Statistical Analysis and Forecasting of Rainfall Patterns and Trends in Gombe North-Eastern Nigeria

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Abstract

Rainfall in Nigeria is highly dynamic and variable on a temporal and spatial scale. This has taken a more pronounced dimension due to climate change. In this study, Standard Precipitation Index (SPI) and Mann-Kendall test statistical tools were employed to analyze rainfall trends and patterns in Gombe metropolis between 1990 and 2020 and the ARIMA model was used for making the forecast for ten (10) years. Daily rainfall data of 31 years obtained from Nigerian Meteorological Agency, (NIMET) was used for the study. The daily rainfall data was subjected to several analyses. Standard precipitation index showed that alternation of wet and dry period conditions had been witnessed in the study area. The result obtained showed that there is an upward trend in the annual rainfall amount received in Gombe over the last 31 years at a rate of 3.98 mm/year. The results for the forecast shows that the annual rainfall to be received in Gombe continues in a range above the mean which serves as an indication that the decade will experience more wet years than dry years. The study concludes that the pattern of rainfall in Gombe is a cyclic pattern. The current trend may affect soil moisture, flooding and subsequently lead to ecological change. The study recommends that inhabitants of the study areas should plan their cropping season based on climatic information of their area.

1. Introduction

It has been observed globally that changes are occurring in the amount, frequencies and types of rainfall. Changes in rainfall amount and frequencies directly affect the stream flow pattern and its demand, spatiotemporal allocation of run-off, groundwater reserves and soil moisture [1, 2]. Consequently, these changes showed the widespread consequences on the water resource, environment, terrestrial ecosystem, ocean, bio-diversity, agricultural and food security. Drought and flood like hazardous events can be occurred frequently because of the extreme changes in rainfall trend [3]. Changes in rainfall and other forms of precipitation will be one of

the most critical factors determining the overall impact of climate change. Climate change is a consequence of global warming caused by both natural processes and human activities that have caused an accumulation of heat-trapping [4]. There are evidence of climate change on all continents with an increasing trend in warming temperature, varying rainfall patterns, more frequent extreme weather events such as wind storm, high rainfall intensity, flood, drought, heat waves, sea level rise along coastal regions and melting glaciers in polar and mountainous regions [4]. The impacts of climate change are being experienced on every continent on agriculture, water resources, human health, terrestrial ecosystems and biodiversity and coastal zones [4]. Rainfall in Nigeria is highly dynamic and variable on a temporal and spatial scale. This has taken a more pronounced dimension due to climate change [5]. The pattern of rainfall in Nigeria is seasonal, the southern part experienced a maximum amount of rainfall twice a year, while the northern experienced a peak value of rainfall only once a year [6]. Climate change has been a major discourse for many researchers with particular interest in the impact of the phenomenon. One major concern of climate change is to study and identify documented changes in the climatic system [7]. The world's climate is changing due to various factors from within and outside the climate system [4]. Just as precipitation patterns vary across the world from year to year, and over decades, however, so do the precipitation effects of climate change, by shifting the wind patterns and ocean currents that drive the world's climate system, climate change will also cause some areas to experience altered precipitation. Steady moderate rains soak into the soil and benefit plants, while the same amounts of rainfall in a short period of time may cause local flooding and runoff, leaving soils much drier at the end of the day. Climate change and global warming has increased at an alarming rate as a result of anthropogenic factors such as urbanization. Therefore, this study is relevant because it will assist researchers to understand the future consequences of rainfall variation due to climate change. Hence, the study of rainfall is important and cannot be overemphasized. However, a study of the rainfall pattern in Gombe metropolis will enhance the understanding of the trend in rainfall and provide a future forecast. This study is limited to rainfall as against other climatic variables as it tends to study the trend in rainfall over Gombe metropolis for 3 decades (1990-2020) and report whether there is major deviation over the years. It also investigated the seasonal rainfall distribution over the study area. Finally, this paper shall seek to establish the real trend of rainfall over the study area and note whether rainfall characteristics and pattern has changed in the study area or not, among other things to achieve.

2. The Study Area

Gombe state (the Jewel in the Savanna) is located within the latitudes $9^o\ 30´$ and $12^0\ 30´$N and longitudes $8^o\ 45´$and $11^o\ 45´$E on the sub –Sudan savanna region of the country at the northeast of river Benue and east of Yankari Game Reserve, as shown in Fig.1. It shares borders with Bauchi state to the west, Adamawa state to the southeast, Taraba state by the southwest, Borno state to the east and Yobe state by the northeast. The state covers a total area of about 20,265 sq km. The approximate altitudes of Gombe ranges from 400-500 m above mean sea level. The topography is mainly mountainous, undulating and hilly in the central and southern parts and open plains in the northern and northeastern parts of the state [8]. Gombe state is a multi-ethnic society that consists of the dominant Fulani tribe, who lived in the Northern part of the Gombe state. Apart from the Fulani, there are also the Tangale, Hausa, Tula, Tera, Waja, Bolewa, and Kanuri. The town is mostly occupied by farmers

