Chapter

Meteorological Drought and Temperature in Sudano-Sahelian Region of Nigeria under Increasing Global Warming

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Abstract

This study examinesmeteorological drought and temperature in the Sudano-Sahelian region of Nigeria under increasing global warming. Rainfall data of 60 years (1961 to 2020) and temperature of 40 years (1981–2020) for nine stations were used to quantify drought occurrences as well as the pattern of temperature. The Bhalme and Mooley Drought Index (BMDI) and Student's t-test were used to indicate if changes have occurred in the amount of rainfall and temperature (increase or decrease) over space and time in the study region. The BMDI was used because it is simple and able to depict historically documented droughts better than other indices. The student's t-test was used to determine if the sub-period means of the series have altered significantly over time. Results show that the spatial and temporal occurrence and duration varied from one sub-area to another. Also, its intensity was mainly from mild to moderate. Results also show a consistent alternation between drought and wet years over the study period. The trend of temperature shows a tendency towards decreasing temperature during the period of study although it was not significant. The study concludes that the study region experiences climate variability that may well be part of global climate change.

Keywords: trends, drought persistence, global warming, Sudano-Sahelian region, meteorological drought, climate change

1. Introduction

Global warming and climate change have dominated conferences, seminars, and discourses for several decades in almost all parts of the earth. This is because several destructive atmospheric, weather, and climatic conditions such as inundation by water, absence or inadequate rainfall, and rising temperatures are being attributed to them [1]. As a result, several studies are being provided to critically look at how these extreme events relate to the duo. Some of these studies on the continent of Africa that have tried to understand the rainfall cycle and pattern include [2–19] amongst others. Those on the trend of temperature include but are not limited to [20–22]. The findings of these studies have generally not been definite and have resulted in diverse opinions and views on the relationship between climate variability and change on one hand and drought and temperature on the other. One of such opinions is that drought that has occurred and may likely occur in the Sahel Region of West Africa is an indicator of climate change. To the proponents of this thought, its long history of occurrence and the probability of reoccurrences in the future are enough evidence [23–25]. In contrast to these arguments are those that argue that though the occurrences of drought and fluctuations in temperature seem unusual in some years and decades past, they generally have not deviated from the long-term probabilities and climate of the area. Olatunde [26, 27] argued that the droughts that have occurred and persisted in the Sahelian part of Africa should be taken as part of the region's climate. This argument is especially cogent when the definition of climate change and/or discontinuity as identifiable changes in the average temperature, precipitation, and wind pattern that persists for a long period typically decades or longer [28] or an abrupt and permanent change in the mean values of these variables during the period of record [29, 30] taken into consideration and the fact that wet periods consistently alternated with the drought periods in most sub-areas of the region. These arguments as well as the issue of limited years of available data suggest the constant need for studies of this nature especially in the Sudano-Sahelian region of Nigeria. This study intends to ascertain if the lack or inadequate rainfall and change in average temperature imply a change in the climate of the area under study.

2. Study area

The study area is made up of the Sudan and Sahel Savanna zones in Nigeria which covers about one-third of its entire land area. It occupies from latitude 10°N to latitude 14°N of the Equator and from longitude 4°E to longitude 14°E of the Prime Meridian (**Figure 1**). The region lies south of the Sahara Desert, extending from the Sokoto plains on the west through the northern parts of the plains of Hausaland to the Chad Basin on the east [32].

The climate of the study area is the tropical wet/dry type, also referred to as Aw. The annual mean rainfall for the zone varies from less than 500 mm in the extreme northeastern part to approximately 1323 mm in the southern part [33, 34]. The wet

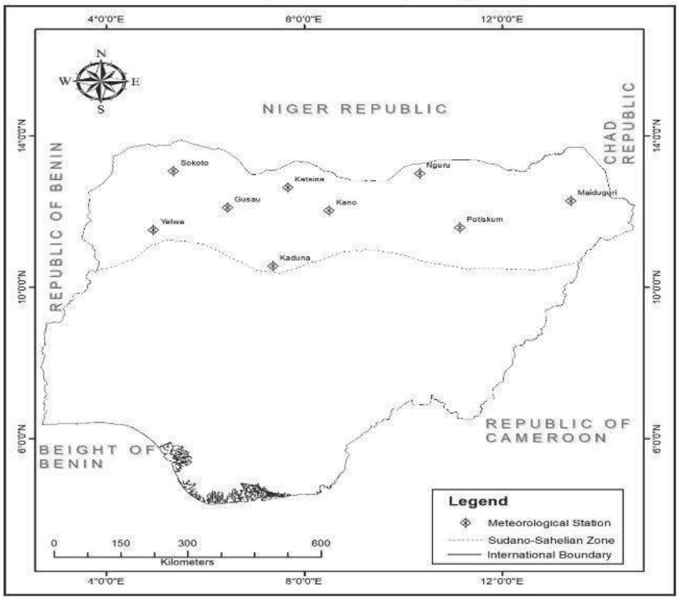

Figure 1.
The Sudano-Sahelian Zone of Nigeria (Adapted from [31]).

