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# The Influence of Local Rainy and Dry Seasons on the Diurnal Temperature Range in Nigeria

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## Abstract

This study analyzed the impact of the local dry and rainy seasons on diurnal temperature range (DTR), for each major climatic zone of Nigeria namely the tropical monsoon, tropical savannah and semi-arid, using meteorological data from thirteen observation stations for the period 1981 to 2021. DTR was computed from the difference of minimum temperature from maximum temperature and yearly and forty one years' monthly averages of DTR and rainfall were computed and plotted in different graphs. The overall results from each climatic zone showed that DTR fluctuates with the seasons and there is an inverse relationship between DTR and rainfall whereby the value of DTR decreases as the rainy season approaches but increases as the rainy season departs ushering in the dry season or conversely DTR increases as the dry season approaches and decreases as the dry season departs ushering-in the rainy season. Secondly, the average yearly patterns of rainfall and DTR are roughly and oppositely shaped parabolas where the peak value of rainfall is diametrically opposite to the trough value of DTR and the least or nil volume of rainfall corresponds to the highest value of DTR. Thirdly, due to the yearly seasonal cycle of dry and rainy seasons in Nigeria coupled with the inverse relationship between DTR and Rainfall, the seasonal plot of DTR and rainfall is also cyclic in pattern with DTR cycle lagging 180 degrees with the rainfall cycle and the intersection of the two cycles represents the departure of one season and onset of another season while each half-cycle represents either the dry or rainy season. Fourthly, the dependence of DTR on any season at hand in Nigeria makes DTR season-forcing. This fourth result is underpinned by a result that showed that the 1981 and 2021 patterns of DTR and 1981 and 2021 patterns of rainfall when compared were similar, the differences were in the volume of rainfall which was due to climate change that has taken place over the four decades and which also impacted DTR since DTR varies inversely with rainfall. Finally and notwithstanding the common grounds of the results stated above, the result further showed that each climatic zone of Nigeria reacts differently to the local and global climate changes leading to the magnitude of DTR and the volume of rainfall being different across climatic zones, with rainfall volume and duration decreasing towards the arid North from the Coastal South while contrariwise DTR increases towards the arid North from the Coastal South.

**Keywords**

Dry Season, Rainy Season, Harmattan Period, Primary and Secondary Axes of a Graph

## 1. Introduction

The Diurnal Temperature Range (DTR) is the difference between the day's highest and lowest temperatures [1] or the difference between the maximum temperature and the minimum temperature recorded in the same day. It describes the within-day temperature variability and reflection of weather stability [2] [3]. Natural factors and human activities affect DTR. Generally it increases with distance from the sea and towards the places where solar radiation is strongest [1]. Specifically, Cloud cover has been attributed as one of the various factors that affect DTR, with a decrease in the DTR being partly related to an increase in cloud cover [4] [5]. Cloud cover, in combination with other damping effects from soil moisture and precipitation, can reduce DTR by 25% - 50% compared with clear-sky days over most land areas [6]. Specifically, precipitation increases the level of soil moisture, enhances surface–air interactions that lead to larger evaporation while cloud cover prevents much of the shortwave solar radiation from reaching the surface of the earth thereby leading to a relatively lower daytime temperature [6] [7]. At night however, the clouds re-emits absorbed long wave radiations back to the earth leading to a slower decrease of temperatures at night when compared to clearer skies [8]. A further explanation for the impact of cloud cover on DTR is that during the day, infrared radiation emitted by the cloud to the earth is much less to the solar radiation scattered back to space thereby making the day cooler while at night, with solar radiation out of the picture, the clouds continue to emit infrared radiation towards the ground thereby keeping the ground warmer than on a clear night sky resulting in a net effect of smaller DTR [9]. Some of the human factors that affect DTR are the anthropogenic effects of urbanization and land use changes [10] [11] Land-use changes from urbanization, creating an urban heat island (UHI), may be partially responsible for the observed warming over land and the decreasing trend of DTR in the investigated cities [12]. Urbanization transforms rural areas to urban within a decade resulting in the increased absorption of solar radiation, a decrease of evapotranspiration, and a release of anthropogenic heat, thereby resulting in a change of air temperatures, horizontal winds, and air quality. Several studies have shown that land use changes induce climate change [13] [14].

