Climatic Mapping and Analysis of Taraba State Central District, North-East, Nigeria

Abstract

Climatic maps have been difficult to generate in Nigeria, not because of a lack of knowledge or expertise but due to a dearth of climatic data. Most of the existing climatic maps are either not reliable or too generalized since only the available data in the state capitals were often used to generate such maps. In this study, online climatic data of rainfall, temperature, relative humidity and solar radiation were used to create the spatial patterns, trends and seasonal patterns of each of the aforementioned climatic elements in Taraba State Central Senatorial District; comprising Bali, Gassol, Gashaka, Gembu, Kurmi and Sardauna LGAs. The results were presented in charts and maps using ArcGIS 10.5 software and the Microsoft Excel package. The spatial pattern of rainfall of the area revealed that the rainfall pattern is 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 were decreasing in Bali, Gashaka and Sardauna LGAs. Rainfall is high from June to September when a minimum of 200 mm monthly rainfall is received in all the five LGAs. The spatial pattern of temperature is inversely related to that of rain, while trends in temperature are increasing in all the LGAs. Relative humidity has similar spatial/seasonal patterns with rainfall but shows 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 on the western side recorded the 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 the use of online climatic data should be encouraged among climate analysts to alleviate the problems associated with in-situ climatic data.

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

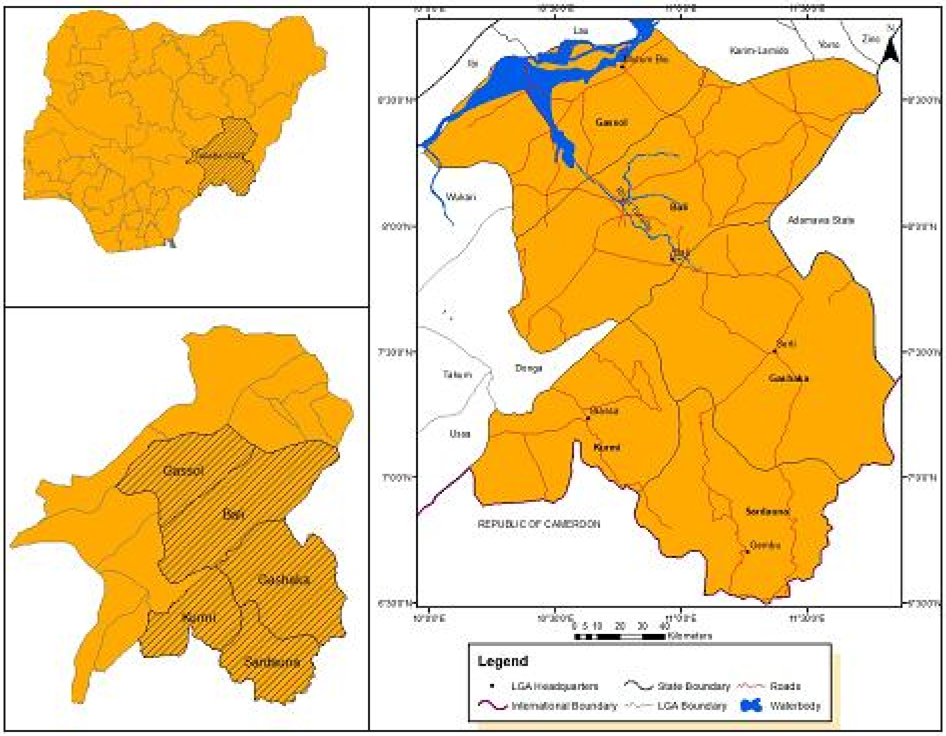
1.0 Introduction

Mapping climate and climatic parameters in developing countries have been confronted with a dearth of climatic data (Tufa, 2019). Due to the reliability of in-situ climatic data, which has various problems highlighted by Ikusemoran as manual data are 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 (Ikusemoran *et al.* 2018). Automatic weather stations were later designed to overcome the problems. However, the stations are also faced with the issues of non-challant attitudes toward weather stations' recorders high cost of acquisition of the instruments leading to the establishment of only a 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) standard, 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 online climatic stations for the provision of online climatic records (Luis, *et al* 2015; Clement *et al,* 2018), and as such, since most of the data are available free online, this climatic data have been utilized for mapping and analysis of climate and climate change variables in developing countries (Olusina & Odumade 2012). Before the advent of online climatic data, 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. Hence, the climatic condition of the only station in the state is generalized for the whole state, which is highly misleading as there are 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). Tracking the climate and its changes calls for the generation of reliable climatic data in numerous places and 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 a lack of data. Therefore, this study uses online climatic data to generate digital maps and analyze climatic variables such as rainfall and rainfall indices, temperature, relative humidity and solar radiation in the study area. The spatial pattern, trends and seasonal pattern of each of the climatic variables were derived, showing the study area's current climatic conditions.

