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Variability in the Long-Term Trends of Rainfall and Temperature over Southern Nigeria

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Abstract

This study investigated the variability in the long-term trends of rainfall and temperature over southern Nigeria. The relationship between the trends of temperature and rainfall was also explored. The results show no significant increasing/decreasing trend in monthly, seasonal and annual rainfall, with a decadal sequence of alternately increasing and decreasing rainfall trend. A significant increasing trend of annual maximum, minimum and mean temperature was detected at the rate of 1.1°C, 1.4°C and 1.2°C / 61 years, respectively, with the highest significant monthly increases observed in February and March. The study identifies two distinct climatological time-periods over southern Nigeria. The first period (1950 – 1980) is characterised by annual mean temperature below the climatological average whilst the second period (1981 – 2010) show a rising annual mean temperature consistently above the climatological average with the exceptions of years 1992 and 1994. Although there was no direct relationship between increasing rainfall and maximum temperature in southern Nigeria, a broad spatial-temporal dependence of rainfall on minimum temperature was observed in the dry season.

Keywords: Rainfall variability, temperature, anomaly, trend, climate change, Nigeria

1.0. Introduction

Climatic variability across spatial and temporal scales are usually detected from the analysis of long-term observational data of specific climatic variables collected over an averaging period of no less than 30 years (Asfaw et al., 2018; Rahmstorf et al., 2017; Subash and Sikka, 2014). As important indicators of climate change, understanding the abrupt or gradual changes in temperature and rainfall trends is essential for evaluating global hydro-meteorological response to climate change (Nguyen et al., 2018; IPCC, 2013). In recent years, studies on the long-term changes in mean annual and seasonal temperature and precipitation has become widespread (Nguyen et al., 2018; Rahmstorf et al., 2017; Zeng et al., 2016; Sun et al, 2015; Ackerley et al., 2014). Some of these studies have focused on global scales (Nguyen et al., 2018; Adler et al., 2017; Rahmstorf et al., 2017; Foster and Abraham, 2015; Liu, 2011; Alexander et al., 2006; Trenberth et al., 2003) whilst others have examined regional (Sun et al, 2015; Bombardi et al., 2014; Ackerley et al., 2014; Williams et al., 2012; Yao et al., 2010; Rauscher et al., 2010) and local scales (Ayanlade et al., 2018; Zeng et al., 2016; Priyan, 2015; Lui et al., 2011).

The globally averaged surface temperature between 1880 and 2012 reveal a linear warming trend of 0.85°C and is projected to rise to between 1.4 and 5.8°C by year 2100 (Keggenhoff et al., 2014; IPCC, 2013, 2007). Some studies suggest that rising temperature may lead to an increase in hydrologic extremes (Westra et al., 2013; Alexander et al., 2006). However, Nguyen et al. (2018) observed insignificant increasing trends in mean annual precipitation for 76 countries and insignificant decreasing trends in 80 countries with variations at local scales of investigation. Although, there has been clear evidence of rising surface temperature over the past decades (Rahmstorf et al., 2017; IPCC, 2013), a number of studies have shown that rainfall patterns and trends have been more variable depending on region and specific atmospheric circulation phenomenon influenced by a warming climate that underlie the risk of floods, drought, loss of biodiversity and agricultural productivity (Asfaw et al., 2018; Ayanlade et al., 2018; Liu and Wu, 2016; van Wilgen et al., 2016; Zeng et al., 2016; Trenberth, 2011). For instance, the climate of Nigeria is mainly influenced by the circulation pattern of the tropical continental air mass that is characterised by dry convection, and the maritime tropical air mass associated with moist convection and cloudiness (Ojo, 1977). The dynamic interactions between these air masses create marked rainfall and temperature contrast between the hinterlands and coastal regions of the country (Abatan et al., 2016).

Most parts of southern Nigeria are coastal areas with high rainfall potential and a dense network of river tributaries. A little increase in rainfall amount, duration or storminess could induce floods and threaten biodiversity in the region. Similarly, rising temperature and delays in the onset of rains could create shifts in the cropping season and reduce agricultural productivity. Hence, to develop effective climate change mitigation and adaptation strategy it is crucial to understand the annual and seasonal variations of the key indicators of temperature and rainfall. Studies have shown a rising trend in air temperature across Nigeria (Ragatoa et al., 2018; Eresanya et al., 2018; Amadi et al., 2014) with varying degree of trends reported at annual and seasonal scales for different ecological regions (Abatan et al., 2018, 2016; Oluwatobi and

Oluwakemi, 2016). There has been more variability in the general trend of precipitation, with rainfall observed to be increasingly less reliable during the crop growing months in the rainforest and guinea savanna agro-climatic zones of southwestern Nigeria (Ayanlade et al., 2018). Odjugo (2005) observed a general decrease in rainfall across the country with a slight increase recorded in the coastal areas. Using a fractional integration technique of time series analysis Yaya et al. (2015) found significantly positive time trend coefficient in rainfall across Nigeria by focusing on anomalies that masked seasonal variation. Akinsola and Ogunjobi (2014) observed statistically significant increases in rainfall and air temperature in Nigeria but with a decadal sequence of alternately increasing and decreasing trends in mean annual rainfall and air temperature. Adejuwon (2012) observed a northward increase in rainfall on the eastern side of the Niger Delta that could be ascribed to rainfall determinant factors different from intertropical discontinuity. Nnaji (2011) found that monthly rainfall in different regions of Nigeria exhibit a tendency for self-organised criticality between 12 and 14 months, with a positive correlation between one and three years and a tendency of randomness in the long run.

Whilst, there are multiple studies assessing rainfall and temperature trends in Nigeria (Ayanlade et al., 2018; Ukhurebor and Abiodun, 2018; Yaya et al., 2015; Akinsola and Ogunjobi, 2014; Adejuwon, 2012; Nnaji, 2011; Omogbai, 2010; Odjugo, 2005), the coastline areas of southern Nigeria are the least studied; creating a comparative dearth of knowledge vis-à-vis other regions of the country. This present study seeks to fill this knowledge gap by examining the trends in annual, monthly and seasonal variations of rainfall and temperature, and their relationships in southern Nigeria. This will help underlie current strategies of climate change adaptation and mitigation in the region.