Studies on the effect of variations in precipitation, long wave radiation, ultraviolet-A (UVA), ultraviolet-B (UVB), cloud cover, water vapor, and urbanization on DTR on a regional scale have been done and Andri Pyrgou *et al.* [12] found a strong relationship between the DTR and observed cloud cover, net long wave radiation, and precipitation, with clouds associated with smaller shortwave and net long wave radiation reduce the DTR by decreasing the surface solar radiation, while atmospheric absolute humidity denotes an increased daytime surface evaporative cooling and higher absorption of the short and long wave radiation. Price *et al.* [15] has examined the seasonality of DTR in Cyprus and found that DTR trend responds differently to the summer months of June, July August (JJA) from the winter months December, January and February (DJF). Nigeria is in the tropics and as such do not experience summer and winter but rainy season where there is precipitation with attendant soil moisture, humidity and cloud cover and dry season when there is lack of precipitation. Dike V. N *et al.* [16] found in their study of Nigeria that DTR trend responds differently from 10˚N down to the coastal South which is humid with much rainfall and vegetation and 10˚N upwards to the arid and semi-arid land (ASAL) North which is mostly dry with sparse vegetation and little rainfall.

Therefore, most of the factors that affect DTR are present in Nigeria, which lies in the tropics and thus experiences a lot of solar radiation energy. In addition, during the rainy season, precipitation is usually preceded by thick rain cloud cover and after the rain fall, the soil becomes moist. Rainfall is a seasonal event and directly measured and recorded in millimeter units at weather observation stations. Therefore, precipitation or lack of it is used as an indicator of the season at hand. Diurnal temperature range (DTR) on the other hand is not directly measured but calculated from measurable scalar quantities which are the minimum and maximum temperatures in units of degree Celsius.

Nigeria has two major yearly seasonal cycles – the rainy or wet season and the dry season. The rainy season is a period of precipitation and then high humidity which is usually preceded by thick rain-clouds. The onset, intensity and departure of the rains reduces towards the arid regions of the North from the coastal south, with the result that the rainy season is more than nine months long in the extreme south, decreasing to about three months on the shores of Lake Chad in the far North [17]. The dry season on the other hand is when there is no precipitation and the surrounding environment is warm and the sky, usually clear. Within the dry season is the Harmattan period when the north-east trade wind is laden with dust from the Sahara desert and blows across the country. The Harmattan is thus, the height of the dry season, with virtually no clouds but with the dust enveloping the atmosphere making visibility low. Nigeria is close to the equator with a relatively high number of annual sunshine hours. Temperature is therefore relatively high throughout the year, with the highest temperatures occurring during the dry season and varies little from the south to the North, with mean annual temperatures around 27˚C [17].

The weather pattern and resultant climate of an area is determined by the winds that blow across it and the winds in turn are caused by the difference in atmospheric pressure. According to Ologe K. O. [16], two belts of high pressure and one belt of low pressure exist which gives rise to the trade winds that prevail in Nigeria. These, according to NIMET [18] are: 1) The Northern Sub-Tropical High Pressure cell known as the Azores High Pressure cell, usually located around latitude 30˚N and stretches east-west across the Sahara desert drives the dry and cool north-east trade winds (or continental winds) from the Sahara desert during the dry season with a great quantity of dust called the Harmattan dust and always produce dry weather; 2) The Southern Sub-tropical High Pressure cell known as St. Helena high pressure cell and located around latitude 30˚S and stretches east-west across the South Atlantic Ocean of the southern hemisphere, drives the moist and warm south west trade winds (or maritime winds) from the Atlantic ocean and produce cloudy skies with the possibility of rain; 3) The Inter-Tropical Discontinuity (ITD) which is a zone of convergence between the moist and warm south west trade winds from the Atlantic Ocean and dry and cool north-east trade winds from the Sahara desert. In order words, this belt of low pressure which stretches east-west across West Africa, is where the two high pressure systems stated above meet and it moves northward and southward so the areas affected by each of the two-wind systems increase or decrease, producing the weather and climate which we experience in Nigeria.