whose major means of survival is agriculture and of course cultivation of crops depends mostly on rainfall. The major farm produce in the study area is maize, groundnut, tomatoes and other vegetables. Gombe has two distinct climates; the dry season (November to March) and the wet season (April to October) with an average rainfall of 850 mm. It has been reported that in West Africa annual rainfall has been observed to decline since the end of 1960s where this decrease ranges from 20% to 40% between 1931-1960 and 1968-1990 [9-12]. In Nigeria however, this declination could be observed in the North west where there is an 8.8% fall from the long-term mean of 1968 to 2008 [9]. Most importantly, a positive increase in annual rainfall of 17.1 mm was observed in North-Eastern Nigeria for the period of 1984-2013 [10]. There is variation in the onset of rains based on the data obtained from ten selected meteorological stations across Gombe state. While rainfall starts in the second week of March in Talasse, Kumo and Gombe other places within the metropolis such as Dukku and Nafada record their first rain mostly around the third week of April or second week of May as the case may be [11]. Consequently, it is evident that there is a minute variation in the beginnings and ends of rainfall within Gombe state. However, it is important to note that in Gombe city, the first rain was recorded to be experienced within the second or third week of March only between nine years out thirty-two that is from 1977-2008 [11]. In essence rains start mostly around April/May and end by October/November with an average rainfall of 907mm or 35.7 inches per year. Furthermore, in Gombe, the wet season is oppressive and overcast and known to be partly cloudy and hot year around. Gombe experiences an extreme seasonal variation in monthly rainfall. The rainy season lasts for 6.9 months. The most rain falls around August with an average total accumulation of 8.3 inches. The dry season however, lasts for 5.1 months, that is, from October twenty eight to April first with an average accumulation of 0.0 inches [11].

3. Materials and methods

Thirty-one (31) years of daily rainfall data for the Gombe metropolis from 1990 to 2020 was obtained from the Headquarters of the Nigerian Meteorological Agency (NIMET) for the purpose of the study. Monthly and Annual average rainfall amount was calculated for the period of study using python programming language. Statistical analyses were performed to assess any significant difference in rainfall in Gombe metropolis within the months and years understudy. Data and graphs were constructed to illustrate the changing trends within the months and the years for the period. Statistical analysis was used to determine the measure of central tendency (mean, range, etc.) and dispersion (S.D., etc.). For identifying the trend in the rainfall data, the Mann-Kendal test was used.
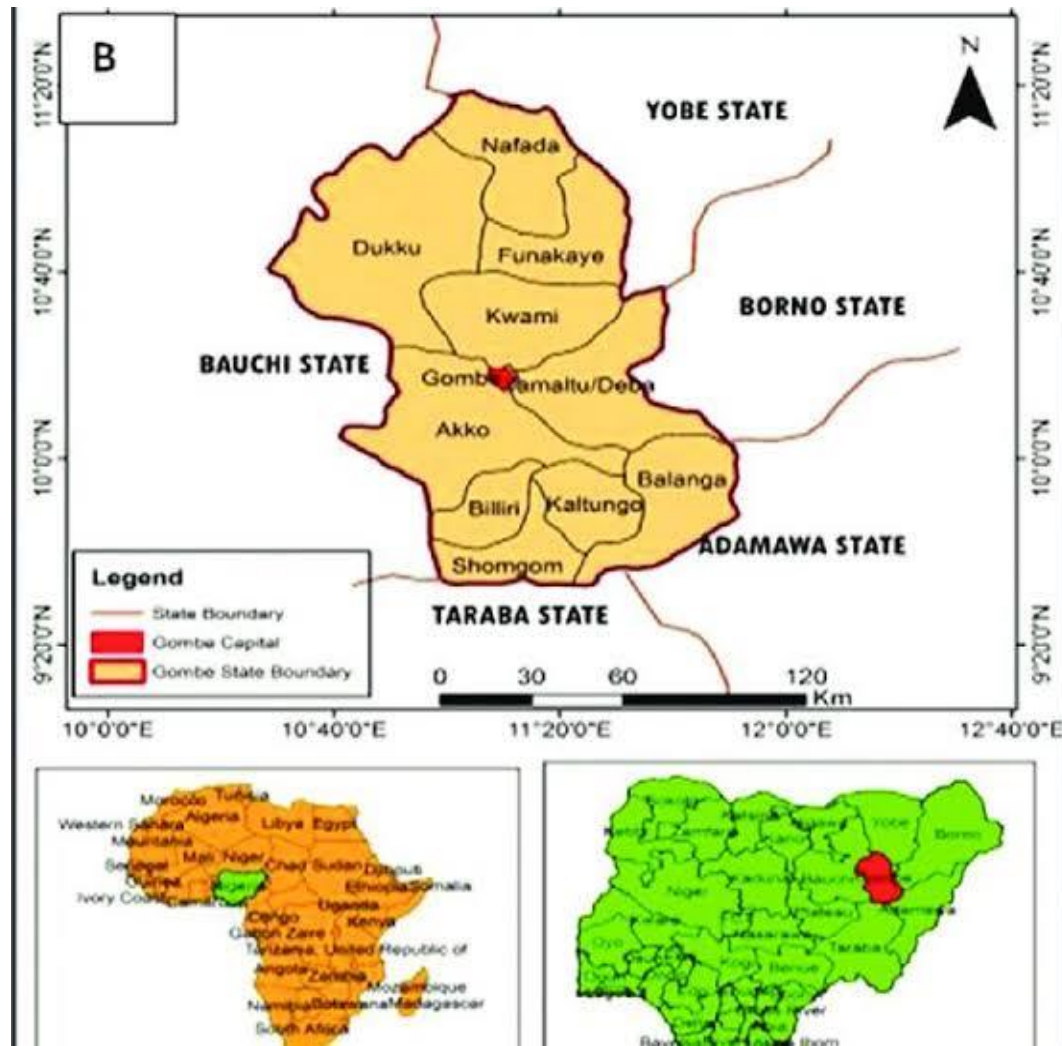
Figure 1: Map of Gombe state, Nigeria [14].