season occurs from April to October with the highest rainfall amount in August, while the dry season is from November to April [35, 36]. The intensity of rainfall is high in July and August, from about 60 mm $hour^{-1}$ to 99 mm $hour^{-1}$ [37]. The rainfall pattern is variable over space and time with inter-annual variability of between 15% and 20% [37, 38].

The climate of the study area is influenced by three air-masses, namely: the tropical maritime (mT); the tropical continental (cT), and the equatorial easterly. The mT and cT meet along a sloping surface known as the Intertropical Discontinuity (ITD). The equatorial easterly is an unstable cool air mass from the east in the upper troposphere along the ITD [32, 34]. The equatorial easterly sometimes undercut the mT or cT air masses to result in line squalls or dust devils respectively [39, 40]. The location of the ITD depends on the season in association with short-period fluctuations. Overall, it is located to the north of the Sudan-Sahel region in July and August, thereby making the area to be completely under the effects of the mT air mass. The reverse is the case from October to May when the ITD is located south of the region causing the cT air mass to prevail over the region [32].

The movement of the ITD is not regular, it varies according to the season. Its retreat towards the south is rapid than its northward progress. Its northward movement is at about 160 km per month while that of the southward retreat is at about 320 km per month [41]. This explains the gentle onset of the rainy season in the study area and northern Nigeria as a whole and its sudden end [42]. The mean highest air temperature occurs during the hot season from March to May while the mean lowest air temperature occurs during the cold season from December to February.

Temporal occurrence of temperature is steadier than that of rainfall, however, the highest diurnal range of temperature is in the dry season. The highest air temperature occurs either in April or May and the lowest between December and February [43]. The mean atmospheric relative humidity is between 70% and 90% during the rainy season and between 25–30% during the dry season [44]. Evapotranspiration is high year-round, the highest amount occurring during the dry season [45]. Sunshine hours depend on latitude and season. The mean annual number of sunshine hours in the study area is high in contrast to the southern part of the country, with very high values in the extreme northeast part. For example, Nguru has a mean annual total of 3177 hours [46]. Overall, values are high during the dry season in the area as a result of low cloudiness compared to the rainy season [47].

The entire study area is covered by Savanna vegetation and classified into Sudan and Sahel with the density of trees and other plants decreasing towards the north. The Sudan and Sahel zones are occasionally together referred to as the Sudano-Sahelian Ecologically Zone (SSEZ).

3. Materials and methods

3.1 Data collection

Sixty years (1961–2020) of rainfall data and forty years (1981–2020) of temperature from nine (9) stations were analysed. These data are secondary and from the archives of NiMet, Abuja, and NASA Data Access Viewer. The criteria used in choosing the stations are; a long period of available rainfall and temperature data; those stations without large missing data for the time under study; those stations that have not been moved since they were established and also the data were subjected to normality distribution test (**Table 1**).

Station	Station No.	Latitude (′N)	Longitude (′E)	Altitude (m)
Yelwa	1004.54	10°53	04°45	224.00
Potiskum	1111.40	11°43′N	11°07′E	487.68 m
Maiduguri	1113.50	11°51′N	13°05′E	348.00 m
Kano	1208.03	12°03′N	08°32′E	475.80 m
Gusau	1206.14	12°10′N	06°42′E	468.00 m
Sokoto	1205.51^{A}	12°55′N	05°12′E	309.00 m
Nguru	1210.52^{E}	12°58′N	10°28′E	341.00 m
Katsina	1307.04	13°0i′N	07°41′E	516.63 m
Kaduna	1007.32	10O41′N	07O19XE	634.00 m

Table 1.
Meteorological stations used.

3.2 Data analysis

The rainfall amounts for months with effective rainfall for plant growth (April to October) for the nine (9) chosen stations were analysed with the Bhalme and Mooley Drought Index (BMDI) to determine drought intensity [48]. For farming activities, the growing season from April to October is taken to be very crucial in drought research and assessments. This is so, as these months are when about 95% of the entire annual rainfall is received in the study area [49].