2.0. Study Area

Southern Nigeria as applied in this study covers the south-south geopolitical zone represented by the states of Akwa-Ibom, Bayelsa, Cross River, Delta, Edo and Rivers. The region occupies a landmass of 84,587 km^2 with varied topographical features consisting of lowlands in the coastal areas and highlands and plateaus in the hinterlands. The area is drained mainly by the Niger and Benue rivers and their tributaries as well as other smaller river systems. The climate of the region is influenced by the regional tropical maritime air mass and the tropical continental air mass (Ojo, 1977) that divides the country into different ecological zones. The tropical maritime air mass is a warm humid and unstable trade wind from the Gulf of Guinea responsible for the rainy season whilst, the tropical continental air mass laden with dust following its enduring track from the Sahara desert is associated with Harmattan and the dry season. The seasonal movement of the inter-tropical discontinuity; a narrow zone of convergence between the tropical maritime and continental air masses is a key determinant of climate over the region (Abatan et al., 2016).The impact of the moisture laden tropical maritime air mass is more prominent in the coastal areas of southern Nigeria where annual rainfall can be over 4,000 mm. This tends to decrease to a range of 2000 – 3000 mm in the hinterlands. Average temperature range is usually very small in the coastal areas (rarely exceeding 2°C) with a maximum of 28°C in the hottest month and 26°C in the coldest month.

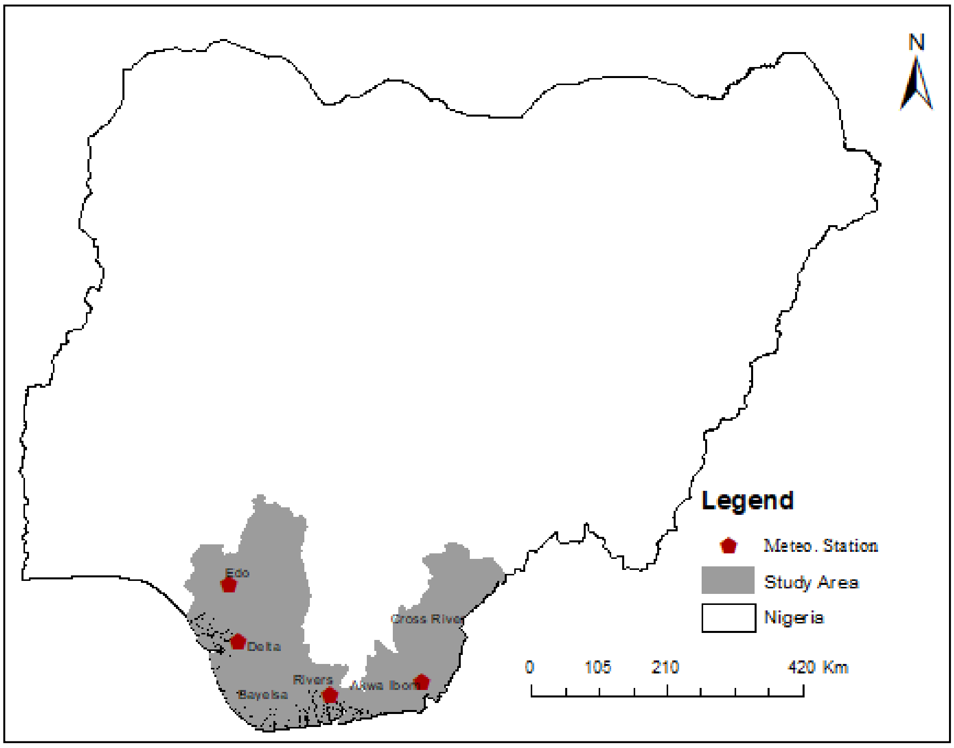

Figure 1: Nigeria showing the study area and meteorological stations

3.0. Methods

3.1. Data collection

Data was obtained from the Nigeria Meteorological Agency (NiMet) for 4 weather stations covering the study area (Figure 1). The dataset for the south-south region was generated by averaging the values of all four stations. The spatial distribution of the weather stations are shown in Figure 1 and their geographic description is provided in Table 1. These stations were chosen because the datasets were of reliably good quality with adequate record of length. A series of monthly rainfall (*R*), maximum (T_{max}) and minimum (T_{min}) air temperature for the period 1950–2010 were analysed for patterns and trends. The monthly dataset was derived from the daily values of the variables of interest averaged over each month. To obtain seasonal data, monthly values were averaged for the months in each season. In this study, dry season = November, December, January, February; and rainy season = March, April, May, June, July, August, September, October. Double-mass curve and autocorrelation analysis was performed on the climatic data to ensure there were no changes in the method of data observation that could introduce errors in the climatic record (Gocic and Trajkovic, 2013; Kohler, 1949).Annual and seasonal relationships between rainfall and temperature were examined using regression analysis. The departure of monthly rainfall and temperature values from their long-term average value (i.e. anomaly) were also computed for the study area.

Table 1: Geographic description of the meteorological station sites

Met. Stn.	**Latitude (°N)**	**Longitude (°E)**	**Elevation (m)**
Calabar (Cross-River)	4.96	8.32	62
Port-Harcourt (Rivers)	4.79	7.02	18
Warri (Delta)	5.52	5.76	6
Benin (Edo)	6.32	5.63	79

3.2. Trend analysis

In this study, the non-parametric Mann-Kendall (Kendall, 1975; Mann, 1945) and Sen's slope estimator (Sen, 1968) were used to detect trends and magnitude, respectively in the climatic variables. The Mann-Kendall test has been widely applied in climatological and hydrological time series analysis to detect trends in a statistical yes/no type hypothesis testing procedure (Gavrilov et al., 2016; Subash and Sikka, 2014; Gocic and Trajkovic, 2013; Douglas et al., 2000) where the null hypothesis (H0) is that the data are independent and identically distributed and the alternative hypothesis (Ha) is that the data contains a monotonic trend over time (Kocsis et al., 2017). No assumption of normality is required by the Mann-Kendall test as the approach utilises only the relative magnitudes of the data rather than the measured values in determining the presence of a monotonic trend in a time series (Subash and Sikka, 2014; Gilbert, 1987). The Mann-Kendall test statistics S is computed as (Eq. 1):

