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Confirmation of Climate Change in Southwestern Nigeria through Analysis of Rainfall and Temperature Variations over the Region

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Abstract: Understanding the variability of precipitation and temperature of a region over a long period gives one an idea about the climate and climate change of such region. The study investigated rainfall and temperature variability in four meteorological stations, namely, Abeokuta (lat.7.01^o N, long.3.2^o E, alt. 67m) , Ibadan (lat.7.43^o N, long.3.9^o E, alt. 227m), Ikeja (lat.6.58^o N, long.3.33^o E, alt. 39m) and Ondo (lat.7.1^o N, long.4.83^o E , alt. 287m) in the south-western region of Nigeria.Monthly rainfall, minimum temperature and maximum temperature data were obtained from Nigeria Meteorological Agency (NIMET) for the period of thirty one years (1980 to 2010) for the study.Descriptive Statistics were deployed to determine the mean, confidence levels, coefficient of kurtosis, skewness and coefficient of variations. A fairly "M-shaped" pattern was observed in the monthly mean rainfall distribution with bi-modal peaks in June and September, with slight dryness experienced in August, referred to as "August break". Analyses of annual trends over a long period revealed a sequence of alternately decreasing and increasing trends in mean annual rainfall and air temperature in region. Generally however, gradients of the trend lines are positive. There is a negative relationship between annual total rainfall and annual average temperature.

Keywords: Climate change, statistical analysis, rainfall, temperature

Introduction

Climate is the average weather over a long period of many years. It differs in regions of the world. Climate depends on different amounts of sunlight received in a region and different geographic factors, such as proximity to oceans and altitude. Climate is typically described by the statistics of a set of atmospheric and surface variables, such as temperature, precipitation, wind, humidity, cloudiness, soil moisture, sea surface temperature, and the concentration and thickness of sea ice. The statistics may be in terms of the long-term average, as well as other measures such as daily minimum temperature, length of the growing season, or frequency of floods. One can have a good understanding of the climate of a location by examining the annual or seasonal averages of two climatic variables: temperature and precipitation.

Climates will change if the factors that influence them vary. In order to change climate on a global scale, either the amount of heat that is let into the system changes, or the amount of heat that is let out of the system changes. The sun provides the energy that drives the climate of the earth. Variations in the composition and intensity of incident solar radiation hitting the earth may produce changes in global and regional climate which are both different and additional to those from man-made climate change.

The Intergovernmental Panel on Climate Change (IPCC) defines climate change as: A change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability orbecause of human activity [1]. The global climate has changed rapidly with the global mean temperature increasing by 0.7 ^{o}C within the last century [1].

Several studies have been carried out in different part of the globe in relation to climatic variations [2-5]. Ayansina and Ogunbo [3] investigated the seasonal rainfall variability in Guinea savannah part of Nigeria and concluded that rainfall variability continues to be on the increase as an element of climate change. Hasanean [4] examined trends and periodicity of air temperature from eight meteorological stations in the east Mediterranean and observed positive significant trends in Malta and Tripoli, and negative trend in Amman. Turkes *et al*. [5] evaluated mean, maximum and minimum air temperature data in Turkey during the period 1929–1999. Their analyses revealed spatiotemporal patterns of long-term trends, change points, and significant warming and cooling periods. Increasing flood risk is now being recognized as the most important sectorial threat from climate change in most parts of the region which has prompted public debate on the apparent increased frequency of extreme, and in particular, on perceived increase in rainfall intensities [6]. Several studies have adduced extreme rainfall to be the major cause of flood worldwide [7-10].

This work is aimed at investigating the pattern of rainfall and temperature, as well as the relationship between them, in four meteorological stations in south-western region of Nigeria on monthly and annual basis.

Methodology

Monthly rainfall, minimum temperature and maximum temperature data for thirty one years (1980 to 2010) of four meteorological stations were collected from Nigeria Meteorological Agency

(NIMET). The stations are, Abeokuta(lat.7.01^o N, long.3.2^o E, alt. 67m) Ibadan (lat.7.43 ^{o} N, long.3.9 ^{o} E, alt. 227m) , Ikeja (lat.6.58 ^{o} N, long.3.33 ^{o} E, alt. 39m) and Ondo (lat.7.1 ^{o} N, long.4.83 ^{o} E , alt. 287m). The stations fall into two climatic regions namely costal (Abeokuta, Ikeja and Ondo) and derived savannah (Ibadan). From the collected data, annual rainfall and annual mean temperature for the stations were calculated. The monthly and annual distributions of rainfall and temperature characteristics across each of the stations were observed and analyzed having taken care of some few incomplete and missing records. Descriptive statistics were used for the analyses. Thus, the mean, minimum, maximum, Kurtosis and skewness of the climatic variables considered were analyzed both on monthly and annual basis. The mean gave information about the centre of the distribution. The coefficients of skewness and kurtosis provided information about the symmetry and length of the tail for certain types of distributions respectively. Skewness was a measure of asymmetry of the probability distribution of a variable from mean. It revealed to us the amount and direction of departure from horizontal symmetry. It can be positive and negative or even undefined. If skewness is zero, the data are perfectly symmetrical.

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The following are the general rules of skewness:

- If skewness is less than -1 or greater than 1, the distribution is highly skewed.
- If skewness is between -1 and - 0.5 or between 0.5 and 1, the distribution is moderately skewed.
- If skewness is between -0.5 and 0.5, the distribution is approximately symmetric.