2.0 Description of Study Area

Taraba State Central Senatorial District comprises the following five LGAs: Bali, Gashaka, Gassol, Kurmi and Sardauna. The districts extends from Latitude 6^0 30' 00'' N to 8^0 48' 46'' N of the Equator, and Longitude 10^0 01' 00'' E to 11^0 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 Senatorial District has a wet and dry climate. The wet season lasts, on average, from April to October (Bako *et al.,* 2016). According to Umar *et al* (2019) the rainy season in the area begins in March or early April and ends in mid-November and that rainfall ranges from 1200 mm^3 in the north to about 3000 mm^3 in the South. This rainfall range is similar to that of Mubi (2010), who stated that the lower drier northern parts mean annual rainfall of 1,500 mm3 while the higher wetter southern part receives a mean annual of 2,033mm^3.



Akinsoji (2016) reported an average total annual precipitation of 1,973 mm^3 at the highest peak in the area and that about 95 % of the yearly rainfall is recorded between April and October, with the highest monthly mean in September. The influence of Sahara Trade Winds

Figure 1. The study area

accounts for the absence of rainfall between December and January. Both topography and altitudes characterize rainfall in this area. Mubi (2010) stated that the mountains of the area aid the high rainfall, while Tagoma and Buba (2012) opined that the local climate is influenced by topography, with different regions receiving a different amount of rainfall, depending on location and altitude and concluded that the wettest parts of the area are located in the mountain ranges in the South. Ikusemoran *et al.* (2018) noted that the latitudinal pattern of rainfall in the entire Taraba State ranges from 946 mm^3 in the extreme north to about 1812 mm^3 on Mambilla Plateau.

Mubi (2010) put the temperature of the area in the range of a mean annual minimum of 20^0 C to a mean annual maximum of 31.7^0 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 15^0 C to 23^0 C because Mambilla Plateau has climatic characteristics typical of a temperate climate and therefore, temperatures are low throughout the year. In the northern part of Bali, for instance, Abubakar and Ibrahim (2016) stated that the temperature in the Bali region is warm to hot throughout the year with a slight cool period between November and February and that temperature ranges between 23^oC and 40^0 C. According to Tagowa and Buba (2012), there is a wide range in relative humidity from 26-78% in the study area's Gashaka Gumti National Park section. On the Mambilla Plateau, the driest months are December and January, with relative humidity dropping to about 15 per cent (Bako *et al.*, 2016).

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 the 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) Online rainfall, minimum/maximum temperature 1950-2000 obtained from DivaGIS climatic data. (iii) Landsat February 8, 4, 2021). (v) Spatial solar radiation data generated from ArcGIS 10.5.

3.2 Methods

The four climatic elements 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 a spatial pattern of Climatic data

Mean annual rainfall data for 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 point were used to interpolate the points using the kriging method of the Arctool box of ArcGIS 10.5. The output map was classified into high, moderately high, moderately low and low rainfall areas. The 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 the Landsat 8 image of February 4, 2021.

3.2.2 Method of generating seasonal climatic data

The monthly climatic data for each twenty-eight-year period (1990-2017) were obtained from power.larc.nasa.gov/data-access-viewer. Climatic parameters data for each month (January-December) were summed and used to generate monthly mean records of the places using a bar graph. The graphs show the mean of each month's climatic parameters, which were used to determine the 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 was obtained by adding the minimum and maximum temperature values of a particular point in a specific 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 the Microsoft Excel environment.

3.3.4 Method of generating rainfall indices

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

The 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).

The 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 Discussion of Results

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 is heavier (1620-1791 mm^3) on the major mountain ranges in the area, such as Mambilla Plateau, the Chappal hills and the Wanga hills in Kurmi LGA. This is evidence of the effects of relief on rainfall in the area. Gembu, Nguroje, Dorofi, Maisamari, Ngel Yaki, Sabere and Warwar in Gembu LGA are among the towns and villages within the high rainfall areas. 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 latitudinally inclined as high rainfall falls within latitudes 6.30 to 7.15^0N, moderately high rainfall from about 7.15^0N to about 7.30^0N. Rainfall pattern is least in the northern part of the study area, where low rainfall between 1054 mm^3 and 1176 mm^3 is found between latitudes 8.10 to about 8.38^0N (Fig. 2a). Except for a small part of the southern part of Gassol LGA, almost the entire LGA had low annual rainfall. Therefore, the area's annual rainfall pattern is affected by both orographic and latitudes. Adebayo and Oruonye (2013), and Ikusemoran *et al.* (2018) reported similar rainfall patterns 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 when a place receives an accumulated amount of rainfall sufficient for growing crops.