3.1 Standard Precipitation Index (SPI)

The SPI was used to analyze the annual mean rainfall of the study area. Positive SPI values indicate greater than mean precipitation while negative values indicate less than mean precipitation, as illustrate in table 1. Formula for SPI is given as:

$$SPI = \frac{x - \bar{x}}{SD} \qquad (1)$$

where:
x: is the Actual rainfall;
$\bar{x}$: is the Mean rainfall and;
S.D = Standard deviation from normal rainfall and is obtained by:

$$S.D = \sqrt{\frac{1}{N}\sum_{i=0}^{N}(x - \bar{x})^2} \qquad (2)$$

N is number of parameters.

Table 1: SPI values.

Value	Rating
≥ 2	Extreme wetness
$< 2 \geq 1.5$	Severe wetness
$\geq 1 < 1.5$	Moderate wetness
$\geq 0.5 < 1$	Mild wetness
< 0.5	Normal
> -0.5	Normal
$\geq -0.5 < -1$	Mild dryness
$\geq -1 < -1.5$	Moderate dryness
$> -2 \leq -1.5$	Severe dryness
≤ -2	Extreme dryness

Source: Adopted from [5].

3.2 The Mann-Kendal test for trend

The Mann-Kendall test analyzes the sign of the difference between later-measured data and earlier-measured data. Each later-measured value is compared to all values measured earlier, resulting in a total of n(n-1)/2 possible pairs of data, where n is the total number of observations [12].

$$s = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(X_j - X_k) \qquad (3)$$

With,

$$sign(x) = \begin{cases} 1 & if\ x > 0 \\ 0 & if\ x = 0 \\ -1 & if\ x < 1 \end{cases} \qquad (4)$$

Where X_f and X_k represent n data points at times j and k, respectively [13].
For higher $n \geq 10$, the MK test statistic (S) follows approximately normal distribution with mean as zero and variance computed as follows;

$$\sigma^2 = \frac{\left\{ n(n-1)(2n+5) - \sum_{j=1}^{p} t_j \left(t_j - 1\right)\left(2t_j + 5\right) \right\}}{18}$$

Where: p is the number of the tied groups in the data set and t_j is the number of data points in the jth tied group.
The probability associated with S and the sample size n were then statistically computed to quantify the significance of the trend. Then the normalized test statistics Z is computed as follows;

$$Z = \begin{cases} \dfrac{S-1}{\sigma} & if\ S > 0 \\ 0 & if\ S = 0 \\ \dfrac{S+1}{\sigma} & if\ S < 0 \end{cases}$$

At 99% significance level, the null hypothesis is rejected if $|Z| > 2.575$ and at 95% significance level, the null hypothesis is rejected if $|Z| > 1.96$. The resulting trend may have any of the three values: positive, negative or zero (no trend) with the corresponding P% of significance level based on the Z values [13].

3.3 ARIMA model

In this study, Autoregressive integrated moving average model or ARIMA was used to predict the future forecast of the rainfall amount. This model predicts future values of time series based on past values. It is based on the statistical concept of serial correlation, where past data points influence future data points. ARIMA combines autoregressive features with those of moving averages. An AR(1) autoregressive process, for instance is one in which the current value is based on the immediately preceding value, while an AR(2) autoregressive process is one in which the current value based on the previous two values. A moving average is a calculation used to analyze data points by creating a series of averages of different subsets of the full data set in order to smooth out the influence of outliers. As a result of this combination of techniques, ARIMA models can take into accounts trends, cycles, seasonality and other non-static types of data when making forecast. ARIMA forecasting is achieved by plugging in time series data for the variable of interest. Statistical software will identify the appropriate number of lags or amount of differences to be applied to the data and check for stationarity. It will then output the results, which are often interpreted similarly to that of a multiple linear regression model [14].

4. Results and discussion

4.1 Annual rainfall trends and pattern

The statistical analysis of rainfall for 31 years (1990-2020) is presented in Table 2. The mean rainfall for Gombe metropolis is 1033.24 mm. The year with the highest annual Rainfall was 2019, which recorded an amount of 1543.6 mm while year 2011 received the lowest annual rainfall of 730mm during the period of study.

Fig.2 exhibits an increase in rainfall from 879.6 mm in 1990 to 1229.4 mm in 1992 followed by a decline to 897.1 mm in 1995. It is observed that there is a rising trend from 730 mm in 2011 until it got to 1543.6 mm in 2019 this is a noticeable upward and downward trend in the annual rainfall amount. The upward trend lasted for about 2-3 years followed by a downward trend for about 3-4 years. This was observed for the first two decades except for the last decade which experienced an upward trend from 2011 to 2019.