The following are the general rules of kurtosis:

- If kurtosis is greater than 3, the distribution is highly leptokurtic i.e. it is sharper than normal distribution, with values concentrated around the mean and thicker tails. This signifies high probability for extreme values.
- If kurtosis is less than 3, the distribution is platykurtic i.e. it is fatter than normal distribution with a wider peak. The probability of extreme values is than for a normal distribution, and the values is wider spread around the mean.
- If kurtosis is 3, the distribution is mesokurtic i.e. it is a normal distribution.

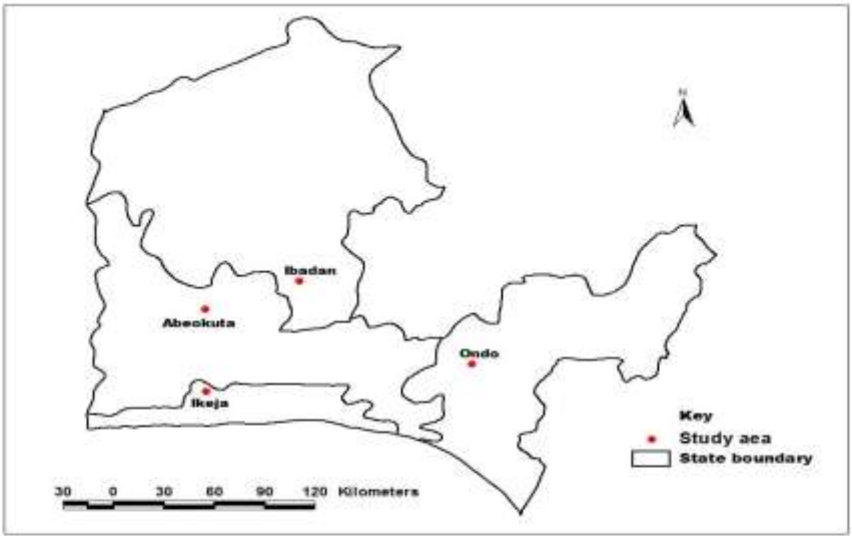

Figure 1: Location of the four meteorological stations on the southwestern map of Nigeria

Results and Discussion

Table 1: Descriptive statistics of the rainfall data for Abeokuta in coastal region

Abeokuta	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean	3.58	25.75	65.91	120.49	157.47	196.09	183.82	113.32	197.59	125.51	18.79	8.95
Std. Dev.	7.18	31.21	48.11	54.09	63.21	78.22	93.32	85.23	74.94	51.48	21.78	19.64
Samp. Var	51.60	974.01	2314.20	2926.26	3995.83	6118.17	8708.21	7263.84	5616.62	2650.41	474.36	385.90
Kurtosis	8.48	-0.17	1.03	1.48	1.23	2.06	0.28	-0.08	0.14	0.18	2.42	5.76
Skewness	2.71	1.01	1.08	1.20	1.01	1.12	0.90	0.80	0.79	-0.31	1.59	2.52
Range	32.50	99.20	198.90	212.20	272.30	385.30	369.20	297.30	287.90	208.20	88.00	71.70
Minimum	0.00	0.00	1.60	45.50	69.40	51.00	46.10	8.00	84.80	8.90	0.00	0.00
Maximum	32.50	99.20	200.50	257.70	341.70	436.30	415.30	305.30	372.70	217.10	88.00	71.70
Count	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	29.00	30.00	30.00
C/Lev.(95.0%)	2.68	11.65	17.96	20.20	23.60	29.21	34.85	31.82	27.98	19.58	8.13	7.34

Table 2: Descriptive statistics of the rainfall data for Ibadan in derived savannah region

Ibadan	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean	4.33	37.47	81.13	123.82	160.44	191.13	179.44	143.98	193.30	182.19	24.12	8.96
Std. Dev	8.42	45.45	52.83	45.56	54.07	81.51	87.58	96.21	64.26	53.78	30.24	17.46
Samp. Var.	70.90	2065.91	2790.63	2075.54	2923.21	6643.98	7669.42	9256.35	4129.94	2892.12	914.54	304.73
Kurtosis	3.02	1.45	0.60	1.02	-0.59	-0.62	-0.25	0.45	-0.50	2.56	6.50	5.71
Skewness	2.02	1.48	0.26	-0.02	0.13	0.32	0.21	0.86	0.57	0.46	2.22	2.41
Range	30.10	165.50	200.40	164.20	213.90	311.80	359.60	381.50	235.80	278.00	139.80	71.40
Minimum	0.00	0.00	0.00	39.50	51.30	61.60	26.20	29.80	92.70	70.00	0.00	0.00
Maximum	30.10	165.50	200.40	203.70	265.20	373.40	385.80	411.30	328.50	348.00	139.80	71.40
Count	30.00	29.00	30.00	30.00	29.00	29.00	30.00	30.00	29.00	30.00	30.00	29.00
C/Lev(95.0%)	3.14	17.29	19.73	17.01	20.57	31.00	32.70	35.93	24.44	20.08	11.29	6.64

