ANALYSIS OF CLIMATE VARIABILITY IN THE CENTRAL DISTRICT OF TARABA STATE, NORTH-EAST, NIGERIA

ABSTRACT

Climatic maps have been very difficult to generate in Nigeria, not because of lack of knowledge or expertise, but due to dearth of climatic data. Most of the existing climatic maps are either not reliable or too generalized since Nigerian Meteorological Agency (NIMET) climatic data which is the only reliable climatic data are available only in the state capitals and which were often used to generate climatic maps. In this study, DivaGIS, WorldClim, NASA Power Project and globalweather climatic data of rainfall, temperature, relative humidity and solar radiation were used to generate the spatial patterns, trends and seasonal pattern of each of the aforementioned climatic elements in Taraba State Central District; comprising Bali, Gassol, Gashaka, Gembu, Kurmi and Sardauna LGAs, . The results were presented in charts and using the bar chart and the kringing tools of Microsoft Excel package and ArcGIS 10.5 software respectively. Spatial pattern of rainfall of the area revealed that the rainfall pattern are influenced by relief and latitudes as Sardauna which is on the plateau in the South has more rains than Gassol in the North. Mountainous and highland areas were also found to have higher rainfall than the immediate environment. Trends in rainfall was decreasing in Bali, Gashaka and Sardauna LGAs. Rainfall is high from June to September when minimum of 200 mm monthly rainfall are received in all the five LGAs. The spatial pattern of temperature is inversely related to that of rainfall, while trends in temperature is increasing in all the LGAs. Relative humidity has similar spatial/seasonal patterns with that of rainfall, but showing decreasing trends in all the LGAs except Kurmi LGA. The spatial pattern of solar radiation was found to be affected by the aspects of the area as Kurmi LGA at the western side recorded highest amount of solar radiation. The pattern of solar radiation in the study area is seasonal because solar radiation is low (less than 20 mj/m^2) in all the LGAs except Kurmi during the rainy season (June – October). It was recommended that ground station climatic data which covers larger areas than in-situ climatic data that are only available in State capitals should be encouraged among the climate analysts to alleviate the problems associated with dearth in in-situ climatic data.

Keywords: *Climatic mapping, climatic parameters, climatic trends, spatial patterns, Taraba State.*

1.0 Introduction

Mapping climate and climatic parameters in developing countries have been confronted with dearth of climatic data (Tufa, 2019;) due to much reliability on in-situ climatic data that are challenged with various problems as highlighted by Ikusemoran *et al.* 2018 that "ground station instruments used for acquisition of climatic data were prone to errors and inconsistencies ranging from inadequate skill, negligence, mechanical problems, inaccessibility due to hazards like heavy rainfall/floods or related occurrences and insurgency". Automatic weather stations were later designed to overcome the problems but the stations are also faced with the problems of non-challant attitudes of weather stations' recorders, high cost of acquisition of the instruments leading to the establishment of only few automatic weather stations (Okechukwu, 2017). Nigerian Meteorological Agency (NIMET) is shouldered with the responsibilities of provision of climatic data, but unfortunately the Director-General/Chief Executive Officer, Prof. Abubakar Mashi on June 11, 2017 reiterated that considering the landmass of Nigeria and going by the World Meteorological Organization (WMO), Nigeria is expected to have about 6000 weather stations but as at then, there were only 54 weather stations in the country (Okechukwu, 2017).

Developed countries have established a lot of satellite climatic stations for provision of online climatic records (Luis, *et al* 2015, Clement, *et al.* 2018) and such since most of the data are available online (many for free), ground station climatic data have been utilized for mapping and analysis of climate and climate change variables in developing countries (Olusina and Odumade 2012). Before the advent of online climatic data, only few places like the state capital and few other places have reliable climatic data. The implication is that mapping the spatial pattern for the entire state becomes impossible and hence, the climatic condition of the only station in the state are generalized on the entire state which is highly misleading as there variations in the climate of political units within a country. It has been established that the climate is changing in Nigeria (Ovuyovwiroye, 2010) and the need to monitor the changes has been emphasized in recent years (Okon *et al.* 2021). Monitoring the climate and its changes calls for generation of reliable climatic data in numerous places and in numerous time periods through illustrative charts, graphs and maps. No known climatic maps of political units such as districts and LGAs within Taraba State exist, which is principally associated with lack of data. The spatial pattern, trends and seasonal pattern of each of the climatic variables were derived from this study which were not known to have existed and which will add to the body of knowledge on climate variations in the area. Therefore, the aim of this study is to generate digital maps and analyze climatic variables such as rainfall and rainfall indices, temperature, relative humidity and solar radiation in the study area using satellite-based climatic data.

2.0 Description of the Study Area

Taraba State Central Senatorial District comprises the following five LGAs: Bali, Gashaka, Gassol, Kurmi and Sardauna. The districts extends from Latitude 6° 30' 00'' N to 8° 48' 46'' N of the Equator, and Longitude 10° 01' 00'' E to 11° 50' 18'' E of the Meridian (Fig. 1). The Republic of Cameroon bounds the district in the South, Adamawa State in the North East, and Karim-Lamido, Ardo-Kola, and Yorro LGAs to the North, Wukari and Donga LGAs, to the West and Ibi LGA to North-West (Fig. 1). The total land area of the district calculated in this study is 32,110.82 km^2. Like most parts of Northern Nigeria, Taraba State Central District has a wet and dry climate. The wet season lasts, on the average, from April to October (Bako *et* *al.*, 2016).

