presented. These general observations may suggest that water balance parameters during the second climatic period deviated from patterns observed in the first climatic period (1943-1977). This pattern is further buttressed in Table 9 as moisture index generally showed evidence of decreasing pattern during

Table 7b. Seasonal Water Distribution over Kano Town 1978-2012.

	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec	Sum
R	0.0	0.3	0.7	20.0	64.4	136.0	240.6	297.6	138.9	13.9	0.0	0.0	912.4
PET	125	138	160	174	172	161	150	150	150	154	142	126	1802
ST	0	0	0	0	0	0	90.6	125	113.9	0	0	0	329.5
∆ST	0	0	0	0	0	0	+90.6	0	-11.1	-140.1	-142	-126	-328.6
AET	0	0.3	0.7	20	64.4	136	150	150	138.9	13.9	0	0	674.2
DEF	125	137.7	159.3	154	107.6	25	0	0	11.1	140.1	142	126	1127.8
SUR	0	0	0	0	0	0	0	147.6	0	0	0	0	147.6

R: Rainfall; PET: potential evapotranspiration; ST: soil storage; AET: actual evapotranspiration; DEF: moisture deficit; SUR: moisture surplus.

Table 8a: Differences and rate of deviation in Rainfall in the second climatic period.

Climatic station	Climatic parameter (mm)	Climatic period	Annual total (mm)	Difference (mm)	% of deviation
Yelwa	Rainfall (mm)	1st climatic period (1943-1977) 2nd climatic period (1978-2012)	990 1004.2	No indication of decrease in the second period	-
Sokoto		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	715.2 647.5	67.9	9.46
Gasau		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	930.6 950.5	No indication of decrease in the second period	-
Katsina		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	728.4 551.1	177.3	24.3
Kano		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	869.7 912.4	No indication of decrease in the second period	-

Table 8b. Differences and rate of deviation in PET in the second climatic period.

Climatic station	Climatic parameter (mm)	Climatic period	Annual total (mm)	Difference (mm)	% of deviation
Yelwa	Potential Evapotranspiration (mm)	1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1771 1796	-25	1.4
Sokoto		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1824 1892	-68	3.7
Gasau		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1757 1804	-47	2.6
Katsina		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1780 1815	-35	1.96
Kano		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1881 1802	No indication of decrease in the second period	-

Table 8c: Differences and rate of deviation in Soil moisture deficit in the second climatic period

Climatic station	Climatic parameter (mm)	Climatic period	Annual total (mm)	Difference (mm)	% of deviation
Yelwa	Soil moisture deficit (mm)	1st climatic period (1943-1977) 2nd climatic period (1978-2012)	954.5 1002.4	-47.9	5.0
Sokoto		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1212.4 1263.3	-50.9	4.2
Gasau		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1053.8 1097.1	-43.3	4.1
Katsina		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1183.8 1277.9	-94.1	7.9
Kano		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	1215.1 1127.8	No indication of decrease in the second period	-

Table 8d. Differences and rate of deviation in moisture storage in the second climatic period.

Climatic station	Climatic parameter (mm)	Climatic period	Annual total (mm)	Difference (mm)	% of deviation
Yelwa	Soil moisture storage (mm)	1st climatic period (1943-1977) 2nd climatic period (1978-2012)	344.4 341.4	3.0	0.87
Sokoto		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	256.9 178.3	78.6	30.6
Gasau		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	314.8 312.4	2.4	0.76
Katsina		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	312.4 256.3	241.1	94.1
Kano		1st climatic period (1943-1977) 2nd climatic period (1978-2012)	15.2 276.3	No indication of decrease in the second period	-

the second climatic period.

These general patterns of increasing and/or decreasing water balance components are similar to observed statistically significant increases in precipitation and air temperature in the vast majority of the country (Egbinola and Amobichukwu, 2013; Akinsanola and Ogunjobi, 2014; Yaya et al., 2015). The observed evidence of increase in annual time series of temperature, potential evapotranspiration, moisture deficit and declining rainfall pattern in the second climatic period for all the synoptic stations are evidence of changing climate and this conforms with findings from other researchers that since the last century, an increase in average global temperature has been observed, and it is expected to increase further in the future (IPCC, 2001, 2007; Brunetti et al., 2009; Stocker et al., 2013). The intensity and frequency of precipitation are also expected to change, despite the trend differing with the season and the region (Gobiet et al., 2014). This will alter river-flow conditions, and in turn hydropower, which has been investigated from single catchments to a global scale (Schaefli et al., 2007; Koch et al., 2011; Majone et al., 2016). Declining

Table 9. Moisture Index over Sudan Savannah Region of Nigeria.