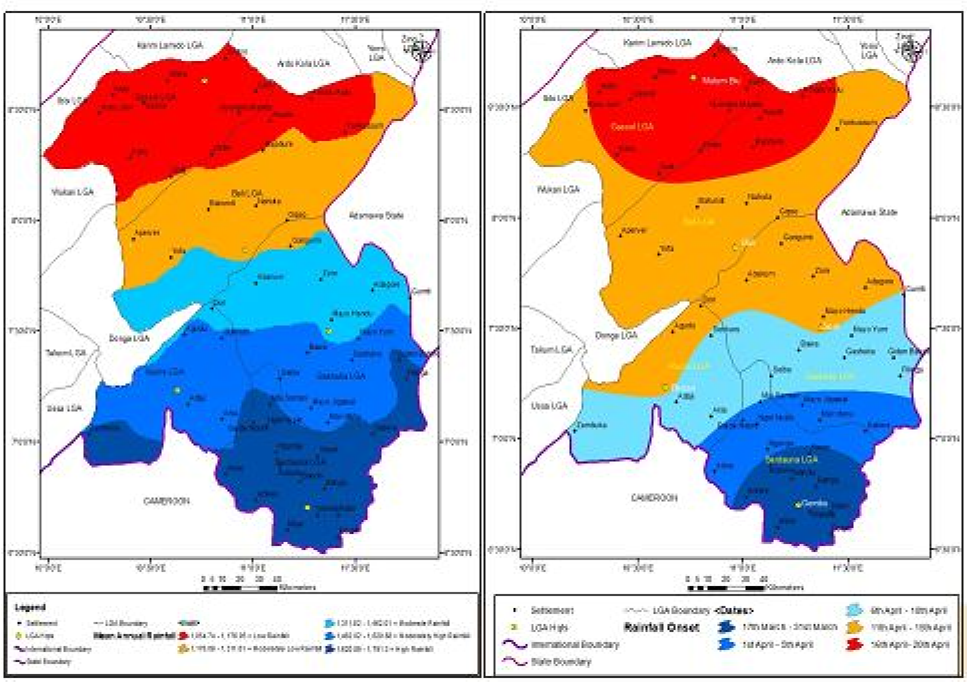


Figure 2a. Spatial pattern of mean annual rainfall. Figure 2b. Spatial pattern of rainfall Onset

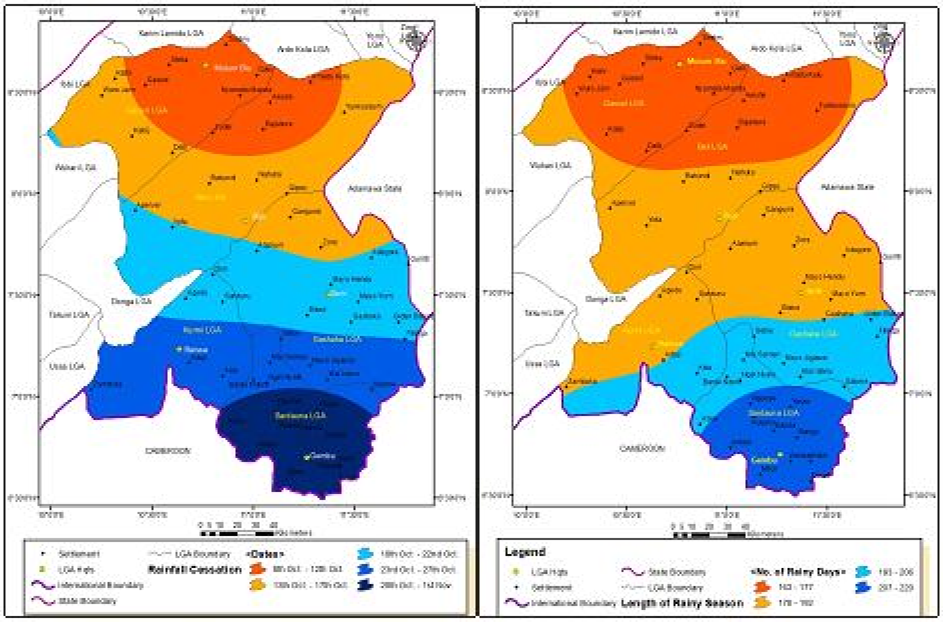


Figure 2c. Spatial pattern of rainfall cessation. Figure 2d. Spatial pattern of the length of rainfall