Generally, the BMDI for a particular month K is determined with the formula:

$$I_k = (Mk/d) + (1 + C)\ I_{k-1} \tag{1}$$

Where:
C is taken as a constant.
d is taken as aconstant.
I_K = drought severity for the Kth month.
$I_{k\text{-}1}$ = drought severity for the (K-1) month.
M = moisture index is determined by.

$$M = 100\ (x – \overline{x})/S \tag{2}$$

In Eq. (2),
X is the monthly rainfall amount;
$\overline{x}$ is the long period average monthly rainfall; and.
S is the standard deviation for the initial month being considered (K-1).
Eq. (1) is therefore given as:

$$I = M/d \tag{3}$$

The values of C and d in Eq. (3) for the Northern area in Nigeria are 0.43 and 38.84, respectively. These constants were derived by [48]. They were used in Eqs. (1) and (3) to determinethe monthly values of BMDI of the stations used. From the values, the averages or seasonal drought index (SDI) series were derived for each year in the study period. The seasonal indices were used to classify a year into any of the following wetness/dryness categories, using [48] classification chart (**Table 2**).

BMDI	The character of anomalous moisture conditions (CAMC)
4.00 or more	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.99 to −0.99	Near normal
−1.00 to −1.99	Mild drought
−2.00 to −2.99	Moderate drought
−3.00 to −3.99	Severe drought
−4.00 or less	Extreme drought

Source: Shuiabu and Oladipo [31].

Table 2.
BMDI classification chart.

The rainfall data were divided into non-overlapping decades; 1961–1970, 1911–1980, and so on to the present decadeof 2011–2020 and temperature decade of 1981–1990, 1991–2000 to the present decade of 2011–2020. Cramer's test as given by [50], was utilized in the compiling of the means of the decades with the mean of the entire study period. In the application of Cramer's test, the mean ($\overline{x}$), and the standard deviation (δ), were determined for the stations and the total number of years under study, N. As mentioned earlier, this was to find out the difference (in terms of a moving t-statistic) between the mean ($\overline{x}k$), for each successive n-year period and the mean ($\overline{x}$) for the entire study period. The t-statistic was taken as:

$$t_k = \left(\frac{n(N-2)}{N - n\left(1 + \tau_k^2\right)} \right)^{1/2} \tau_k \tag{4}$$

with τ_k as a standardized measure of the difference between means given as:

$$\tau_k = \frac{\overline{x}k - \overline{x}}{\delta} \tag{5}$$

with $\overline{x}k$ as the mean of the sub-period of n-years. $\overline{x}$ and δ as the mean and standard deviation of the entire series respectively and τ_k as the value of the student t-distribution with N-2 degrees of freedom. It was then compared against the "students" t-distribution table, at a 95% confidence level as regards the two-tailed form test. When t_k was outside the bounds of the two-tailed probability of the Gaussian distribution (equal to 1.96 at 95% confidence level), a significant shift from the mean was assumed.

The temperature series were divided into 30-year overlapping sub-periods of 1981–2010 and 1991–2020, while the rainfall series were divided into 30-year non-overlapping sub-periods of 1961–1990 and 1991–2020 as recommended by the World Meteorological Organisation. The student's t-test, t_d, was later used to ascertain if the sub-period means have deviated significantly in the occurrence of wet and dry years through time. The statistics, t_d, was calculated using:

$$t_d = \frac{\left(\overline{X}_2 - \overline{X}_1\right) - \left(\mu_2 - \mu_1\right)}{\left[\frac{N_2 S_2^2 + N_1 S_1^2}{N_2 + N_1 - 2} \cdot \frac{1}{N_2} + \frac{1}{N_1}\right]^{1/2}} \tag{6}$$

with $(\overline{X}_1–\overline{X}_2)$ being the difference in group means, $(\mu_2–\mu_1)$, was the expected differences (set equal to 0), N_2 and N_1 being the number of cases in each sub-sample, and S_2 and S_1 were the respective standard deviations. When t_d was outside the bounds of the two-tailed probability of the Gaussian distribution, equal to 1.96 at 95% confidence level, a significant deviation and shift from the mean were assumed.