Table 3: Descriptive statistics of the rainfall data for Ikeja in coastal region

Ikeja	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean	14.03	29.53	71.94	137.02	193.19	296.58	190.82	92.71	185.98	152.78	77.46	25.51
Std Dev.	32.72	39.02	40.53	80.18	66.28	112.12	146.37	92.75	91.78	63.46	48.64	28.45
Samp.Var.	1070.50	1522.20	1642.59	6428.39	4393.41	12571.21	21423.21	8602.49	8422.99	4027.7	2366.12	809.37
Kurtosis	21.22	9.34	-0.68	0.49	-0.19	0.82	0.70	4.63	-0.11	1.80	0.81	-0.39
Skewness	4.35	2.66	0.16	1.03	0.42	0.87	1.28	1.88	0.56	1.07	1.00	0.94
Range	174.40	188.50	150.00	309.90	265.20	484.60	518.30	415.00	370.70	305.40	207.80	87.70
Minimum	0.00	0.00	5.80	26.40	88.60	134.10	48.70	4.10	29.20	37.30	1.20	0.00
Maximum	174.40	188.50	155.80	336.30	353.80	618.70	567.00	419.10	399.90	342.70	209.00	87.70
Count	30.00	29.00	29.00	29.00	29.00	30.00	30.00	29.00	30.00	30.00	30.00	30.00
C/Lev.(95.0%)	12.22	14.84	15.42	30.50	25.21	41.87	54.65	35.28	34.27	23.70	18.16	10.62

Table 4: Descriptive statistics of the rainfall data for Ondo in coastal region

Ondo	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Mean	6.84	32.46	101.22	172.14	179.69	246.04	236.27	165.80	274.46	176.45	45.46	10.60
Std. Dev.	10.82	34.69	54.08	89.98	65.21	64.58	113.91	105.37	96.71	61.00	35.93	18.78
Samp. Var.	117.00	1203.74	2924.44	8097.15	4252.62	4170.91	12975.94	11103.68	9353.74	3720.76	1290.81	352.69
Kurtosis	2.29	0.70	-0.37	6.50	4.31	0.96	0.92	0.74	2.22	0.48	1.91	2.48
Skewness	1.78	1.22	0.00	2.05	1.51	0.89	0.86	0.90	1.03	0.45	1.25	1.85
Range	38.80	125.40	212.80	471.70	324.10	266.70	491.20	424.80	458.20	265.90	149.30	65.20
Minimum	0.00	0.00	0.00	41.60	86.60	140.80	61.00	30.10	98.40	66.40	0.00	0.00
Maximum	38.80	125.40	212.80	513.30	410.70	407.50	552.20	454.90	556.60	332.30	149.30	65.20
Count	29.00	30.00	29.00	29.00	29.00	28.00	27.00	27.00	27.00	26.00	26.00	28.00
C/Lev.(95.0%)	4.11	12.96	20.57	34.23	24.81	25.04	45.06	41.68	38.26	24.64	14.51	7.28

