



Analysis of Climate Change in Rainforest Ecosystems of Southwestern Nigeria

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Abstract

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Increasing global climate change affects ecological systems worldwide and raises concerns on the vulnerability of products and services from the forest. This study investigated climate change in forests of southwest Nigeria, using six forest reserves in three of the six states in this region. Remotely sensed air temperature (°C) and rainfall (mm/yr) of these forests for 60 years were obtained from the Climate Research Unit Time Series (CRU-TS) of University of East Anglia, UK. The data were subjected to time series and regression analyses to determine the occurrences of abrupt changes in temperature and rainfall values over the forest reserves, while temporal and spatial trends were also investigated. Analysis of long-term trends in the time series suggested a sequence of alternately decreasing and increasing trends in mean annual precipitation and air temperature in these forests for the period of study. Also, analysis of the air temperature indicated that the average temperature had increased significantly over the 60-year period, rainfall increased insignificantly with high variability (CV=±13.3%). Results further indicated that there have been statistically significant increased air temperatures and rainfall in all the forest reserves especially in the second 30-year period (1983-2012) at about 5% and 43% respectively. This change in climate could reduce the natural ability of forests in providing ecosystem services. Hence, forest-dependent communities should adopt strategies to cope with the changing climate.

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INTRODUCTION

Global warming is a sustained increase in the average temperature of the earth (Nzeh *et al.*, 2017). There is a worldwide consensus that global warming is a real, rapidly advancing and widespread threat facing humanity this century (IPCC 2007). Scientists have presented evidence and tested models to substantiate this truly alarming fact (Chaudhary and Aryal, 2009). Climate is one of the most important determinants of vegetation patterns globally. Thus, climate change can significantly alter the distribution, structure, ecology and the numerous services of forests (Ravindranath *et al.*, 1997). The global climate has changed rapidly with the global mean

temperature increasing by 0.7°C within the last century (IPCC, 2007). However, the rates of change are significantly different across regions (IPCC 2007). This is primarily due to the varied types of land surfaces with different surface albedo, evapotranspiration and carbon cycle (Meissner *et al.*, 2003; Snyder *et al.*, 2004; Dang *et al.*, 2007). The forest reserves of southwestern Nigeria are not left out in the threat posed by climate change. Southwestern Nigeria has 67 constituted forest reserves with a forest area cover of 564,055 hectares as shown in Table 1 (FORMECU, 1998). The rainforests of Southwestern Nigeria occupy an intermediate position between the upper and lower guinea forests which is part

of an extensive vegetal cover stretching from Sirea Leone to the Ghana-Togo Border. It consists of clusters of contiguous forest reserves spanning part of Ogun, Ekiti and Osun States. These reserves include Omo, Oluwa, Shasha, Ife and Ago-Owu forest reserves. Prior to the creation of state administration in Nigeria, these five forest reserves were all part of the then Shasha Forest Reserve established in 1925 (Isichei, 1995).

Climate change affects agriculture and forestry through increased temperatures, elevated CO₂ concentration, precipitation changes, increased weeds, pests and disease pressure, and increased vulnerability of organic carbon pools (Tubiello et al., 2008). Eboh (2009) reported that countries in sub-Saharan African, including Nigeria are likely to be negatively affected most due to their

geographical location, low incomes, low institutional capacity as well as their greater reliance on climate-sensitive renewable natural resources sectors like agriculture. The Intergovernmental Panel on Climate Change (IPCC, 2007) highlighted the need for more detailed information on climate change at regional and local scales, which is of particular interest to nations and economic groups. However, despite the multitude of studies that have been carried out globally on the assessment of climate change, studies on the long-term spatio-temporal variability and trend in temperature and rainfall are very limited in Africa. Hence, this study investigated the occurrence of climate change by evaluating long-term climate data (rainfall and temperature) to determine climate variation in some selected forest reserves of southwestern Nigeria.

Table 1. Total land area and Forest Reserves in Southwestern Nigeria

States	Total Land Area (km ²)	Number of Forest Reserves	Area of Forest Reserves (ha)
Osun	9,491	11	91,268
Ekiti	6,353	10	303
Ondo	15,500	16	3076
Ogun	16,086	9	275,362
Oyo	27,848	18	169,173
Lagos	3,939	03	6,8373

Source: FORMECU (1998), Modified.

MATERIALS AND METHODS

Study Area

The study was carried out in the tropical rainforest ecosystem of southwestern Nigeria, which lies between Latitudes 5.91° to 9.29° N and Longitude 2.79° to 6.11° E. The climate is characterized by wet and dry seasons which are associated with the Southwest monsoon wind from the Atlantic Ocean and Northeast trade wind from the Sahara Desert respectively. The temperature ranges between 21°C and 34°C while the annual rainfall ranges between 1500 mm and 3000 mm. Six forest reserves were randomly selected from three states (Ekiti, Ondo and Osun) out of the six southwestern Nigeria states. These forest reserves are: Akure and Ala (Ondo State), Eda and Ikere (Ekiti State) and, Shasha and Ago-owu (Osun State). The study area is bounded in the East by Edo and Delta States, in the North by Kwara and Kogi States, in the West by the Republic of Benin and in the South by the Gulf of Guinea. The vegetation is made up of fresh water swamp and mangrove forest at the belt, the lowland forest stretches inland to Ogun and part of Ondo state while secondary forest is towards the northern boundary where derived and southern savanna exist (Agboola, 1979).

Data Collection and Analysis

This study primarily made use of secondary data. The coordinates of each forest reserve (Figure 1) were obtained using a hand held Global Positioning System (GPS) device. Remotely sensed climate data on the spatiotemporal pattern of temperature and rainfall of the selected forest reserves were taken from the Global Gridded Climatology (CRU TS 3.21) which was presented at a new high resolution (0.5° latitude /longitude) and made available by the Climate Impacts LINK project, Climate Research Unit (CRU), University of East Anglia, Norwich, UK. The 0.5° resolution dataset of monthly surface-based climate parameters obtained covers the period between 1953 and 2012 (60 years). The CRU data were obtained and interpreted as outlined by Mitchell and Jones (2005) and New *et al.* (1999).