4. Results and discussion

4.1 Frequency distribution of drought series

The results of the analysis of the occurrence of drought, in the study area, using BMDI are depicted in **Figures 2–10**. They show that the occurrences and intensity of drought in sub-areas of the study area vary over time and space. This is exemplified by some sub-areas with intermittent years of drought and wetness. Yelwa sub-area experienced such a situation, even though droughts of mild and moderate intensities prevailed between 1965 and 1991. The later years of study, 2010–2020 also experienced a drought of mild intensity. Potiskum sub-area values also indicated years of drought and wetness throughout the study period with intensity varying between mild and moderate and a reduction in the drought intensity towards the end of the study period. This same situation also occurred in Gusau and Kaduna sub-areas. For Kaduna, the years between 1961 and 2011 were those of alternating wet and drought with intensity being mild.

Some sub-areas experienced very clear and distinct periods of drought. Generally, Maiduguri drought for example can be categorized into before the 1980s with

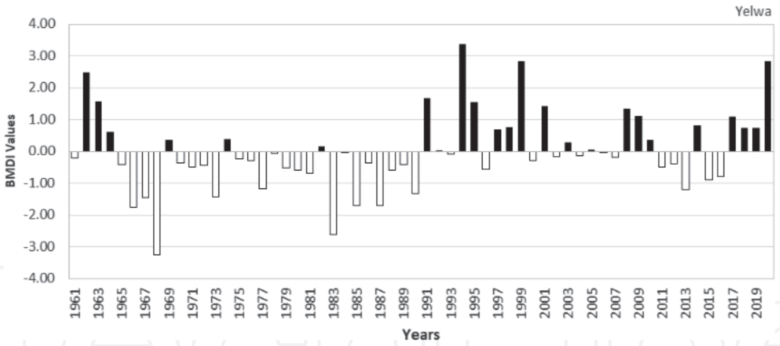

Figure 2.
Annual fluctuations in Bhalme and Mooley drought index for Yelwa.

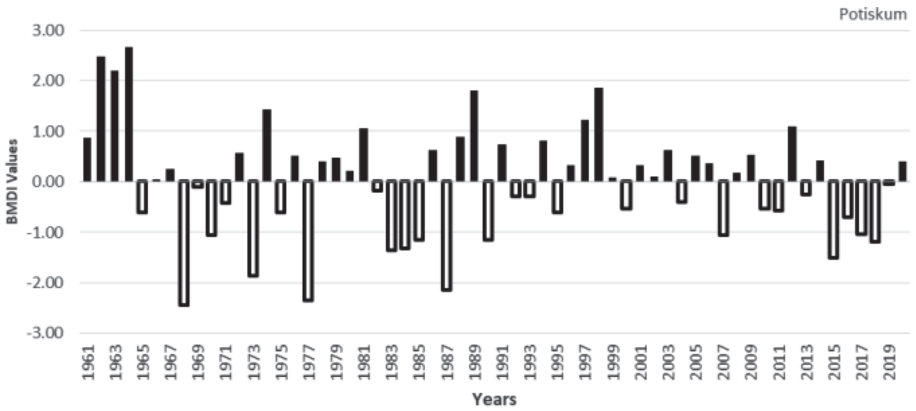

Figure 3.
Annual fluctuations in Bhalme and Mooley drought index for Potiskum.

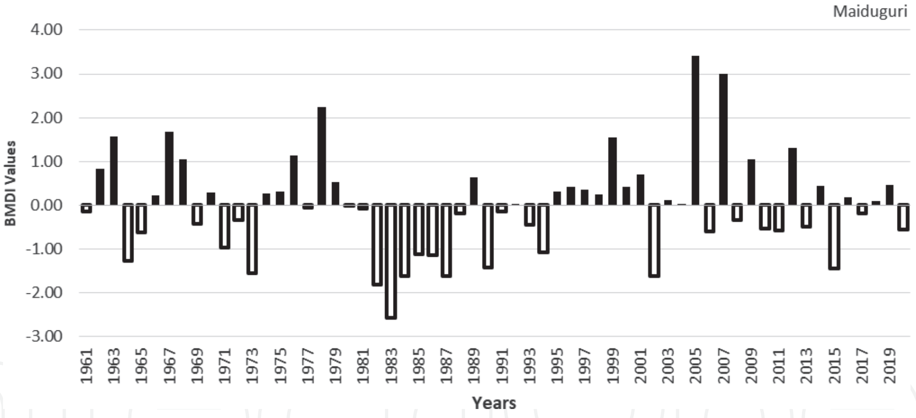

Figure 4.
Annual fluctuations in Bhalme and Mooley drought index for Maiduguri.