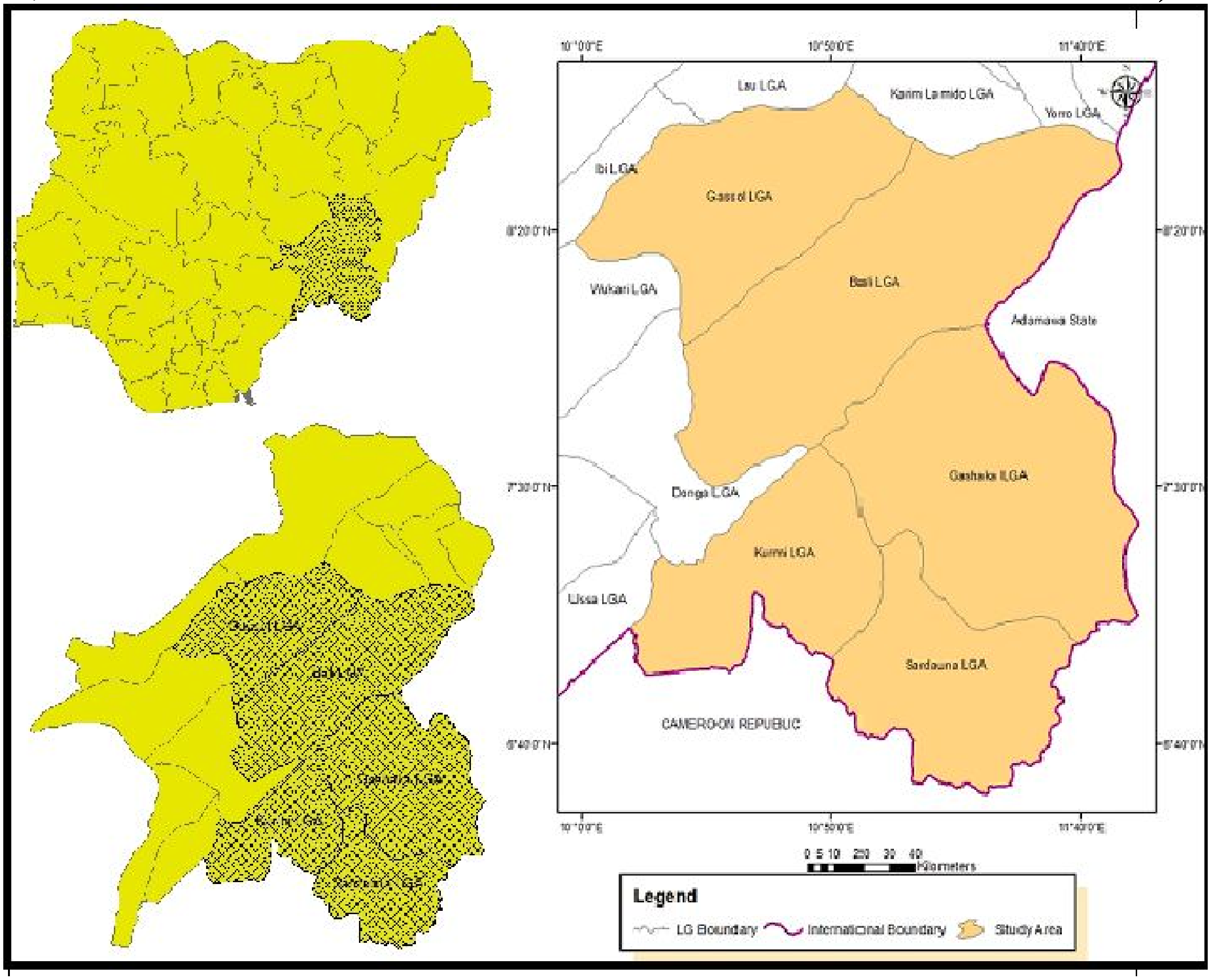

Figure 1. Taraba Central District in Taraba State

Akinsoji, (2016) reported an average total annual precipitation of 1,973 mm at the highest peak in the area and that about 95 % of the yearly rainfall is recorded between April and October, with highest monthly mean in September. The influence of Sahara Trade Winds accounts for the absence of rainfall between December and January. Rainfall in this area is influenced by both relief and altitudes. Mubi (2010) stated that the high rainfall is aided by the mountains of the area while Tagoma and Buba (2012) opined that the local climate is influenced by topography, with different regions receiving different amount of rainfall, depending on location and altitude and concluded that the wettest areas of the area are located in the mountain ranges in the south. Ikusemoran *et al.,* (2018) noted the latitudinal pattern of rainfall in the entire Taraba State ranges from 946 mm in the extreme north to about 1812 mm on Mambilla Plateau.

Mubi (2010) put the temperature of the area on the range of mean annual minimum of 20□ C to mean annual maximum of 31.7□ C which is similar to that of Tagowa and Buba (2012) who put the mean minimum temperature as 20.9° C while the mean maximum is 31.9° C. Bako *et al.,* (2016) recorded minimum temperatures range of Mambilla Plateau between 15□ C to 23□ C because Mambilla Plateau has climatic characteristics typical of a temperate climate and therefore, temperatures are low throughout the year. At the northern part like Bali for instance, Abubakar and Ibrahim (2016) stated that the temperature in Bali region is warm to hot throughout the year with a slight cool period between November and February and that temperature ranges between 23 and 40□ C. According to Tagowa and Buba (2012), there is a wide range in relative humidity from 26-78% in the GGNP section of the study area. On the Mambilla Plateau, the driest months are December and January with relative humidity dropping to about 15 percent (Bako *et al.,* 2016). The amount of rainfall is also influenced by the relief of the area as the Mambilla Plateau comprising of Chappal Gangirwal and Wadi records higher rainfall than the plains (Adebayo and Oruonye (2013).

3.0 Materials and Methods

3.1 Materials

The following materials were acquired for this study: (i) Taraba State Political map generated in 2019 by UN/OCHA for delineation of Districts (ii) ArcGIS 10.5 software for processing the spatial data such as spatial pattern of all the climatic elements and rainfall indices (iii) Daily, monthly and annual mean rainfall of all the headquarters of each of the five LGAs within the study area between 1990 and 2017, minimum/maximum temperature (1979-2014), relative humidity (1979-2014), and solar radiation (1979-2014) of Bali, Gashaka, Gassol, Kurmi and Sardauna LGAs (all obtained from power.larc.nasa.gov/data-access-viewer) (iv) rainfall, minimum/maximum temperature 1950-2000 obtained from DivaGIS climatic data. (iii) Landsat 8 Feb, 4, 2021). (v) Spatial solar radiation data was generated from the solar radiation module of the spatial analyst of the Arctoolbox in ArcGIS 10.5 using the ASTERDEM V2 DEM data of the study area

3.2 Methods

The four climatic elements that were analyzed for this study include: rainfall, temperature, relative humidity and solar radiation. These four climatic parameters were considered because of their great influence on the general climate of an area.

3.2.1 Method of generating spatial pattern of Climatic data

Mean annual rainfall data for a period of fifty years were obtained from DivaGIS climatic data. Two hundred and seventy two (272) equidistant points covering the entire study area were generated using the fishnet module of ArcGIS 10.5. The generated points were used to extract the values of the rainfall data through the “extract by point” module of ArcGIS 10.5. The coordinates and the rainfall value of each of the points were used to interpolate the points using kriging method of the Arctool box of ArcGIS 10.5. The output map was classified into four: high, moderately high, moderately low and low rainfall areas. Spatial pattern of rainfall shows the areas with high or low mean annual rainfall within the study area. The same procedures (using power.larc.nasa.gov/data-access-viewer climatic data instead of DivaGIS climatic data because of the non-availability of spatial data in power.larc.nasa.gov/data-access-viewer which is a point data) were used to generate the spatial patterns of mean temperature, relative humidity through kriging module of the ArcGIS 10.5. The solar radiation tool of the Arctool box of ArcGIS 10.5 was used to create the spatial pattern of solar radiation of the areas using Landsat 8 image of February 4, 2021.

3.2.2 Method of generating seasonal climatic data

The monthly climatic data for each of the twenty eight years (1990-2017) period were obtained from power.larc.nasa.gov/data-access-viewer. Climatic parameters data for each of the months (January-December) were summed and were used to generate monthly mean records of the places using bar graph. The graphs show the mean of the climatic parameters of each month which was used to determine mean monthly records of the climatic elements according to the seasons in Nigeria; June-October and November-March.

3.2.3 Method of generating trends of climatic parameters

The mean annual temperature will be obtained by adding the values of minimum and maximum temperature of a particular point in a particular year and dividing the results by two using Microsoft Excel. The data were processed into line graphs while the trends, R^2 and other parameters were added in Microsoft excel environment.

3.3.4 Method of generating rainfall indices

Rainfall Onset: The formula for calculating rainfall onset (Nieuwolt, 1982).

Number of days in the rainfall onset month (51 minus the accumulated rainfall before the onset month)/Total rainfall in the onset month.

Rainfall Cessation (Nieuwolt, 1982).

Number of days in the rainfall cessation month (51 minus the accumulated rainfall after the cessation month /Total rainfall in the month of rainfall cessation.

Length of rainy season (Nieuwolt, 1982).

Cessation days minus onset days.