The relative settlements close to the CRU gridded point stations are Oba-Ile (Lat 5.25° N and Long 7.27° E), Deji camp (Lat 5.78° N and Long 7.20° E), Omuo-Ekiti (Lat. 5.72° N, Long. 7.75° E), Iworoko (Lat. 5.27° N and Long. 7.73° E), Laderu (Lat 4.25° N and Long. 7.25° E) and Awopeju (Lat. 4.77° N and Long. 7.23° E) for Akure, Ala,

Eda, Ikere, Ago Owu and Shasha forest reserves respectively (Figure 2). The downloaded climate data (in Netcdf format) were extracted from selected stations

within the study area using the FERRET software on LINUX operating system. The data were analysed to examine rainfall and temperature for variabilities.

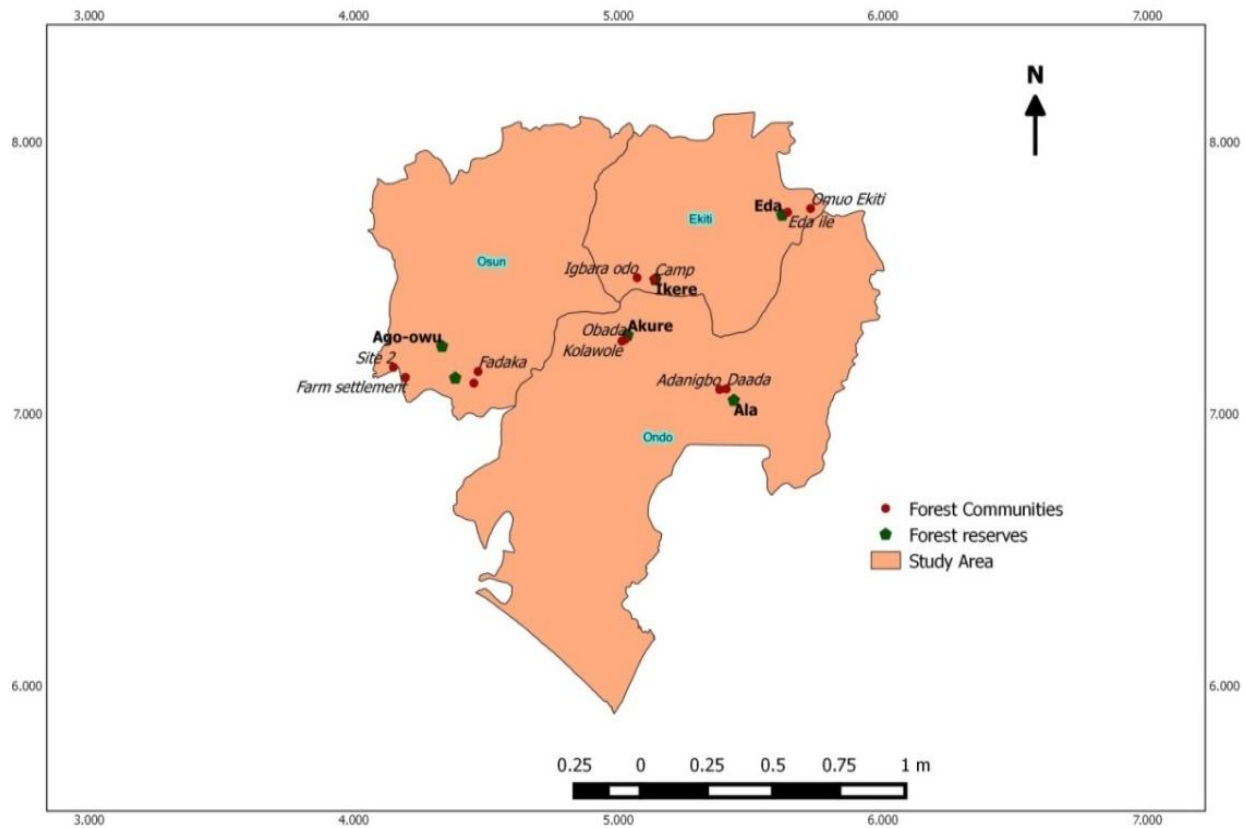


Figure 1. Map of study area showing selected forest reserves and communities

Coefficient of variation (CV) with respect to inter-annual variability was measured by the standard deviation of rainfall over the area of study. Higher values of CV indicate larger inter-annual variability and vice versa. Long time series of rainfall (30 years and above) in monsoon season was used to calculate the Standard Precipitation Index (SPI) of the forest reserves.

The climate data obtained from CRU were subjected to time series and regression analyses using Microsoft Excel software. Rainfall variability index was computed as the standardize precipitation departure. This partitions the available rainfall time series into different climatic regimes such as dry climatic year (-0.6 to -3), normal climatic year (± 0.5) and wet climatic years (0.6 to 3).

Rainfall variability index (δ_i) was calculated as

$$\delta_i = (P_i - \mu) / \sigma.$$

Where δ_i is rainfall variability index for year i , P_i is annual rainfall for year i , μ and σ are the mean annual rainfall and standard deviation respectively between 1953 and 2012. Temperature data were averaged while rainfall data for each gridded point stations were summed for the period. Also, the data for each station was summed to annual for rainfall time series and anomaly. The annual data were averaged and subdivided into six non-overlapping decades 1, 2, 3, 4, 5 and 6 as follows: 1953-1962, 1963-1972, 1973-1982, 1983-1992, 1993-2002 and 2003-2012. Comparisons were made among the decadal averages to investigate changes. Trend analyses were performed on the rainfall and temperature data obtained.