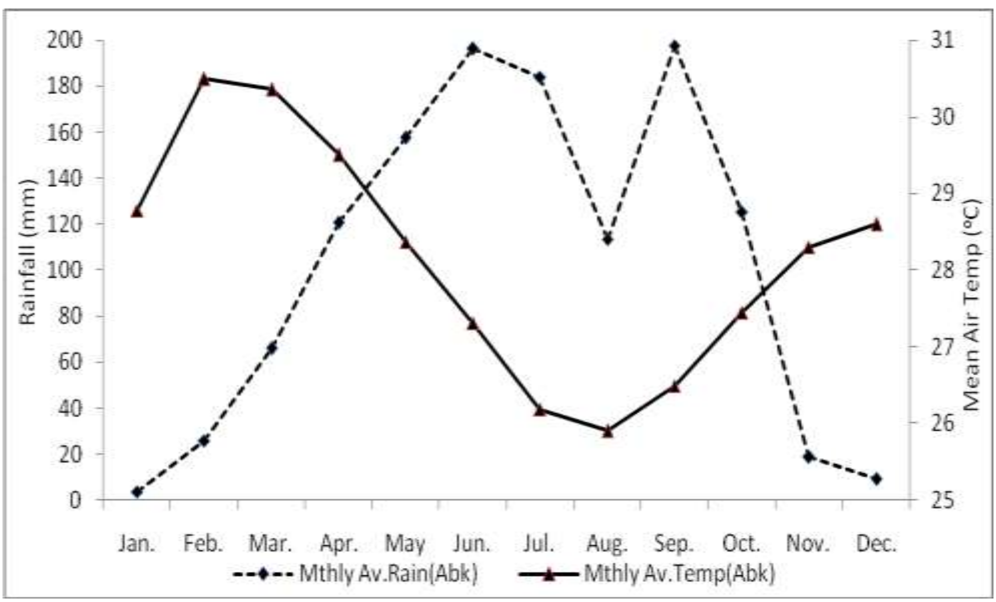

Figure 1: The monthly variations of rainfall and temperature at Abeokuta station

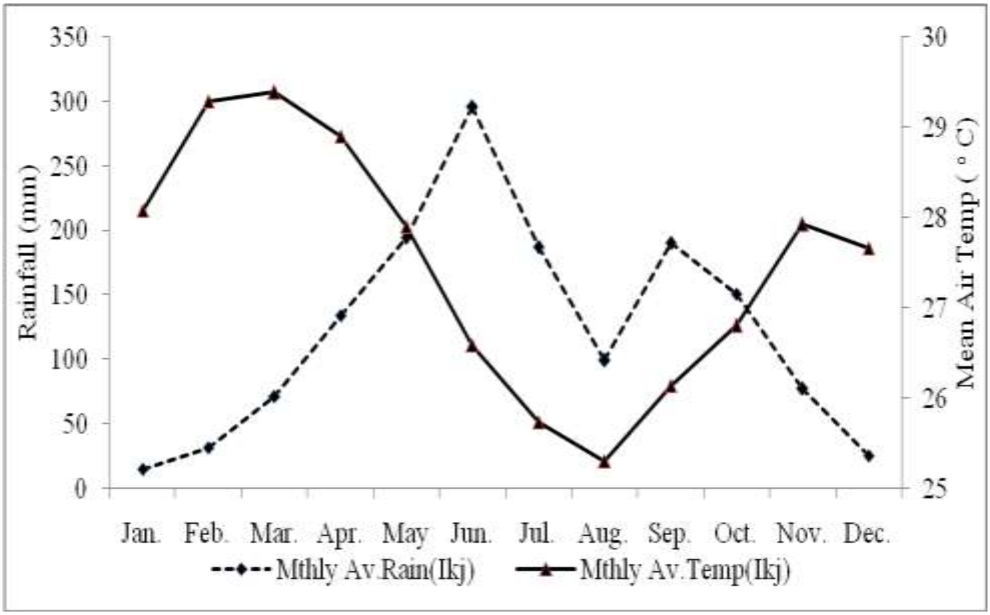

Figure 2: The monthly variations of rainfall and temperature at Ibadan station

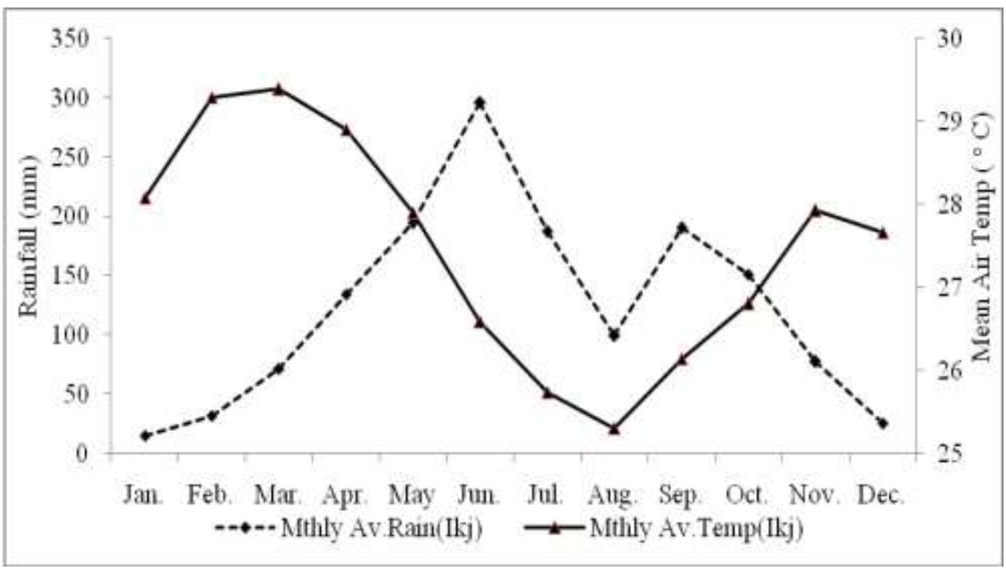

Figure 3: The monthly variations of rainfall and temperature at Ikeja station

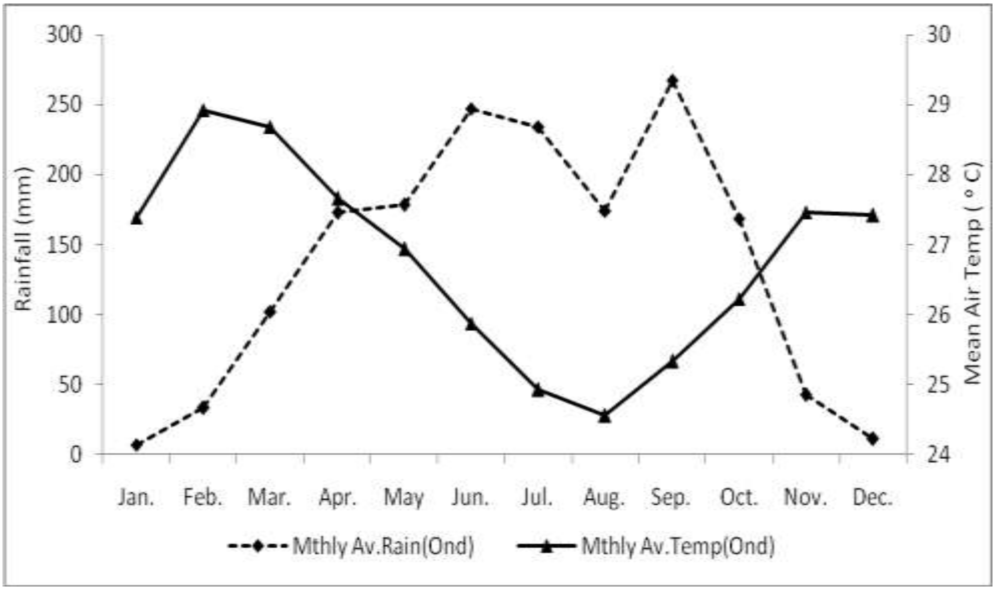