The spatial pattern of rainfall onset is shown in Fig. 2b, where the southern part of Sardauna LGA (about 6.30^{o}N to about 6.45^{0}N) has the earliest onset between 17^{th} and 31^{st} 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 1^{st} and 5^{th} April annually. These findings tally with that of Adebayo and Umar (2005) that on the Mambilla Plateau, rainfall onset starts around March 20 in the North and April 5 in the South. In the northern part of the study area comprising Bali and Gassol LGAs, rainfall onset is delayed till around 16^{th} to 20^{th} April annually, which is different from that of Adebayo and Oruonye (2013), who quoted May 10 annually as rainfall onset in Gassol LGA.

According to Adebayo and Umar (2005), rainfall cessation is the termination of the effective rainy season, which does not imply the last day it rains in a year but 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 cease earlier in the north than in the southern Mambilla Plateau area. Rainfall cessation dates for larger parts of the Mambilla Plateau to about 7.00^{0}N is between October 28 and November 1. Beyond about 7.45^{0}N, especially in Bali and Gassol LGAs, rainfall cessation is between 8^{th} and 17^{th} October. These findings are similar to that of Adebayo and Umar (2005), who stated that rainfall cessation in the entire Taraba State lies between 16^{th} and 26^{th} October in the north. Adebayo and Oruonye (2013) also recorded similar cessation dates of October 11 in Gassol and October 21 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 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 the duration of the rainy season (Adebayo and Umar, 2005). The spatial pattern of the length of the rainy season is shown in Fig. 2d where, as expected, the Mambilla Plateau, with early rainfall onset and late cessation, has the longest 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. LRS at the central part of the study area from about 7.28^{0}N to about 8.10^{0}N had LRS between 178 and 192 days, while the extreme northern parts of Bali and Gassol LGAs recorded 163-177 days. Therefore, it was concluded that LRS is shorter in the parts of the north than in 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.

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

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 (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 (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 (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 (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 (1990-2017) contributes about 13.5% (R2) to the variation in rainfall

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 decline in rainfall might be connected to the increase in temperature and decrease in relative humidity and solar radiation (Tables 1-4), respectively. An increase in temperature and decrease in relative humidity and solar radiation inhibit rainfall formation (Olayinka *et al,* 2015; Díaz-Torres, 2017). Oruonye (2014) 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.

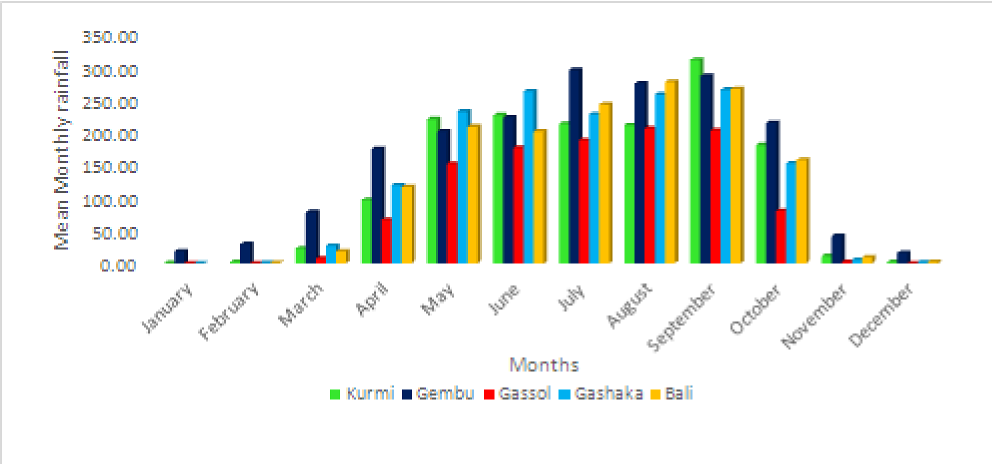


Figure 3. Mean Monthly Rainfall

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 the mean monthly rainfall in November is less than 100 mm). Rainfall is high from June to September when a minimum of 200 mm^3 monthly rainfall are received in all the five LGAs in the study area, as shown in Fig. 3. These findings agree 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 (Tagowa and Buba, 2012); therefore, monthly rainfall is very low or even zero in all the LGA except Gembu, with less than 50 mm^3 rainfall during this period. The same is also experienced during the January to March dry season when only Gembu recorded more than 50 mm^3 rains.