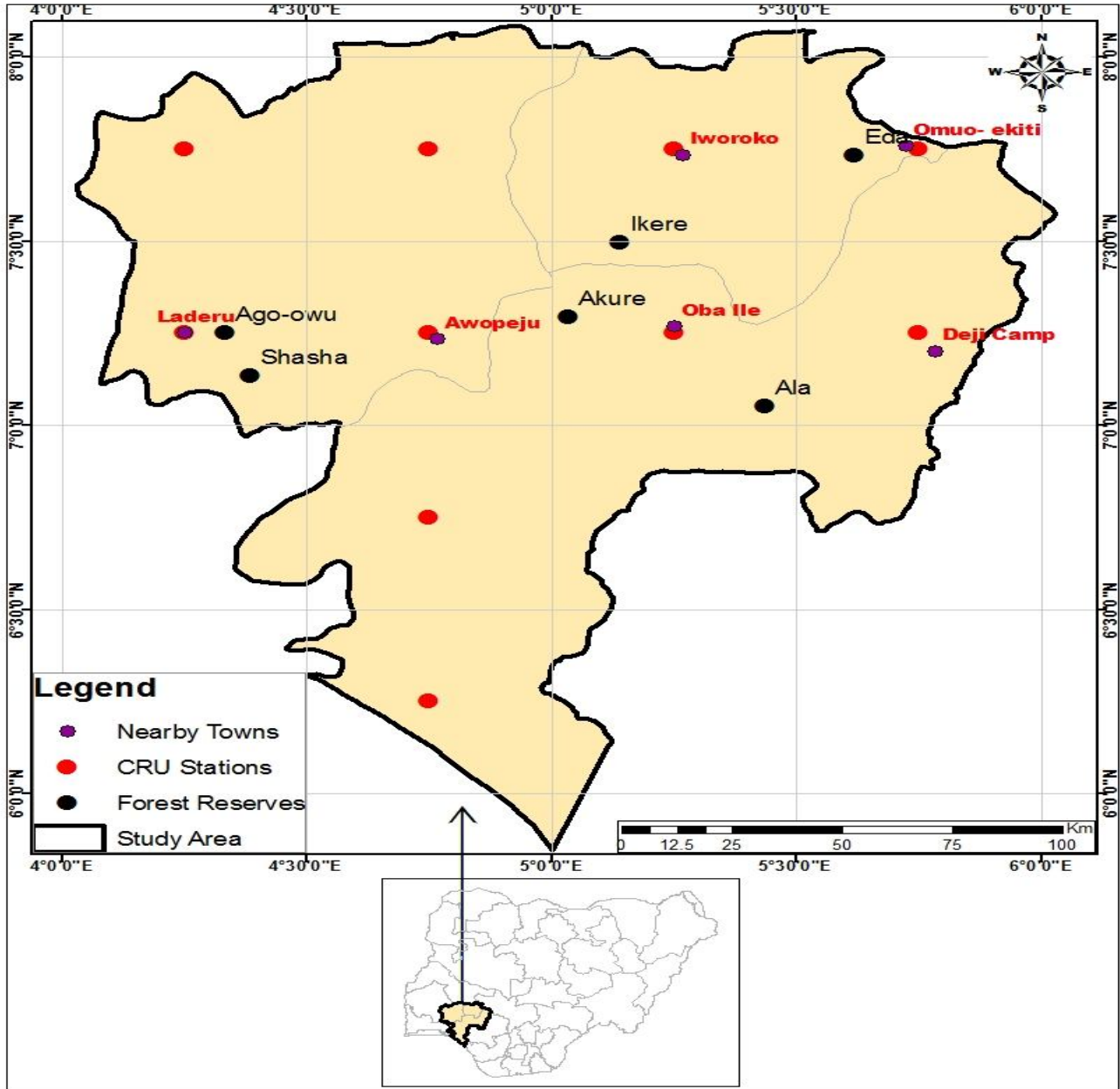


Figure 2. Map of study area showing the nearest CRU grid point stations to the forest reserve

RESULTS

Temporal time series distribution and cumulative departures of mean annual temperature showed positive trend of annual temperature in the study area (Figure 3). The highest and lowest temperature for Akure forest reserve during the 60-year period was 31.9°C and 29.7°C respectively. Ala forest reserve had 32.2°C and 31.4°C for highest and lowest temperature respectively. Shasha and Ago-Owu forest reserves had highest temperatures of 32.5°C and 31.9°C respectively, while Eda and Ikere forest reserves had highest temperatures of 31.7°C and 31.8°C respectively.

Generally, a near flat trend in the mean annual rainfall was recorded for the study locations between 1953 and 2012 (Figure 4). Hence, there was no significant increase in the rainfall amount. The minimum annual rainfall for Akure, Ala, Ago-Owu, Shasha, Eda and Ikere were 1088.5 mm/year, 1231.3 mm/year, 1000.8 mm/year, 1077.1 mm/year, 1045.1 mm/year and 1952.9 mm/year respectively while the maximum rainfall was 2322.6 mm/year, 2184.8 mm/year, 2087.3 mm/year, 2288.0 mm/year, 1959.9 mm/year and 1952.9 mm/year respectively. Also, rainfall patterns showed high variability across locations.