Figure 4: The monthly variations of rainfall and temperature at Ondo station

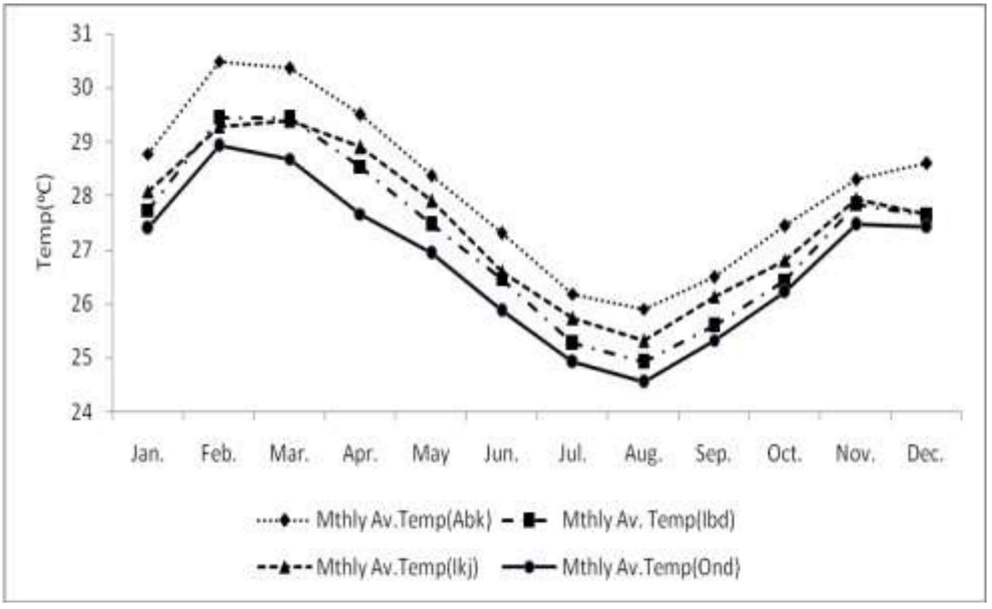

Figure 5: Monthly average temperature for Abeokuta, Ibadan, Ikeja and Ondo

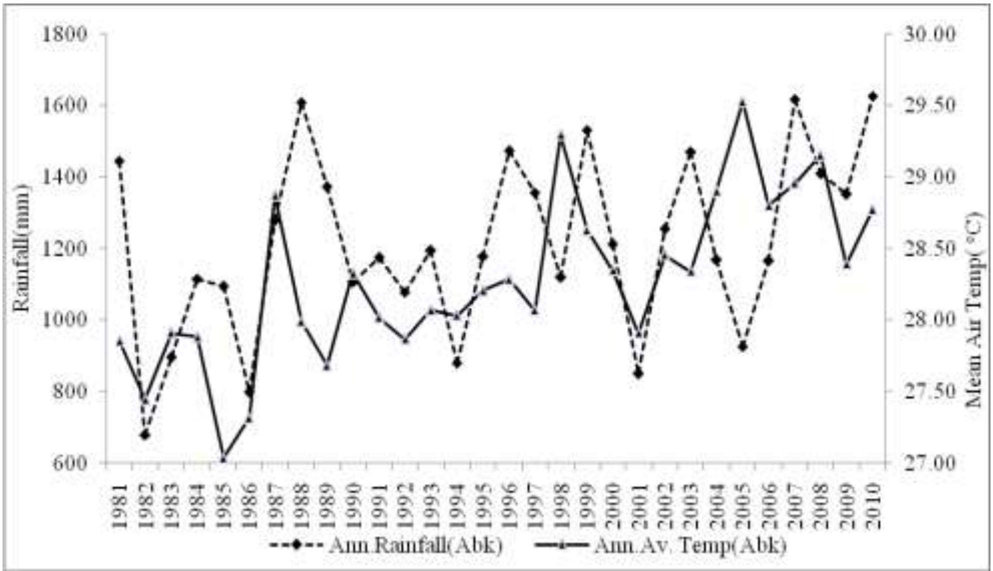

Figure 6: The annual variations of rainfall and temperature at Abeokuta station

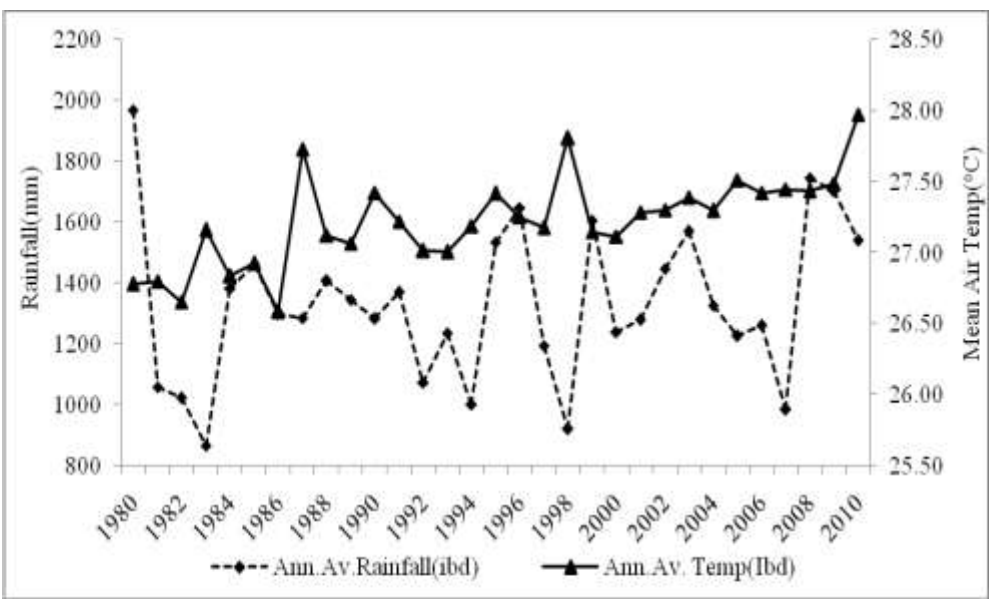

Figure 7: The annual variations of rainfall and temperature at Ibadan station