Table 2: Statistical Analysis of rainfall in Gombe metropolis from 1990 to 2020.

Year	Rain(mm)	Mean(mm)	SPI	Skewness(Z_1)	Kurtosis(Z_2)
1990	879.6	1033.235	-0.86218	1.402466	0.853135
1991	935.7	1033.235	-0.54735	1.234196	0.461888
1992	1229.4	1033.235	1.100844	1.094411	-0.39686
1993	1143.3	1033.235	0.617664	0.977966	-0.4158
1994	1174.3	1033.235	0.791631	1.363108	0.708652
1995	897.1	1033.235	-0.76397	0.721836	-1.35582
1996	1149.3	1033.235	0.651335	1.028626	-0.36202
1997	894.5	1033.235	-0.77856	0.842127	-1.30485
1998	1110.4	1033.235	0.433035	1.057188	-0.26676

| 1999	1225.5	1033.235	1.078958	1.162039	-0.09297
2000	1062.6	1033.235	0.164789	0.940807	-0.80185
2001	829.9	1033.235	-1.14109	1.354528	0.743289
2002	881.6	1033.235	-0.85095	1.19563	0.172348
2003	1023.8	1033.235	-0.05295	1.043876	-0.40102
2004	1023.6	1033.235	-0.05407	2.100489	4.24822
2005	975.5	1033.235	-0.324	1.778852	3.888157
2006	967.4	1033.235	-0.36946	1.088959	-0.17818
2007	881.3	1033.235	-0.85264	1.244156	0.205105
2008	945.4	1033.235	-0.49292	1.393289	1.844933
2009	923.2	1033.235	-0.6175	0.408183	-1.43427
2010	756.5	1033.235	-1.553	0.648829	-1.07654
2011	730	1033.235	-1.70171	1.284581	0.739105
2012	1197.3	1033.235	0.920704	1.116702	-0.33252
2013	1051.2	1033.235	0.100814	2.917949	9.157108
2014	912.3	1033.235	-0.67867	1.069517	-0.05063
2015	1007	1033.235	-0.14723	1.110838	-0.12884
2016	970	1033.235	-0.35487	1.244582	1.286052
2017	1025.4	1033.235	-0.04397	0.686023	-1.25671
2018	1294	1033.235	1.463369	1.381907	0.778398
2019	1543.6	1033.235	2.864084	0.898763	-0.63573
2020	1389.6	1033.235	1.99986	0.911271	-0.47009
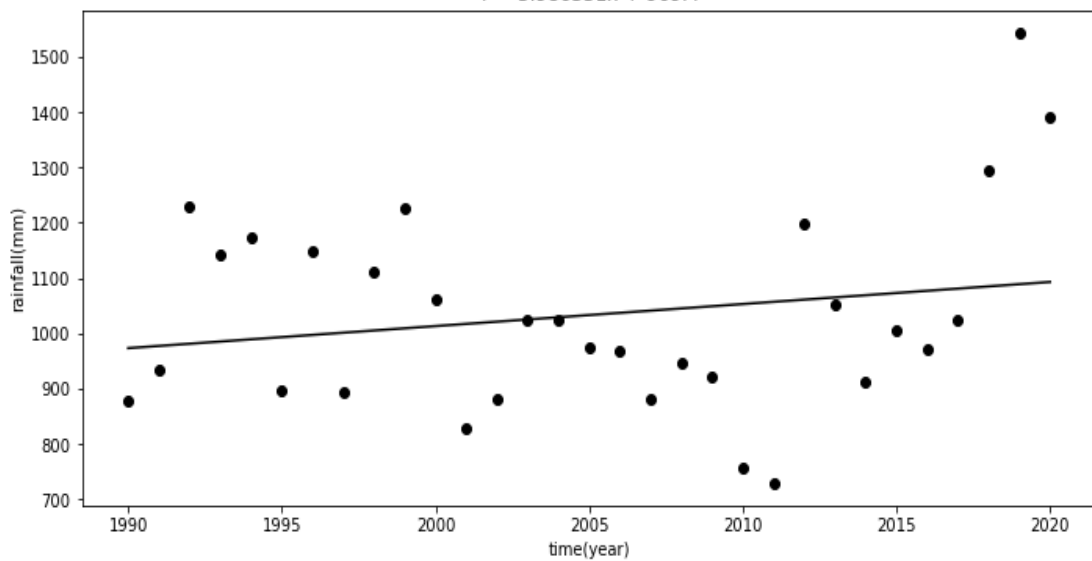
Figure 2: Plot of annual rainfall pattern for Gombe 1990-2020.