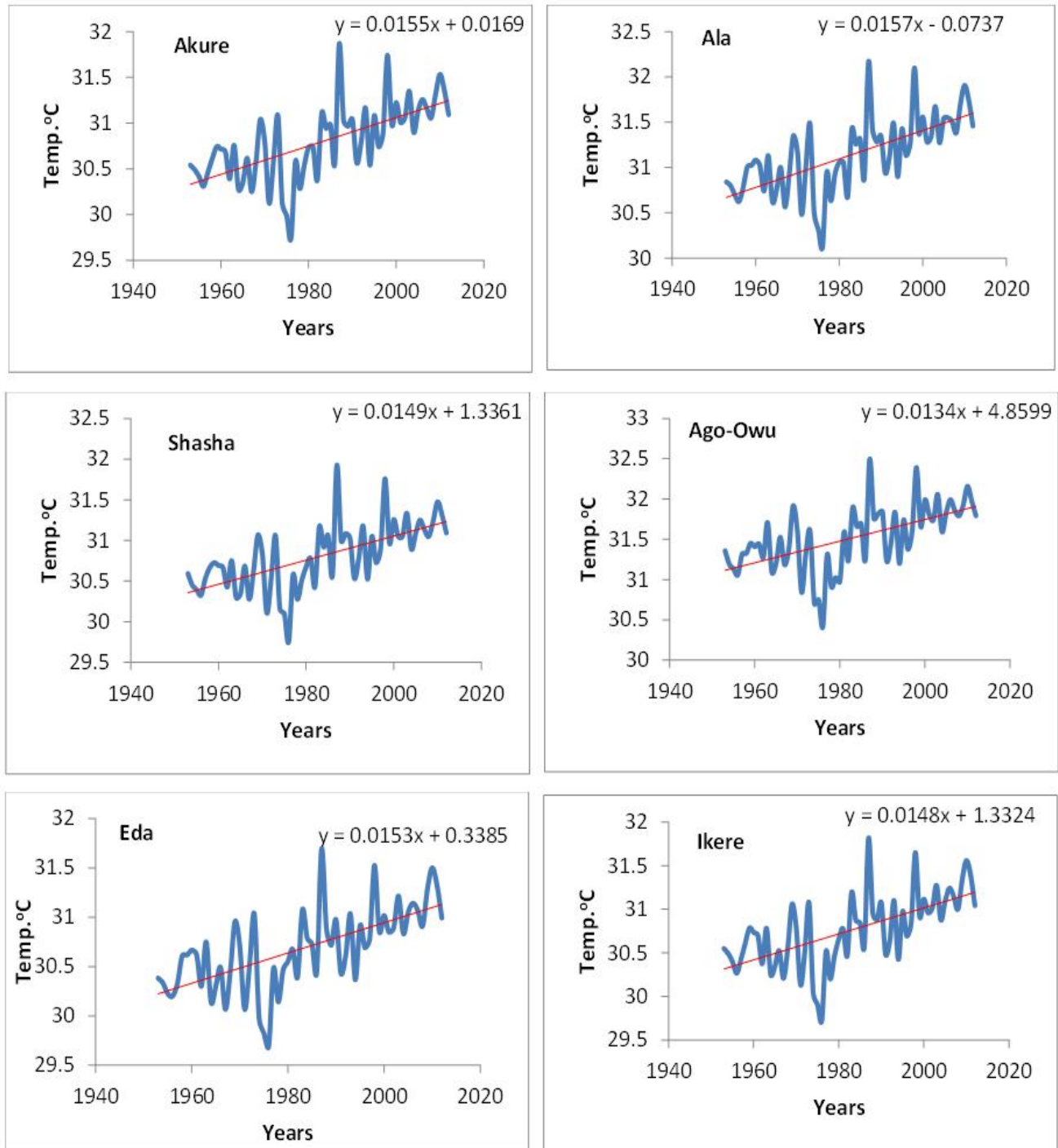


Figure 3. Time series plot of mean annual temperature between 1953-2012 for the forest reserves

Long-Term Annual Rainfall Variability in the Study Area (1953-2012)

Annual and decadal rainfall variability indices for the forest reserves showed an apparently random succession of dry, normal and wet years from 1953- 2012 (Figure 5). There were 18 dry years, 28 normal years and 14 wet years in Akure, 20 dry years, 19 normal years and 21 wet years in Ala, 18 dry years, 29 normal years and 13 wet years in Shasha, 21 dry years, 21 normal years and 18 wet years in Ago-Owu, 14 dry years, 27 normal years and 19

wet years in Ikere and 19 dry years, 26 normal years and 15 wet years in Eda forest reserve.

Across the study area, more wet years were observed between 1985 and 2012. Also, 1991 was the wettest year (2.66). The driest (-1.82) and wettest years (2.61) in Ala forest reserve were 1982 and 1963 respectively. In Akure forest reserve, the driest (-1.75) and wettest years (2.30) were 1978 and 1991 respectively. The years 1963 (2.63) and 1991 (2.30) were the wettest years in Ago-Owu and Shasha forest reserves respectively, while the driest year

was 1978 (-1.92). Similarly, the wettest year in Ikere and Eda forest reserves was 1991 with rainfall index of 2.30 and 2.42 respectively while the driest years were 1978 (-2.04) and 1982 (-2.09) respectively.

Long-Term Decadal Temperature and Rainfall Variability in the Study Area

Decadal temperature variability indices for the study area showed that the first three decades (decades 1, 2 and 3)

had lower temperature than the last three decades (Decades 4, 5 and 6) (Figure 6). This was applicable to all the forest reserves studied. The decadal rainfall variability index as presented in Figure 7 showed that decade 3 (1973-1982) was extremely dry (-2.5) in Ala forest reserve. Decades 1, 2 and 6 were normal years (± 0.5), while the other two decades 4 and 5 were wet years. Except for decade 2 that was wet and decade 4 that was normal, similar trend was observed in Akure.