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(x_j - x_i) \qquad (1)$$

Where x_i and x_j are the data values in time series i and j ($j>i$), n is the number of data points, and sgn($x_j - x_i$) is calculated as (Eq. 2):

$$sgn(x_j - x_i) = \begin{cases} +1, \text{if} x_j - x_i > 0 \\ 0, \text{if} x_j - x_i = 0 \\ -1, \text{if } x_j - x_i < 0 \end{cases} \qquad (2)$$

The variance of S is computed as (Eq. 3):

$$\mathrm{VAR}(S) \quad = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{h} t_a(t_a-1)(2t_a+5)\right] \qquad (3)$$

Where n is the number of data points in the time series, h is the number of tied groups (i.e. a set of data having the same value) and t_a is the number of data in the pth group.

If the value of S is positive it indicates an increasing trend whilst a negative S value indicates a decreasing trend with time. In cases where n> 10, the standard normal variate test statistics Z is computed as (Eq. 4):

$$Z_s = \begin{cases} \dfrac{S-1}{[\mathrm{VAR}(S)]^{1/2}} & \text{if } \; S > 0 \\ 0 & \text{if } \; S = 0 \\ \dfrac{S+1}{[\mathrm{VAR}(S)]^{1/2}} & \text{if } \; \mathrm{S} < 0 \end{cases} \qquad (4)$$

Positive values of $Z_s$show increasing or upward trend whilst negative values indicate decreasing or downward trend. The hypothesis test of trend in this study was at the significance level of α = 0.05 and α = 0.01. The null hypothesis is rejected and there is significant trend in the time series if the absolute value of Z_s is greater than $Z_{s-\alpha/2}$; where $Z_{s-\alpha/2}$ is obtained from the standard normal distribution table.The null hypothesis is rejected if Z_s is greater than 1.96 and 2.58 at α = 0.05 and α = 0.01, respectively (Gocic and Trajkovic, 2013).

After the detection of trend in the time series, the Sen's (1968) slope estimator was applied to calculate the change pertime period in the sample of N pairs of data where the N slope estimate, Q, for each station is given as (Eq. 5):

$$Q = \frac{x_i - x_k}{i - k} \qquad (5)$$

Where x_i and x_k are data values at during time periods i and k, respectively, and where $i>k$; N is the number of data pairs for which $i>k$. The median N values of Q is Sen's estimator of slope. In the case where there is only one datum in each time period (Eq. 6):

$$N = \frac{n(n-1)}{2} \tag{6}$$

Where n is the number of time periods. If in one or more time periods there are multiple observations, then $N < \frac{n(n-1)}{2}$, where n is no longer the time period but the total number of observations (Gilbert, 1987). The N values of Q are ranked from smallest to largest, and the Sen's estimator or the median slope is computed as (Eq. 7):

$$Q_m = \begin{cases} Q_{[(N+1)/2]} & \text{if } N \text{ is odd} \\ \frac{1}{2}\left(Q_{[N/2]} + Q_{[(N+2)/2]}\right) & \text{if } N \text{ is even} \end{cases} \tag{7}$$

The value of Q_m show the steepness of the trend. The confidence interval of the time slope is computed as (Eq. 8):

$$C_\propto = Z_{1-\propto/2}\sqrt{\mathrm{VAR}(S)} \tag{8}$$

Where $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table and VAR(S) is computed in Eq. (3). This is followed by the computation of $M_1 = (N - C_\alpha)/2$ and $M_2 = (N + C_\alpha)/2$. The lower and upper limits of the confidence interval are the M_1th largest and (M_2 + 1)th largest of the N ordered slope estimates, respectively (Gilbert, 1987). The seasonal Kendall slope estimator is computed for the individual N_i slope estimates for the ith season as (Eq. 9):

$$Q_i = \frac{x_{il} - x_{ik}}{l - k} \tag{9}$$

Where x_{il} is the datum for the ith season of the lth year, and x_{ik} is the datum for the ith season of the kth year, where $l>k$. This computation is done for each of the K season before ranking the $N_1 + N_1 + \cdots + N_k = N$ individual slope estimates and finding their median (Gilbert, 1987).

The computations were carried out in MAKESENS excel template and Addinsoft's XLSTAT (2019).

4.0. Results and Discussion

4.1. Spatial-temporal variability of rainfall and temperature

There was marked variation in the mean monthly rainfall and temperature in the different meteorological stations of the south-south region (Table 2). In three (Calabar, Warri, Benin) out of four stations, July received the most amount of rainfall with Warri registering the highest monthly mean rainfall of 465±20.1 mm. However, the wettest month for Port-Harcourt was September with a mean of 373±13.0 mm. For the south-south region, July received the most rainfall. All stations recorded a double rainfall peak, one in July and another in September with the exception of Calabar which had rainfall peaks in July and August. Consistent with observations in Obot et al (2010) Calabar also had the highest annual rainfall (Table 3).The south-south region follows a bi-modal rainfall distribution pattern with very significant rainfall in all but the dry season months of November, December, January and February. More than 90% of the total rainfall was received in the rainy season (Table 3). This is similar to findings in Adejuwon (2012).

Maximum temperature was generally higher in the dry season than the rainy season whilst minimum temperature was more varied across the stations (Table 3). He et al (2015) observed a prevalence of higher temperatures during dry conditions. The highest maximum temperature was recorded in February in all stations as well as the south-south region (Table 2).Higher minimum temperature occurred between March and May in Port-Harcourt; May and April in Warri, and February and May in Calabar and Benin, respectively. The lowest minimum temperature of 22.1°C was recorded during the dry season months of December and January in the south-south region where the mean temperature ranged between 25°C – 28°C with a higher range over the hinterland and a lower range over the coast. The annual minimum and maximum temperature across the stations were consistent with finding in a similar study (Amadi et al., 2004).