The location of the ITD is therefore a major factor in determining the weather regime of a particular region in Nigeria [17] [18].

The aggregate effect of the trade winds that blow across Nigeria is the five climate systems based on the Koppen-Geiger climate classification system [19]. These five Nigerian Climate systems are: Tropical rainforest (Af), Tropical Monsoon (Am), Tropical Savannah (Aw), Semi-Arid, Steppe, hot (BSh) and Arid, Desert, hot (BWh). These can be approximated to majorly three distinct climate zones namely, the tropical monsoon climate in the south, a tropical savannah climate for most of the central regions, and a Sahelian hot and semi-arid climate in the north of the country [20]. These three major climatic zones have existing observational data. Unfortunately, the tropical rainforest and Sahel-arid climatic zones have no observational data specific to these areas.

Therefore, in this study, we examined the impact that the rainy and dry seasons in Nigeria have on DTR and furthermore for each of her climatic zones.

## 2. Study Area and Data Sources

Nigeria lies within latitudes 4˚N and 14˚N and longitudes 2˚E and 15˚E, and has a total area of approximately 925,796 sq km, bounded in the South by the Atlantic Ocean, and in the North by the Sahara desert.

For this study, data is sourced from the Nigeria Meteorological Agency (NIMET) which has weather observation stations across Nigeria. However, no data exist specifically for the Tropical rainforest and the desert-arid climatic zones. Data from thirteen observation stations were sourced for this study distributed as shown in Table 1 and Figure 1.

The map of the study area showing the areal extent of the climatic zones and the weather observation stations within each climatic zone where data was sources is shown in Figure 1.

Table 1. Location of data sources.

| Climatic Zone | Number of Data Points | Meteorological Stations | Longitude (˚E) | Latitude (˚N) |
|---|---|---|---|---|
| Tropical Rainforest (Af) | 0 | None | Not Applicable | |
| Tropical Monsoon (Am) | 4 | 1) Yenegoa<br>2) Port Harcourt<br>3) Owerri<br>4) Calabar | 1) 06.25˚E<br>2) 07.12˚E<br>3) 07.03˚E<br>4) 08.35˚E | 04.92˚N<br>04.85˚N<br>05.48˚N<br>04.97˚N |
| Tropical Savannah (Aw) | 5 | 1) Abuja<br>2) Enugu<br>3) Ilorin<br>4) Kaduna<br>5) Yola | 1) 07.48˚E<br>2) 07.00˚E<br>3) 04.54˚E<br>4) 07.45˚E<br>5) 12.47˚E | 09.07˚N<br>06.50˚N<br>08.89˚N<br>10.60˚N<br>09.23˚N |
| Steppe (Semi-Arid), (BSh) | 4 | 1) Sokoto<br>2) Katsina<br>3) Kano<br>4) Maiduguri | 1) 05.20˚E<br>2) 07.68˚E<br>3) 08.53˚E<br>4) 13.08˚E | 12.92˚N<br>13.02˚N<br>12.05˚N<br>11.85˚N |
| Arid Desert (BWh) | 0 | None | Not Applicable | |

Source: Echebima and Obafemi 2023; NIMET (2017) for the coordinates of the locations.

