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GEOSPATIAL TECHNIQUES FOR MAPPING AND ANALYSIS OF CLIMATIC VARIABLES IN GOMBE STATE, NORTH-EAST NIGERIA.

Ikusemoran Mayomi[1], Ezra Andrew[2] and Yusuf Bello[3]
[1] Remote Sensing/GIS Unit, Department of Geography, University of Maiduguri, Borno State
[2]Climatology/GIS, Adamawa State Post Primary School Management Board, Yola
[3]Climatology Unit, Department of Geography, Federal University, Dutsin-Ma, Katsina State
yomiomoolu@gmail.com

ABSTRACT

This study was carried out to apply satellite- based climatic data in geospatial environment to downscale climatic data into smaller political units and to generate and analyse thematic maps of climatic variables in Gombe State. Spatial climatic data on rainfall, minimum and maximum temperature were obtained from DivaGIS climatic data, while water vapour, solar radiation and wind speed were derived from the WorldClim climatic data. Monthly climatic records from 1981-2021 in twenty-four points evenly spread across Gombe State on rainfall, minimum/maximum temperature and relative humidity were obtained from NASA Power Project to generate the trends and seasonal patterns of temperature and rainfall. Daily climatic records of rainfall were also acquired from globalweather climatic data between 1979 and 2013 and processed to derive the values of rainfall indices using Nieuwolt formula. The monthly climatic records were processed using the kriging module of ArcGIS to transform the point climatic data to spatial data. The result revealed that rainfall in Gombe State occurs mainly between May and September with the peak in August, while the trends in rainfall was decreasing at the southern and northern parts of the state but increasing at the central region. Rainfall onset occurs in the 1st or 2nd week of May in the south, but late (1st week of June) in the north. Rainfall cessation at the central and northern parts of the state occurs in the 3rd or 4th weeks of September, while the southern part experiences late cessation between the 1st and 3rd week of October. The LRS ranges from 95-111 and 160-175 days in the northern and southern parts respectively. High relative humidity was recorded between May and October with the peak in August. Spatial patterns of solar radiation and wind speed were also generated and analyzed. Awareness of the use of satellite based climatic data and geospatial techniques for downscaling climatic data were recommended in order to ease the problems of lack or inadequate climatic data for spatial mapping. Causal factors for the spatial patterns of climatic variables in Gombe state was suggested for further studies.

Keywords: Climatic variables; Rainfall indices; Geospatial techniques; satellite-based climatic data; Gombe State

INTRODUCTION

Climate is defined as the long-term pattern of weather conditions in a place or region (Intergovernmental Panel on Climate Change (IPCC, 2007). In recent decades, climate change has become a global phenomenon as it has dominated environmental discussion all over the world (Ati *et al*, 2021). Climate change referred to as any significant change in the measures of weather elements such as temperature, rainfall, wind pattern and others, lasting for an extended period of time (Nigerian Meteorological Agency (NiMet), 2017 in Abaje and ladipo, 2019). Based on the report of United Nations Framework Convention on Climate Change (UNFCCC, 2011), the World Meteorology Organization opined that climate change results when greenhouse gases in the atmosphere absorb some of the Earth's outgoing heat radiation, re-radiate it back towards the surface, warm the Earth's surface as well as the lower atmosphere resulting into global increase in temperature. Globally, the 4th assessment report of climate change by IPCC (2007) concluded that global climate change is real and that 'warming is unequivocal'. The report of IPCC (2023) showed that despite having the least contribution to global warming and lowest emissions, Africa is the most vulnerable continent to climate change impacts under all climate scenarios above 1.5 ºC. The panel concluded that there is more than 50% chance that global temperature rise in Africa will reach or surpass 1.5 ºC between 2021 and 2040. NiMet (2023) noticed the effects of climate change in Nigeria and warned on the increasing concentration of greenhouse and the potential consequences. African Development Bank (ADB, 2023) noted that the climate of the Sudano-Sahelian region of Nigeria is influenced by three air-masses, namely: the tropical maritime (mT); the tropical continental (cT), and the equatorial easterly.
The climate of Gombe State has impacted on the people and the general environment because of high vulnerability and low adaptive capacity (Bello, 2022), it is an important factor in the determination of spatial patterns of settlement (Ikusemoran *et al*, 2018). Bello and Paul (2018) highlighted the

influence of temperature on loss of soil moisture, Ezra *et al*, (2020) emphasized the effects of agro-climatic variables on crop yield while Ezra *et al*, (2021) pointed out the effects of climatic variables on surface water. Climatic variables also determine some of the human activities of the inhabitants. For instance, agriculture is the main occupation of the people of Gombe State as about 65% of the populace engage in crop production (Dan *et al*, 2019). The knowledge of the spatial patterns of rainfall indices such as onset, cessation and length of rainy season for instance, can also help the farmers to plan the periods of their crop production. Despite all these benefits of data on climate and climatic variables, no adequate thematic maps and data/information on the climate in the state are available. Recent or temporal spatial and seasonal patterns as well as the trends of the climatic variables in the state are either very scanty or not available at all. For instance, the only reliable climatic records in Nigeria today is Nigeria Meteorological Agency (NIMET), unfortunately climatic data of only the state capitals of most of the states (including Gombe State) are available. Hence, such data can only be used to prepare thematic maps for Nigeria as a whole but not individual state because the generation of spatial pattern of thematic maps largely depends on data of many points within each State. However, in recent years the use of ground based climatic data has been substituted by more reliable satellite-based data which are free from human errors and have been widely used and confirmed adequate by various authors (Luis, *et al*, 2015, Clement, *et al*, 2018, Ikusemoran *et al*, 2018). With the use of satellite based climatic data, downscaling of climatic data for generation of thematic maps for smaller political units such as States and Local Government Areas becomes possible. In this study, satellite-based climatic data was obtained while geospatial techniques were used to generate thematic maps and charts showing the spatial and seasonal patterns of climatic variables as well as the trends for the analysis of the climate of Gombe State. Therefore, mapping and analysis of the spatial and seasonal patterns as well as the assessment of the nature of the trends of these climatic variables in Gombe State were carried out. The climatologists and meteorologists make use of these climatic variables in their activities especially for teaching-learning, training and research processes.

The Study Area

The political units, relief and drainage of the study area is shown in Fig. 1.