4.0 Results and Discussion

4.1. Spatial pattern of mean annual rainfall

Fig. 2a shows the spatial pattern of mean annual rainfall in the study area. The amount of annual rainfall was heavier (1620-1791 mm) on the major mountain ranges in the area such as Mambilla Plateau, the Chappal hills and the Wanga hills in Kurmi LGA. This is an evidence of the effects of relief on rainfall in the area. Among the towns and villages within the high rainfall areas are Gembu, Nguroje, Dorofi, Maisamari, Ngel Yaki, Sabere and Warwar in Sardauna LGA. Zambuka in Kurmi LGA. Gidan Bature and Filinga in Gashaka LGA are also within the high rainfall areas. The spatial pattern of annual rainfall is also latitudinal inclined as high rainfall falls within latitudes 6.30 to 7.15□N, moderately high rainfall from about 7.15□N to about 7.30□N. Rainfall pattern is least at the northern part of the study area where low rainfall between 1054 mm and 1176 mm was recorded between latitudes 8.10 to about 8.38□N (Fig. 2a). Except a little part of the southern part of Gassol LGA, almost the entire LGA had low annual rainfall. Therefore, the pattern of annual rainfall in the area is affected by both relief and latitudes. Adebayo and Oruonye (2013), Ikusemoran *et al.* (2018) reported similar rainfall pattern in the area and the effect of latitudes and relief on the patterns.

4.1.1 Rainfall indices

Among the numerous rainfall indices, only the onset, cessation and length of rainfall season are discussed in this study. Rainfall onset refers to the time a place receives an accumulated amount of rainfall sufficient enough for the growing crops.

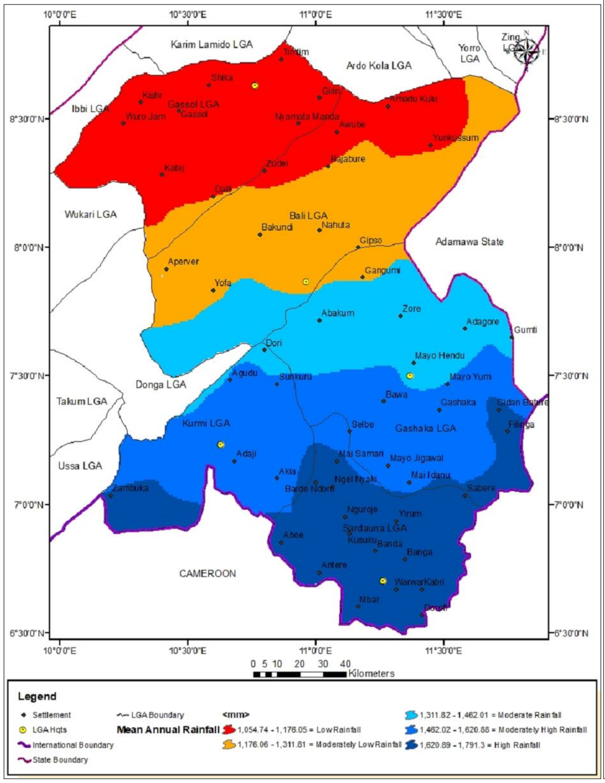

Figure 2a. Spatial pattern of mean annual rainfall.

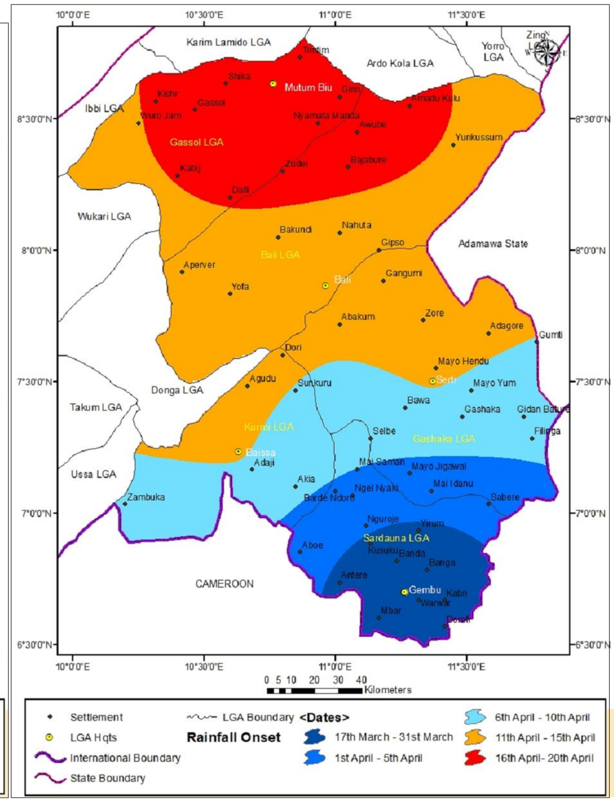

Figure 2b. Spatial pattern of rainfall Onset

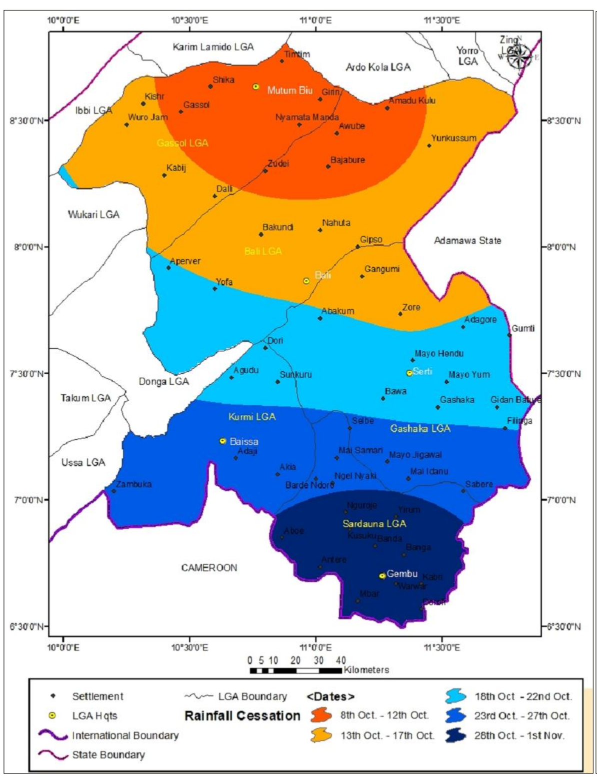

Figure 2c. Spatial pattern of rainfall cessation.

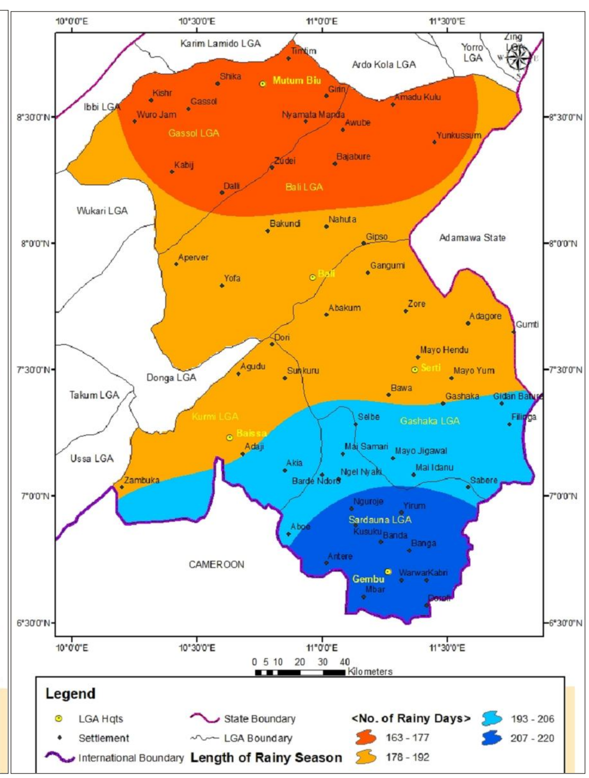

Figure 2d. Spatial pattern of length of rainfall

The spatial pattern of rainfall onset is shown in Fig. 2b where the southern part of Sardauna LGA (about 6.30 to about 6.45□N) has the earliest onset between 17th and 31st March, while the northern/southern parts of Sardauna and Gashaka LGA around Nguroje, Ndoro, Maisamari, Sabere and Ngel Yaki in Sarduna LGA and Mai Idanu and Mayo Jigawal in Gashaka LGA receives rainfall between 1st and 5th April annually. This findings tally with that of Adebayo and Umar, (2005) that on Mambilla Plateau, rainfall onset starts around 20th March in the North and 5th of April in the South. At the northern part of the study area comprising Bali and Gassol LGAs, rainfall onset is delayed till around 16th to 20th April annually which is different from that of Adebayo and Oruonye (2013) who quoted 10th May annually as rainfall onset in Gassol LGA. The difference might be due to the sources and accuracy of the climatic data that were used.