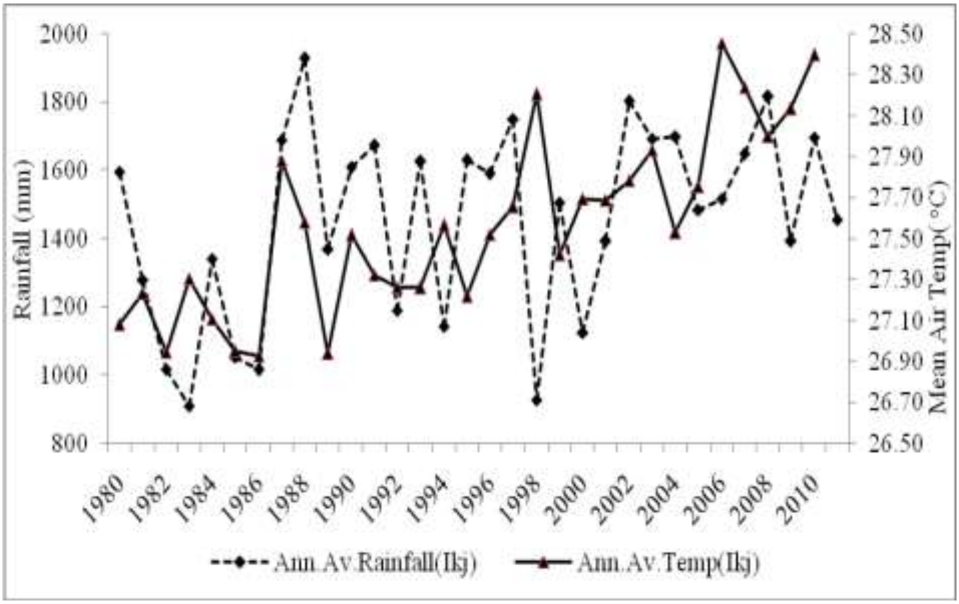

Figure 8: The annual variations of rainfall and temperature at Ikeja station

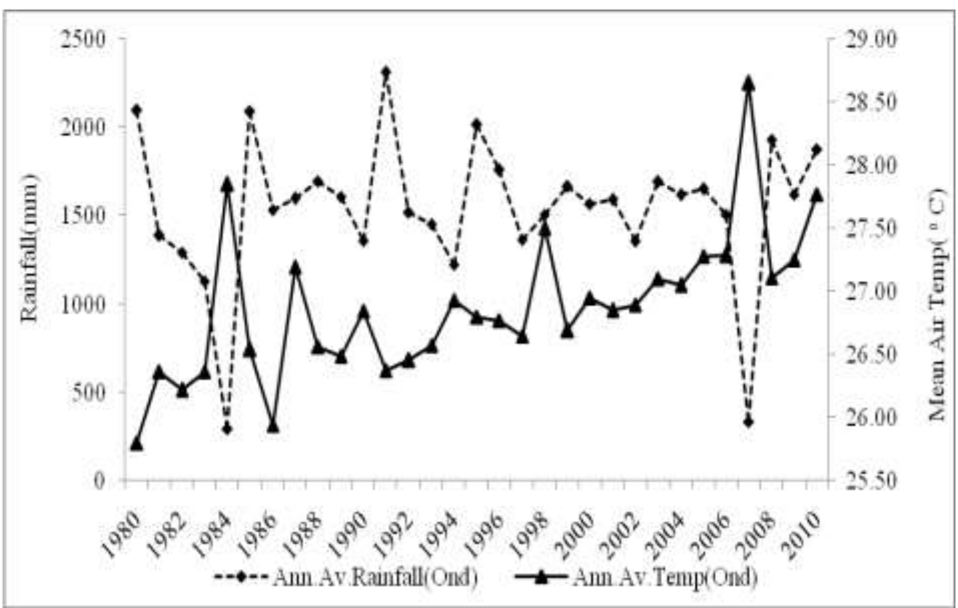

Figure 9: The annual variations of rainfall and temperature at Ondo station
Trend line equations for annual total rainfall (T_R) t = time in year

Trend line equations for annual total rainfall (T_R) t = time in year

$T_R = 10.76t + 1046.20$ (Abeokuta) ……….(1)