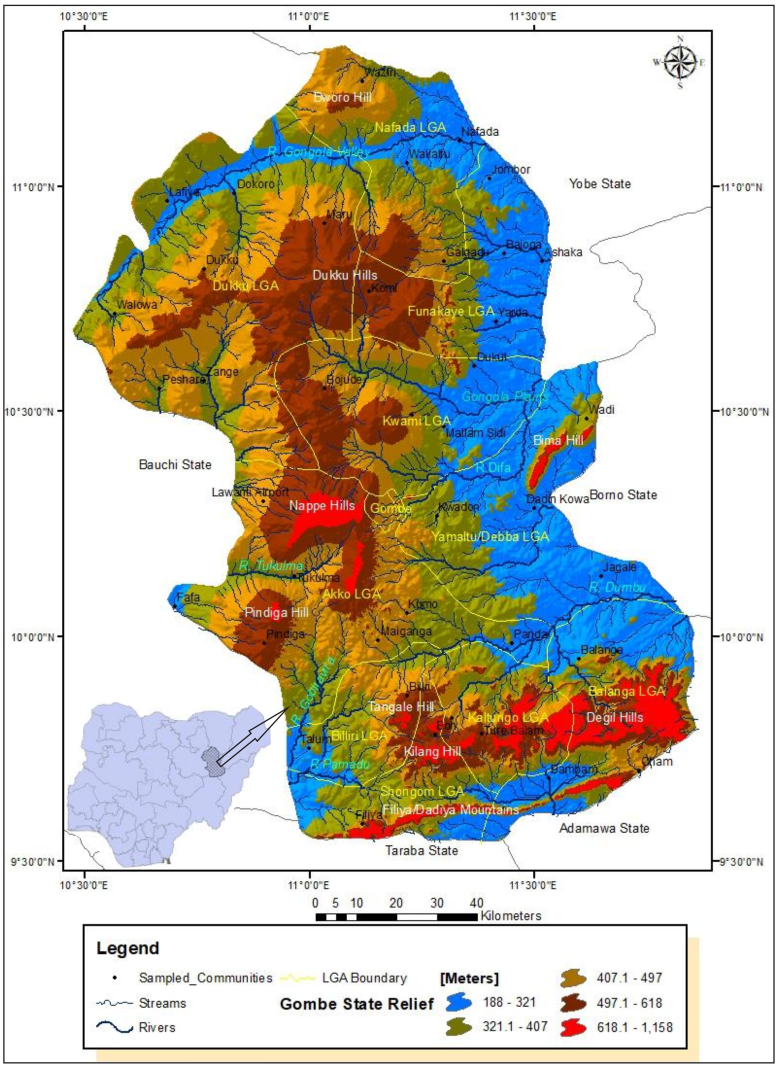

Figure 1. The Study Area: Political, Relief and Drainage

Gombe State was carved out from Bauchi State on 1st October, 1996. The State, with a total land area of 26, 258.6 km^2 is bounded by Bauchi and Borno States in the West and East respectively, Adamawa and Taraba States to the South, and Yobe State in the North. The least elevation (188 m above sea level) is found around the plains along River Gongola while the highest elevation of about 1158 m is found on the highland areas (Fig. 1). According to Mbaya *et al*, (2019), the soils of Gombe state comprises 30% from Gombe Sandstones and 25% from basement complex rocks. Other soil types are derived from Bima sandstone (Bima hills and Gombe town), Basalt rocks (Kilang, Tangale, Nyawur-Lunguda plateaus) and Kerri Kerri sandstones. The State lies within the savanna woodland vegetation types with *Butyrospermum, paradoxum, Tamarin indica, Parkia biglibosa, Aflexia Africana* trees and grasses (Ikusemoran *et al*, (2016). The National Population and Housing Census of Nigeria (2007) in Samasundara and Bachama (2019) recorded the population of the State as 2,365,040 inhabitants with 1,244,228 males and 1,120,802 females, while Local Government Areas (LGAs) with population density above one hundred and fifty persons per square kilometres (except Gombe LGA, the State Capital) include Biliri (267), Kaltungo (177), Funakaye (162) and Shongom (159). All these LGAs except Funakaye LGA are located in the southern part of the State where the climate is more conducive (Bello *et al*, 2020), vegetation is denser (Ikusemoran *et al*, 2016) and the soils are more fertile (Mbaya *et al*, 2019). Abbas *et al*, (2019) has noted that the physical environment greatly influences the settlement pattern of the inhabitants of Gombe State. The state falls within the Koppen's 'Aw' Tropical Continental climatic classification type (Koppen, 1884) characterised by two dominant air masses; Tropical Maritime Air Mass which originates from Atlantic Ocean brings rain into all parts of Gombe State from May to September commonly called the rainy or wet season. The northern parts of the State experiences rainfall between May and September, hence, rainfall amount decreases from the south to the north but with a single peak in August and a mean annual rainfall of about 863.2 mm. The Tropical Continental Air Mass takes its source from Sahara Desert in the North-East and brings harmattan; a cold and dusty air that occurs in Gombe state from December to February. Generally, maximum temperature which is about 38°C occurs between March and May, while minimum temperature of about 25°C is experienced during the cold season between December and January. The mean annual temperature however, is about 32°C.

MATERIALS AND METHODS

Materials

The following materials were acquired for this study: (i) Political map of Gombe State, georeferenced and digitized in ArcGIS 10.7.1 to form the base map. (ii) Global Positioning system (GPS) which was used to obtain the coordinates of all the sampled settlements in Decimal Degrees and added to the base map through the text tab delimited of Microsoft Excel. (iii) Digital Elevation Models (DEM) of Gombe State obtained on line from ASTER V_2 (2011) DEM data for generating the relief of the State. (iv) Diva GIS v.7.5 mean spatial data (1950-2000) of rainfall, minimum and maximum temperature of Gombe State for mapping the spatial patterns of rainfall, minimum, maximum and mean temperature. (v) 2-meter resolution spatial climatic data of solar radiation, wind and water vapour obtained on-line from WorldClim 2.0 Beta Version 1 representing spatial mean monthly climatic data of the three climatic variables produced by Steve and Robert (2016). (vi) Daily rainfall record from January 1979 to December 2013 (a period of thirty-five-years) of twenty-four 'stations' within or close to Gombe State boundary, obtained on-line through globalweather.tamsu.edu. for the determination of rainfall onset, cessation and lengths of rainy season (vii) Monthly and annual records of all the sampled climatic variables in this study for generating the seasonal and trends of each of the climatic parameters.

Methods

The shape file of Gombe State was created using ArcGIS 10.7.1 software. Fifty-three (53) towns/villages as well the LGA boundaries of all the LGAs were added to the shape file. The shape file was used to carve out all the spatial data like the DEM data and the spatial climatic data of wind, solar radiation and water vapour. Each of the extracted elements was classified into five for easy and uniformity of analysis, while appropriate measuring units were assigned to each of the climatic elements. A total number of one thousand, one hundred and twenty (1,120) points of about 4 km equal interval were generated within the shape file of Gombe State using the create fishnet module of ArcGIS 10.7.1 which was used to extract the values of rainfall, minimum and maximum temperature from the DivaGIS 7.5 climatic spatial data set produced by Roberts, *et al*, (2012) using the extract values to point in the ArcGIS 10.7.1 software. The values of the minimum and maximum temperature were added and divided by two to obtain the mean temperature. The obtained values of each climatic variables were used for interpolating the climatic data using the kringing method.

The spatial climatic data of water vapour, wind speed and solar radiation were obtained from Worldclim V_2 climatic data through http://worldclim.ord/version2. The shapefile of Gombe State was used to extract the state from the spatial data set and like the DivaGIS, the 1,120 points were used to interpolate the extracted maps. Daily climatic records of rainfall (1979-2013) were acquired from globalweather climatic data (globalweather.tamsu.edu) and processed to derive the values of rainfall indices (onset, cessation and length of rainy season) using Nieuwolt formula. Though, globalweather climatic online data has no recent data (it terminates in July, 2014), but it has more places with climatic data (twenty-four points spread evenly across the state) than the NASA power project climatic data which has recent climatic data but fewer places across the state. In point interpolation, the more the points, the more accurate the spatial data which justifies the choice of the use of globalweather climatic data for generating the spatial pattern of rainfall indices. The Nieuwolt (1982) formula for calculating rainfall onset, cessation and length of rainy seasons were adopted in this study: Rainfall Onset = *Number of days in the rainfall onset month (51minus the accumulated rainfall before the onset month)/Total rainfall in the onset month.* The obtained value was checked on the pentad table to determine the actual date of onset/cessation. Rainfall Cessation = *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.* The obtained value was checked on the pentad table to determine the actual date of onset/cessation. Length of Rainy Season (LRS) = *The pendat value of rainfall cessation minus the pentad value of rainfall onset multiplied by 5.* The result was checked on the pentad table under pentad and date of year to determine the actual number of rainy days.

Monthly climatic records from 1981-2021 in twenty-three points within Gombe State on rainfall, minimum/maximum temperature and relative humidity were obtained from National Aeronautics and Space Administration (NASA, 2022) Power Project derived online through http://power.larc.nasa.gov to generate the trends and seasonal patterns of temperature and rainfall. Spatial pattern of relative humidity which is not available in the Worldclim data was generated through interpolation of the mean annual relative humidity of each of the twenty-three points in the state using point method by interpolating the values of each point through the kringing module of ArcGIS 10.7.1. The annual climatic records of precipitations and mean temperature (derived from the monthly data) were used to create the trends of rainfall and temperature for some selected locations in the state. The output spatial patterns were classified into five classes for analysis. The mean of all the monthly climatic records in all the points were computed, the results were used to generate climatic chats and tables for analysis of the seasonal patterns of the climatic elements.