Climatic Year	Yelwa station			Sokoto Station			Gusau Station			Katsina station			Kano Station		
	Ia	Ih	Im	Ia	Ih	Im	Ia	Ih	Im	Ia	Ih	Im	Ia	Ih	Im
1943-1977	53.9	10.5	-22	67	0.60	-39	59.9	9.8	-26	65.5	7.1	-33	68	8.2	-31
1978-2012	55.8	7.9	-26	66.8	0.05	-40	60.8	10.3	-26	70.4	0.06	-42	63	8.2	-29

Ia : Index of aridity; Ih: Index of humidity; Im : Moisture Index.

rainfall amount is an important limiting factor for rain-fed crop production which is widely practiced in the study area. The observed decreasing rainfall amount in the extreme northern parts of the basin will exercerbate the ongoing impacts of variability, with serious implications for sustainable socio-economic lives, including decline in agricultural yeilds and farmer-herdmen crises which is already evident in the region. Studies have also linked pests attack and development of crop diseases, witting and desiccation of crops to reducing annual rainfall amount (Thompson and Amos, 2010; Obi, 2010; Aondoakaa, 2012; Singh et al., 2014). For example, Obi (2010) reported evidence of reducing pesticide sensitivity due to decreasing precipitation. His study added that pest population may increase across the northern Nigeria and threaten food production. In a simalr study, NEMA (2010) reported the outbreak of pests and diseases due to meteorological drought condition in part of Borno State, in northern Nigeria.

Evidence of rising temperature has the tendency to trigger hydo-meteorological droughts. As temperature rises, crops will loses water rapidly through transpiration thereby increasing crop water need. High potential evapotranspiration (PET) is usually observed during high temperature conditon (Audu et al., 2013). Thus, higher value of PET, means increased moisture loss, leading to deficit water balance which is unfavourable to crops. Crops growing under low soil moisture, yield little and poor quality seeds. As reported by Obi (2010), while increase in temperature is expected to elongate the growing season in temperate region, such an increase in the tropics will result in decimated agricultural output due to aggravating soil evaporation rate and invariably drought. Increasing temperature weakens plants and their leaves wither easily hence there is poor photosynthesis (Audu et al., 2013). Kim (2009) established that rising temperure will result in reduced crop quantity and quality due to the reduced growth period following high levels of temperature rise; reduced sugar content, bad coloration, and reduced storage stability in fruits; increase of weeds, blights, and harmful insects in agricultural crops; reduced land fertility due to the accelerated decomposition of organic substances. Apart from crops, animals also die in large number during prolonged drought as a result of heat stress, dehydration and attack by drought induced diseases.

CONCLUSION AND RECOMMENDATIONS

The study revealed that rainfall amount decreased from a very high value in the extreme northwest of the Sudan Savannah to a very low value in Katsina. The continuous decrease in rainfall amount in 1940s, 1950 and between 1970 and 1990 could be as a result of reversible climatic fluctuation and not climate change. This is because the 70 years of rainfall data for stations like Yelwa, Sokoto and Gusau revealed little or no evidences of statistically significant downward trends in annual rainfall distribution, but rather repeated drought periods caused by large scale shifts in the general global circulation. Repetition of drought within the present climate regime could be expected and should be planned for. Katsina and Kano however showed strong evidence of trend in rainfall distribution. For temperature, there is strong evidence of increasing trends for all the stations in the region which agrees with the global trend. The deviation in seasonal distribution of water balance components, in general may suggest a proof of changing climatic pattern towards the beginning of the 1980s, a period that coincide with intensified global and regional large-scale sea-surface temperature anomaly (SSTA) which is also reported to have affected the Sahelian climate. The region is gradually been encroached by desert from the extreme northeast. This has implications for socio-economic development of the study area especially coupled with the attendant consequences of increasing population and economic activities in the region. There is thus need to plan for and design sustainable water resources management techniques in different sectors-agriculture, irrigation and dams, water supply to adapt to the quasi-periodic patterns of rainfall fluctuation.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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