Table 2: Mean monthly rainfall and temperature over different meteorological stations and the south-south region

S/N	MET. STN.	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
	Rainfall												
1	Calabar	30.8±4.05	47.0±6.82	164±9.84	225±9.08	279±10.3	403±17.6	446±18.8	410±18.8	405±15.7	320±12.8	160±10.5	37.3±5.53
2	Port Harcourt	29.0±3.33	61.4±6.43	127±8.95	175±11.0	254±9.34	274±10.4	357±17.8	310±16.3	373±13.0	270±12.7	101±8.05	27.9±3.65
3	Warri	28.7±3.80	61.6±5.69	137±9.06	217±10.8	272±10.1	356±15.2	465±20.1	356±22.1	455±17.7	313±17.7	98.8±9.41	30.8±5.68
4	Benin	13.4±2.83	45.5±5.16	113±6.51	171±10.4	216±10.2	266±11.1	356±18.4	290±21.1	353±13.5	247±10.9	66.6±6.64	23.3±4.07
	South-South Region												
5		25.5±2.25	53.8±4.68	135±6.20	197±6.91	255±5.86	325±7.27	406±12.7	341±15.1	396±9.91	288±9.23	107±6.18	29.8±3.19
	Mean Temperature												
1	Calabar	27.2±0.09	28.4±0.12	28.0±0.11	27.6±0.08	27.1±0.06	26.2±0.07	25.2±0.08	25.1±0.06	25.6±0.06	26.1±0.06	26.8±0.06	27.0±0.07
2	Port Harcourt	26.8±0.12	27.9±0.14	27.9±0.14	27.7±0.10	27.2±0.10	26.3±0.08	25.5±0.07	25.5±0.08	25.8±0.06	26.3±0.07	26.8±0.08	26.5±0.09
3	Warri	27.4±0.12	28.4±0.08	28.6±0.09	28.3±0.07	27.7±0.06	26.7±0.08	25.6±0.06	25.6±0.12	26.0±0.08	26.8±0.07	27.9±0.11	27.4±0.09

4	Benin	27.4±0.12	28.7±0.11	28.6±0.10	28.1±0.10	27.4±0.07	26.4±0.07	25.3±0.08	25.1±0.08	25.7±0.11	26.6±0.10	27.7±0.12	27.3±0.14
	South-South Region												
5		27.2±0.09	28.3±0.09	28.3±0.10	27.9±0.07	27.4±0.06	26.4±0.06	25.4±0.06	25.3±0.06	25.8±0.06	26.4±0.06	27.3±0.07	27.1±0.08
	Maximum Temperature												
1	Calabar	31.8±0.08	33.4±0.13	32.2±0.15	31.7±0.08	31.0±0.07	29.5±0.10	28.1±0.11	27.7±0.10	28.7±0.09	29.6±0.07	30.7±0.07	31.4±0.09
2	Port Harcourt	32.5±0.11	33.2±0.20	32.7±0.17	32.2±0.13	31.3±0.12	30.0±0.11	28.7±0.10	28.7±0.12	29.2±0.08	30.3±0.10	31.3±0.10	31.9±0.11
3	Warri	32.4±0.10	33.4±0.09	33.2±0.11	32.7±0.08	31.9±0.09	30.3±0.10	28.6±0.09	28.3±0.20	29.2±0.12	30.7±0.10	32.3±0.08	32.3±0.08
4	Benin	32.6±0.11	34.0±0.12	33.5±0.11	32.7±0.14	31.7±0.08	30.3±0.08	28.4±0.10	28.1±0.12	29.0±0.13	30.6±0.08	32.2±0.08	32.4±0.09
	South-South Region												
5		32.3±0.08	33.5±0.10	32.9±0.11	32.3±0.08	31.5±0.06	30.0±0.07	28.4±0.08	28.2±0.09	29.0±0.07	30.3±0.06	31.6±0.07	32.0±0.07
	Minimum Temperature												
1	Calabar	22.7±0.15	23.7±0.16	23.6±0.10	23.5±0.09	23.2±0.08	22.8±0.07	22.4±0.09	22.5±0.06	22.5±0.06	22.5±0.07	22.9±0.07	22.7±0.09
2	Port Harcourt	21.1±0.21	22.5±0.17	23.2±0.17	23.2±0.09	23.1±0.13	22.7±0.07	22.3±0.06	22.4±0.07	22.4±0.06	22.4±0.06	22.3±0.08	21.1±0.14

3	Warri	22.4±0.19	23.5±0.13	24.1±0.10	24.0±0.09	23.6±0.08	23.2±0.13	22.7±0.07	22.8±0.12	22.8±0.07	22.9±0.07	23.4±0.18	22.4±0.14
4	Benin	22.1±0.19	23.3±0.14	23.7±0.13	23.5±0.11	23.1±0.10	22.5±0.09	22.1±0.10	22.0±0.10	22.4±0.15	22.5±0.17	23.1±0.20	22.3±0.24
	South-South Region												
5		22.1±0.14	23.2±0.12	23.6±0.10	23.5±0.08	23.2±0.07	22.8±0.07	22.4±0.06	22.4±0.07	22.5±0.06	22.6±0.07	22.9±0.10	22.1±0.12

Table 3: Mean seasonal and annual rainfall (with percentage contribution) and temperature for different meteorological stations and the south-south region

S/N	MET. STN	DRY SEASON	WET SEASON	ANNUAL
	Rainfall			
1	Calabar	274.9 (9%)	2650 (91%)	2925
2	Port-Harcourt	219.0 (9%)	2140 (91%)	2359
3	Warri	219.9 (8%)	2569 (92%)	2789
4	Benin	148.8 (7%)	2012 (93%)	2160
	South-South Region			
5		215.7 (8%)	2343 (92%)	2559
	Mean Temperature			
1	Calabar	27.4	26.4	26.7
2	Port-Harcourt	27.0	26.5	26.7
3	Warri	27.8	26.9	27.2
4	Benin	27.8	26.6	27.0
	South-South Region			
5		27.5	26.6	26.9
	Maximum Temperature			
1	Calabar	31.8	29.8	30.5
2	Port-Harcourt	32.3	30.4	31.0
3	Warri	32.6	30.6	31.3
4	Benin	32.8	30.5	31.3
	South-South Region			
5		32.4	30.3	31.0
	Minimum Temperature			
1	Calabar	23.0	22.9	22.9
2	Port-Harcourt	21.8	22.7	22.4
3	Warri	22.9	23.2	23.1
4	Benin	22.7	22.7	22.7
	South-South Region			
5		22.6	22.9	22.8