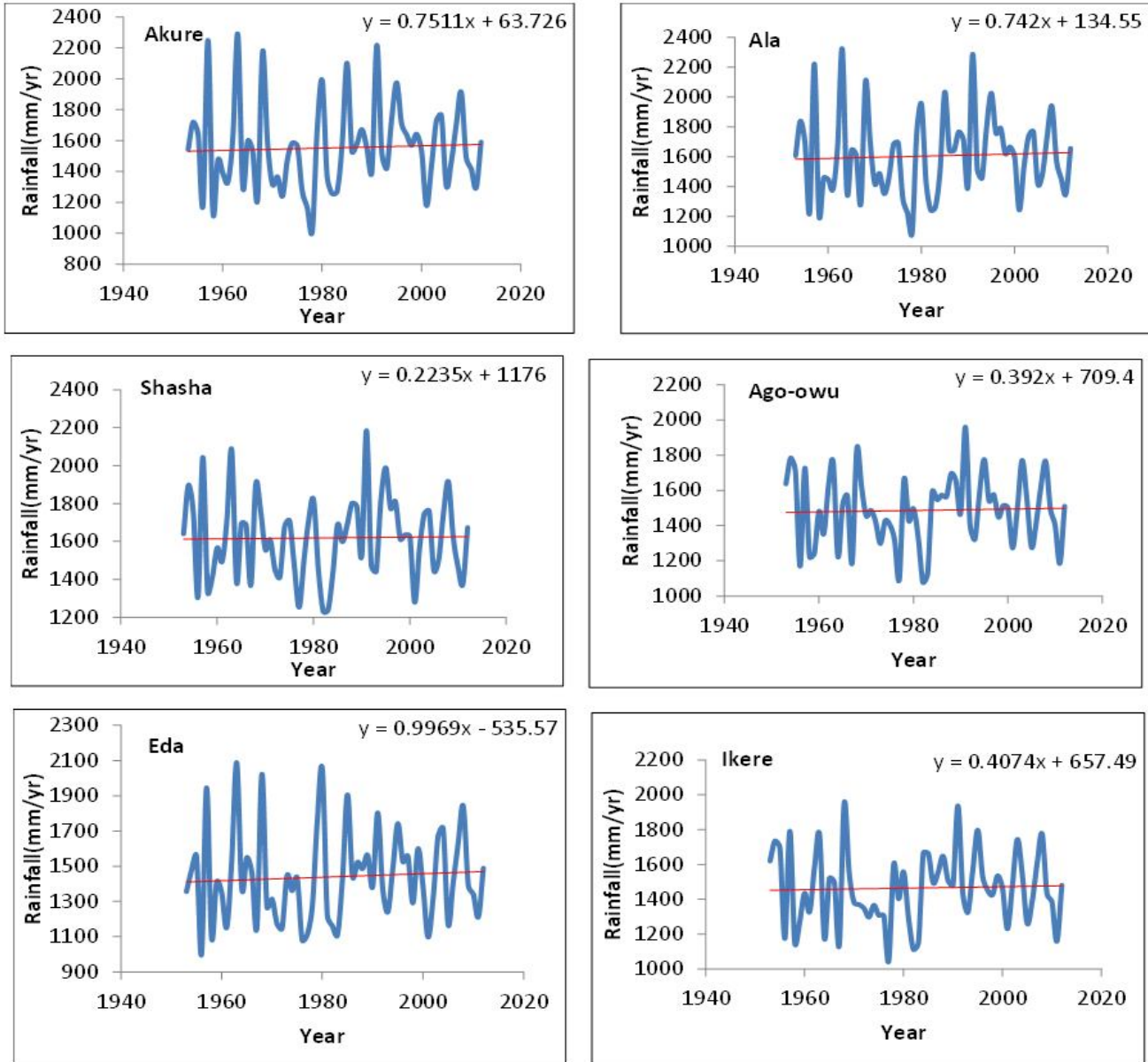


Figure 4. Time series plot of mean annual Rainfall between 1953-2012 for the forest reserves

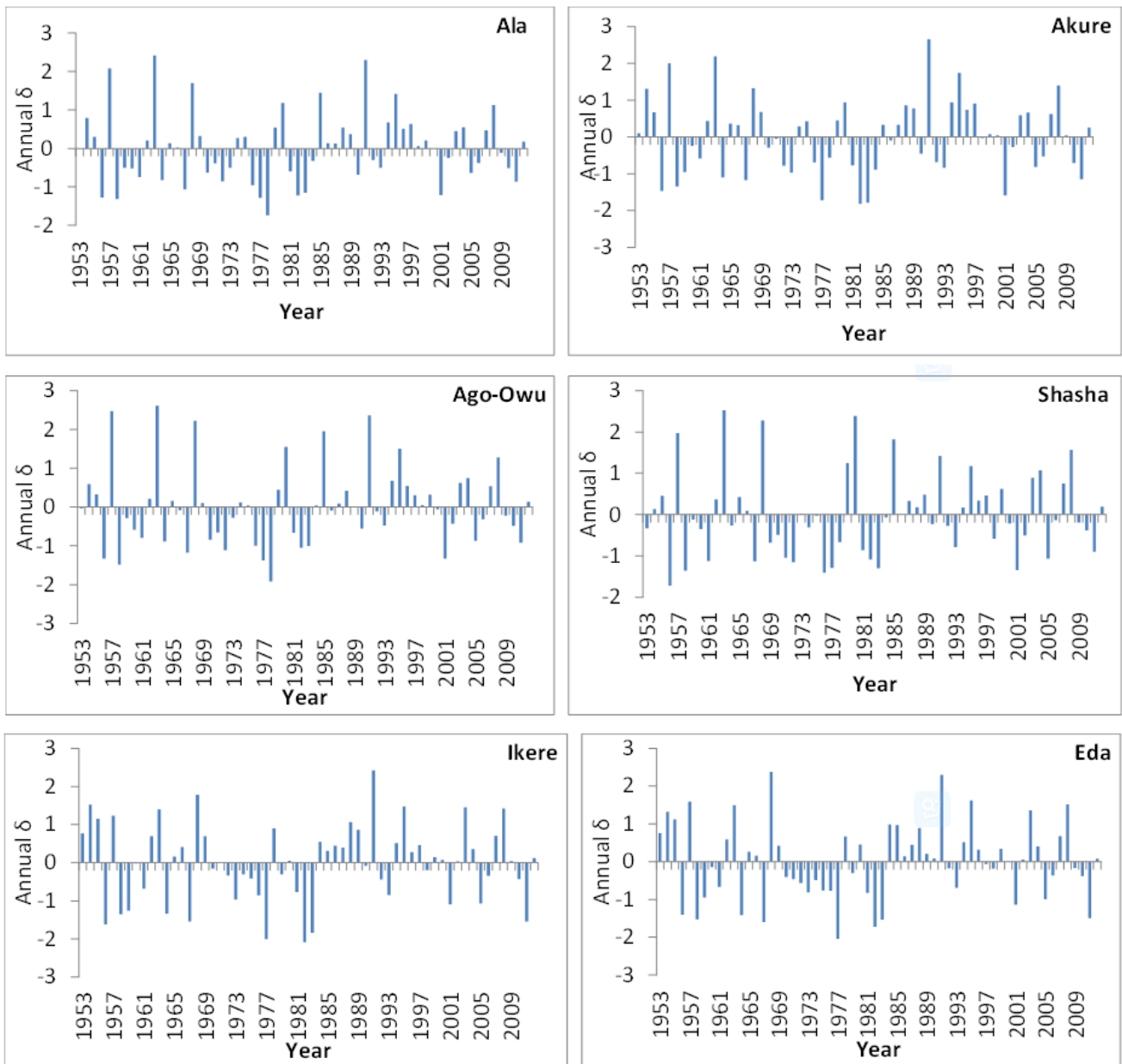


Figure 5. Rainfall variability index for mean annual Rainfall between 1953-2012 for the forest reserves

Shasha forest reserve had extremely dry years and extremely wet years in decade 3 (-1.7) and decade 4 (1.8) respectively while the three other decades were normal (± 0.5). Similarly, Eda and Ikere forest reserves had same trend with Shasha forest reserve. However, Ago-Owu forest reserve had dry conditions in decades 1 (1.3) and 3 (1.3). Decades 2 and 5 were normal and decades 4 and 6 were wet. Generally, there were more wet decadal years in the second 30 year-period (i.e. 1983-2012).