$T_R = 5.25t + 1247.80$ (Ibadan) ……….(2)

$T_R = 11.32t + 1267.90$ (Ikeja) ……….(3)

$T_R = 2.23t + 1500.70$ (Ondo) ……….(4)

Trend line equations for annual mean temperature (θ) t = time in year

$\theta = 0.047t + 27.54$ (Abeokuta) …….(5)

$\theta = 0.024t + 26.83$ (Ibadan) ……….(6)

$\theta = 0.039t + 26.94$ (Ikeja) ……….(7)

$\theta = 0.041t + 26.22$ (Ondo) ……….(8)

Tables 1 to 4 showed the descriptive statistics of the four meteorological stations on monthly basis. Figures 1 to 4 showed the monthly variations of rainfall and temperature of stations under consideration, while Figure 5 showed the monthly variation of mean temperature of all the stations combined. The annual variations of rainfall and temperature for Abeokuta, Ibadan, Ikeja and Ondo stations were respectively shown in Figures 6, 7, 8 and 9.

(a) Monthly average and annual total rainfall trend

Generally, there was no month of the year that recorded zero as mean rainfall in all the stations considered. As far as monthly distribution of rainfall is concerned, a fairly "M-shaped" pattern of rainfall with bi-modal distribution was observed in the four stations under consideration. Two distinct peaks occurred in June and September with a little break/reduction of rainfall in August between the peaks. The primary and highest peak of rainfall was recorded in June in the coastal region of Ikeja. The primary peaks of other stations occurred in September. The "August break" may be due to the African-easterly Jet and over lain of the area by the Continental Tropical air mass as it was observed by other investigators [11-12]. Analyses of annual trends over a long period revealed a sequence of alternately decreasing and increasing trends in mean annual rainfall and air temperature in south western Nigeria during the study period. Generally over the years, there was an increasing trend in rainfall in all the stations under consideration in the coastal and derived savannah regions of southwestern of Nigeria. The gradients of the trend lines equations (Equations (1) to (4)) revealed the average annual increase in temperature as 10.76mmyr^{-1}, 5.25mm yr^{-1} , 11.32mm yr^{-1} and 2.23mm yr^{-1} for Abeokuta, Ibadan, Ikeja and Ondo respectively.

Abeokuta

Table1 showed that, zero value of minimum rainfall was recorded in January, February, November and December. Abeokuta recorded highest mean value of rainfall of 197.59mm in September with maximum value of rainfall of 436.30mm in June. Highly skewed rainfall was recorded in seven months (January, March, April, May, June, November and December) ; while rainfall was approximately symmetric in five months (February, July, August, September, and October). Kurtosis analyses showed that the distribution of rainfall in ten months (February to November) in Abeokuta were platykurtic, two months (January and December) were leptokurtic.

The average annual total rainfall over the period of consideration was for Abeokuta was 1213.1 mm. The maximum annual total rainfall of 1625.4mm occurred in the year 2010 while the minimum annual total rainfall of 677.1mm occurred in the year 1982. Generally over the years, there is an increasing trend in annual total rainfall. The rainfall distribution over the years was highly skewed while Kurtosis analyses showed that the distribution is platykurtic.

Ibadan

Ibadan recorded zero value of minimum rainfall in five months, namely, January, February, March, November and December. Ibadan recorded highest mean value of rainfall of 193.30mm in September with maximum value of rainfall of 411.30mm in August. Highly skewed rainfall was recorded in Ibadan in four months, namely: January, February, November and December. August and September recorded moderately skewed rainfall while approximately symmetric rainfall was recorded in six months (March, April, May, June, July and October). Kurtosis analyses showed that the distribution of rainfall in January in Ibadan was mesokurtic, nine months (February to October) were platykurtic and two months (November and December) were leptokurtic.

The average annual total rainfall over the period of consideration was for Ibadan was 1331.8 mm. The maximum annual total rainfall of 1967.7mm occurred in the year 1980 while the minimum annual total rainfall of 677.1mm occurred in the year 1982. Generally over the years, there is an increasing trend in annual total rainfall. The skewness of the annual total rainfall distribution was 0.3031, implying that the distribution is approximately symmetric. While the Kurtosis analyses of 0.00125 revealed that the distribution was platykurtic.

Ikeja

Ikejarecorded zero value of minimum rainfall in January, February and December. Highest mean value of rainfall of 296.58mm was recorded in June with maximum value of rainfall of 618.70mm also in June. The skewness of rainfall was high in Ikeja during the following six months: January, February, April, August and October. Rainfall in June, September, November and December were moderately skewed. While in March and May, the rainfall was approximately symmetric. Kurtosis analyses showed that the distribution of rainfall in nine months (March, April, May, June, July, September, October November and December) were platykurtic and three months (January, February and August) were leptokurtic.

The average annual total rainfall over the period of consideration was for Ikeja was 1454.7 mm. The maximum annual total rainfall of 1927mm occurred in the year 1988 while the minimum annual total rainfall of 909.1mm occurred in the year 1983. Generally over the years, there is an increasing trend in annual total rainfall. The skewness of the annual total rainfall distribution was -0.491, implying that the distribution is approximately symmetric. While the Kurtosis analyses of -0.893 revealed that the distribution was platykurtic.