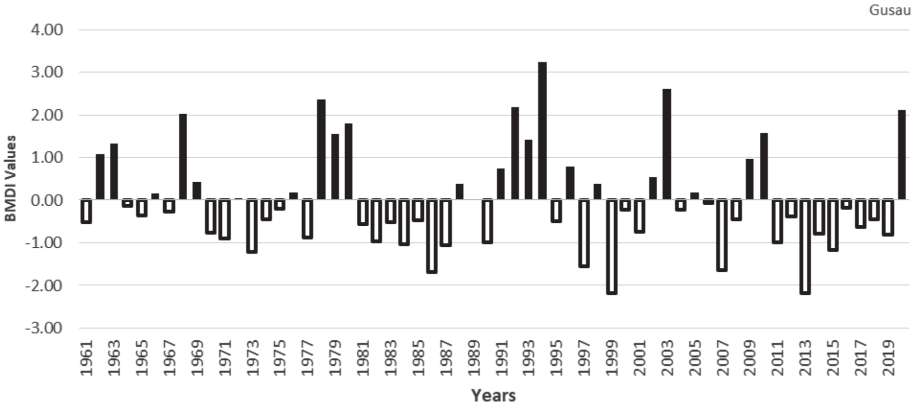

Figure 5.
Annual fluctuations in Bhalme and Mooley drought index for Gusau.

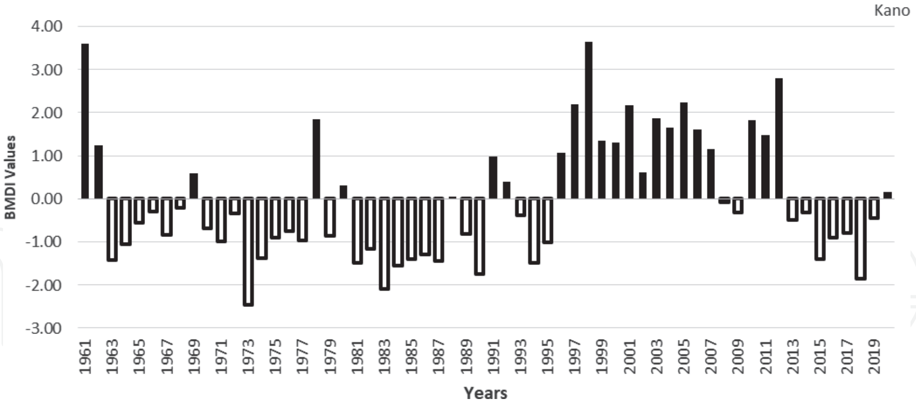

Figure 6.
Annual fluctuations in Bhalme and Mooley drought index for Kano.

drought years and intensity that were less than moderate. This was followed by the drought of the 1980s with an intensity of between mild and moderate and the post-1980s with intermittent drought and wet years and reduced drought intensity of less than moderate. In Kano, drought dominated from the beginning of the study period to 1995, while for Sokoto and Katsina the drought years were 1967 to 1995 and 1967 to 2000 respectively with the intensity ranging from mild to moderate. Nguru also experienced similar droughts situation between 1969 and 2015.

The occurrences of drought as discussed above and wet years in the study area as exemplified in Kano between 1996 and 2010, in Sokoto and Katsina after 1995 and

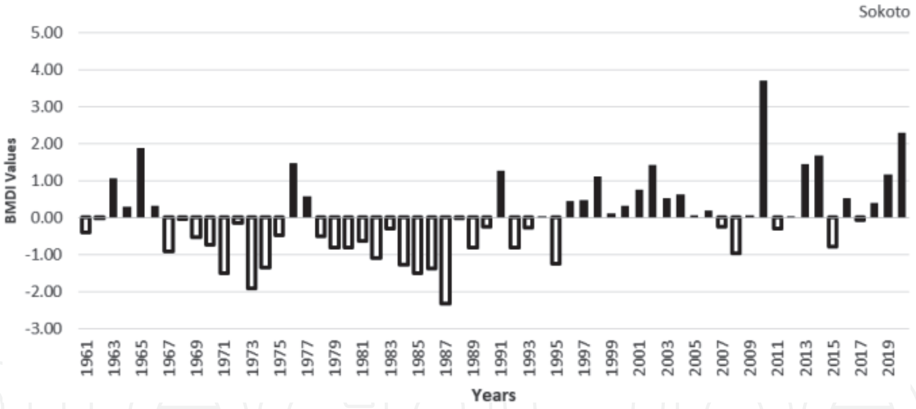

Figure 7.
Annual fluctuations in Bhalme and Mooley drought index for Sokoto.