Long -Term Trend Statistics for Rainfall in the Study Area

Summary of trend and slopes estimates for the rainfall 1953-1982 and 1983-2012 for the forest reserves are presented in Table 3. About 100% of the study area exhibited negative trends for the first 30-year period

(1953-1982) and second 30-year period (1983-2012). There were tendencies towards decrease in rainfall for both periods but the decrease in rainfall is higher in the first period than in the second period. However, the long-term period (1953-2012) showed slightly positive trend. Generally, the result showed a relative slight increase in rainfall in the study area, although there was no significant change in the rainfall trend except in Eda forest reserve (1953-1982) ($P \geq 0.008$) and Ikere forest reserve ($P \geq 0.008$) that are significant at 10%.

Long-Term Summary of Descriptive Statistics for Rainfall in the Study Area

A summary statistic of the long-term (temporal) series for the respective forest reserves is given in Table 4. Rainfall varied mostly in Shasha forest reserve with CV of 18.3% within the 60 year-period (1953-2012). The rainfall values for Akure ranged from 1088.5 to 2322 mm/yr. In Ala forest reserve its values ranged from 1231.3-2184.8 mm/year with CV of 13.3%. In Ago-Owu, rainfall ranged from 1000.8- 2087.8 mm/year with a CV of 17.9%. Shasha had rainfall range of 1013.1-2288 mm/year with CV of 18.3%. Eda rainfall ranged from 1077.1- 1959.9 mm/year with a CV of 13.3% and Ikere rainfall ranged from 1045.1-1952.9 mm/year with a CV of 14.1%. The CV for annual rainfall in the study area was generally high; ranging from 13.3% in Ala to 18.3% in Shasha forest reserve for the long-term period (1953-2012).

Long-Term Trend Statistics for Temperature in the Selected Forest Reserves

Summary of monotonic trend and slopes estimate for the temperature series of the forest reserves is presented in Table 5. The results showed that significant increase in temperature occurred in all the forest reserves especially in the second 30 year-period (1983-2012). Long-term mean temperature (1953-2012) exhibited positive trends in all the forest reserves except during the first 30-year period where the slope (mm/year²) showed a slight

decrease; -0.002, -0.004, -0.009, - 0.003, -0.005 and -0.002 were observed in Ala, Shasha, Ago-Owu, Akure, Ikere and Eda forest reserves respectively. Also, the results showed higher significance for the long-term mean temperature (1953-2012) than for the 30-year periods (1953-1982 and 1983-2012) for the study area.

Summary of Descriptive Statistics of Temperature in the Study Area

Summary of trends estimated for 1952–1983 and 1983–2012 periods are presented in Table 6 for the forest reserves. Generally, variability is low with CV ranging from 0.9 to 1.4 % for annual temperature. Temperature ranged from 29.7°C to 31.79°C in Akure, 30.1°C to 32.2°C in Ala, 30.4°C to 32.5°C in Ago-Owu, 29.8°C to 31.9°C in Shasha, 29.7°C to 31.7°C in Eda and 29.7°C to 31.8°C in Ikere forest reserves. Temporal averages across the forest reserves showed that minimum, mean and maximum temperature increasing across the study area.

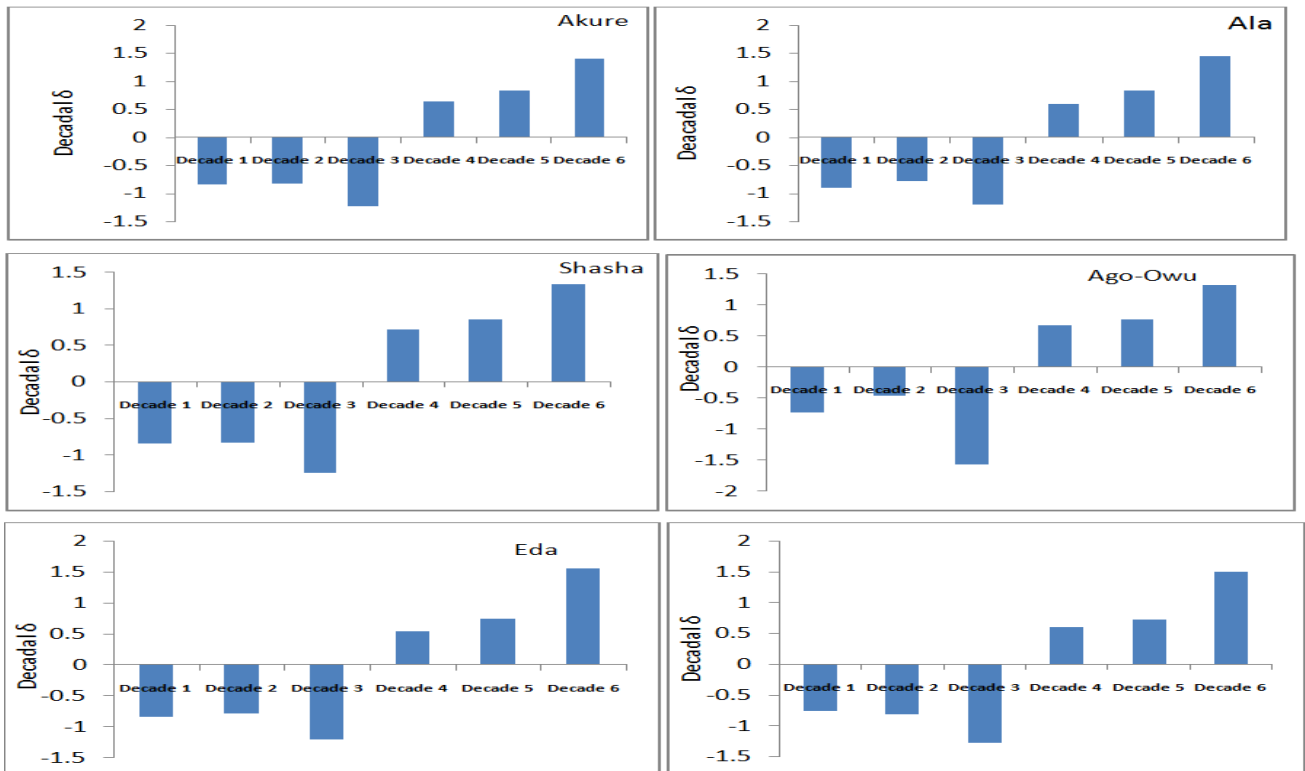


Figure 6. Decadal anomaly for mean annual temperature (°C) between 1953-2012 for the forest reserves