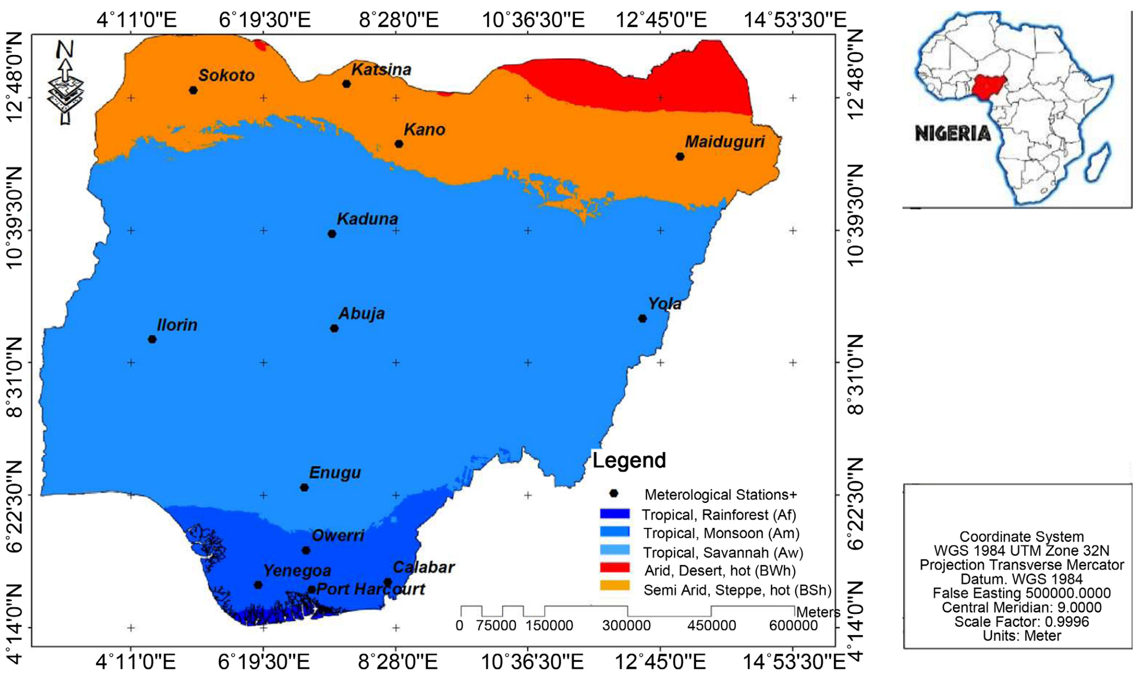


Figure 1. Koppen-Geiger climate classification map for nigeria and location of data sources. Source: Echebima and Obafemi 2023; Beck, H.E. *et al.* (2018) for the Climate map.

## 3. Method of Data Analysis

For this study, the monthly maximum temperature ($T_{\max}$), monthly minimum temperature ($T_{\min}$) and monthly rainfall measured and recorded by the Nigerian Meteorological Agency (NIMET) at thirteen different observation stations were used for the period spanning 1981 to 2021- a span of forty one years

Diurnal temperature range (DTR) defines as the difference of $T_{\min}$ from $T_{\max}$ is computed thus:

$$\text{DTR} = T_{\max} - T_{\min} \tag{1}$$

This study also involved the computation of yearly and 41 years' averages of DTR and also of rainfall and the general formula for computing an average is defined as:

$$A = \frac{1}{n}\sum_{i=1}^{n} a_i \tag{2}$$

$A$ = arithmetic mean (average),

$n$ = number of values,

$a_i$ = data set values.

Microsoft EXCEL software was used for the data spreadsheet, data computations and plotting of graphs. Four different plots were produced out of this; the year-by-year monthly pattern of DTR and rainfall, the seasonal pattern of DTR and rainfall, comparison and difference plot of 1981 DTR versus 2021 DTR and comparison and difference plot of 1981 rainfall versus 2021 rainfall.

The year-by-year monthly pattern or response of DTR is obtained by plotting the 41-years' average monthly DTR and the 41-years average monthly total rainfall in juxtaposition on the vertical (primary and secondary) y-axes while the horizontal x-axis is the months of the year. The seasonal pattern or response is similar to the first plot but this time horizontal x-axis started at the month of the onset of the rainy season and ends at the month of the end of the dry season. The first graph gives a general perspective of the year-by-year influence of rainfall on DTR and helps to establish the onset and departure of the rainfall and the second graph establishes the seasonal response of DTR with rainfall.

The comparison and difference plots were produced to underpin the seasonality of DTR and rainfall patterns. Should the patterns be the same, after four decades, then it indicates that DTR is responding to the season and rainfall volume is responding to climate change. Four decades is long enough time for the impact of climate change to be felt and any changes in the volume of rainfall will therefore be indicative of the impact of climate change on rainfall and by extension on DTR (since DTR value is influenced by Rainfall).