According to Adebayo and Umar (2005), rainfall cessation is the termination of the effective rainy season which does not anyway implies to the last day it rains in a year but to when rains can no longer be assured for the rest of the year. The spatial pattern of rainfall cessation in the study area is shown in Fig. 2c where rains ceases earlier in the north than the southern Mambilla Plateau area. Rainfall cessation dates for larger parts of the Mambilla Plateau to about 7.00□N is between 28th October and 1st November. Beyond about 7.45□N, especially in Bali and Gassol LGAs, rainfall cessation is between 8th and 17th October. This findings are similar to that of Adebayo and Umar (2005) who stated that rainfall cessation in the entire Taraba State lies between 16th and 26th October in the North. Adebayo and Oruonye (2013) also recorded similar cessation dates of 11th October in Gassol and 21st October in Gembu on Mambilla Plateau. Adebayo and Umar (2005) concluded that rainfall onset and cessation are determined by the movement of ITD with its strong relationship with the latitudes of the place which makes stations in lower latitudes to have earlier rainfall onset than those in the higher latitudes. The southward movement of ITD is said (Adebayo and Umar 2005) to be twice as fast as its northern movement which is the reason for late rainfall cessation in Bali and Gassol LGAs in the higher latitudes of the study area.

The difference between rainfall onset and cessation dates is what is referred to as the Length of Rainy Season (Adebayo and Umar, 2005). The spatial pattern of length of rainy season is shown in Fig. 2d where, as expected Mambilla Plateau with early rainfall onset and late cessation has the longest length of days between 207 and 220 days. Which is the same as the 220 days recorded by Adebayo and Umar, (2005) and similar to that of Adebayo and Oruonye (2013) with 210 days in Mambilla Plateau. The central part of the study area from about 7.28□N to about 8.10□N had LRS between 178 and 192 days, while the extreme northern parts of Bali and Gassol LGAs recorded 163-177 days. Therefore, is was concluded that LRS is shorter in the northern parts than the southern counterparts.

4.1.2 Trends in rainfall

The pattern of rainfall trends in the five LGAs within the study area is shown in Table 1.

LGAs	Rainfall Trends	R Square (R^2)	Interpretations
Bali	y = -8.0818x + 1606.2	$R^2 = 0.0318$	Rainfall decreases by 8.1 mm for every increase in one year. The period of the study (1990-2017) contributes about 3.2% (R2) to the variation in rainfall
Gembu	y = -10.614x + 2002.6	$R^2 = 0.0966$	Rainfall decreases by 10.6 mm for every increase in one year. The period of the study (1990-2017) contributes about 9.6% (R2) to the variation in rainfall
Gashaka	y = -6.059x + 1625.8	$R^2 = 0.015$	Rainfall decreases by 6.1 mm for every increase in one year. The period of the study (1990-2017) contributes about 1.5% (R2) to the variation in rainfall
Gassol	y = 9.198x + 958.51	$R^2 = 0.1029$	Rainfall increases by 9.2 mm for every increase in one year. The period of the study (1990-2017) contributes about 10.3% (R2) to the variation in

			rainfall
Kurmi	y = 8.9646x + 1398.4	$R^2 = 0.1346$	Rainfall increases by 9.0 mm for every increase in one year. The period of the study (1990-2017) contributes about 13.5% (R2) to the variation in rainfall

Table 1. Values of rainfall trends/R^2 and their interpretations

Source: Generated from the rainfall data obtained from power.larc.nasa.gov/data-access-viewer

While the trends in rainfall in Gembu, Bali and Gashaka LGAs are decreasing, that of Kurmi and Gassol were found to be increasing. The highest decrease in rainfall was recorded at Gembu with 10.6 mm for every increase in one year. The decrease in rainfall might be connected to the increase in temperature and decrease in relative humidity and solar radiation (Tables 1-4) respectively. Increase in temperature and decrease in relative humidity and solar radiation inhibit rainfall formation (Olayinka *et al.* 2015; Díaz-Torres, 2017). Oruonye (2014) who all used ground station climatic data also reported increasing rainfall in Gassol but decreasing rainfall in Gembu.

4.1.3 Seasonal pattern of rainfall

The seasonal pattern of rainfall which was derived from the bar chart of the mean monthly rainfall in the study is shown in Fig. 3.