RESULTS

The spatial patterns of mean annual rainfall, onset, cessation and length of rainy season are shown in Figs 2a-2d. Figs 3a-3d show the maximum, minimum and mean temperature as well as the mean relative humidity. Fig. 4 shows the Seasonal patterns of maximum, minimum and mean temperature. Figure 5. Shows the seasonal pattern of relative humidity. Figs 6a-6c show the spatial pattern of mean annual water vapour, wind speed and solar radiation

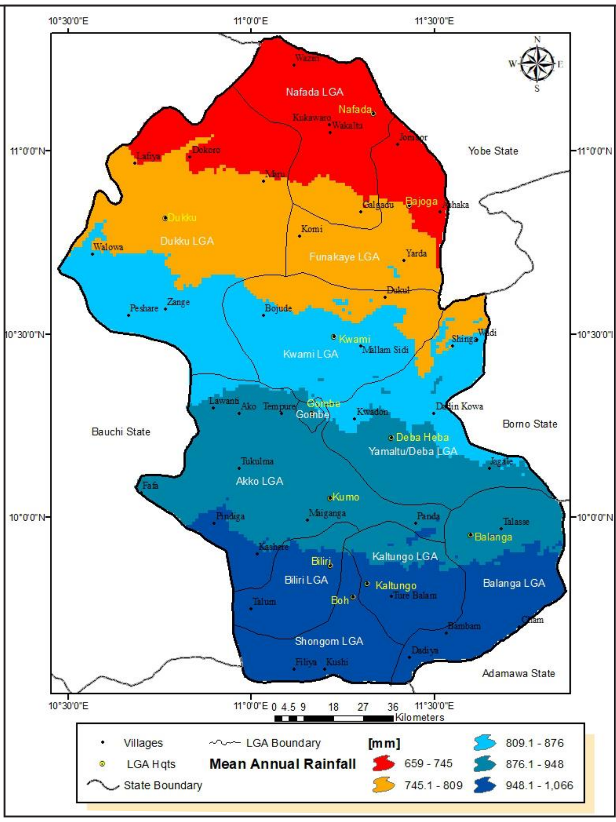

Figure 2a. Mean Annual Rainfall

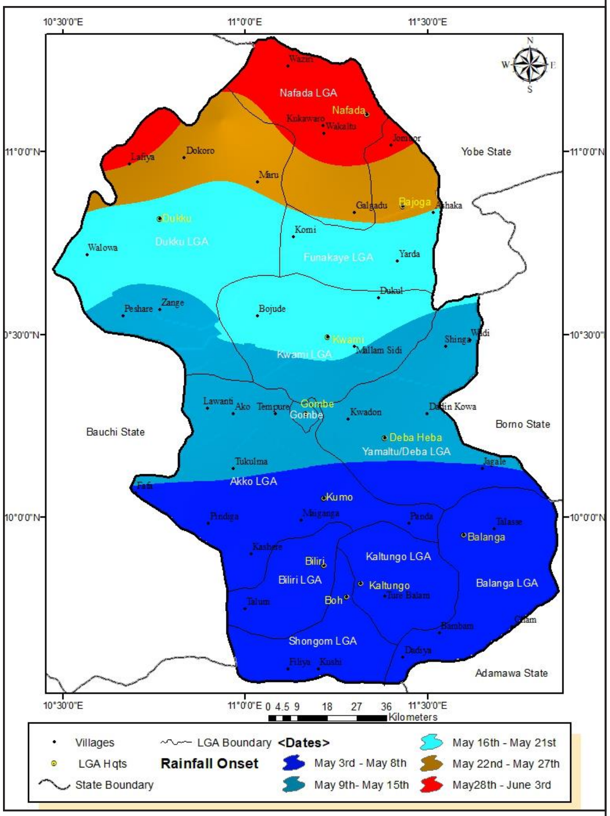

Figure 2b. Rainfall Onset

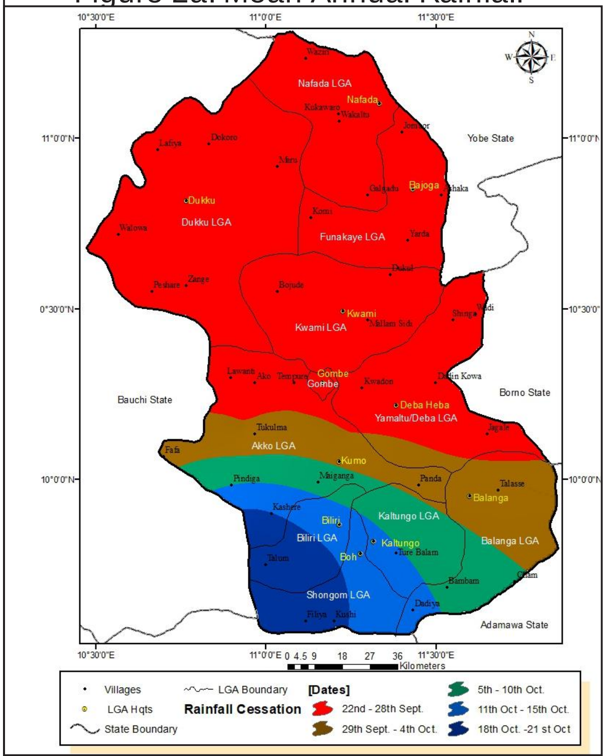

Figure 2c. Rainfall Cessation

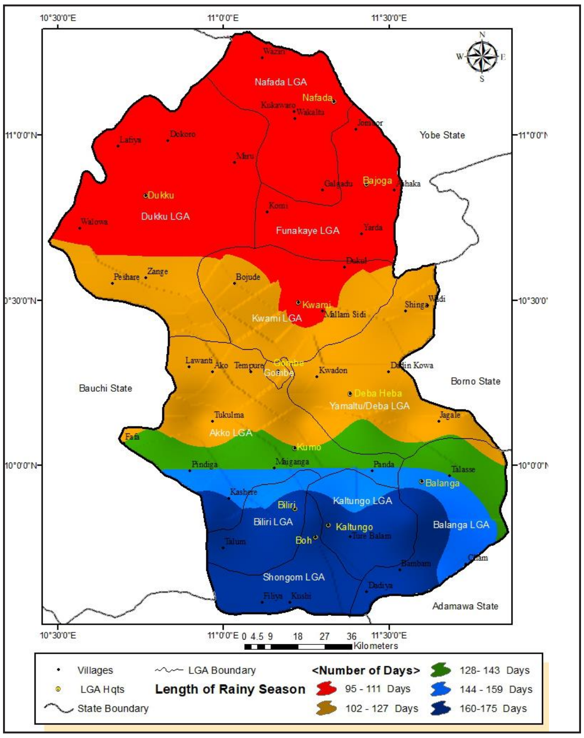

Figure 2d. Length of Rainy Season

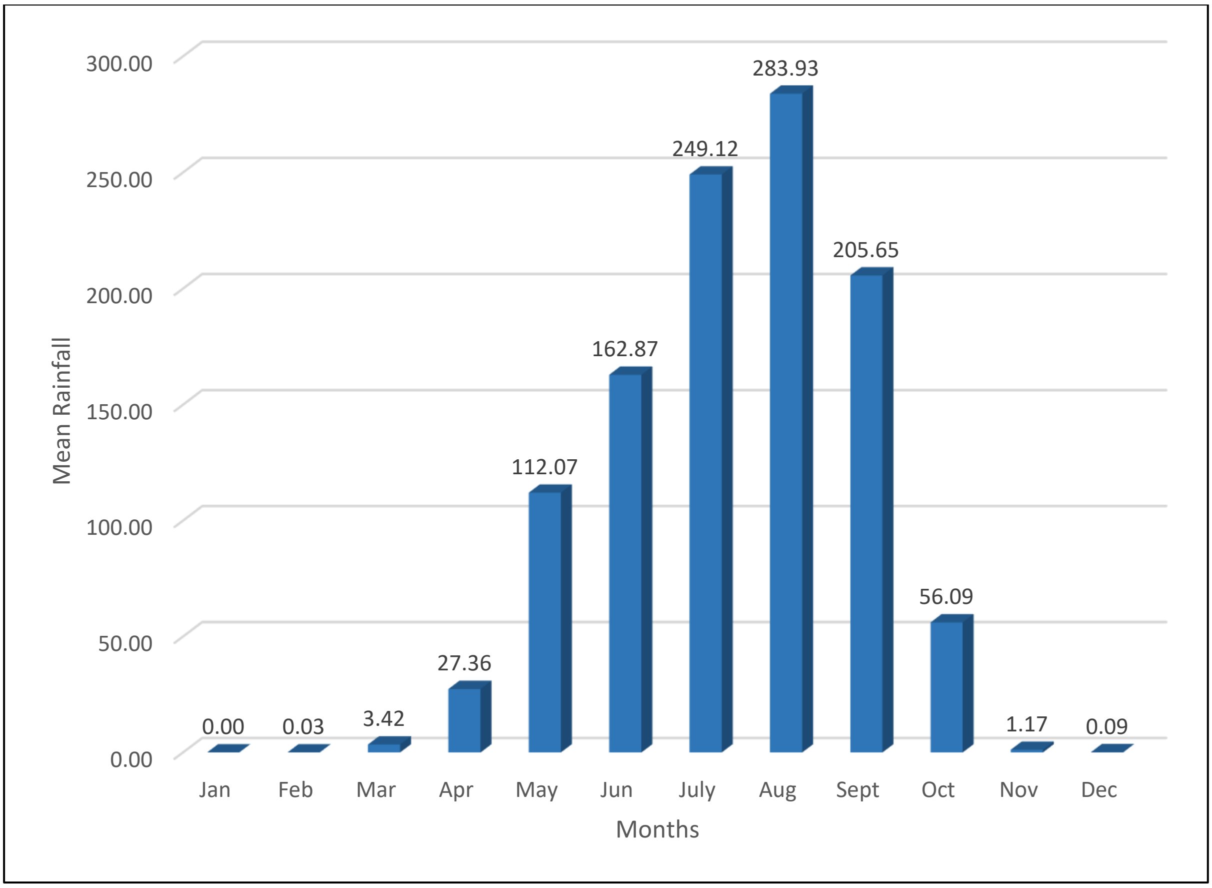

Figure 2e. Seasonal pattern of rainfall in Gombe State

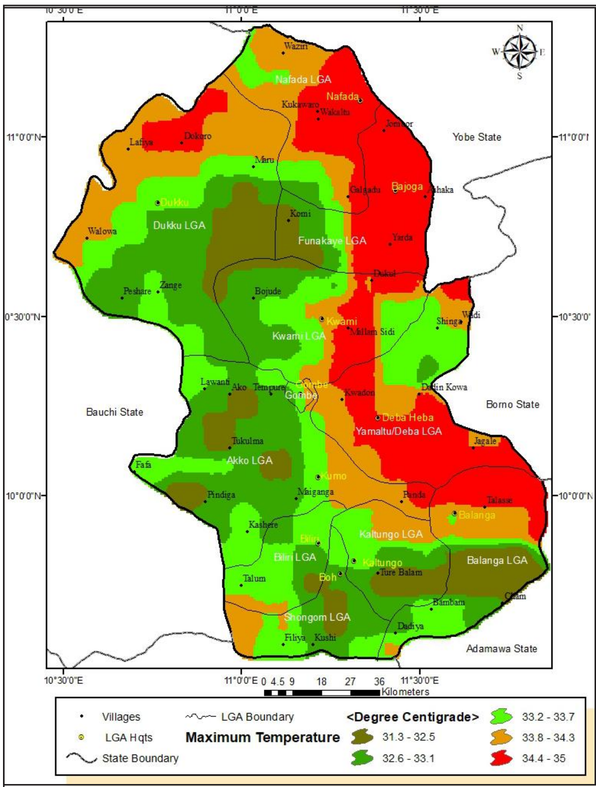

Fig 3a. Maximum Temperature

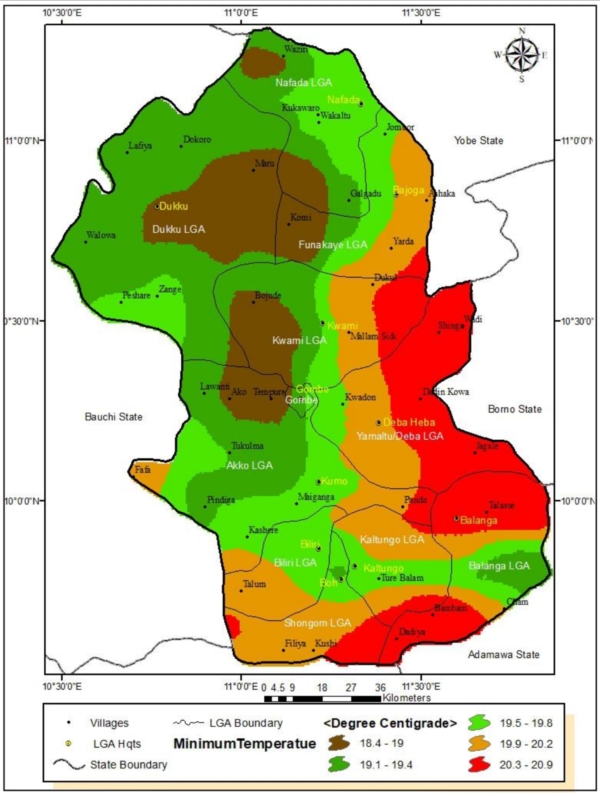

Figure 3b. Minimum Temperature

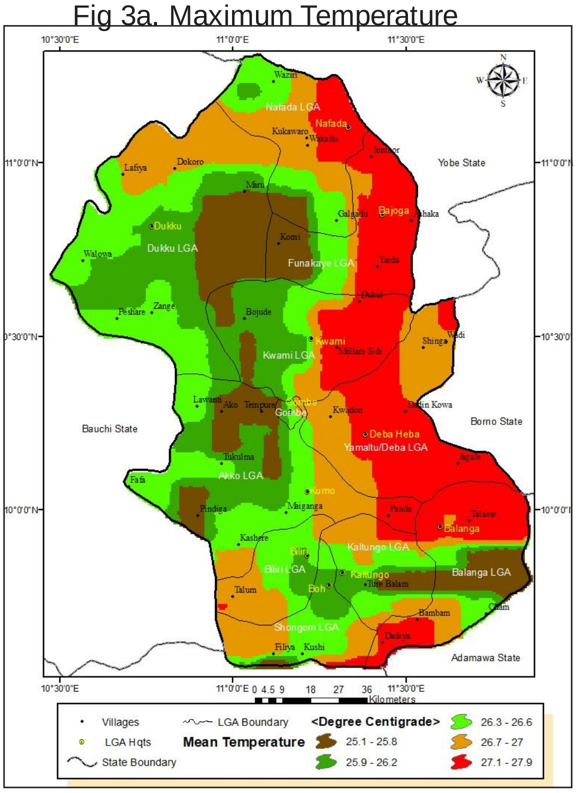

Figure 3 c. Mean Temperature

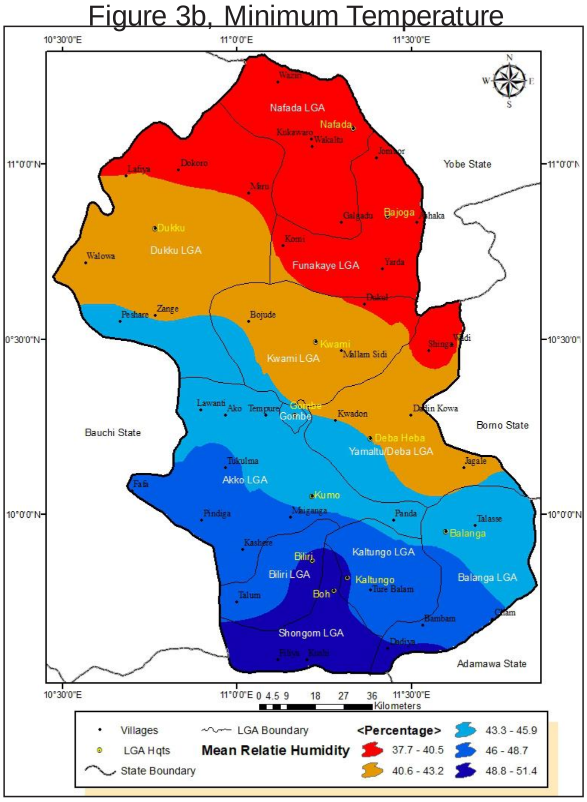

Figure 3d. Mean Relative Humidity

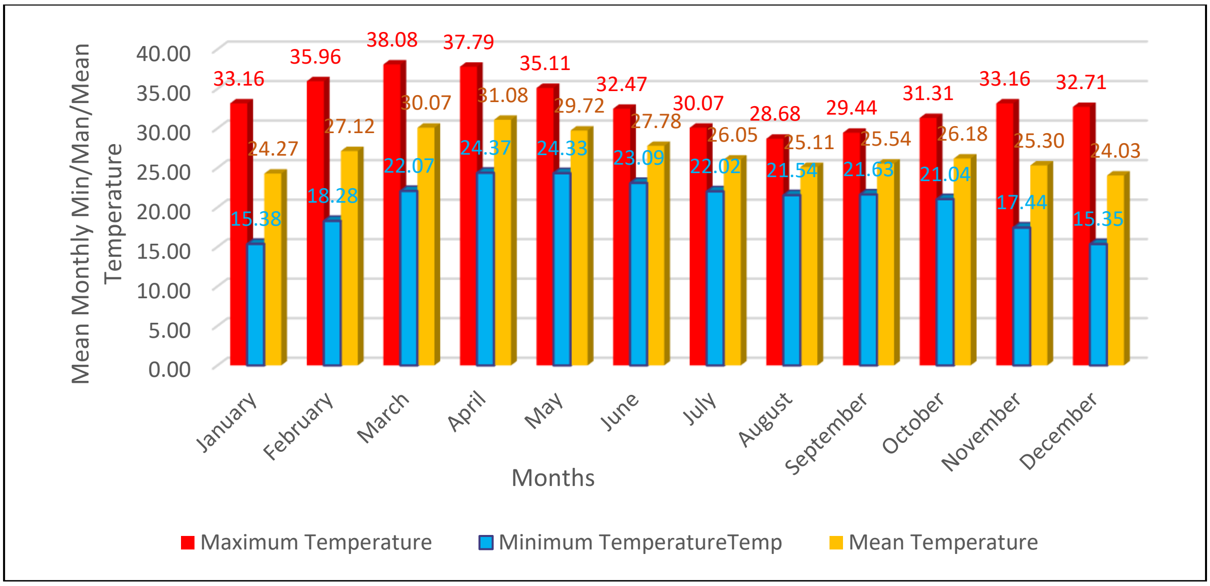

Figure 4. Seasonal patterns of maximum, minimum and mean temperature

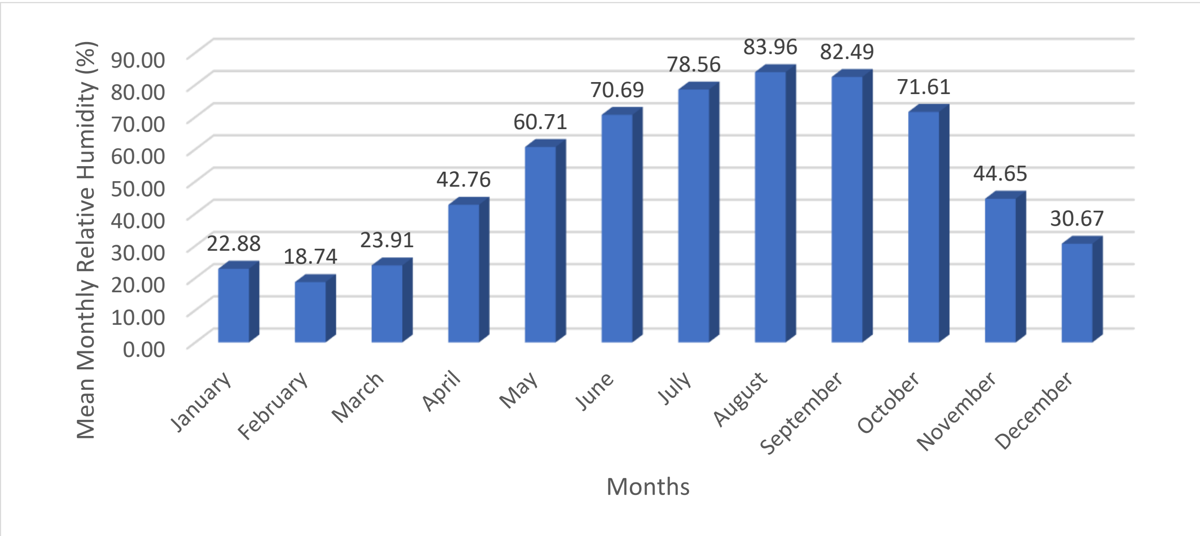

Figure 5. Seasonal pattern of relative humidity

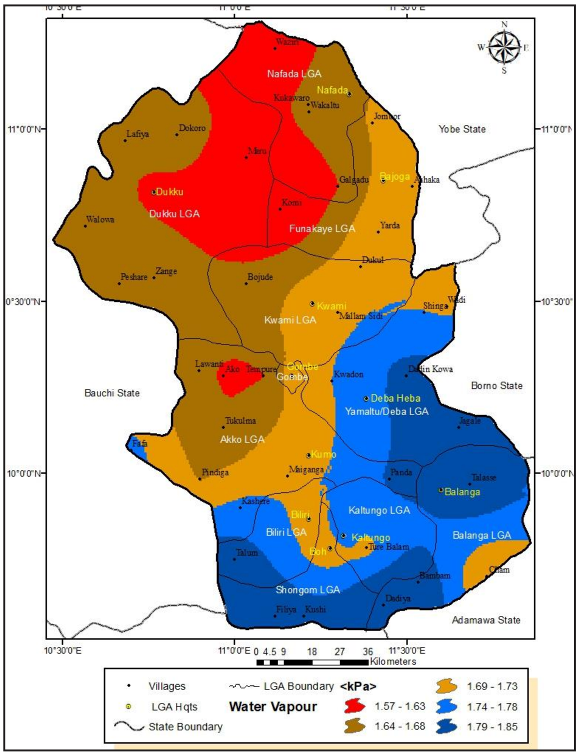

Figure 6a. Water Vapour

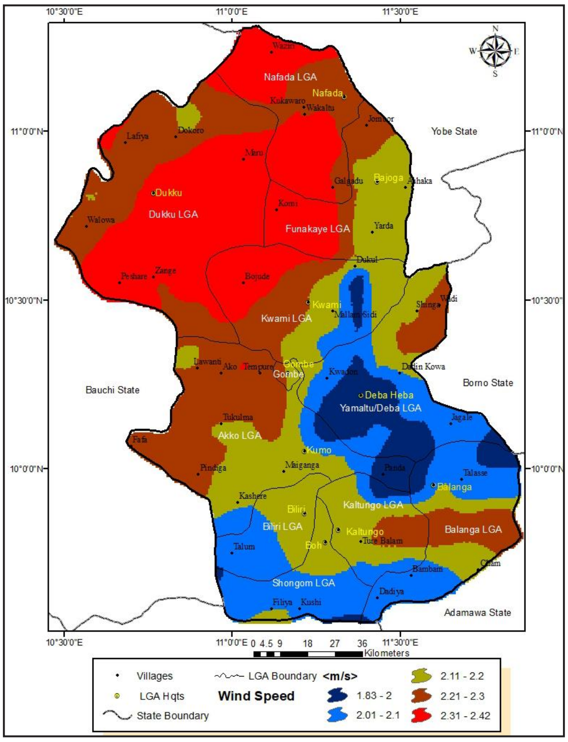

Figure 6b, Wind Speed

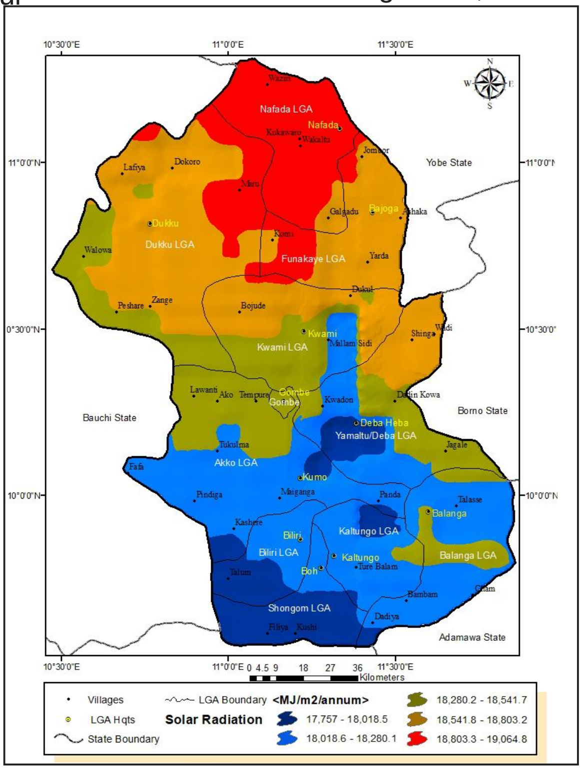

Figure 6c. Solar Radiation

Table 1. Values of some climatic variables in selected settlements in Gombe State.