## 4. Results and Discussion

### 4.1. Tropical Monsoon Climate Zone, NIGERIA

The general yearly response of DTR to rainfall in the tropical monsoon climate is shown in **Figure 2** and summarized as follows:

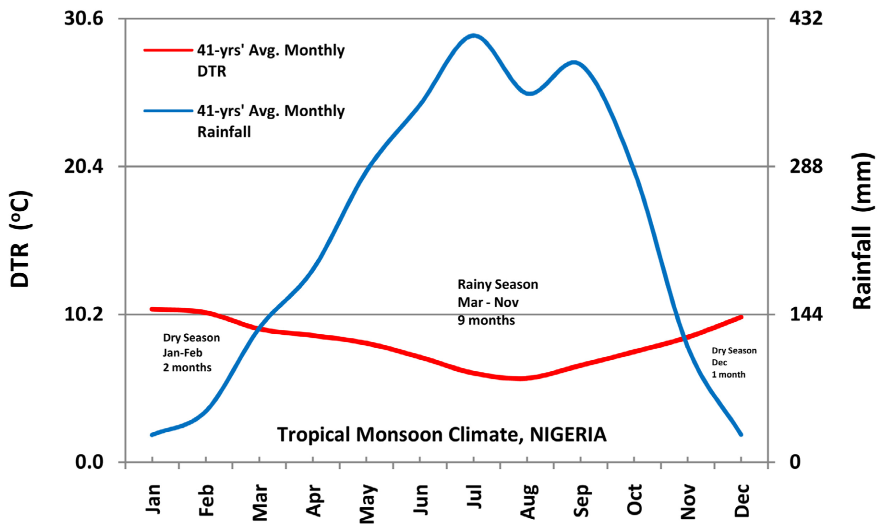


**Figure 2.** 41-Years' (1981-2021) average monthly DTR and monthly rainfall for the tropical monsoon climate, NIGERIA.

1) The value of DTR was high in January but decreased as the rainy season approached and increased as the rainy season departed, ushering in the dry season, leading to the rough parabolic shape of DTR and an equally rough but inverted parabolic shape of rainfall with the DTR trough corresponding to the rainfall peak.

2) There is an average of nine months of rainfall in a year starting in March and ending November with a 41-years average total volume of 2686 mm with double peaks in July (416 mm) and September (387 mm) corresponding to the equinoxes.

3) The lowest average monthly value of DTR is 5.8˚C in August between the period of two rainfall peaks in July and September while the maximum average monthly value of DTR on the two sides of dry season was 10.6˚C in January which corresponded to the least rainfall of 27 mm.

4) There was a short spell of dry season between the two rainfall peaks called "August break" which usually spans about two weeks in Nigeria.

The seasonal plot made by starting the horizontal x-axis with the onset of rainy season in March and ended in February with departure of dry season is shown in Figure 3.

Continuing from the listing of results from above, it can be inferred from Figure 3 that:

5) The season by season pattern of Rainfall and DTR exhibited rough sinusoid with DTR pattern 180 degrees out of phase with the Rainfall pattern, due to the inverse relationship between DTR and rainfall - an increase in rainfall leads to a decrease in DTR and vice versa.

6) In the rainy season, the peak period of rainfall coincided with the trough of DTR and in the dry season, the peak value of DTR coincides with the trough of rainfall.