It was observed that the rainfall starts in early weeks of April and peaks in the month of August and then approaches an end in October when it seizes. The rainfall patterns show seasonality with the wet season starting from April/ May to October, and November to March as the dry season. The trend of rainfall indicates an increasing pattern from the beginning to the end of the series at a rate of 3.98mm/year. This result agreed to the outcome of some researchers like [15] reported that annual rainfall in Michika is increasing; also the result seems to be in agreement with the studies of [16, 17] which reported that precipitation pattern for Gombe is

increasing. The findings from other researchers revealed that the deviation of rainfall pattern for Gombe station against the other stations is in line with the global patterns of climatic variables. Fig. 3 is the plot of SPI values for Gombe between 1990 and 2020. The SPI plot shows that Gombe metropolis experienced an even number of wet and dry years in the first decade under investigation but a slight decrease in the number of rainy days, but in the second decade, the area experienced a long duration of dry years with increasing level of dryness, this was attached to the fact that in the raining days, little amount of rainfall were received and drought were experienced and in the third decade, the wet years were very 'wet' and the dry years ranged from normal dry to mild dryness due to the increase in the raining days in this decade. This change in the level of wet years confirms the overall increasing trend in the rainfall pattern.
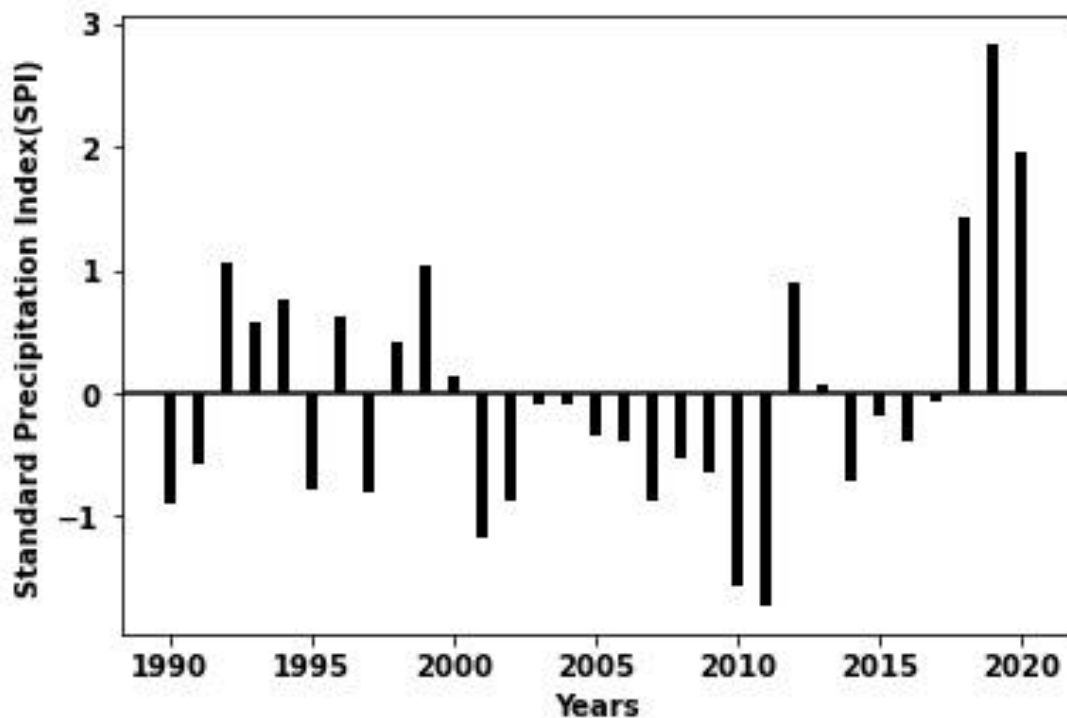

Figure 3: Standard precipitation indexes for Gombe between 1990 and 2020.

4.2 Seasonal variation of rainfall

Table 3 shows the statistics for the monthly and annual pattern for rainfall in Gombe metropolis, the Skewness(Z_1) and Kurtosis(Z_2). Values indicate normality in all the months except for the months June, August and October which show significant deviation from normal. The rainy months in Gombe ranges from April to October with the peak value occurring mostly in August. Fig. 4 shows that throughout the period of study the rainfall pattern in Gombe metropolis maintain the same nature of seasonality, as the rainy season starts at the early days of April, peaks mostly in August and ends in the late days of October. It was noticeable that in some years, the months of March and November recorded some amount of rainfall but the effect of this rainfall was insignificant in the year total. Figure 4 reported the highest monthly rainfall received in Gombe was in August of the year 2013, a value of 578.3mm. This shows that the number of rainy days affects the total rainfall received in a particular time period, due to the fact that the months with more raining days receives the more rainfall amount.

Table 3: Summary statistics for Rainfall in Gombe metropolis 1990-2020.