Towns	LGAs	Mean Annual Rainfall (mm)	Rainfall Onset (Days)	Rainfall Cessation (Days)	Length of Rainfall (No. of Days)	Maximum Temperature (°C)	Minimum Temperature (°C)	Mean Temperature (°C)	Mean Relative Humidity (%)	Mean Solar Radiation	Mean Wind Speed	Mean Water Vapour
Akko	Akko	896	12th May	27th Sept	119	32.55	18.83	25.68	47.88	18,341	2.26	1.62
Kashere	Akko	953	5th May	15th Oct	159	33.28	19.64	26.51	47.16	18,029	2.11	1.75
Kumo	Akko	917	8th May	3rd Oct	128	33.32	19.54	26.40	44.98	18,122	2.12	1.71
Lawanti	Akko	885	12th May	26th Sept	119	33.14	19.24	26.33	44.81	18,325	2.20	1.64
Maiganga	Akko	937	7th May	8th Oct	143	32.93	19.51	26.32	46.48	18,172	2.13	1.73
Pindiga	Akko	963	7thMay	9th Oct	144	32.55	19.29	25.74	46.70	18,111	2.24	1.68
Tukulma	Akko	908	10th May	30th Sept	116	32.42	19.37	26.30	45.16	18,264	2.20	1.64
Balanga	Balanga	925	6th May	1st Oct	152	33.70	20.34	27.13	45.18	18,298	2.08	1.79
Bambam	Balanga	972	4th May	8th Oct	163	33.44	20.68	27.06	47.70	18,066	2.05	1.82
Cham	Balanga	989	6th May	5th Oct	150	32.55	19.82	23.31	46.35	18,184	2.14	1.68
Dadiya	Balanga	1002	4th May	11th Oct	164	33.07	20.60	27.12	48.83	18,042	2.03	1.84
Talasse	Balanga	924	7th May	30th Sept	143	34.19	20.49	27.24	44.73	18,189	2.03	1.82
Biliri	Biliri	963	3rd May	12th Oct	167	33.17	19.48	26.18	49.11	18,156	2.17	1.72
Talum	Biliri	974	3rd May	20th Oct	164	33.60	20.11	27.97	47.83	17,929	2.03	1.80
Dukku	Dukku	791	19th May	24th Sept	109	33.20	18.90	25.99	41.72	18,722	2.32	1.62
Gale	Dukku	791	18th May	26th Sept	110	33.73	19.27	26.53	42.14	18,477	2.21	1.64
Ashaka	Funakaye	733	19th May	23rd Sept	108	34.95	19.92	27.39	38.91	18,688	2.18	1.71

Bajoga	Funakaye	740	20th May	23rd Sept	106	34.91	19.77	27.39	39.05	18,721	2.18	1.70
Gombe	Gombe	899	12th May	25th Sept	118	33.49	19.25	26.35	43.49	18,317	2.19	1.70