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 ^{0}C. Adebayo and Oruonye (2013) recorded similar mean temperature of 21.39 ^{0}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 ^{0}C. This finding is however different from that of Adebayo and Oruonye (2013) who recorded mean annual temperature of Gassol as 34.22 ^{0}C.

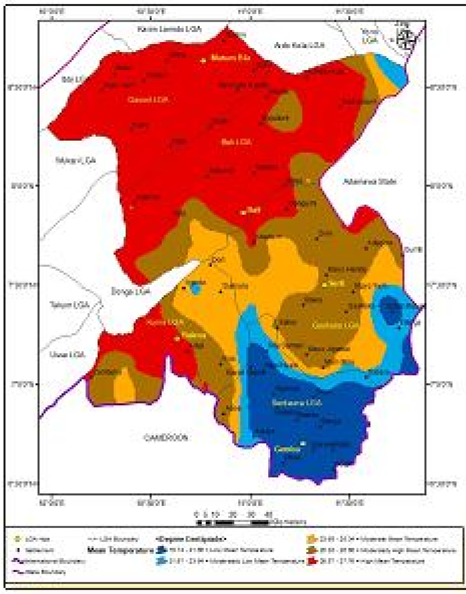


Figure 4a. Mean annual temperature

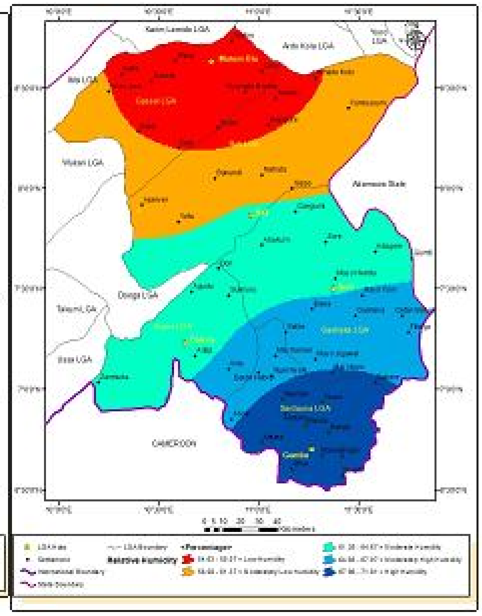


Figure 4b. Mean annual relative humidity

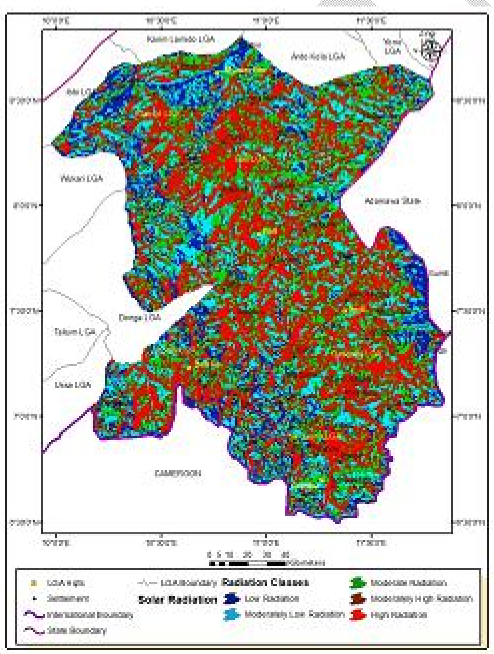


Figure 4c. Spatial pattern of solar radiation

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 (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 (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 (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 (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 (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 a very slow rate of less than four (4) ºC 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