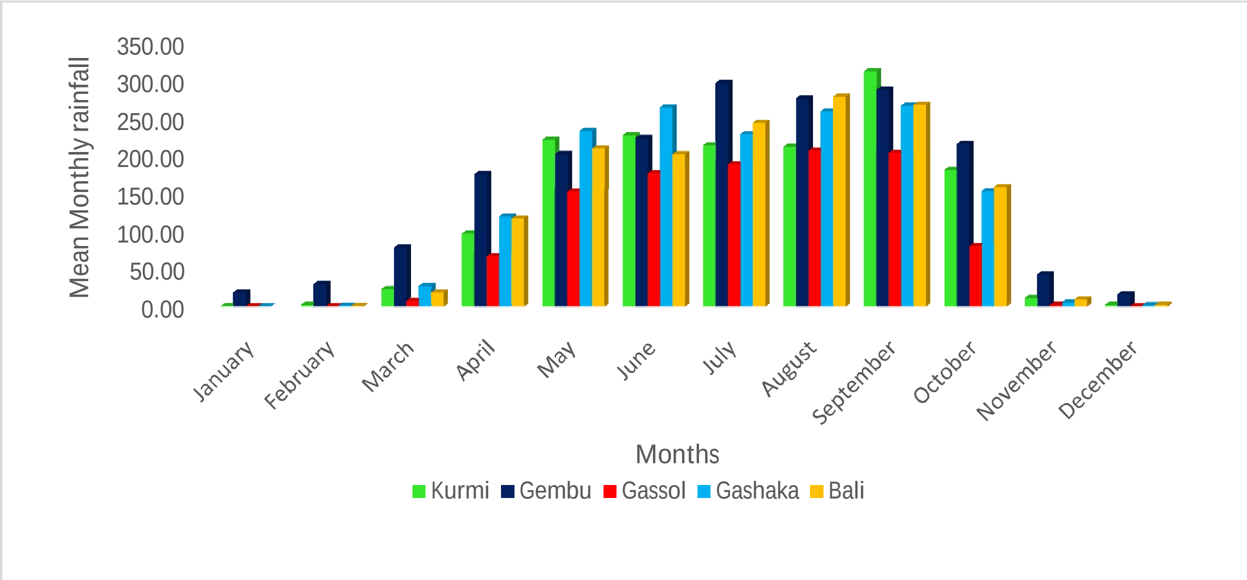

Figure 3. Mean Monthly Rainfall

Fig. 3 shows that only Gembu in Sardauna LGA, receives more than 50 mm rainfall in March among all the five LGAs. This means that proper rainfall begins in April and ends in October in all LGAs except Sardauna LGA. Sardauna LGA experiences rains from March to November (though mean monthly rainfall in November is less than 100 mm). Rainfall is high from June to September when minimum of 200 mm monthly rainfall are received in all the five LGAs in the study area as shown in Fig. 3. This findings agrees with that of Mubi (2010), Akinsoji, (2016), Tagowa and Buba (2012) that rainfall begins from Mid-March and ends in October in most parts of the study area. November and December and parts of January are the harmattan periods in the study area. Therefore, monthly rainfall is very low or even zero in all the LGA except Sadauna with less than 50 mm rainfall during this period. The same is also experienced during the dry season of January to March when only Sardauna LGA recorded more than 50 mm rains. This study highlights rainfall variations among the LGAs within the study area which were generalized in the works of previous studies (Mubi (2010); Akinsoji, (2016); Tagowa and Buba (2012)

4.2 Temperature

4.2.1 Spatial pattern of mean annual temperature

Fig. 4a shows the spatial pattern of mean annual temperature in the study area. The patterns of temperature is inversely related to that of rainfall. Regions with high rainfall such as the Mambilla Plateau has the least temperature and vice versa. Latitudes and altitudes were found in this study to have much influence on the spatial patterns of temperature in the study area. Mambilla Plateau and their associated mountain ranges like Chappal hills around the border of Cameroon in Gashaka LGA have the least temperature ranging from 21.67-23.64 □C. Adebayo and Oruonye (2013) recorded similar mean temperature of 21.39 □C at Gembu. Other highlands/hills regions in the area as shown in the relief map in this study such as Shebshi hills at the north-western side of Bali LGA, Wanga Highlands in southern Kurmi LGA and Bajabure hills in Bali LGA all have lower temperature than the surrounding environment. At the northern half of the study area comprising the entire land area of Gassol LGA and substantial part of Bali LGA, mean temperature is highest ranging from 26.57 to 27.76 □C. This finding is however different from that of Adebayo and Oruonye (2013) who recorded mean annual temperature of Gassol as 34.22 □C.

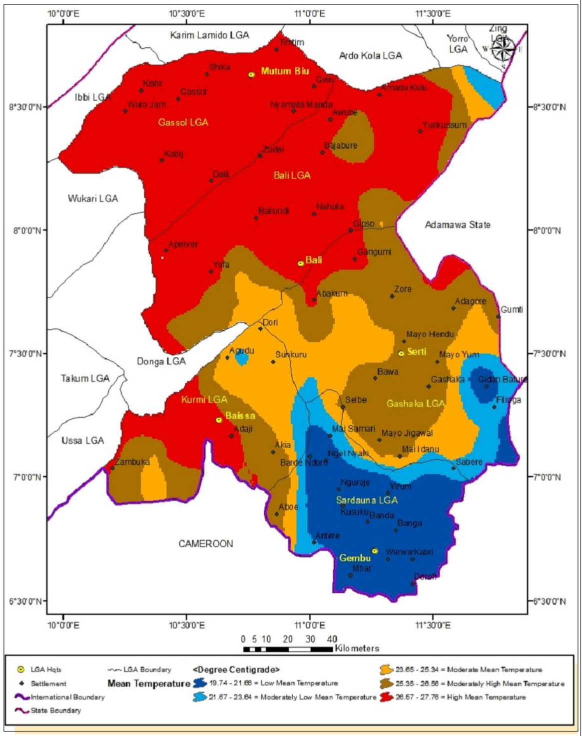

Figure 4a. Mean annual temperature

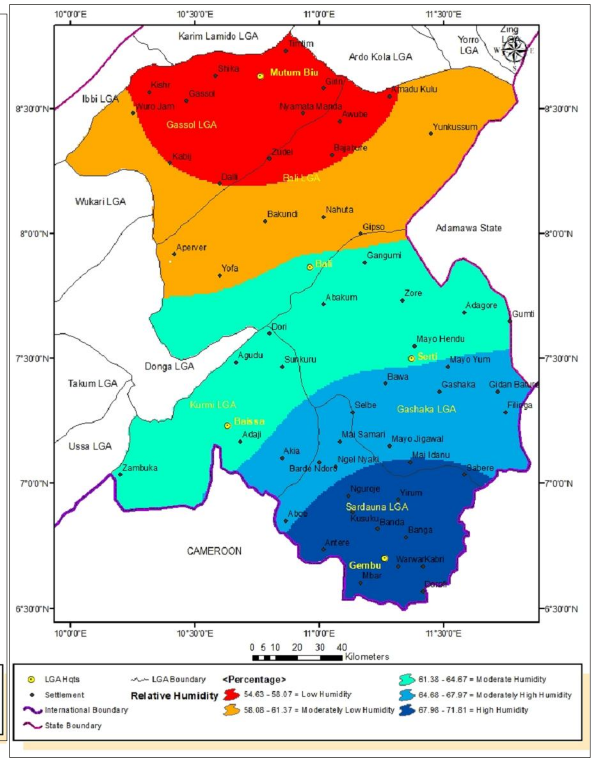

Figure 4b. Mean annual relative humidity

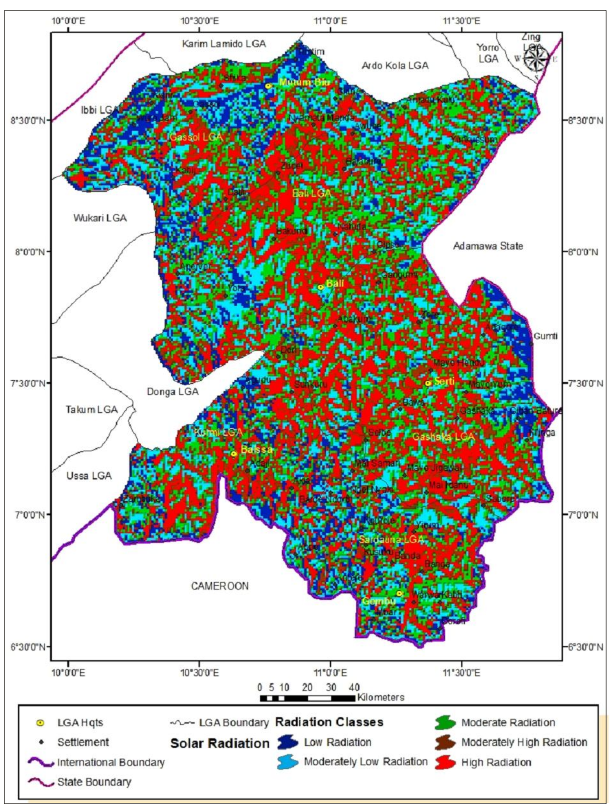

Figure 4c. Spatial pattern of solar radiation

4.2.2 Pattern of trends in Mean Temperature

The pattern of trends of temperature in the five LGAs is shown in Table 2.