Kaltungo	Kaltungo	973	4th May	11th Oct	165	33.36	19.44	26.00	48.82	18,180	2.18	1.76
Ture Balam	Kaltungo	986	4th May	10th Oct	162	32.32	19.64	26.09	47.92	18,123	2.14	1.72
Bojude	Kwami	828	16th May	25th Sept	113	32.94	18.90	25.82	42.81	18,634	2.33	1.64
Kwami	Kwami	835	16th May	24th Sept	110	33.86	19.44	26.49	41.15	18,506	2.20	1.72
Mallam Sidi	Kwami	821	16th May	24th Sept	111	34.50	19.87	27.06	41.18	18,253	2.14	1.72
Kukawaro	Nafada	694	1st June	24th Sept	96	34.54	19.44	26.94	37.91	18,857	2.29	1.64
Nafada	Nafada	700	1st June	24th Sept	97	36.01	19.48	27.18	38.04	18,881	2.25	1.67
Boh	Shongom	989	4th May	13th Oct	167	32.67	19.38	25.90	49.10	18,101	2.18	1.72
Filiya	Shongom	1017	3rd May	17th Oct	163	33.60	19.89	26.51	50.05	17,865	2.09	1.81
Kushi	Shongom	1043	3rd May	16th Oct	164	33.06	19.96	26.39	50.73	17,915	2.07	1.80
Deba	Yamaltu/Deba	911	10th May	26th Sept	122	34.35	20.11	27.20	42.99	17,892	1.83	1.76
Dadin Kowa	Yamaltu/Deba	868	11th May	24th Sept	121	34.35	20.53	27.25	42.05	18,316	2.10	1.80
Kwadon	Yamaltu /Deba	865	12th May	26th Sept	119	34.27	19.75	26.93	43.22	18,269	2.03	1.73
Shinga	Yamaltu/Deba	811	13th May	23rd Sept	115	33.32	20.44	26.78	40.26	18,643	2.20	1.74

Source: Derived from the spatial maps of each climatic units (Authors, 2022)

DISCUSSION

Analysis of Rainfall

Spatial pattern of mean annual rainfall. The spatial pattern of rainfall in Gombe State as shown in Fig. 2a is highly influenced by latitudes which has also been noted by previous authors (Yusuf and Yahaya, 2017, Bello, *et al,* 2019). Rainfall ranges from 659 to 1066 mm in the state. The highest ranges from 948.1-1060 mm at the southern part of the state covering the entire Shongom LGA and substantial