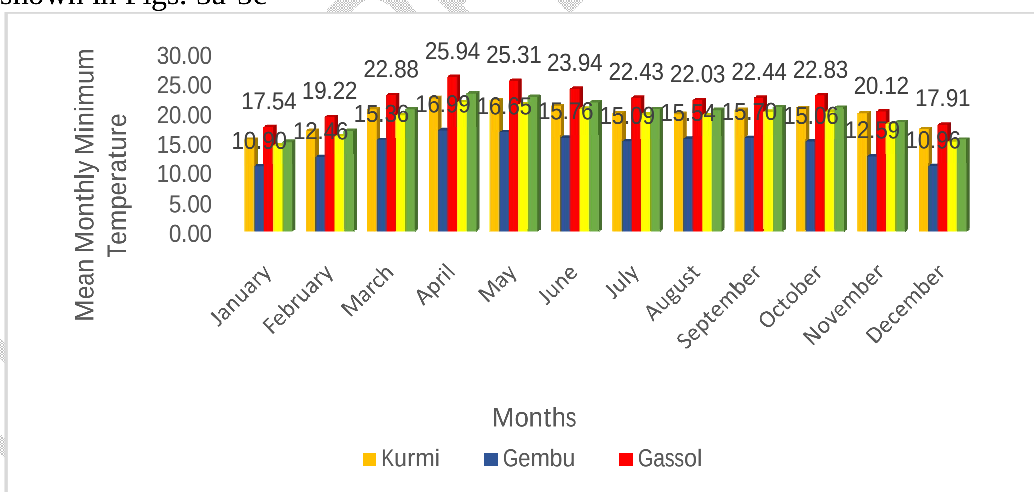


Figure 5a. Mean Monthly Minimum Temp. *Data labels for Gassol and Gembu only

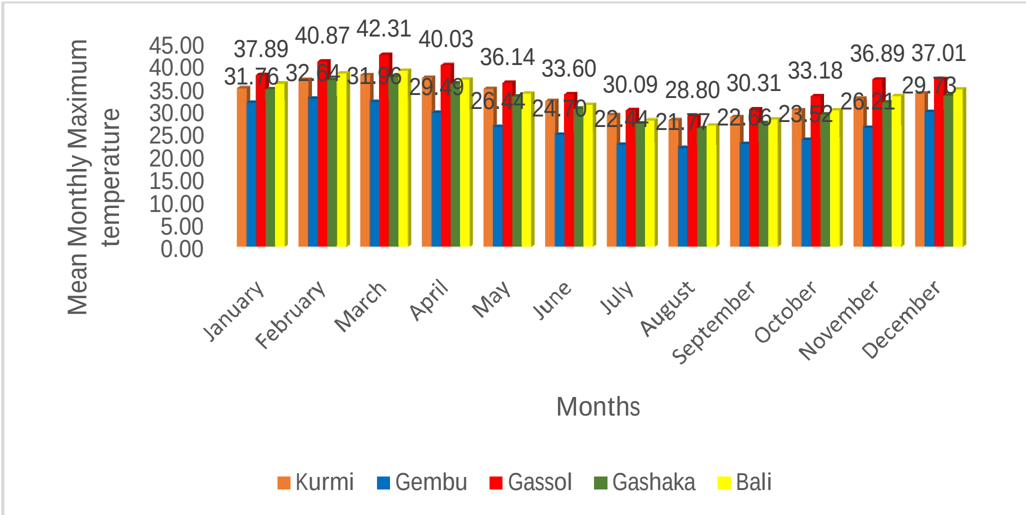


Figure 5b. Mean Monthly Maximum Temp. *Data labels for Gassol and Gembu only

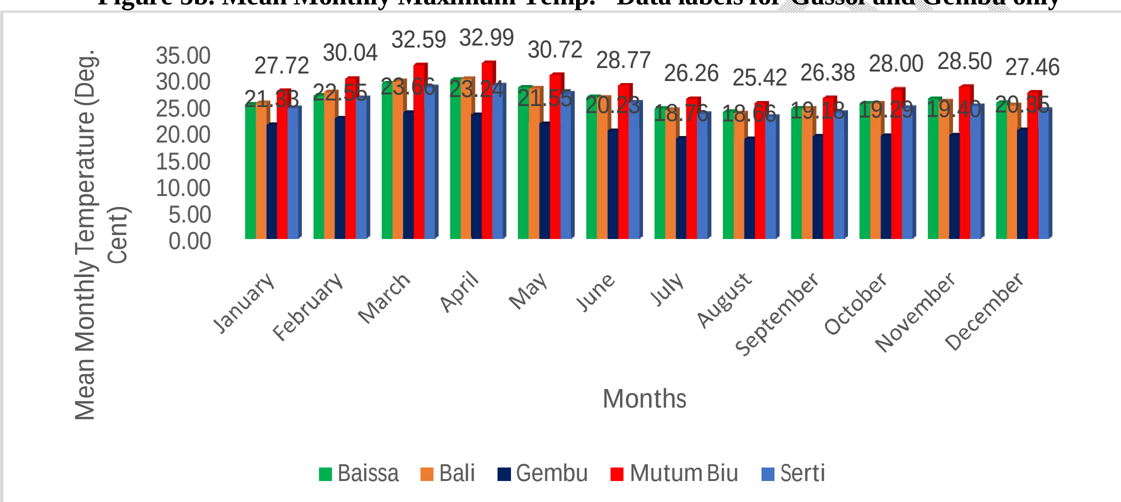


Figure 5c. Mean Monthly Temp. *Data labels for Gassol and Gembu only

The mean monthly minimum temperature is highest in Gassol LGA throughout the months. The minimum temperature is more than 25 ^{0}C between April and May. However, the peak in April when the minimum temperature is as high as 25.94 ^{0}C (Fig. 5a). Minimum monthly temperatures are also high in Baissa and Bali LGAs throughout the year. Gembu in Sardauna LGA recorded the least mean monthly temperature throughout the year. The minimum monthly temperature in Gembu (Sardauna LGA) was as low as about 10 ^{0}C during the harmattan period in December and January. April and May recorded the only months with above 25 ^{0}C in Sardauna LGA with the peak in April when minimum monthly temperature is 16.99 ^{0}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 ^{0}C during the dry season (January – March) but the peak was February with 32.64 ^{0}C. The least monthly maximum temperature at Gembu occurred in August which is at the peak of the rainy season with 21.77 ^{0}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 latitudinally. 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 study area's spatial pattern of mean annual relative humidity. The spatial pattern of relative humidity is directly related to rainfall but inversely related to temperature, and in areas with high rainfall, the low temperature has high relative humidity. This finding shows that rainfall and temperature largely determine the spatial pattern of relative humidity. Therefore, these three climatic elements are very important in the determination of the climate of a place. The relative humidity percentages in Kurmi and Bali LGAs are generally between 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 is shown in Table 3.