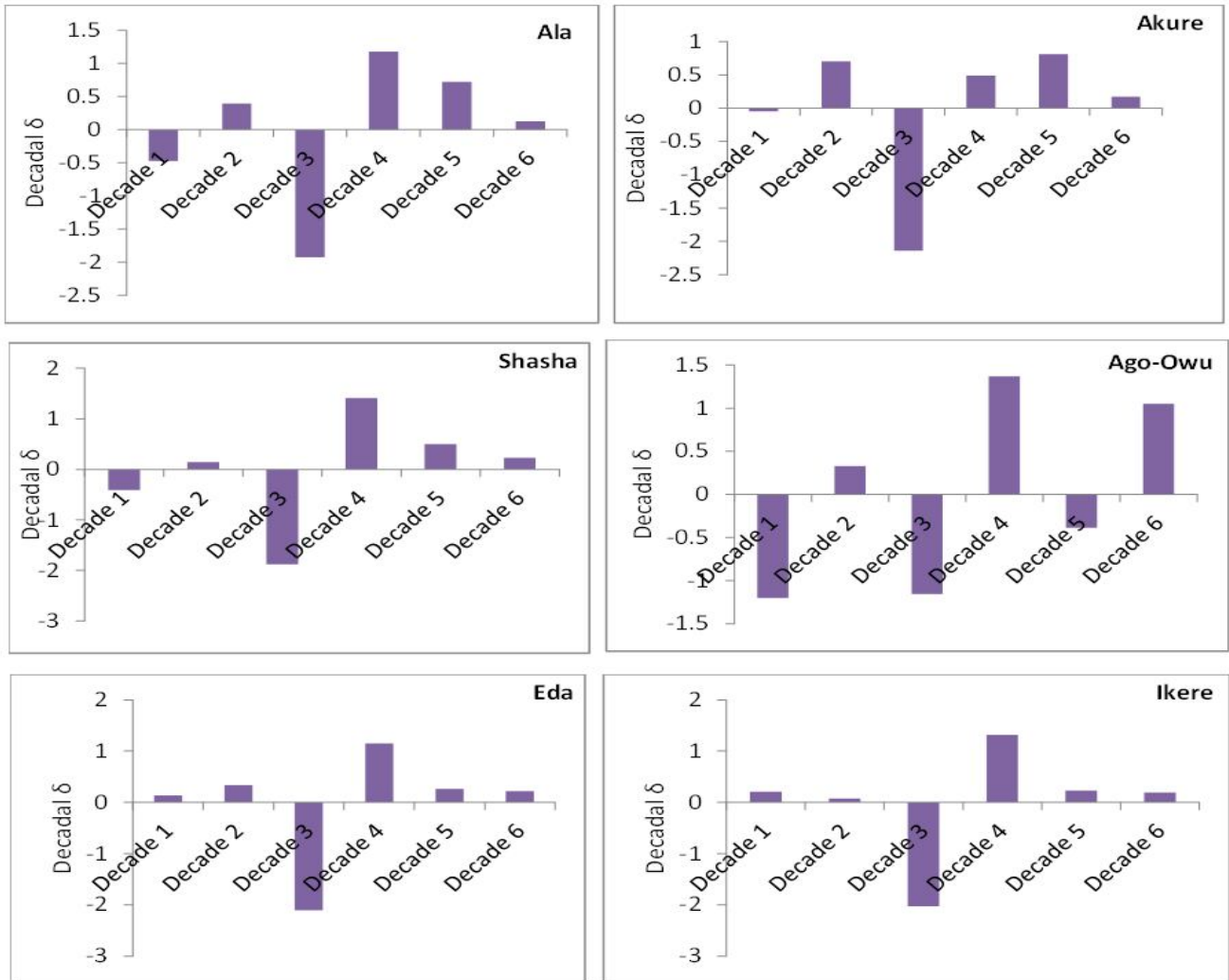


Figure 7. Decadal anomaly for mean annual Rainfall (mm) between 1953-2012 for the forest reserves

Table 3. Annual rainfall (mm/year) trend statistics in the selected forest reserves

Forest Reserve	Period	Slope (mm/year ²)	P value
Ala	1953-1982	-6.19	0.19
	1983-2012	-0.76	0.87
	1953-2012	0.22	0.89
Shasha	1953-1982	-6.99	0.31
	1983-2012	-4.70	0.35
	1953-2012	0.75	0.73
Ago Owu	1953-1982	-2.20	0.73
	1983-2012	-1.79	0.69
	1953-2012	1.00	0.61
Akure	1953-1982	-6.96	0.29
	1983-2012	-3.78	0.45
	1953-2012	0.74	0.72
Ikere	1953-1982	-8.24	0.08+
	1983-2012	-4.08	0.30
	1953-2012	0.41	0.79
Eda	1953-1982	-7.71	0.08+
	1983-2012	-2.85	0.46
	1953-2012	0.39	0.79

+ Change is significant at 0.10 level of significance.