parts of Biliri, Kaltungo and Balanga LGAs. Major communities in this zone include Bambam, Biliri, Cham, Dadiya, Filiya, Kaltungo, Kashere, Pindiga, Talum and Ture Balam. The northern part of the state comprising major parts of Nafada and northern parts of Funakaye and Dukku LGAs recorded the least amount of rainfall, that is, 659-745 mm. Latitude 11°N northward completely fall within the least rainfall range. Table 1 shows the actual rainfall amount in some towns and villages. The rainfall amounts are similar to that of Ahmad and Ibrahim, (2017); Bello *et al,* (2020).

5.1.2. Spatial pattern of rainfall onset. The spatial pattern of rainfall onset in Gombe State as shown in Fig. 2b is similar to that of the mean annual rainfall (Fig. 2a) as places with high rainfall amount (southern parts) recorded early rainfall onset (between May 3rd and May 8th). The northern region of the state with less amount of rainfall for instance, had late rainfall onset between May 28th and June 3rd. This means that about a month difference exists between rainfall onset in the north and southern part of Gombe State. The specific rainfall onset in some important towns/villages are shown in Table 1. Gombe and Dadinkowa towns for instance, recorded rainfall onset on 12th and 11th May respectively which are contrary to that of Audu *et al,* (2019) who recorded 25th and 30th of May respectively. The assertion that rain begins in the second week of March in Gombe, Kumo and Talasse by Ahmad and Ibrahim (2017) and that rainfall starts in early April in Gombe town (Abe *et al,* 2022) should not be confused with rainfall onset because when rain starts or ends is not the same as rainfall onset or cessation.