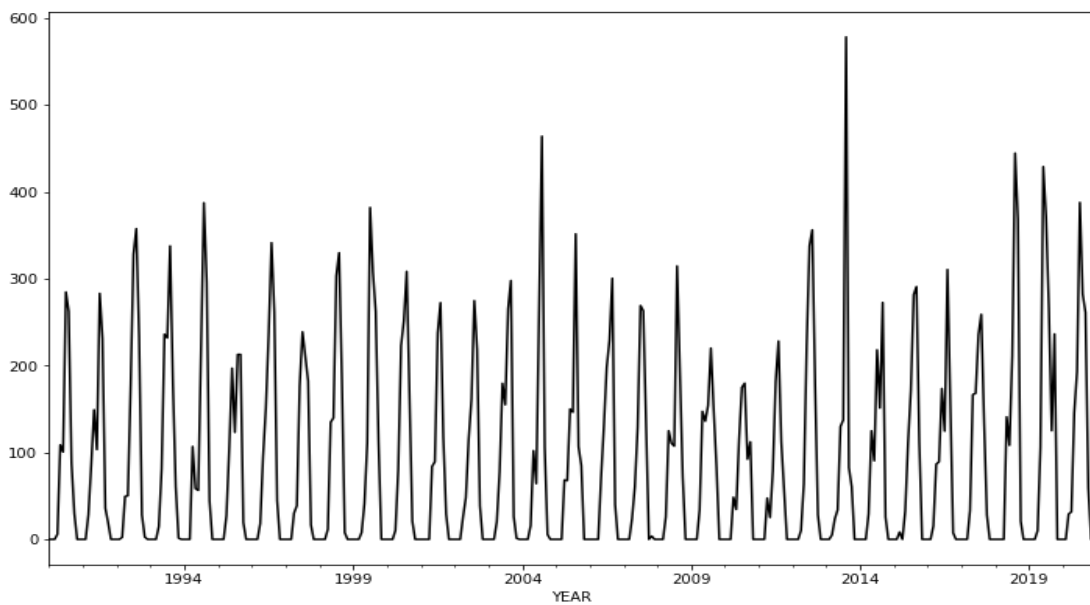|	April	May	June	July	August	September	October	Annual
Mean(mm)	29.12	86.7	143.24	230.14	299.3	187.2	49.34	1033.24
SD	26.89	40.54	69.88	78.23	87.3	80.9	46.89	181.14
Z_1	1.410	0.281	2.23	0.437	1.203	0.288	2.36	0.854
Z_2	1.698	-1.011	7.84	-0.558	2.453	-0.677	7.59	0.906
Min value(mm)	0.00	25.1	56.4	107.3	151.1	35.9	0.00	730
Max value(mm)	106.9	166.6	429	387.8	578.3	368.2	236.4	1543.6

Figure 4: Time series plot of monthly rainfall from 1990 to 2020.

The results of the Mann-Kendall test are represented in Table 4 showing the nature of the trends in the various months. From the results and in Fig.4, there is a decreasing trend at the start (April) of the rainy season and an increasing trend at the end of the season (September and October). The Mann-Kendall test results for the first decade show a downward trend for April, May, August, October and also the annual rainfall, but all of which is insignificant. In the second decade, no significant trend was observed, while in the third decade, a significant upward trend was observed in May and in the annual means of rainfall. In the overall period of study, it was observed that the end of the rainy season and the annual mean rainfall are having an upward trend, though insignificant like the other time series.

4.3 Decadal variation of rainfall

Table 4 shows the decadal view of trends during the rainy months and on the yearly basis. The results show that in the first decade, the starts of the seasons have a downward trend with a mean rainfall of 1063.8 mm and the resulting upward trend in the first decade was a result of the increasing trend in June and September in that decade. In the second decade, dry years were experienced throughout the decade and

ranged from normal dry to severe dryness. The rainy months in this decade mostly had downward trend or no trend at all with mean rainfall of 920.8 mm. In the third decade, the overall increasing trend resulted due to the increasing trend in the rainy months; the mean amount of rainfall in the decade was 1112 mm. The test results show that the increasing trend in the third decade is significant and from Fig. 5, the third decade (2011-2020) is the decade with the highest mean rainfall, this was because of the increasing raining days in the decade.

Table 4: Mann-Kendall Test results for monthly, annual and decadal Rainfall in Gombe metropolis.

Time series	1990-2000				2001-2010			
	Test Z	Trend	p-value	significance	Test Z	Trend	p-value	Significance
April	-1.38	Downward	0.168	No	1.91	Upward	0.057	No
May	-1.03	Downward	0.301	No	0.00	No trend	1	-
June	0.69	Upward	0.491	No	0.00	No trend	1	-
July	0.34	Upward	0.730	No	-0.60	Downward	0.549	No
August	-0.34	Downward	0.730	No	-1.80	Downward	0.072	No
September	0.86	Upward	0.389	No	-0.40	Downward	0.69	No
October	-0.17	Downward	0.863	No	1.69	Upward	0.110	No
Annual	0.34	Upward	0.730	No	-1.20	Downward	0.231	No