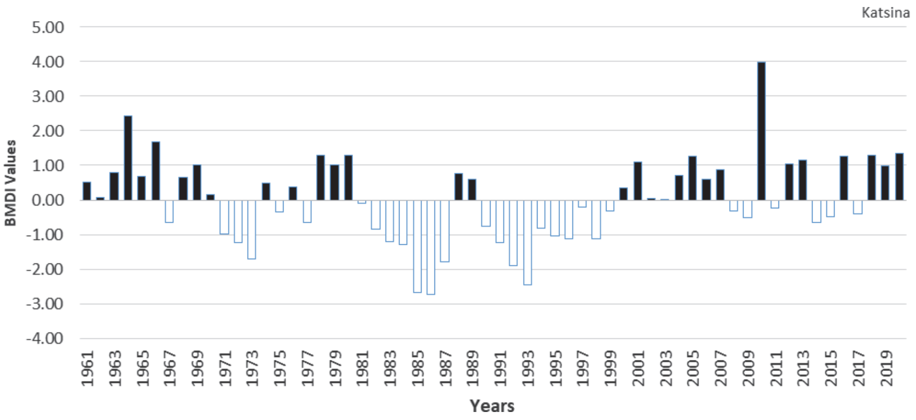

Figure 8.
Annual fluctuations in Bhalme and Mooley drought index for Katsina.

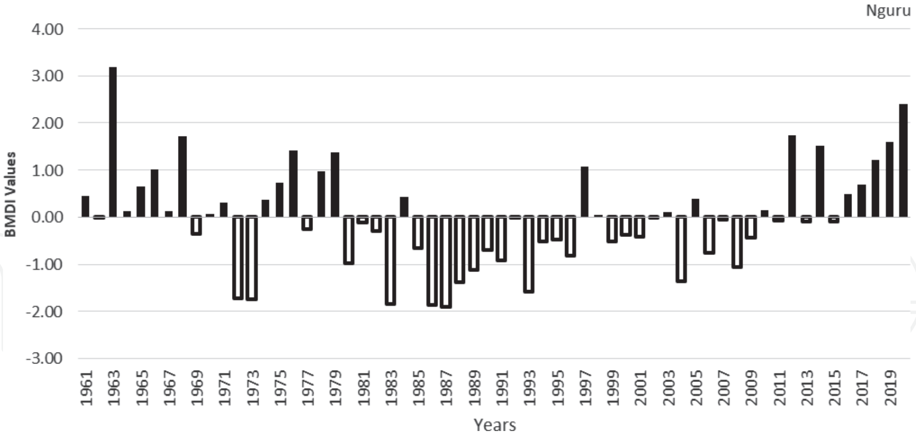

Figure 9.
Annual fluctuations in Bhalme and Mooley drought index for Nguru.

2000 respectively (with few drought years and reduce intensities), before 1969 and after 2015 in Nguru and between 2011 and 2020 in Kaduna indicate a constant shift in the climate of the study area. This shift from findings seems more temporary than permanent and therefore, indicates climate variability than climate change. This variability in climate in more recent years has been exemplified in the Kaduna sub-area that before 2013 had indicated wet years in earlier studies [19, 50] had by 2013 to 2020 turned to drought. This however is in agreement with other studies that indicated the return of drought in the sub-area [14, 17, 27]. This notion of

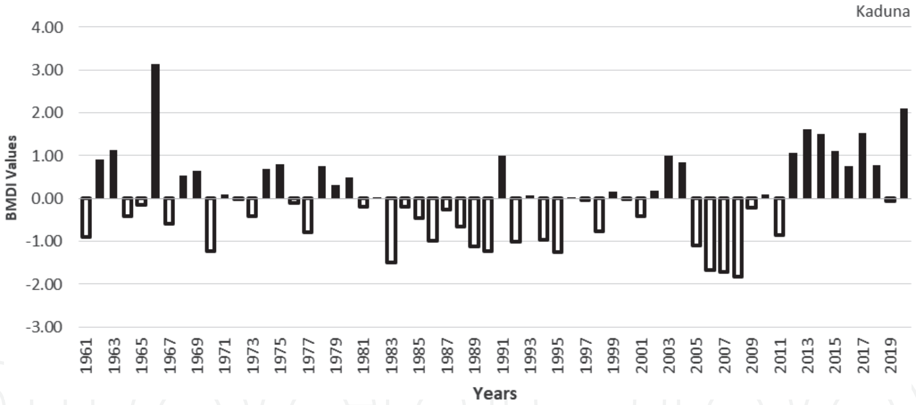

Figure 10.
Annual fluctuations in Bhalme and Mooley drought index for Kaduna.

climate variability is further supported by the fact that throughout the study period, the intensity of drought fluctuated between mild and moderate and never increased to severe or extreme.