5.1.3. Spatial pattern of rainfall cessation. Fig. 2c shows the spatial pattern of rainfall cessation in the State. Rainfall cessation ranged from 22nd September at the extreme north to 21st October in the south. More than half of the land area of the state beginning from about 11 °N northward experienced early rainfall cessation between 22nd and 28th of September. A small land area at the extreme south-western part of the state precisely in Biliri and Shongom LGAs had late rainfall cessation between 18th and 21st of October. Almost a month difference also exists between rainfall cessation in the northern and southern Gombe State. In Table1. rainfall cessation dates in important towns and villages are shown. Gombe and Dadinkowa for instance have rainfall cessation on 25th September and 24th September respectively. Audu *et al,* (2019) reported 12th of October as cessation dates for both towns. The variations in the results are largely due to the authenticity of the data and the methods applied for the computation of rainfall indices

Spatial pattern of Length of Rainy Season (LRS). The spatial pattern of LRS is shown in Fig. 2d. The pattern is similar to that of mean annual rainfall as earlier reported by Ahmad and Ibrahim (2017) that there is high correlation between rainfall amount and length of rainfall in the state. The northern part of the state recorded lower LRS within a range of 95-111 days which is about three to three and a half months, likely between June and August, while, the southern parts experienced LRS of 160-175 days, that is, about five to five and a half months, that is May to September and half of October. Ahmad and Ibrahim (2017), noted the disparity between the LRS in north and southern Gombe and concluded that there was significance difference in the variance. LRS values of some settlements as obtained in this study are shown in Table 1. For instance, the following days of LRS were recorded: Gombe (118), Dadinkowa (121) Dukku (109), Kumo (128) and Biliri (167). Audu *et al,* (2019), however, derived different LRS of 140 and 136 days for Gombe and Dadinkowa respectively. Ahmad and Ibrahim (2017) obtained 35-59 days (about only one to two months) for Biliri, while 17-75 days (less than a month to two months) was recorded for Dukku. Ministry of Agriculture, Gombe State (2015) in Dan *et al,* (2019) recorded 160 days at the extreme southern part of the State, 155 days at Kumo and also 155 days at the extreme north of the state. One factor that must be considered in LRS determination is that LRS must correlate with rainfall amount, onset and cessation. All the obtained figures in this study can be considered to be more accurate and more realistic because they reflect the pattern of rainfall amount, onset and cessation.

5.1.5. Seasonal pattern of rainfall. The seasonal pattern of rainfall in Gombe State as shown in Fig. 2e revealed that rainfall above 100 mm in the state are recorded between the months of May and September with the peak in August. Existing studies with similar findings that rainfall in Gombe State are mainly within May and September with a single peak in August include Amos *et al,* (2015); Bello *et al,* (2019). Annual mean rainfall between November and April was discovered to be either zero or very low with April recording the highest amount which is less than 30 mm. Abe *et al,* (2022); Ahmad and Ibrahim (2017); Bello *et al,* (2019) recorded similar findings.

Rainfall trends across Gombe State

Table 2 shows the equations and the R-square values and their interpretations of some selected settlements (Kushi at the extreme south, Tukulma at the central, Kukawaro at the north and Shinga at the East.

Table 2. Interpretations of rainfall values and their respective R^2s

Places	LGA	Rainfall Trends	R2	Interpretation
Kushi	Shongom	Y = -11.382x + 1247.6	0.3003	Rainfall decreases by -11.4 mm at every annual increase. The study period (1981-2021) contributes about 3.0% to the variation in rainfall.
Tukulma	Akko	Y = 2.2678x + 963.57	0.009	Rainfall increases by 2.3 mm at every annual increase. The study period (1981-2021) contributes about 0.01% to the variation in rainfall.
Shinga	Yamaltu	Y = 1.9036x + 860.36	0.0095	Rainfall increases by 1.9 mm at every annual increase. The study period (1981-2021) contributes about 0.01% to the variation in rainfall.
Kukawaro	Nafada	Y = -0.2397x + 814.65	0.0002	Rainfall decreases by -0.2 mm at every annual increase. The study period (1981-2021) contributes 0.00% to the variation in rainfall.

Source: Calculated by the Authors (2022)

Table 2 shows that rainfall trends are decreasing at Shongom LGA and Nafada LGA which are at the southern and northern parts of the state respectively. However, the trend equations show that the decrease at Shongom LGA with high annual rainfall is higher than that of Nafada with lesser amount of rainfall (Table 1). At the central region of the State comprising Akko and Yamaltu/Debba LGAs, increase in the trends of rainfall were recorded which is latitudinal in nature because the equations of increase in rainfall and the contribution to the variations in Akko LGA (south of the central part) are less than the level of increase in Yamaltu/Debba LGA (north of the central part). Similar pattern of rainfall trends and the latitudinal inclination were also reported by Bello *et al*, (2019)

Analysis of Temperature

Spatial pattern of maximum temperature. Though maximum temperature ranged from 31.3 to 35 ˚C (Fig. 3a), the areas with low minimum temperature such as Bworo, Dukku Nappe, Degil and Pindigal hills (Fig.1) all have lower maximum temperature between 31.3 and 32.5 ˚C. The plains of River Gongola (Fig.1) experience high maximum temperature (34.4 – 35 ˚C) except Bima Hill and the environs with lower maximum temperature. The high maximum temperature along the valley of River Gongola might be due to the negative effect of heat emission from River Gongola.

Spatial pattern of minimum temperature. The spatial pattern of minimum temperature as shown in Fig. 3b has very close relationship with the relief and drainage of the State (Fig.1). Minimum mean temperature which usually occurs during the wet season ranges from 18.4 to 20.9 ˚C. The mountains and hills like, Bworo hill in Nafada LGA, Dukku hills in Dukku, Nafada and Funakaye LGAs and the Nappe hills in Akko LGA, Degil and Pindigal hills in Balanga and Akko LGAs respectively (Fig. 1) all recorded lowest minimum temperature ranging from 18.4 to 19 ˚C. The River Gongola plains especially in Kwami, Yamaltu Debba and northern Balanga LGAs and the Dadiya plains in Balanga LGA recorded the highest minimum temperature of 20.3 to 20.9 ˚C. The obtained minimum temperature for Gombe, Biliri and Dadin Kowa in this study as shown in Table 1, are similar to that of Bello (2022).

Spatial pattern of mean temperature. Mean temperature in Gombe State ranges from 25.1 to 27.9 ˚C). Four areas have low mean temperature; Dukku hills (covering parts of Dukku, Funakaye Nafada and Kwami LGAs), Nappe hills in Akko and Kwami LGAs, Pindiga hill in Akko LGA and the Degil mountain range in Balanga and Kaltungo LGAs. However, the River Gongola plain because of the influence of water emission, and the plain of Dadiya in Balanga LGA recorded the highest amount of mean temperature ranging from 27.1 – 35 ˚C. Bello, (2022) obtained mean temperature of Gombe (27.71), Nafada (29.28), Dadin Kowa (25.7) and Biliri (27.32) using in-situ climatic data obtained from Gombe State Agricultural Development Project (GADP) and NiMet which has similar pattern with the generated values of these settlements in Table 1.

Seasonal Pattern of Temperature

The highest mean maximum temperature occurs in March and April with mean maximum at 38.08˚C and 37.37 ˚C respectively. This finding is similar to that of Ahmad and Yahaya (2017) who recorded mean maximum monthly temperature of 37ºC in March and April in the State. The high maximum monthly temperature during this period (March-April) is due to the influence of the dry season when rainfall is scanty or zero and relative humidity is also very low which leads to high maximum temperature. The months of June to October (wet season) record low mean maximum monthly temperature when the values were generally below 32.5°C with the least in August (28.68°C). The least minimum monthly temperature occurs between November and January when the cold and dry North-East Trade Wind covers the State (Wannah and Mbaya 2012, Bello, 2022). Mean monthly temperature is highest between March and May (period of dry season) and least from November to February when harmattan is severe in the state. The pattern of monthly minimum, maximum and mean temperature is generally similar to that of Adam, (2019), Yahaya and Yusuf, (2019), Bello, (2022).