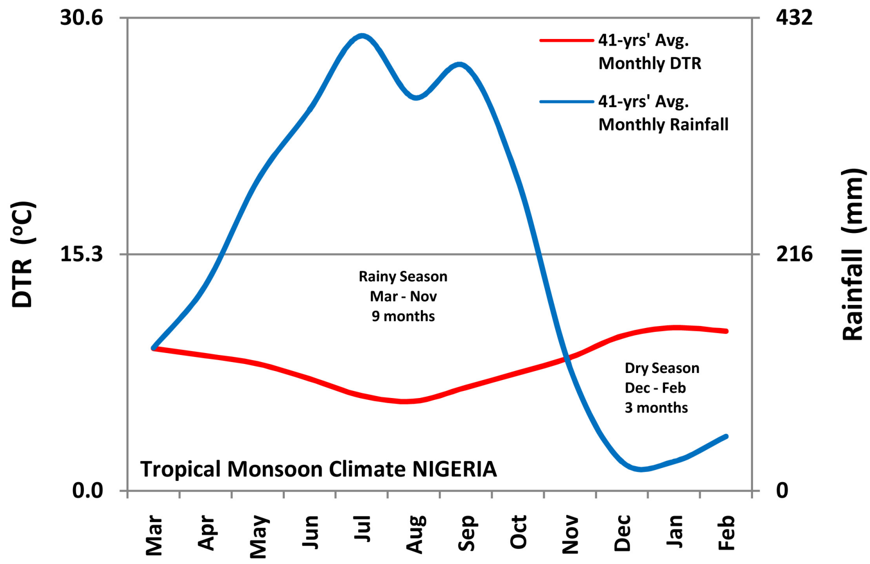


**Figure 3.** Seasonal plot of 41-Years' (1981-2021) average monthly DTR and rainfall tropical monsoon climate, NIGERIA.

7) The intersection of the two graphs marks the departure of one season and onset of another, in this case, cessation of rainy season and onset of dry season.

8) Each half cycle of the rough sinusoid represents a season – dry or rainy season.

For the reason that rainfall is characterized by thick rain cloud cover while dry season, in contrast is characterized by clear skies, the plot above also showed the influence of (rain) cloud cover, subsequent precipitation and increases in soil moisture on DTR and proved that an increase in these factors leads to a decrease in DTR. This underpins the fact that DTR in the tropical monsoon climate is season forcing.

To further investigate this assertion the seasonality of DTR, the comparison and difference plot of DTR in 1981 and 2021 (four decades apart) was made and is shown in **Figure 4**, while that for rainfall is shown in **Figure 5**.

It is evident from **Figure 4** (and continuing with the listing of results from above) that:

9) The patterns of DTR in 1981 and in 2021 are similar, notwithstanding the 41 years gap and also similar to the 41-years average juxtaposed in the plot (which was described in item (2) above), which implied that the DTR pattern was a response to the season at any given time or year, but the magnitude of the values depended on climate change.

10) The lowest average monthly value of DTR in 1981 was 5.4˚C in August and 6.5˚C also in August 2021, while it was 5.8˚C in August for the 41-years' average monthly lowest value of DTR.

11) The maximum value of DTR was 10.2˚C in February 1981 and 11.4˚C also in February 2021 while the 41-years average maximum value was 10.6˚C in January.

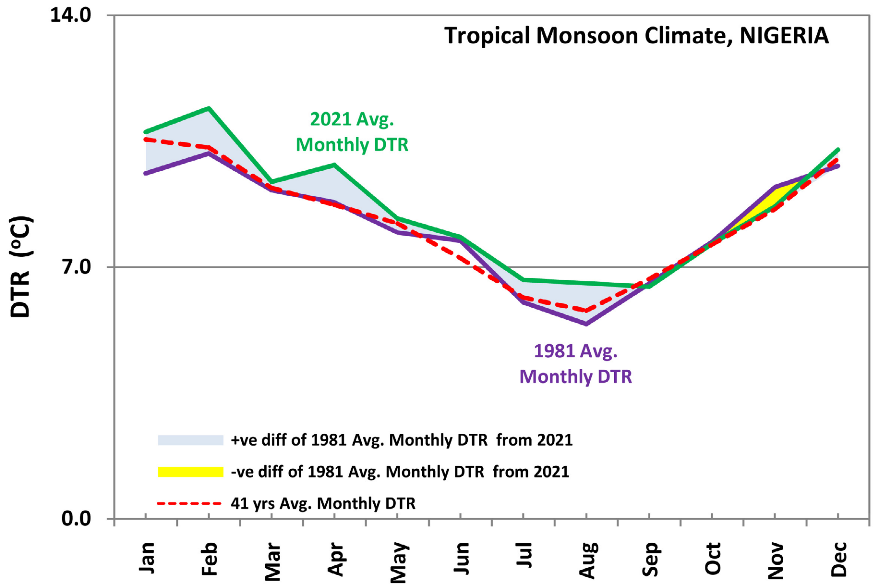


**Figure 4.** Comparison of pattern and difference plot of 1981 DTR and 2021 DTR, tropical monsoon climatic zone, NIGERIA.