LGAs	MeanTemp. Trends	R Square (R^2)	Interpretations
Bali	y = 0.0351x + 25.656	$R^2 = 0.4178$	Temperature increases by 3.5 ^{0}C for every increase in one year. The period of the study (1990-2017) contributes about 41.8% (R2) to the variation in mean temp.
Gembu	y = 0.008x + 20.535	$R^2 = 0.0217$	Temperature increases by 0.8 ^{0}C for every increase in one year. The period of the study (1990-2017) contributes about 21.7% (R2) to the variation in temperature
Gashaka	y = 0.013x + 25.137	$R^2 = 0.043$	Temperature decreases by 1.3 ^{0}C for every increase in one year. The period of the study (1990-2017) contributes about 4.3% (R2) to the variation in temperature.
Gassol	y = 0.0343x + 28.103	$R^2 = 0.282$	Temperature increases by 3.43 ^{0}C for every increase in one year. The period of the study (1990-2017) contributes about 28.2% (R2) to the variation in temperature
Kurmi	y = 0.0176x + 22.058	$R^2 = 0.1285$	Temperature increases by 1.76 ^{0}C for every increase in one year. The period of the study (1990-2017) contributes about 12.85% (R2) to the variation in rainfall

Table 2. Values of temperature trends/R^2 and their interpretations

Source: Generated from the rainfall data obtained from power.larc.nasa.gov/data-access-viewer

The trends in temperature in all the LGAs were increasing though at very slow rate of less than four (4) mm in all the LGAs within the study area. The R^2 were high in Bali, Gembu and Gassol LGAs but lower in Gashaka and Gembu LGAs. Oruonye (2014) also recorded increasing temperature in Gassol and Gembu LGA. The non-relationships between the trends of rainfall and mean temperature in the study area could be attributed to the heterogeneous terrain of the area where other than latitudes, rainfall occurs due to several other factors such as relief, aspect and solar radiation.

4.2.4 Seasonal pattern of monthly temperature

The seasonal pattern of monthly minimum, maximum and mean temperature in the study area is shown in Figs. 5a-5c

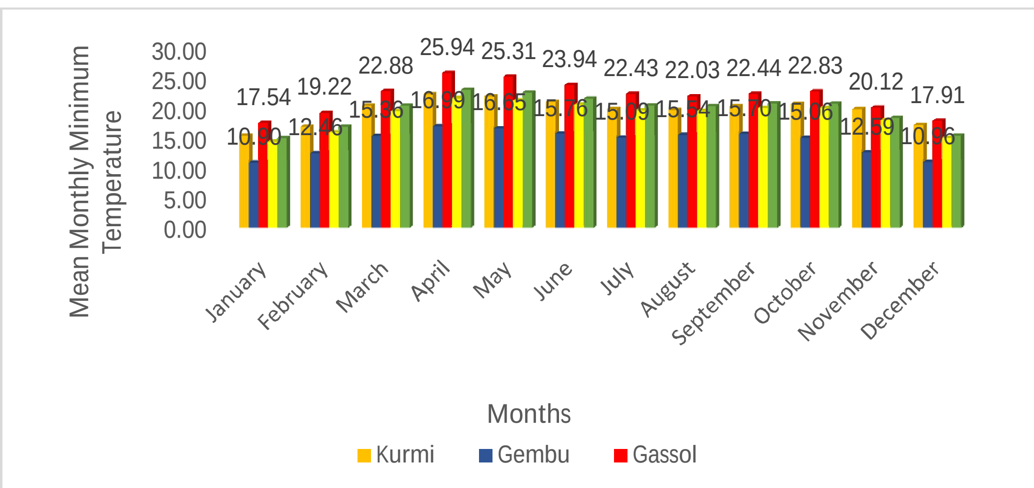

Figure 5a. Mean Monthly Minimum Temp. *Data labels for Gassol and Gembu only

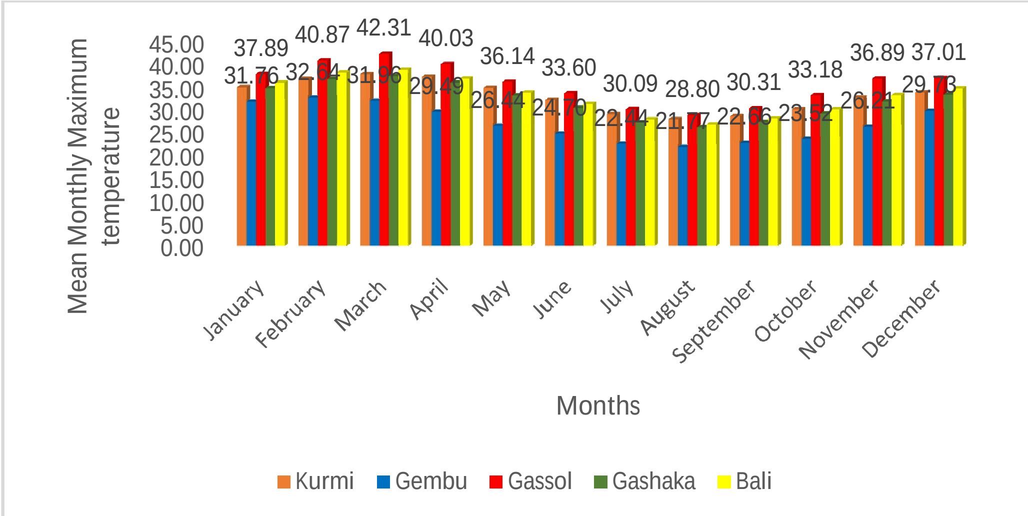

Figure 5b. Mean Monthly Maximum Temp. *Data labels for Gassol and Gembu only

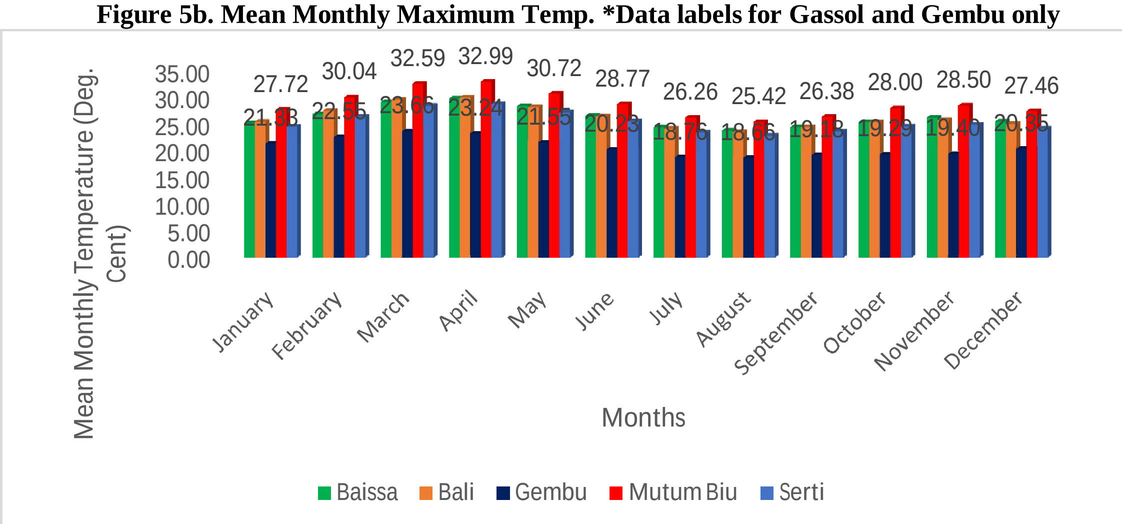

Figure 5c. Mean Monthly Temp. *Data labels for Gassol and Gembu only

Mean monthly minimum temperature is highest in Gassol LGA throughout the months. Minimum temperature is more than 25 □C between April and May but the peak in April when minimum temperature is as high as 25.94 □C (Fig. 5a). Minimum monthly temperature are also high in Baissa and Bali LGAs throughout the year. Gembu in Sardauna LGA recorded the least mean monthly temperature throughout the year. Minimum monthly temperature in Gembu (Sardauna LGA) was as low as about 10 □C during the harmattan period in December and January. April and May recorded the only months with above 25 □C in Sardauna LGA with the peak in April when minimum monthly temperature is 16.99 °C. This finding is similar to that of Adebayo and Umar (2005) who recorded minimum temperature in December and January in Gembu with 10.4 and 11.6 respectively but with June as the peak.