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

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 (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 (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 (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 (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 (1990-2017) contributes about 33.5% (R2) to the variation in humidity

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

The trends in relative humidity were directly inversely related to temperature because the humidity in all the LGAs was decreasing (except Kurmi LGA) while the temperature in all the

LGAs was increasing. The relative humidity increase rate in Kurmi was, however, lower than the rate of decrease in the other LGAs. The R^2 in Kurmi LGA is very high; in recent years, the LGA's relative humidity has been increasing.

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 is generally high 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 the harmattan and dry season (November to March), when the percentage 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 its peak and descends to 74.55% in November.

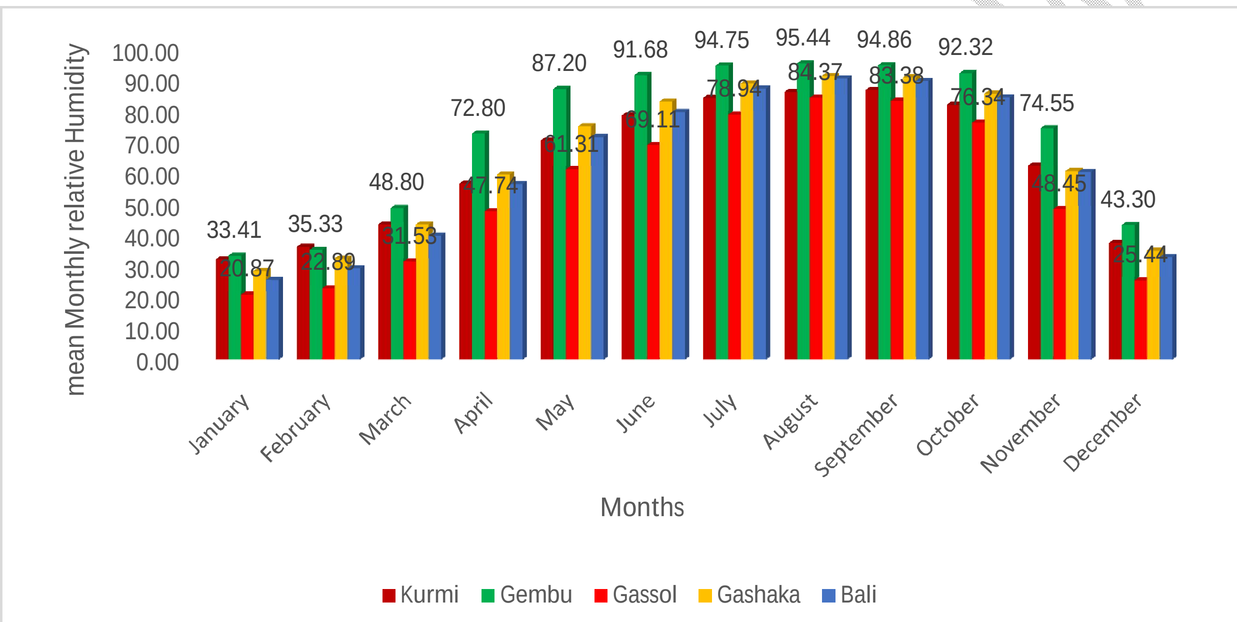


Figure 6. Mean Monthly Relative Humidity. *Data labels for Gassol and Gembu only

The pattern in Fig. 6 is slightly different from that of Adebayo and Umar (2005) on the humidity on the 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 the 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 was 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 and major parts of Gashaka LGA (except the rain shadow region) have the highest amount of solar radiation.