Temperature Trends
Table 3 shows the trends in minimum, maximum and mean temperature in four selected points in the State. All the temperature variables (minimum, maximum and mean) were found to be increasing in all the sampled parts of the state. The rate of increase in mean temperature at Shongom for instance (47.6%) is far higher than the rate of increase in the other parts of the State. This finding explained why Shongom LGA with the highest amount of rainfall and highest relative humidity is experiencing decrease in rainfall trends (Table 2) as high mean temperature decreases rainfall amount (Bello *et al*, 2020).

Table 3. Trend equations and their R2 of temperature in selected communities, Gombe State.

Places	LGA	Maximum Temperature	R^2	Minimum Temperature	R^2	Mean Temperature	R^2
Kushi	Shongom	y = 0.0746x + 33.548	0.4652	y = 0.0363x + 17.633	0.3781	y = 0.0554x + 25.59	0.4759
Tukulma	Akko	y = 0.0372x + 34.571	0.2071	y = 0.0246x + 17.157	0.2115	y = 0.0309x + 25.864	0.243
Shinga	Yamaltu	y = 0.0246x + 35.773	0.0955	y = 0.0177x + 17.592	0.1204	y = 0.0212x + 26.683	0.1196
Kukawaro	Nafada	y = 0.0354x + 36.666	0.196	y = 0.0257x + 17.615	0.2668	y = 0.0305x + 27.14	0.2515

Source: Computed by the Authors, (2022)

Relative Humidity
The mean relative humidity ranges from 37.7% at the northern part of the state to 51.4% at the southern part (Fig. 3d). The spatial pattern of the mean relative humidity is latitudinally inclined and has a close relationship with the spatial pattern of rainfall. This finding shows that rainfall has great effect on relative humidity in Gombe State. Generally, mean relative humidity in the State can be considered to be low as was highlighted by Balzerek *et al.,* (2003) in Bello, (2022) that humidity is high during the wet season but very low in the dry season. Almost the entire Shongom LGA and parts of Biliri, Balanga and Kaltungo recorded the highest amount of relative humidity in the state (48.8-51.4%). The entire Nafada LGA and almost all the land area of Funakaye LGA have low relative humidity ranging from 37.7-40.5% (Fig.3d). Looking at the spatial pattern of other climatic variables and relative humidity (Figs 2a-2c)), it was discovered that rainfall is the principal determinant of relative humidity in the State. The seasonal pattern of relative humidity is presented in Fig. 5. Low relative humidity occurs between December and March with the least in February, while high figures were recorded between May and October when relative humidity is above 50% with the peak in August (86.96%) which conforms with that of Yusuf (2022). Therefore, the seasonal pattern of relative humidity is similar to that of rainfall (Fig 2a) which again shows the influence of rainfall on relative humidity.

Water Vapour
The spatial pattern of water vapour in Gombe State is shown in Fig. 6a. Water vapour is low in the southern parts as well as the Gongola plains in some part of Yamaltu Debba and the northern part of Balanga LGAs. The areas with high water vapour are the areas with high amount of rainfall (Fig 2a and Fig. 6a), low solar radiation (Fig. 6c) which increases water vapor in the atmosphere) and areas with low wind speed (Fig. 6b) which also increases the amount of water vapour in a place. The peak of Nappe hill in Akko LGA was also found to record high water vapour. The northern part of the state with low rainfall (Fig.2a), high solar radiation (Fig. 6c) and high wind speed records low amount of water vapour. Therefore, rainfall amount, solar radiation and wind speed are major determinants of the amount of water vapour in the area. Like other climatic variables, the amount of water vapour in some selected settlements are presented in Table 1.

Wind Speed
Wind speed is lowest at the central part of Yamaltu/Deba LGA including the location of Deba which is the LGA headquarters and also around Panda community at the extreme south-western part of Akko LGA (Fig. 6b). Generally, the Gongola

plains in southern part of Yamaltu/Debba and the northern part of Balanga LGAs, the plains of River Dadiya in southern Balanga LGA, Rivers Jalango and Pamada in Shongom and Biliri LGAs and the plains of Gobiravira in south -western part of Akko LGA all have low wind speed. Though, the wind speed in the northern region of the State is generally high, but the wind speed along the Gongola valley in the northern region, is lower. The wind speed on Bima hills (Yamaltu/Deba LGA), Degil Mountain ranges (Balanga LGA), Filiya Mountain ranges (Shongom LGA) and Bworo hills in Nafada LGA (Figs 1 and 6b) are all higher than their immediate environment. Therefore, other than climatic factors, relief plays major impact on the spatial pattern of wind speed in the state.

Solar Radiation

The spatial pattern of solar radiation is shown in Fig. 6c. Solar radiation from the southern part to about 10°N where the amount of rainfall is high (Fig. 2a) early, late and longer rainfall onset, cessation and LRS respectively (Figs. 2a, 2b and 2c), high relative humidity (Fig 3d) and high concentration of water vapour (Fig. 6c) has low solar radiation. The northern part of Gombe State has high solar radiation. In this region, rainfall amount is low, rainfall onset is late with early rainfall cessation and shorter LRS, relative humidity and water vapour are also low. All these spatial patterns of climatic variables in the northern region, help to increase the solar radiation in the area.

Generally, the spatial pattern of all the climatic variables in Gombe State are either influenced by relief or by latitudes. The influence of latitudes on spatial patterns of climatic variable cannot be overemphasized. Taking Kumo and Biliri for example, the two communities as shown in Fig.1 is about a distance of 20.8km apart (by crow flies) but as revealed in Table 1, the climatic variables of the two communities are far apart because of their latitudinal differences. Gombe and Dadin-Kowa with close latitudinal location but a distance of about 36.12 km (crow flies) have similar records of climatic elements (Table 1).

CONCLUSION AND RECOMMENDATIONS

The use of geospatial techniques and satellite-based climatic data for downscaling climatic data for mapping and analysis of climatic variables in Gombe State has been carried out in this study. It has been proven beyond doubts that geospatial techniques have the capabilities of mapping climatic variables, while satellite-based climatic data has helped to overcome the problems associated with in-situ climatic data that have been found to be scanty, unavailable, unreliable and costly to obtain. The seasonal pattern of rainfall Gombe State shows that rainfall occurs mainly between May and September with the peak in August. The trends in rainfall shows that rainfall is decreasing in at the north and southern parts of the state. While the spatial pattern of rainfall is mainly latitudinally inclined, amount of rainfall and rainfall indices (onset, cessation and LRS) generally impact each other. Rainfall onset in most places in the state occurs in May but at the extreme northern part, in the first week of June. Rainfall cessation at the central and northern parts of the state occurs in the 3rd or 4th weeks of September, while the southern part of the state experiences late cessation between the first and third week of October. The northern part of the state recorded lower LRS within a range of 95-111 days, while, the southern parts experienced LRS between 160-175 days. The patterns of rainfall indices are expected to help the farmers to decide when to plant their crops. The spatial pattern of the mean relative humidity is latitudinally inclined and has a close relationship with the spatial pattern of rainfall. Low relative humidity occurs between December and March with the least in February, while high humidity was recorded between May and October when relative humidity is above 50% with the peak in August. Rainfall amount, solar radiation and wind speed are major determinants of the amount of water vapour in Gombe State, while relief was discovered to have major impact on the spatial pattern of wind speed in the state. Generally, the climatic variables in the southern part of the state are more conducive for human habitation and more suitable for crop production which no doubt, have contributed to the high population density in the southern part of the state than the northern areas. Elaborate causal factors of the spatial patterns of climatic variables in Gombe State is recommended for further studies. The following recommendations are proffered:

(i) The use of satellite-based climatic data for downscaling climatic data into political units within the country for spatial and seasonal mapping and assessment of climate and climate change

(ii) Climatologists, meteorologists, academicians and other relevant agencies in climate and climate change monitoring and management should be encouraged to obtain and apply satellite-based climatic data in their data generation and analysis.

(iv) The generated climatic maps in this study should be used by Gombe State government, organizations and individuals for effective planning and management of climate, climate change, and planting seasons of agricultural activities such as crops in the various parts of the state.

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