Mean monthly maximum temperature as shown in Fig. 5b has similar patterns with that of the monthly minimum temperature where Gassol and Gembu recorded the highest and the least respectively through the year. High maximum temperature were recorded in all the LGAs from January to April and in November and December. Low maximum monthly temperature were recorded during the rainy season (May to October) in all the five LGAs within the study area. Gembu in Sardauna LGA for instance had more than 30 °C during the dry season (January – March) but the peak was February with 32.64 °C. The least monthly maximum temperature at Gembu occurred in August which is at the peak of the rainy season with 21.77 °C. Adebayo and Umar (2005) also recorded August as the least monthly maximum temperature but with a value of 22.3 which is similar to the finding in this study.

Gassol and Gembu in Sardauna LGAs recorded the highest and least mean temperature in all the months among the five LGAs (Fig. 5c). Mean temperature in all the LGAs increases during the dry season; January-April but starts decreasing from May to October which is the rainy season in the area. The months of November and December recorded higher temperature than the months of rainy season in all the LGAs. Adebayo and Umar (2005) recorded similar patterns of mean temperature in Sardauna LGA. The pattern of minimum, maximum and mean monthly temperature varies latidunally. The mountainous southern part of Sardauna LGA had lower minimum, maximum and mean temperature than the other parts of the area, while Gassol LGA at the extreme north, had the highest in all the three units.

4.3 Relative Humidity

4.3.1 Spatial pattern of mean annual relative humidity

Fig. 3b shows the spatial pattern of mean annual relative humidity in the study area. The spatial pattern of relative humidity is directly related to rainfall but inversely related to temperature. Areas with high rainfall but low temperature has high relative humidity. This finding shows that the spatial pattern of relative humidity are largely determined by rainfall and temperature. Therefore, these three climatic elements are very important in the determination of the climate of a place. The percentages of the relative humidity in Kurmi and Bali LGAs are generally between about 61 and 68%, while that of Bali and Gassol recorded the least ranging from 55% to 62%.

4.3.2 Pattern of trends of relative humidity (1990-2017)

The pattern of the trends of relative humidity in the five LGAs within the study area are shown in Table 3.

LGAs	Humidity Trends	R Square (R^2)	Interpretations
Bali	y = -0.1354x + 64.861	$R^2 = 0.1828$	Humidity decreases by 13.5 % for every increase in one year. The period of the study (1990-2017) contributes about 18.3% (R2) to the variation in humidity
Gembu	y = -0.0864x + 73.636	$R^2 = 0.1012$	Humidity decreases by 8.64 % for every increase in one year. The period of the study (1990-2017) contributes about 10.1% (R2) to the variation in humidity
Gashaka	y = -0.076x + 66.01	$R^2 = 0.05$	Humidity decreases by 7.6 % for every increase in one year. The period of the study (1990-2017) contributes about 0.5% (R2) to the variation in humidity
Gassol	y = -0.11x + 56.233	$R^2 = 0.1031$	Humidity decreases by 1.1 % for every increase in

			one year. The period of the study (1990-2017) contributes about 10.3% (R2) to the variation in humidity
Kurmi	y = 0.034x + 25.687	$R^2 = 0.3347$	Humidity increases by 3.4 % for every increase in one year. The period of the study (1990-2017) contributes about 33.5% (R2) to the variation in humidity

Table 3. Values of relative humidity trends/R^2 and their interpretations

Source: Generated from the rainfall data obtained from power.larc.nasa.gov/data-access-viewer

The trends in relative humidity was directly inversely related to temperature because humidity in all the LGAs were decreasing (except Kurmi LGA), while temperature in all the LGAs were increasing. The rate of increase of relative humidity in Kurmi was however lower than the rate of decrease in the other LGAs. The R^2 in Kurmi LGA is very high, that is in recent years, relative humidity has been increasing in the LGA.

4.3.3 Seasonal pattern of relative humidity

The seasonal pattern of relative humidity in the study area is shown in Fig. 4c. Relative humidity in all the LGA are generally high in all the LGAs during the rainy season, that is, from April to October but lower during the harmattan season (November to February). In Gembu for instance, the least relative humidity occurs during harmattan and dry season (November to March) when the percentages of humidity is generally less than 50%, but higher during the rainy season ranging between 72.80 in April to 95.44% in August when rainfall is at peak and descends to 74.55% in November.

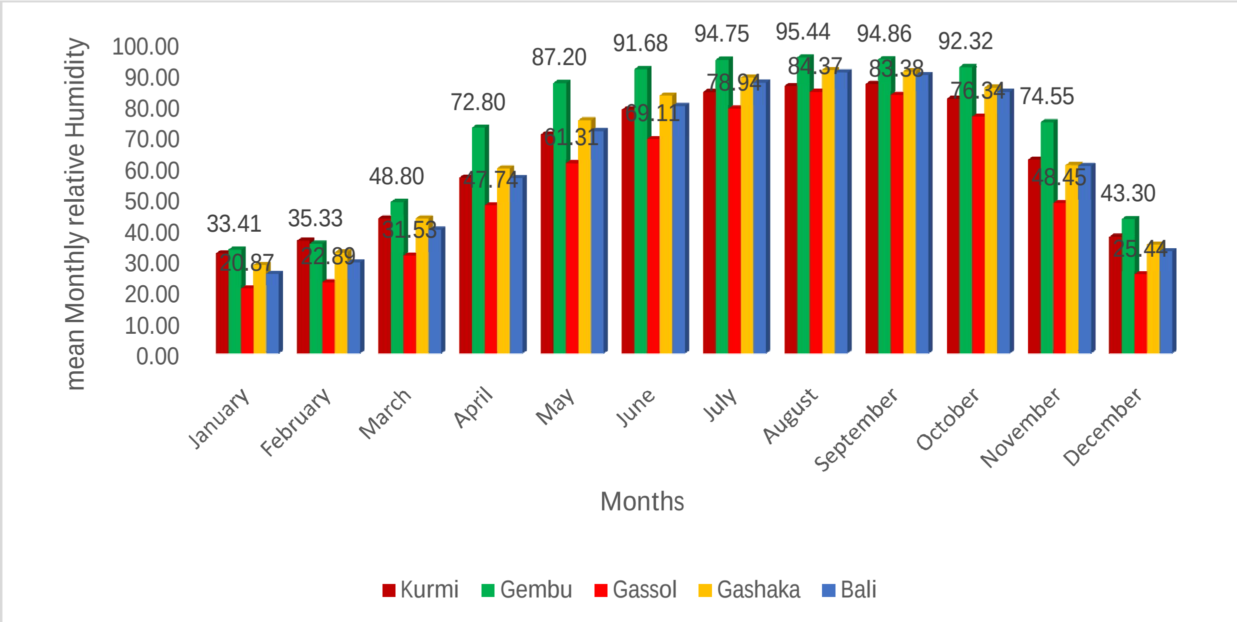

Figure 6. Mean Monthly Relative Humidity. *Data labels for Gassol and Gembu only

The pattern in Fig. 6 is slightly different from that of Adebayo and Umar (2005) on the humidity on Mambilla Plateau which is about 50% in February rises to about 90% in July, and starts declining till December when relative humidity is about 66.6% in Gembu town. The spatial patterns of Kurmi, Bali and Gashaka LGAs are very similar. Gassol LGA recorded the least relative humidity ranging from 20.87% in January when harmattan is at its peak to 84.37% in August when rainfall is at its peak.