4.2 Occurrences of droughts in the sub-periods

4.2.1 Decades

The occurrences of drought within decades varied during the period of study from one sub-area to another. This means the drought percentages of occurrence are not the same. Kano and Nguru experienced drought in four decades of the six decades considered, that is 66.66% drought to 33.33% of wetness. The decades 1961–1970, 1971–1980, 1981–1990, and 2011–2020 were those of droughts with that of 1981–1990 being significant. Other decades were wet with 2001–2010 being significant (**Table 3**). In Nguru, the first and last decades of the study were wet,

Sub-period	Yel	Sok	Gus	Kad	Kat	Kan	Ngu	Pot	Mai
1961–									
1970	−0.62	0.20	0.69	1.35	1.95	−0.31	1.77	1.14	1.11
1971–								—	
1980	−1.31	−1.49	0.35	0.39	−0.01	−1.58	−0.19	0.68	0.21
1981–	—	—	—		—	—	—	—	—
1990	1.99*	2.13*	1.62	−1.73	2.09*	2.16*	2.29*	0.85	2.43*
1991–					—				
2000	2.03*	0.78	1.49	−0.89	2.26*	1.84	−1.46	0.75	0.52
2001–									
2010	1.03	1.44	0.72	−1.56	1.65	2.39*	−0.73	0.27	1.42
2011–			—					—	
2020	1.23	1.59	1.45	2.20*	1.32	−0.65	2.47*	0.67	0.00

**Significant at $p < 0.05$.*
Source: Section 3.2.
Yel, Yelwa; Sok, Sokoto; Gus, Gusau; Kad, Kaduna; Kat, Katsina; Kan, Kano; Ngu, Nguru; Pot, Potiskum; Mai, Maiduguri.

Table 3.
Decadal analysis of drought.

with that of the last decade being significant. Other decades were those of drought with that of 1981-1990 being significant.

In some sub-areas such as Yelwa, Kaduna, Katsina, and Potiskum, the drought decades constituted about 50% the same as the wet decades (50%), although the decades were not the same in all the sub-areas of study. In Yelwa three consecutive decades of 1961–1970, 1971–1980, and 1981–1990 were those of drought with the value for 1981–1990 being significant. Other decades were wet with that of 1991–2000 being significant. Katsina sub-area also experienced the same situation, and the decades with droughts were 1971–1980, 1981–1990, and 1991–2000 with the last two being significant. These decades were also those of drought in the Potiskum sub-area, although without any being significant. Other decades were wet and were not significant in both sub-areas. In Kaduna, the drought decades were 1981–1990, 1991–2000 and 2001–2010 although with values that were not significant. Other decades in this sub-area were wet with the last, 2011–2020 being significant.

The situations experienced in Sokoto and Gusau sub-areas were slightly different from the above. Drought dominated in 1971–1980 for Sokoto and 2011–2020 for Gusau, while the decade 1981–1990 was a drought decade in both sub-areas although it was significant in Sokoto but was not in Gusau. Other decades were wet for both sub-areas. This indicates that the drought decades constituted about 33.33% while the wet decades constituted about 66.66%. Maiduguri sub-area had 1981–1990 as a significant drought decade. Other decades were wet although not significant. This indicated 16.66% of the decades were drought-dominated. The above percentages of drought and wetness do not suggest a permanent shift in

Stations	Sub-periods	Mean	SD	t_d
Yelwa	1961–1990	897.75	172.14	3.63*
	1991–2020	1082.78	213.43	
Sokoto	1961–1990	588.82	139.29	3.40*
	1991–2020	714.02	141.30	
Gusau	1961–1990	852.84	146.30	0.59
	1991–2020	885.01	256.73	
Kaduna	1961–1990	1251.80	241.01	0.14
	1991–2020	1259.96	216.14	
Katsina	1961–1990	577.71	163.12	0.21
	1991–2020	586.47	153.83	
Kano	1961–1990	743.80	226.64	4.12*
	1991–2020	1059.35	344.66	
Nguru	1961–1990	431.57	117.25	0.91
	1991–2020	459.83	120.26	
Potiskum	1961–1990	646.75	186.90	0.26
	1991–2020	656.94	88.88	
Maiduguri	1961–1990	553.37	141.46	1.57
	1991–2020	613.93	152.00	

**Significant at $p < 0.05$.*

Table 4.
Values for student's t*-test (30 years non-overlapping).*

climate. It shows more of an alternation between drought and wetness and therefore climate variability.