Ondo

Like Ikeja, Ondo equally recorded zero value of minimum rainfall in January, February and December. Highest mean value of rainfall of 274.46mm was recorded in September with maximum value of rainfall of 556.60mm also in September. The skewness of rainfall was high in Ondo during the following seven months: January, February, April, May, September, November and December. Rainfall in June, July and August were moderately skewed. While in March and October, the rainfall was approximately symmetric. Kurtosis analyses showed that the distribution of rainfall in ten months (January, February, March, June, July, August, September, October November and December) were platykurtic and two months (April and May) were leptokurtic. Ondo recorded an average annual total rainfall of 1536.4mm over the period of consideration. The maximum annual total rainfall of 2310.2mm occurred in the year 1991 while the minimum annual total rainfall of 293.8mm occurred in the year 1984. Generally over the years, there is an increasing trend in annual total rainfall. The skewness of the annual total rainfall distribution was -1.31, implying that the distribution is approximately symmetric. While the Kurtosis analyses of 3.38 revealed that the distribution was highly leptokurtic.

(b) Monthly average and annual average temperature trend

Generally, the monthly average temperature in all the stations considered followed the same shape of oscillating pattern with the maximum mean temperature occurring in February-March and the minimum mean temperature occurring in August. Figure 5 revealed that the mean temperature each month generally increase in the order: Ondo, Ibadan, Ikeja and Abeokuta; with respective monthly mean values of 26.78^{o}C, 27.23^{o}C, 27.48^{o}C and 28.14^{o}C. The corresponding altitude of the stations are: 287m (Ondo), 227m (Ibadan), 39m (Ikeja) and 67m (Abeokuta).The order of trend in monthly mean temperature of these stations is attributed to the combined effect of altitudes, in "that the higher we go, the cooler it is" coupled with the nearness of Ikeja to the sea. There is a negative correlation between the monthly mean temperature and monthly mean rainfall, that is, as the amount of rainfall increased, the temperature decreased. The correlation coefficients between the monthly mean temperature and monthly mean rainfall were -0.716, -0.673, -0.504 and -0.621 respectively for Ondo, Ibadan, Ikeja and Abeokuta respectively. For January, February and March the monthly mean temperature distributions were moderately skewed. In case of April, September to December, the distributions were highly skewed. While for May to August, the distributions were approximately symmetric. Kurtosis analyses showed that the distribution of mean temperature in nine months (January to August, and November) were platykurtic and three months (September, October and December) were leptokurtic. Generally over the years, there was an increasing trend in temperature in all the stations under consideration in the coastal and derived savannah regions of southwestern of Nigeria. The gradients of the trend lines equations (Equations (5) to (8)) revealed the average annual increase in temperature as 0.0474 ^{o}Cyr^{-1}, 0.0244^{o}C yr^{-1} , 0.039 ^{o}C yr^{-1} and 0.0406^{o}C yr^{-1} for Abeokuta, Ibadan, Ikeja and Ondo respectively.

The average annual mean temperature for Abeokuta was 28.27^{o}C. The maximum annual mean temperature of 29.53^{o}C occurred in the year 2005 while the minimum annual mean temperature of 27°C occurred in the year 1985. Kurtosis analyses of the average annual mean temperature distribution was platykurtic, while the skewness of the distribution was approximately symmetric.

The analysis revealed that the average annual mean temperature for Ibadan was 27.22°C. The maximum annual mean temperature of 27.97°C occurred in the year 2010 while the minimum annual mean temperature of 26.58°C occurred in the year 1986. Kurtosis analyses of the average annual mean temperature distribution was platykurtic, while the skewness of the distribution was approximately symmetric.

The average annual mean temperature for Ikeja was 27.56°C. The maximum annual mean temperature of 28.45°C occurred in the year 2006 while the minimum annual mean temperature of 26.93°C occurred in the year 1986. Kurtosis analyses of the average annual mean temperature distribution was platykurtic, while the skewness of the distribution was approximately symmetric.

The average annual mean temperature for Ondo was 26.87°C. The maximum annual mean temperature of 28.65 °C occurred in the year 2007 while the minimum annual mean temperature of 25.8°C occurred in the year 1980. Kurtosis analyses of the average annual mean temperature distribution was platykurtic, while the distribution was moderately skewed.

Conclusion

The analysis of rainfall and temperature over four meteorological stations in southwest Nigeria, falling into the coastal and derived savannah climatic regions has been studied extensively. It was observed that the monthly rainfall pattern followed a bi-modal distribution with three stations (Abeokuta, Ibadan and Ondo) having primary peak in September while that of Ikeja occurred in June. The secondary peak for Ikeja was experienced in September with others recording theirs in June."August break" was attributed to the Africa Eastern Jets and Tropical continental air mass of the West African Monsoon.

There was generally an increasing trend in rainfall amounts and frequency from January to June and decreasing trend from September to December in all the stations. Generally, the monthly average temperature in all the stations considered followed the same shape of oscillating pattern with the maximum mean temperature occurring in February-March and the minimum mean temperature occurring in August. The monthly mean temperature was discovered to be a function of altitude of the station as well as the nearness to the coast.

There was an increasing trend in temperature in all the stations for the period under consideration. Having studied and analyzed the rainfall and temperature pattern of southwestern Nigeria for about three decades, the increasing trends of both rainfall and temperature is an indicator that this region is having its fair share in the global climate change.

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