4.4.3 Pattern of trends of Solar Radiation

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

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

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 (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 (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 (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 (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 (1990-2017) contributes about 12.9% (R2) to the variation in radiation

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, humidity, and low temperature, recorded a decrease in solar radiation. Other locations in the remaining LGA with lower rainfall and humidity and higher temperature than that of Gembu had an increase in solar radiation. Kurmi LGA, despite its location in lower latitude recorded a high amount of radiation than the neighbouring Sardauna LGA, with only 0.41 mj/m^2

4.4.4 Seasonal pattern of Solar Radiation

The seasonal pattern of solar radiation in the study area is shown in Fig. 7, which indicates 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 Adebayo and Umar (2005), who recorded a decrease in sunshine from January to August.

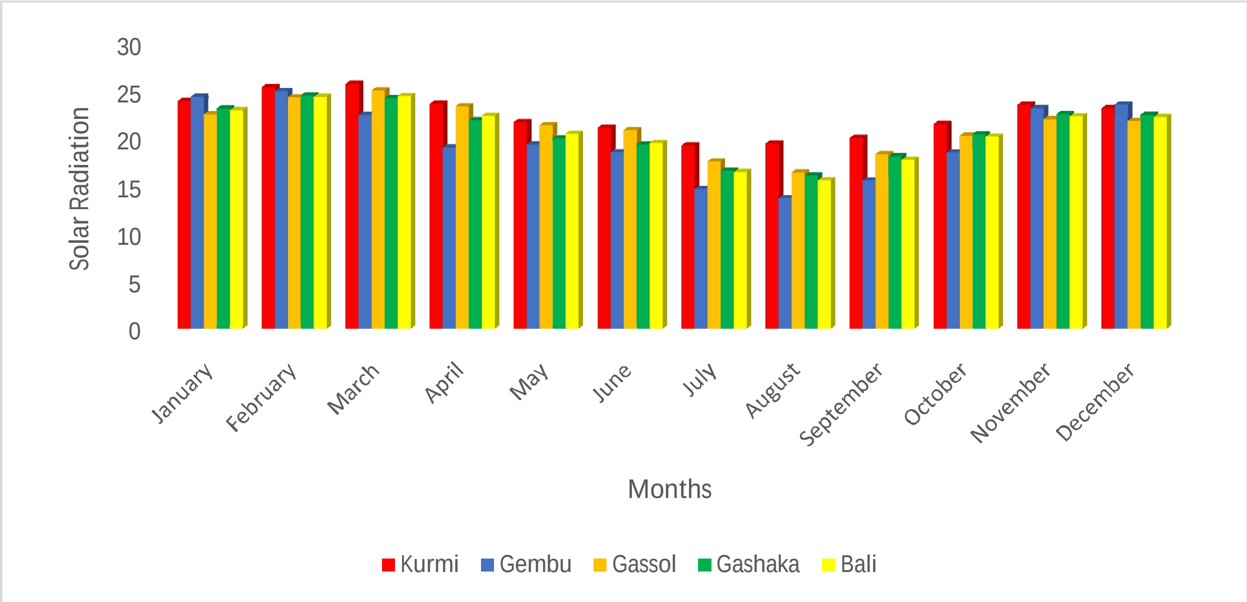


Figure 7. Mean Monthly Solar Radiation.

5.0 Conclusion.

Mapping and analysis of climatic parameters (rainfall and rainfall indices, temperature, relative humidity and solar radiation) using online climatic data have been carried out in this study. The output results were 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, GIS for digital mapping using climatic data has created a more reliable and highly visual impression of climatic maps, as revealed in this study. Finally, the output climatic charts, graphs and maps serve as a dedicated 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.

6.0 Recommendations

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

(i) The use of online climatic data should be encouraged among 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 of the stakeholders on the existing online data and how they can be acquired and processed to climatic data.

(iii) Extensive training in GIS techniques for acquiring online climatic data and mapping using climatic records is required.

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