4.2.2 Sub-periods (30 year non-overlapping)

Values of the student's *t*-test show a significant deviation in trend from the sub-period, 1961–1990 to the sub-period, 1991–2020 (**Table 4**). These values show a significant deviation and shift towards a positive and increasing trend in the series of Yelwa, Sokoto, and Kaduna. For these stations/sub-areas, the sub-period of 1991–2020 appears to be wetter than the preceding sub-period of 1961–1990.

4.3 The trend in temperature of study area

4.3.1 Decadal

The decades 1961–1970, 1971–1980, and 1981–1990 were those of decrease of temperature in Yelwa with that of 1981–1990 being significant. These decreases were in the early decades of the study period. However, in Kaduna, the decreases were in the decades of 1981–1990, 1991–2000, and 2001–2010 without any being significant. The decreases occurred mainly within the mid-decades of the study period. The decreases in Katsina temperature occurred in the decades 1971–1980, 1981–1990, and 1990–2000 with the last two being significant. Also, Potiskum was with a decrease in average decadal temperature in 1971–1980, 1981–1990, and 2011–2020 without any being significant. These three decades constitute 50% of the study period. This indicates a shift in the climate of these sub-areas particularly of the

Stations	Sub-periods	Mean	*SD*	t_d
Yelwa	1981–2010	27.99	0.46	−1.31
	1991–2020	27.83	0.50	
Sokoto	1981–2010	29.03	0.43	−1.94
	1991–2020	28.72	0.74	
Gusau	1981–2010	26.82	0.52	−0.61
	1991–2020	26.74	0.53	
Kaduna	1981–2010	25.85	0.58	−1.51
	1991–2020	25.58	0.75	
Katsina	1981–2010	26.75	0.55	−0.67
	1991–2020	26.65	0.57	
Kano	1981–2010	26.81	0.60	−1.17
	1991–2020	26.63	0.54	
Nguru	1981–2010	27.97	0.47	−0.95
	1991–2020	27.85	0.47	
Potiskum	1981–2010	27.26	0.53	0.80
	1991–2020	27.36	0.48	
Maiduguri	1981–2010	27.90	0.43	1.10
	1991–2020	28.01	0.37	

Table 5.
Student's t-test (t_d) *analysis for temperature (30-years overlapping).*

element of temperature. Sokoto and Gusau had two decades (about 33.33% of decades) each with a decrease in temperature; 1971–1980 and 1981–1990 for Sokoto and 1981–1990, 2011–2020 in Gusau with only that of 1981–1990 in Sokoto being significant. The decadal value of 1981–1990 for Maiduguri was also significant and was the only decade (about 16.66% of decades) with a decrease in the sub-area during the study period.

All other decades in the stations/sub-areas indicated increases in temperature with the following being significant; 1991–2000 (Yelwa), 2011–2020 (Kaduna), 2001–2010 (Kano), and 2011–2020 (Nguru). These situations indicate fluctuations in the average decadal temperature of the study area and back up the assertion of climate variability being dominant as opposed to change in the climate of the study area.

4.3.2 Sub-periods (30 year overlapping)

The values of the student's *t*-test (**Table 5**) show deviation and shift in trend from the sub-period, 1981–2010 to the sub-period, 1991–2020. They indicate a shift towards decreasing temperature (negative) in the series for most of the stations used during the study except for Potiskum and Maiduguri that indicated an increasing (positive) trend However, both increasing and decreasing trends were not significant.

5. Conclusion

This study's findings indicate that there is no consistent increase in the occurrence of droughts in the study area and period considered. Years of drought alternated with those of wet years in all the stations and sub-areas of study. This indicates that drought and its variability are a part of the climate of the area. The fact that the intensity of the drought remained between mild and moderate and did not become worse throughout the study period indicates that there was no permanent shift towards drought that can suggest a change in the climate of the area. Also, the changes observed in the temperature of the study area (both increases and decreases) were not significant to conclude that global warming with the attendant climate change is underway. To ascertain the true situation of the state of the climate in the study area, rainfall and temperature data, and where possible, of other climatic variables such as wind, insolation and relative humidity of several more years and decades would be required.

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