4.2. Trends in monthly, seasonal and annual rainfall and temperature

Generally, no significant increasing/decreasing trend was detected in monthly, seasonal and annual rainfall over the south-south region of Nigeria (Table 4). However, significant decreasing trend was observed in September in the Warri station at the rate of 119 mm/61 years, and October and dry season in the Calabar station at the rate of 96 mm and 29 mm/61 years, respectively. Similar to findings in the present study, Obot et al (2010) observed no significant trend in the annual rainfall of Calabar. Interestingly, an increasing but non-significant (P>0.05) trend was observed in annual and seasonal rainfall in the Benin station (Table 4). Across the south-south region the average rainfall anomaly (Figure 2) show an alternating decadal sequence of increasing and decreasing rainfall trends (Figure 3).This is consistent with findings in a similar study (Akinsanola and Ogunjobi, 2014). Based on anomalies, 30out of the 61 years were categorised as dry (i.e. years with anomalies below the average) and 31 years were classified as wet (i.e. years with anomalies above the average) with a respective annual rainfall average of 2559 mm suggesting that deviations from the climatological average are not significant.

A significant increasing trend (1.1 °C/ 61 years) of annual maximum temperature was observed over the south-south region (Table 4).Increasing trends in monthly and seasonal maximum temperature was also observed across the stations with the exception of Warri where there was no significant trend in most of the months (April to August, November and December). The highest significant increase of 1.9 °C/ 61 years was observed during the month of February whilst the lowest increase of 0.8 °C/ 61 years was observed during the months of April and May. Similarly, a significant increasing trend of annual minimum temperature of 1.4 °C/ 61 years was observed over the south-south region with a higher significant increase of 2.0 °C/ 61 years recorded during the month of March followed by 1.9 °C/ 61 years in the month of February. All months and season showed increasing trend in minimum temperature across the south-south region. This is consistent with findings in other similar studies (Ragatoa et al., 2018; Amadi et al., 2014). Subash and Sikka (2014) also observed significant increasing trend of annual minimum temperature over India.

Mean temperature shows significant increasing trend in all months and seasons across all stations except during the dry season in Benin where there was a non-significant increasing trend. Higher significant mean temperature of 1.9 °C/ 61 years was observed during the month of February whilst lower increase of 0.8 °C/ 61 years was obtained during the month of May.

Standardized temperature anomaly in the south-south region show two distinct climatological time-periods. The first period of 1950 – 1980 is characterised by annual average temperature below the climatological average whilst the second period of 1981 – 2010 show rising annual mean temperatures consistently above the climatological average with the exception of years 1992 and 1994 (Figure 2). In the 61 year period under review, 35 years were classified as warm as they had anomalies above the average, whilst 26 years were categorized as cool with anomalies below the average (Figure 3). Generally, increase in the number of warmer years per decade tend to correspond with increase in the number of dryer years with the exception of the 1991-1999 decade where increase in the number of warmer years mirrored that of wet years. Overall, significant increasing trend in annual mean temperature of 1.2 °C/ 61 years was observed over the south-south region. This is 58% higher than the 0.5°C/ 100 years observed over India (Subash and Sikka, 2014).

Table 4: Sen's estimator of slope for monthly, annual and seasonal rainfall, and mean, maximum and minimum temperature for different meteorological stations and the south-south region

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual	Wet	Dry
Rainfall															
CB	-0.12	-0.28	0.59	0.11	0.72	0.03	1.47	1.50	-1.18	**-1.57***	-0.75	-0.11	-0.12	0.10	**-0.48***
PH	-0.14	0.00	-0.66	-0.76	0.79	0.66	-0.00	-0.51	-1.03	-0.97	-0.24	0.00	-0.28	-0.29	-0.17
WR	-0.13	-0.03	0.33	-0.56	0.33	0.08	-1.22	0.74	**-1.96***	-0.78	-0.05	-0.11	-0.29	-0.35	-0.14
BN	0.00	0.15	0.02	0.29	0.37	-0.58	-0.59	1.58	-0.19	0.10	0.07	0.00	0.25	0.31	0.06
SS	-0.04	-0.17	0.07	-0.24	0.58	0.46	0.08	0.72	-1.01	-0.86	-0.30	-0.19	-0.12	-0.02	-0.16
T Mean															
CB	**0.02****	**0.04****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****
PH	**0.03****	**0.04****	**0.03****	**0.03****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.03****	**0.02****	**0.02****	**0.02****	**0.03****
WR	**0.02****	**0.03****	**0.02****	**0.01****	**0.01****	**0.01****	**0.01***	**0.01****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.01****	**0.02****
BN	**0.03****	**0.04****	**0.03****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.03****	**0.03****	**0.03****	**0.02****	0.03
SS	**0.02****	**0.03****	**0.03****	**0.02****	**0.01****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****
T Max															
CB	**0.03****	**0.04****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.03****
PH	**0.04****	**0.03****	**0.03****	**0.03****	**0.02****	**0.03****	**0.01****	**0.02****	**0.02****	**0.02****	**0.03****	**0.03****	**0.03****	**0.02****	**0.03****
WR	**0.02****	**0.02****	**0.01***	0.00	0.00	0.00	0.00	0.00	**0.02****	**0.01***	0.01	0.00	**0.01****	**0.01***	**0.01****
BN	**0.03****	**0.03****	**0.02****	**0.01****	**0.01***	**0.02****	**0.02****	**0.01****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.01****	**0.03****
SS	**0.03****	**0.03****	**0.02****	**0.01****	**0.01****	**0.02****	**0.01****	**0.01***	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.01****	**0.02****
T Min															
CB	0.01	**0.03****	**0.03****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.01***	**0.02****	**0.02****	**0.02****
PH	0.02	**0.04****	**0.03****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.01***	**0.02****	**0.02****	**0.02****
WR	0.02	**0.03****	**0.03****	**0.02****	**0.02****	**0.02****	**0.01****	**0.02****	**0.02****	**0.02****	**0.02****	**0.03****	**0.02****	**0.02****	**0.03****
BN	**0.04****	**0.04****	**0.04****	**0.04****	**0.03****	**0.03****	**0.02****	**0.03****	**0.02****	**0.03****	**0.04****	**0.04****	**0.03****	**0.03****	**0.04****
SS	0.02	**0.03****	**0.03****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****	**0.02****