Table 4. Descriptive statistics for annual rainfall (mm/year) in the selected forest reserves

Forest Reserve	Period	Min.	Max.	Mean	SDEV	CV (%)
Akure	1953-1982	1088.5	2322.6	1563.9	303.97	19.4
	1983-2012	1243.2	2287.6	1647.2	232.52	14.1
	1953-2012	1088.5	2322.6	1605.6	271.58	16.9
Ala	1953-1982	1243.2	2287.6	1647.2	232.52	14.1
	1983-2012	1231.3	2084.1	1597.3	222.78	13.9
	1953-2012	1231.3	2184.8	1619.2	214.61	13.3
Ago Owu	1953-1982	1126.7	1959.9	1520.7	179.68	11.8
	1983-2012	1098.7	1906.1	1470.7	209.14	14.2
	1953-2012	1000.8	2087.3	1440.7	257.77	17.9
Shasha	1953-1982	1013.1	2288	1508.5	322.43	21.4
	1983-2012	1179.1	2217.3	1596.9	236.24	14.8
	1953-2012	1013.1	2288	1552.7	283.76	18.3
Eda	1953-1982	1237.4	2184.8	1641	207.58	12.6
	1983-2012	1077.1	1836	1452.2	211.12	14.5
	1953-2012	1077.1	1959.9	1486.5	197.40	13.3
Ikere	1953-1982	1045.1	1952.9	1426.1	225.99	15.8
	1983-2012	1149.4	1936.5	1504	181.79	12.1
	1953-2012	1045.1	1952.9	1465.1	207.10	14.1

SDEV is Standard deviation; CV is co-efficient of variation.

Table 5. Trend Statistics for annual temperature in the selected forest reserves

Forest Reserve	Period	Slope	Pvalue
Ala	1953-1982	-0.002	0.72
	1983-2012	0.012	0.06+
	1953-2012	0.016	<0.01**
Shasha	1953-1982	-0.004	0.55
	1983-2012	0.009	0.19
	1953-2012	0.013	<0.01**
Ago Owu	1953-1982	-0.009	0.17
	1983-2012	0.009	0.15
	1953-2012	0.013	<0.01**
Akure	1953-1982	-0.003	0.58
	1983-2012	0.010	0.09+
	1953-2012	0.016	<0.01**
Ikere	1953-1982	-0.005	0.49
	1983-2012	0.012	0.07+
	1953-2012	0.015	<0.01**
Eda	1953-1982	-0.002	0.74
	1983-2012	0.014	0.03**
	1953-2012	0.015	<0.01**

+change is significant at 0.05 level of significance, **change is significant at 0.01 level of significance.

Table 6. Descriptive Statistics for annual temperature in the selected forest reserves

Forest Reserve	Period	Min	Max	Mean	SDEV	CV (%)
Akure	1953-1982	29.7	31.1	30.50	0.29	1.0
	1983-2012	30.5	31.9	31.08	0.30	1.0
	1953-2012	29.7	31.9	30.79	0.42	1.4
Ala	1953-1982	30.0	31.0	30.85	0.29	0.9
	1983-2012	30.9	32.2	31.43	0.30	1.0
	1953-2012	30.1	32.2	31.14	0.42	1.3
Ago Owu	1953-1982	30.4	31.8	31.03	0.32	1.0
	1983-2012	30.4	31.9	31.24	0.32	1.0
	1953-2012	30.4	32.5	31.51	0.41	1.3

Shasha	1953-1982	30.5	31.9	31.08	0.31	1.0
	1983-2012	29.8	31.1	30.51	0.28	0.9
	1953-2012	29.8	31.9	30.79	0.41	1.3
Eda	1953-1982	29.7	31.0	30.40	0.31	1.0
	1983-2012	30.4	31.7	30.95	0.31	1.0
	1953-2012	29.7	31.7	30.68	0.42	1.4
Ikere	1953-1982	29.7	31.1	30.48	0.31	1.0
	1983-2012	30.4	31.8	31.03	0.32	1.0
	1953-2012	29.7	31.8	30.75	0.42	1.4

SDEV is Standard deviation; CV is Coefficient of variation.

DISCUSSION

Long-Term Temperature Analysis (1953-2012) in the Study Area

The steady increase in the mean annual temperature of the study area from 1953-2012 agrees with the findings of Odjugo (2010) who reported temperature increase in the coastal and semi- arid cities of Nigeria between 1901 and 2005. This study further confirms the widespread of temperature increase in recent times from these regions to the rainforest ecology of Nigeria. Agboola and Ojeleye (2007) reported that increasing temperature resulted in reduced crop yield. Hence, the observed warming temperature may negatively impact on crop production in the study area and consequently affect the livelihood of the forest community.

Long- Term Rainfall Analysis (1953-2012) in the Study Area

The analysis of long-term rainfall database that showed the erratic change in rainfall pattern with slight increase in annual rainfall corroborate previous studies that reported the absence of any significant trend in rainfall pattern but the presence of large variability along 60-year period (Liu *et al.*, 2004; Roderick and Farquhar, 2004). Rainfall irregularity is a major concern since it affects forest productivity. Regardless of rainfall sufficiency, irregularity of rainfall adversely affects plants when it coincides with crucial stage of growth (Rudolf and Hermann, 2009).

Long – Term Decadal Temperature and Rainfall Variability in the Study Area

The steady increase in the decadal temperature variability of the study area from decade 4 (1983-1992) to decade 6 (2003-2012) is an indication of global warming since temperature increase became a trend. Anthropogenic activities such as excessive tillage, excessive use of nitrogen fertilizer, deforestation, burning of bush, fossil fuels (oils, natural gas and coal), wood, wood products and solid wastes have been linked to global warming (Nzeh *et al.*, 2017) Hence, these activities are to be investigated and discouraged in the study area. Also, the decadal rainfall variability in the study area that indicated shift from extremely dry years to extremely wet years

between the third decade 1973-1982 and fourth decade (1983-1992) across all the forest reserves except Akure corroborates that global warming has the capacity to increase rainfall as reported by Idowu *et al.* (2011). However, the effects of such rapid climatic change may become unsuitable when it leads to erosion and flooding.

Long-Term Annual Rainfall Variability in the Study Area (1953-2012)

The higher occurrence of wet years observed in the second 30-year period in all the study area indicates that rainfall is gradually increasing after a successive period of dry years. This corroborates the report of Adefolalu *et al.* (2007) that there has been a progressive increase in August rainfall over southern Nigeria in the last five decades with attendant flooding. This hampers farm produce processing, destroys habitats and restricted movement in forest communities.

CONCLUSION AND RECOMMENDATION

The study established that the forest reserves of southwestern Nigeria has experienced climate change within the period of 1953 to 2012. Hence, the impact of climate change cannot be ruled out in the rainforest ecosystem of Nigeria. It is therefore advised that adaptation strategies should be adopted.

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