| Time series	2011-2020				1990-2020			
	Test Z	Trend	p-value	significance	Test Z	Trend	p-value	Significance
April	-0.30	Downward	0.763	No	-0.19	Downward	0.846	No
May	2.40	Upward	0.017	Yes	0.28	Upward	0.777	No
June	1.40	Upward	0.162	No	0.18	Upward	0.860	No
July	1.40	Upward	0.162	No	-0.95	Downward	0.340	No
August	0.20	Upward	0.842	No	-0.39	Downward	0.697	No
September	0.80	Upward	0.424	No	0.11	Upward	0.916	No
October	0.00	No trend	1	-	1.04	Upward	0.297	No
Annual	2.19	Upward	0.028	Yes	0.42	Upward	0.671	No
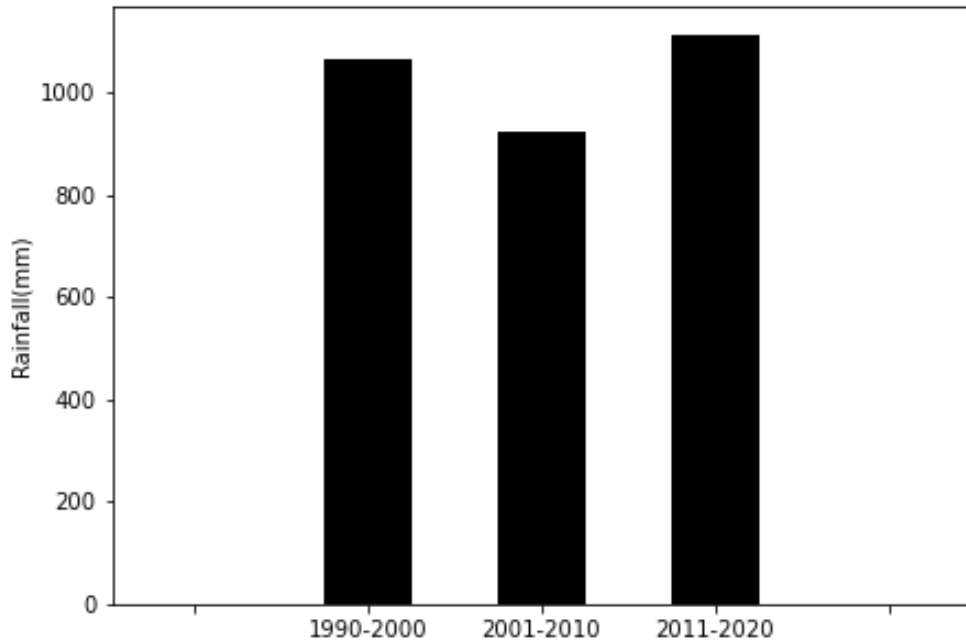
Figure 5: Decadal plot of mean Rainfall.

4.4 Number of rainy days and annual rainfall amount

Fig.6 presented the relationship between the annual rainfall amount and the number of rainy days. This comparison shows that the years with a higher number of days received a high amount of rainfall while the years with lower number of raining days received lower amount of rainfall, it also reflects that the raining days with higher raining days received rainfall above the mean which is considered wetness. The occurrence of drought in the year 2001 could also be attributed to the reduction in the rainy days of that year. Most years with high rainy days but with total rainfall below the mean, is attributed to the fact that the amount of rainfall received in most of the raining days were mostly little drizzling. The comparison between the driest and the wettest years is presented in Fig.7. It is observed that the wet year had early start with its peak value also early in June and experienced more raining days of up to 92 rainy days, while the dry year had a late rainy season.
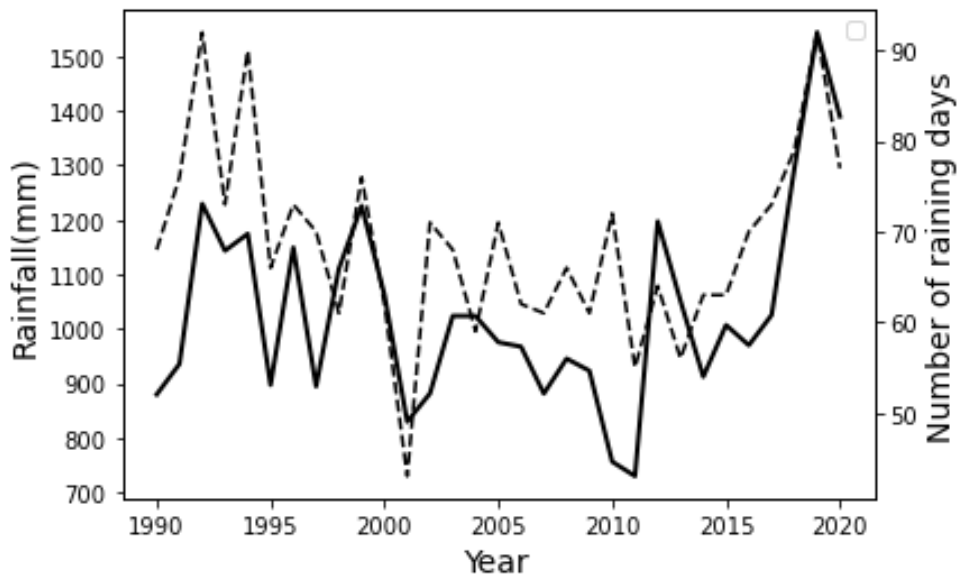