Bold values with * and ** indicate statistical significance at 95% and 99% confidence level, respectively, with regards to the Mann-Kendall test (+ for increasing and – for decreasing)

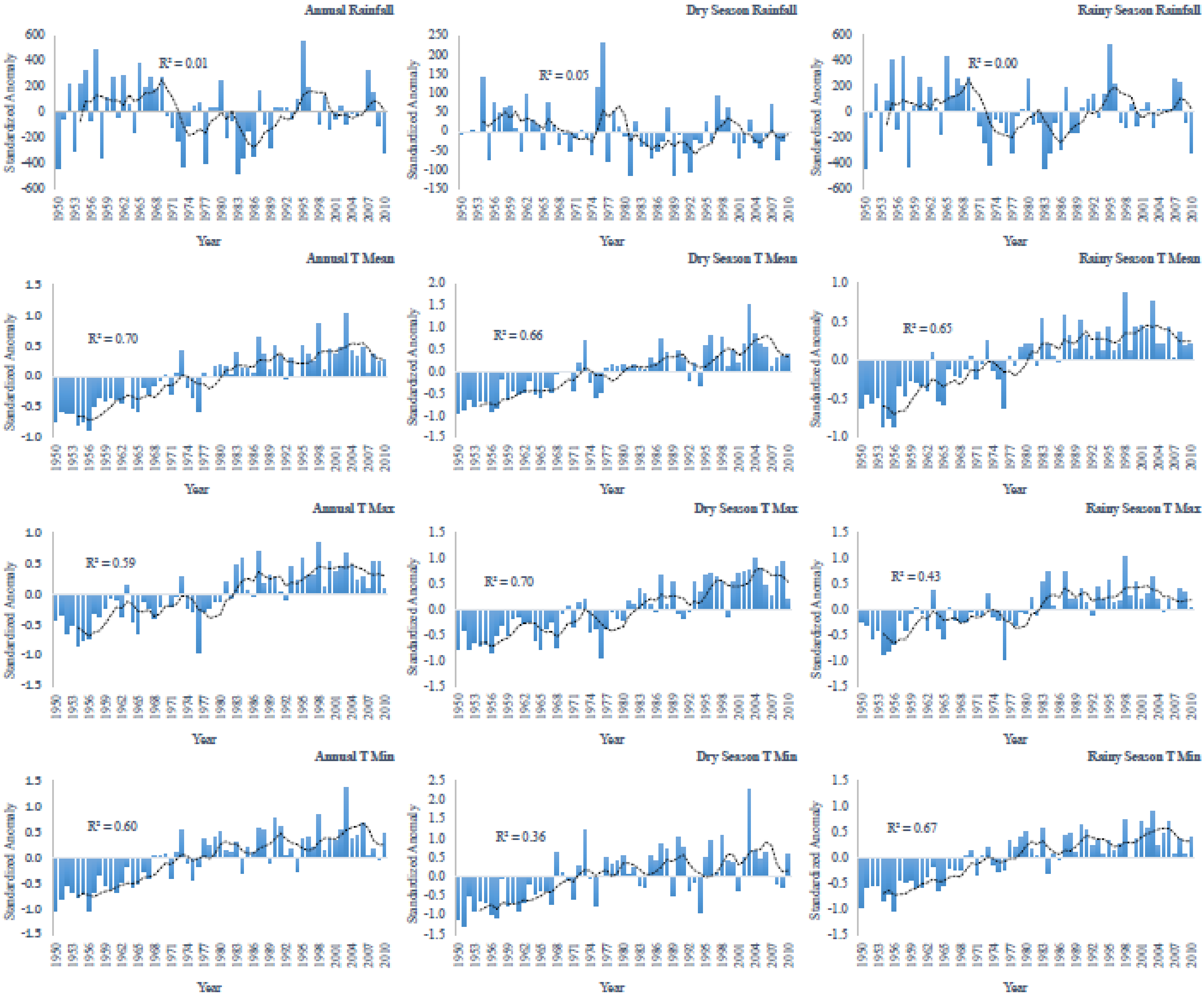

Figure 2: Standardized rainfall and temperature anomalies for the south-south region. Dashed black lines represent the 5-year moving average