4.4 Solar Radiation

4.4.1 Spatial pattern of solar radiation

Fig. 4b shows the spatial pattern of mean annual radiation in the study area. Low solar radiation were recorded in two major places (i) the Benue plains mainly at the central part of Gassol LGA. (ii) the rain shadow area of the Mambilla, that is, around Chappal hills bordering Nigeria and Cameroon in Gashaka LGA. The central portions of Gassol and Bali LGAs as well as major parts of Gashaka LGA (except the rain shadow region) have highest amount of solar radiation.

4.4.3 Pattern of trends of Solar Radiation

The pattern of the trends of solar radiation in the five LGAs within the study area are shown in Table 4.

Bali	y = 0.0362x + 20.058	$R^2 = 0.3242$	Radiation increases by 3.62 mj/m^2 for every increase in one year. The period of the study (1990-2017) contributes about 32.4% (R2) to the variation in radiation
Gembu	y = -0.0041x + 19.909	$R^2 = 0.0029$	Radiation decreases by 0.41 mj/m^2 for every increase in one year. The period of the study (1990-2017) contributes about 0.29% (R2) to the variation in radiation
Gashaka	y = 0.019x + 20.443	$R^2 = 0.1174$	Radiation increases by 0.2 mj/m^2 for every increase in one year. The period of the study (1990-2017) contributes about 11.74% (R2) to the variation in radiation
Gassol	y = 0.0256x + 20.698	$R^2 = 0.1883$	Radiation increases by 2.56 mj/m^2 for every increase in one year. The period of the study (1990-2017) contributes about 18.8% (R2) to the variation in radiation
Kurmi	y = 0.0176x + 22.058	$R^2 = 0.1285$	Radiation increases by 1.76 mj/m^2 for every increase in one year. The period of the study (1990-2017) contributes about 12.9% (R2) to the variation in radiation

Table 4. Values of solar radiation trends/R^2 and their interpretations

Source: Generated from the rainfall data obtained from power.larc.nasa.gov/data-access-viewer

Table 4 shows that only Gembu in Sardauna LGA with high rainfall and humidity and low temperature recorded decrease in solar radiation. Other locations in the remaining LGA with lower rainfall and humidity and higher temperature than that of Gembu had increase in solar radiation. Kurmi LGA despite its location in lower latitude recorded high amount radiation than the neighboring Sardauna LGA with only 0.41

4.4.4 Seasonal pattern of Solar Radiation

The seasonal pattern of solar radiation in the study area is shown in Fig. 7 which shows that Baissa in Kurmi LGA recorded the highest amount of solar radiation in all the months. The pattern of solar radiation in the study area is seasonal because solar radiation is low (less than 20 mj/m^2) in all the LGAs except Kurmi during the rainy season especially from July to September, while the hamattan and dry season periods of November to March experienced the highest amount of radiation above 20 mj/m^2 . At Gembu in Sardauna LGA, radiation decreases from March to August which is different from the report of Adebayo and Umar (2005) who recorded decrease in sunshine from January to August.

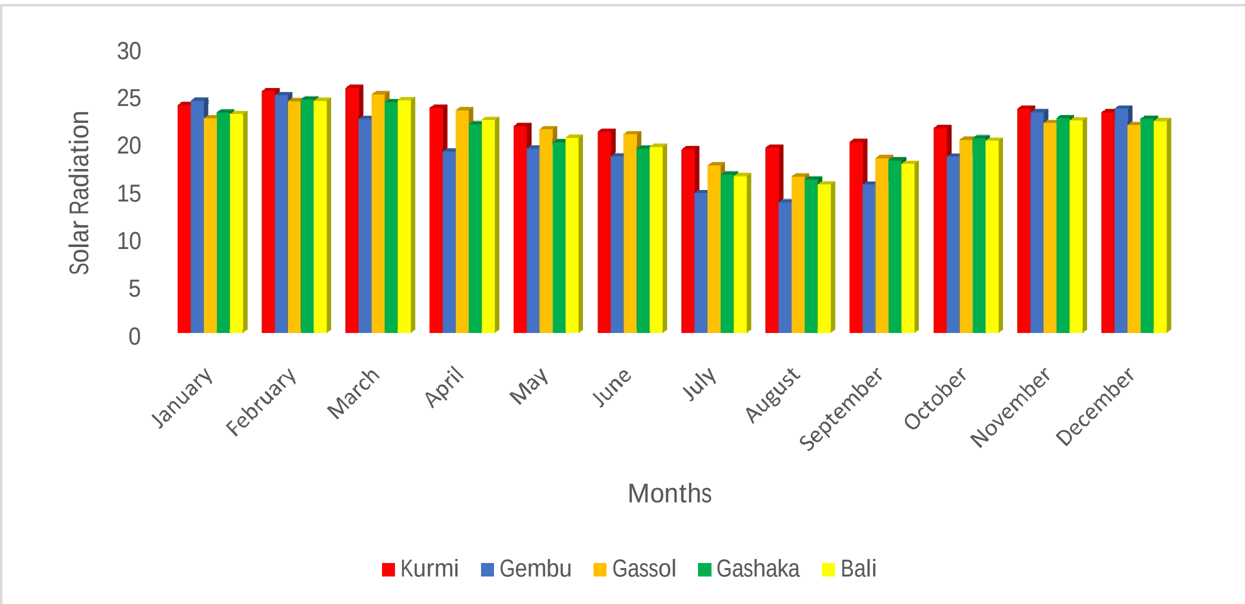

Figure 7. Mean Monthly Solar Radiation.

5.0 Recommendations

The following recommendations are proffered from the findings in the study:

(i) The use of online climatic data should be encouraged among the climate analysts to alleviate the problems associated with in-situ climatic data such as: non-availability in most areas, incompleteness of many records, human problems and therefore non-reliability of such data.

(ii) Awareness and training the stakeholders on the existing online data and how they can be acquired and processed to climatic data

(iii) Extensive training in using GIS techniques for acquisition of online climatic data and mapping, using the climatic records.

6.0 Conclusion.

Mapping and Analysis of climatic parameters (rainfall and rainfall indices, temperature, relative humidity and solar radiation) using online climatic data has been carried out in this study. The output results were found to be similar to existing works that were generated using in-situ climatic data. The findings show that it is time to discard the use of in-situ climatic data that are sometimes found wanting in the areas of completeness of records, data coverage and reliability and therefore make use of online climatic data that are reliable, cover many smaller units and with many years of records. With this data usage, spatial climatic maps can easily be generated instead of the hitherto and the current popular use of point climatic data (like that of a state capital) to generalize the condition of a region (an entire state). Furthermore, the use of GIS for digital mapping using climatic data has resulted into creation of more reliable and high visual impression climatic maps as revealed in this study. Finally, the output climatic charts, graphs and maps serve as reliable data bank to the stakeholders such as Geographers, Climatologists, Meteorologists and environmental analysts for effective monitoring, planning and decision making on climate and related areas for sustainable utilization of the climatic elements in the environment. Climatic mapping of other districts and the entire Taraba State is recommended for further studies.

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