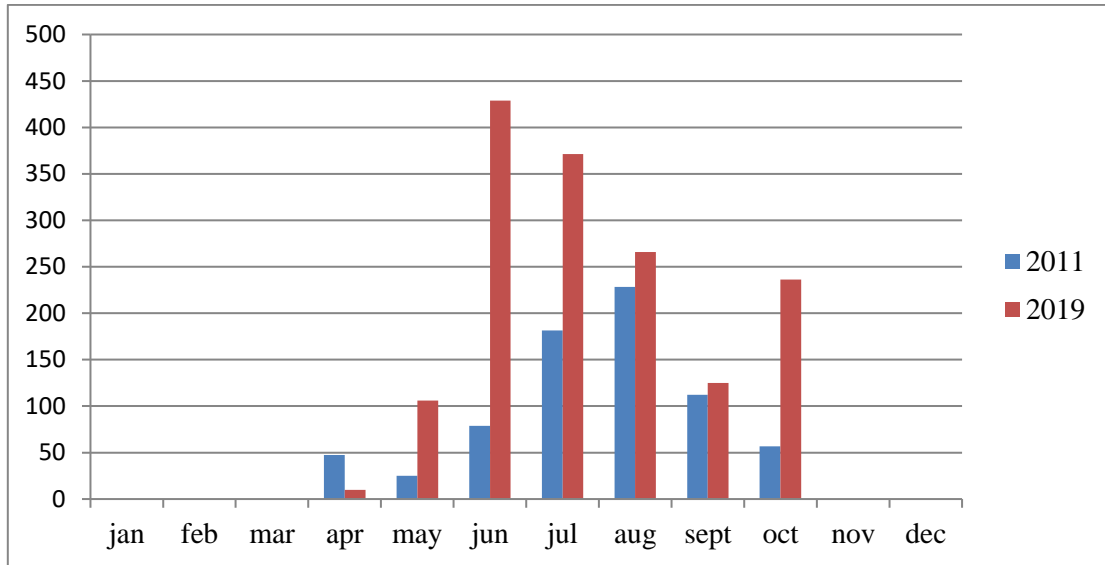*Figure 6: Plot of annual Rainfall and raining days.*

Figure 7: Comparison between the driest and wettest year.

4.5 Forecasting using ARIMA model

Fig.8 shows the forecast for Gombe rainfall for the next five years using the ARIMA model based on this study. The ARIMA model that best fit the dataset was the $(2, 0, 2) (5, 1, 2)_{12}$. This model was trained based on the previous values of monthly rainfall in Gombe and tested over the last 8 years, and the predicted rainfall values matched the actual values with 95% confidence level. This model was then used to make the forecast for 10 years that reveals that the rainfall of Gombe continues in a range above the current mean (an indication of wet years), with starts of the rainy season in April, peaking at August and ends at October. It is predicted by this model that in the year 2022, the rainfall starts in April with an amount of 29 ± 5 mm and peaks at August with an amount of 300.6 ± 10 mm and ends in October at 43.8 ± 5 mm and an annual total of 1005 ± 100 mm. It is observed that there is a tendency of a spike, which could cause a much higher peak in August.
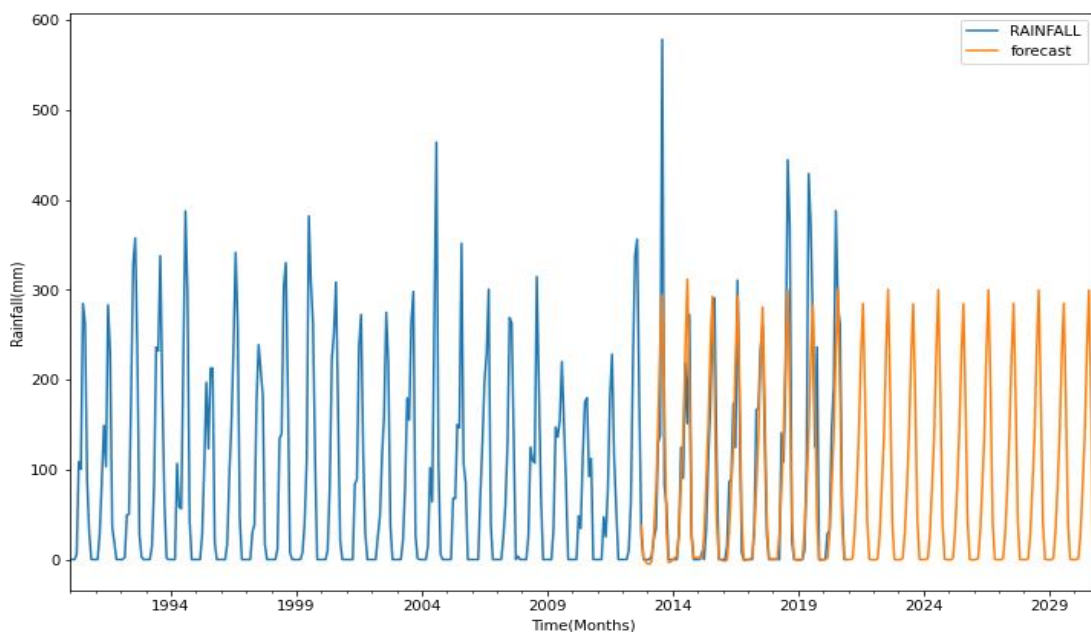

Figure 8: Forecast of the monthly Rainfall in Gombe Metropolis using ARIMA Model.

5. Conclusion

From the study, climate variability and climate change seem to have taken the center stage in Gombe with gradual but consistent increase in rainfall recorded in the last three decades and sharply represented in the immediate past decade. It is concluded that the nature of rainfall is a cyclic pattern and is currently increasing at 3.98 mm/year. The implication of these findings is the annual occurrence of urban floods within the Gombe town. It is clear from these results that the substantial increase in annual rainfall yield is predominantly a result of an increase in September and October rainfall. It is also concluded from the forecast that the coming amounts of annual rainfall ranges above the current mean indicating a decade with more wet years than dry years.

Acknowledgements

Conflict of interest

Authors declare that they have no conflict of interest.

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