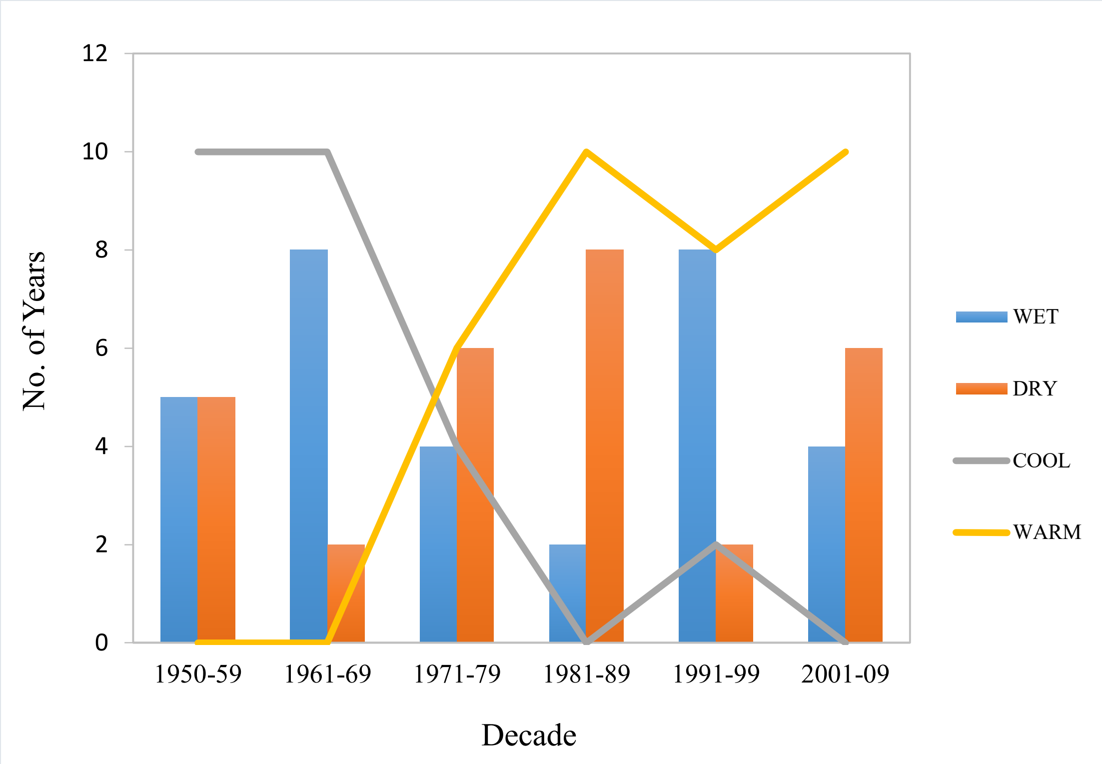

Figure 3: Number of wet/dry and cool/warm years per decade in relations to rainfall and temperature anomaly in the south-south region.

4.3. Relationship between rainfall and temperature

The relationship between rainfall and temperature over the south-south region is shown in Figure 4 while the linear regression models of rainfall-temperature relationships over different meteorological stations are shown in Table 5. Consistent with findings in other studies (Nkuna and Odiyo, 2016; He et al., 2015; Zhao and Khalil, 1992) there was a negative relationship between annual rainfall and maximum and mean temperature in the south-south region of Nigeria (Figure 4A and B). However, a negative but statistically insignificant relationship was observed between annual rainfall and minimum temperature (Figure 4C). With respect to seasonality, statistically significant (P<0.00) negative relationships were observed between rainfall and mean, maximum and minimum temperature during the rainy season (Figure 4G, H and I).The relationship between rainfall and temperature was more varied during the dry season. Whilst a significant (P<0.00) negative relationship was observed between rainfall and maximum temperature (Figure 4E), the relationship between rainfall and mean temperature was negative but statistically insignificant (Figure 4D). Interestingly, significantly (P<0.00) positive relationship was obtained between rainfall and minimum temperature (Figure 4F) in the dry season, although the model explains less than 10% variation in the data (R^2 = 0.05).A previous study have shown that higher temperature usually accompanied water-deficient conditions whilst lower temperatures accompanied wet conditions (He et al., 2015).Although there was no direct relationship between increasing rainfall and maximum temperature over southern Nigeria, rainfall appears to have large-scale spatial-temporal dependence on minimum temperature in the dry season in all but the Calabar meteorological station (Table 5). This may suggest the likely influence of several different mechanisms including changes in cloud cover, heat balance and rainfall pattern in different local landscape region (Zhao and Khalil, 1992).

Based on observed rainfall-temperature relationship in this study it can be suggested that temperature play a direct or indirect role in influencing rainfall and in the context of climate change should not be studied separately. More in-depth studies are required to fully understand the extent of interaction between temperature and rainfall at local, regional and global scales and how climate change is likely to influence hydrological processes in future.

Table 5: Linear regression models of rainfall-temperature relationships over different meteorological stations in the south-south region of Nigeria

S/N	Met. Station	Timescale	Parameter Relationship	Regression equation	R^2	Significance F
1.	Calabar	Annual	Rain vs. T Mean	y = -97.0x + 2833.9	0.42	0.00
			Rain vs. T Max	y = -69.1x + 2350.7	0.51	0.00
			Rain vs. T Min	y = -58.6x + 1586.1	0.07	0.00
		Dry Season	Rain vs. T Mean	y = -29.7x + 881.8	0.11	0.00
			Rain vs. T Max	y = -30.6x + 1040.8	0.22	0.00
			Rain vs. T Min	y = -3.77x + 155.2	0.00	0.51
		Rainy Season	Rain vs. T Mean	y = -77.2x + 2365.1	0.37	0.00
			Rain vs. T Max	y = -51.2x + 1857.8	0.38	0.00
			Rain vs. T Min	y = -79.6x + 2153.7	0.17	0.00
2.	Port-Harcourt	Annual	Rain vs. T Mean	y = -56.1x + 1695.3	0.18	0.00

			Rain vs. T Max	y = -52.3x + 1818.8	0.41	0.00
			Rain vs. T Min	y = 25.4x - 372.3	0.04	0.00
		Dry Season	Rain vs. T Mean	y = 0.91x + 30.2	0.00	0.79
			Rain vs. T Max	y = -13.8x + 499.5	0.10	0.00
			Rain vs. T Min	y = 10.7x - 177.7	0.07	0.00
		Rainy Season	Rain vs. T Mean	y = -58.8x + 1827.5	0.26	0.00
			Rain vs. T Max	y = -39.9x + 1480.3	0.29	0.00
			Rain vs. T Min	y = -50.0x + 1401.8	0.07	0.00
3.	Warri	Annual	Rain vs. T Mean	y = -88.6x + 2642.9	0.32	0.00
			Rain vs. T Max	y = -70.0x + 2422.1	0.48	0.00
			Rain vs. T Min	y = -9.70x + 456.8	0.00	0.18
		Dry Season	Rain vs. T Mean	y = 6.45x - 124.5	0.00	0.16
			Rain vs. T Max	y = -6.95x + 281.7	0.01	0.12
			Rain vs. T Min	y = 10.3x - 179.8	0.04	0.00
		Rainy Season	Rain vs. T Mean	y = -75.7x + 2360.5	0.33	0.00
			Rain vs. T Max	y = -52.9x + 1942	0.36	0.00
			Rain vs. T Min	y = -78.2x + 2138.1	0.15	0.00
4.	Benin	Annual	Rain vs. T Mean	y = -61.8x + 1849.4	0.32	0.00
			Rain vs. T Max	y = -51.3x + 1786.7	0.50	0.00
			Rain vs. T Min	y = -13.8x + 493.0	0.01	0.00
		Dry Season	Rain vs. T Mean	y = 1.07x + 7.65	0.00	0.70
			Rain vs. T Max	y = -7.64x + 288.2	0.04	0.00
			Rain vs. T Min	y = 4.21x - 58.4	0.02	0.01
		Rainy Season	Rain vs. T Mean	y = -46.2x + 1482.1	0.26	0.00

	Rain vs. T Max	y = -35.7x + 1342.9	0.32	0.00
	Rain vs. T Min	y = -29.4x + 920.3	0.06	0.00

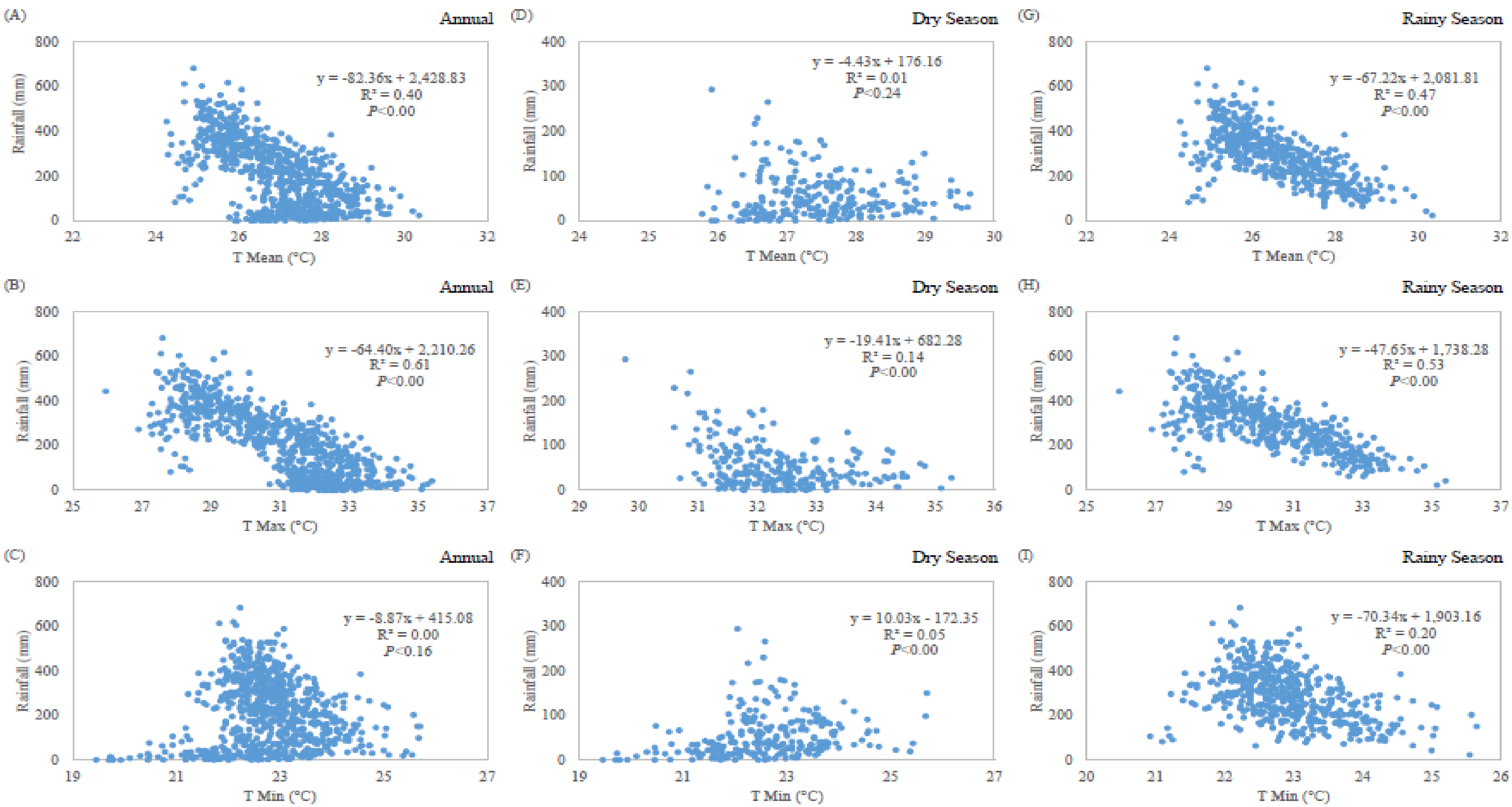

Figure 4: Rainfall-Temperature relationship in the south-south region of Nigeria

5.0. Conclusion

This study examined the variability in the long-term trends of monthly, annual and seasonal rainfall, maximum, minimum and mean temperature over southern Nigeria. The relationship between temperature and rainfall over southern Nigeria was also investigated. The study show a bi-modal rainfall distribution pattern with over 90% of total rainfall received during the rainy season. No significant increasing/decreasing trend was observed in the monthly, annual and seasonal rainfall over the region. This study also provides evidence of rising maximum, minimum and means temperature over southern Nigeria with a decadal sequence of increasing and decreasing rainfall trend. Although there was no direct relationship between increasing rainfall and maximum temperature in the region, rainfall appears to have large-scale spatial-temporal dependence on minimum temperature in the dry season suggesting the likely influence of diverse physically different mechanisms. Based on the observed spatial and temporal variability of rainfall and temperature in this study, it is recommended that studies investigating trends in rainfall and temperature consider not just temporal but spatial dimensions in their analysis to adequately capture the influence of local scale controls on trends.

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