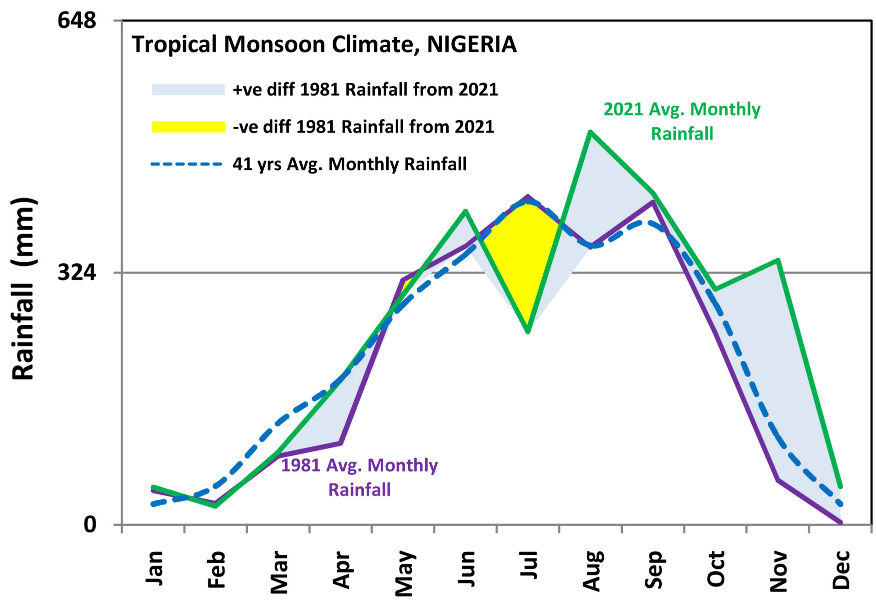


**Figure 5.** Comparison of rainfall pattern and difference plot of 1981 and 2021 rainfall, tropical monsoon climatic zone, NIGERIA.

12) There is no broad difference in the DTRs of 1981 and 2021 and even with the 41 years' average. The tolerance is about ±0.5˚C from the 41 years' average monthly average DTR. The differences seen in the values are due to variations in rainfall pattern which in itself is usually affected by climate change as shown in Figure 5.

In a similar fashion, the comparison and difference plots for the 1981 and 2021 rainfall are shown in Figure 5, with the 41-years average monthly rainfall juxtaposed.

Continuing with the listing of results from above, the result from Figure 7 showed that;

13) The patterns of Rainfall in 1981 and in 2021, a lapse of four decades are similar in shape as described in (2) above which is a response to the season at hand but the volume of rainfall varied due to climate change as there is evidence of heavy downpour in 2021 with possible flooding.

14) The average annual rainfall volume was 2439 mm in 1981 and 2922 mm in 2021 while the 41 years average annual rainfall was 2610 mm.

15) During the rainy season, the maximum volume of average monthly rainfall recorded in 1981 was 422 mm in July compared to 504 mm in August 2021 while the 41-years' average monthly rainfall peaked in July with 415 mm.

It is inferred that the dry and rainy seasons still prevailed in tropical monsoon climatic zone of Nigeria within the four decades studied. The differences observed in the onset, intensity, and departure of the events observed within them is as a result of climate change.

These analyses for the tropical monsoon climatic zone of Nigeria were repeated for the Tropical Savannah and Semi-Arid Steppe climatic zones, as there was no tropical rainforest and arid desert climatic zone specific data available for analysis at the time of publishing. The results are presented below with graphical plots shown from Figures 6-13.

### 4.2. Tropical Savannah Climate Zone, NIGERIA

The general yearly response of DTR to rainfall in the tropical savannah climate is shown in Figure 6 and the results are summarized as follows:

1) The value of DTR in January was high but decreased as the rainy season

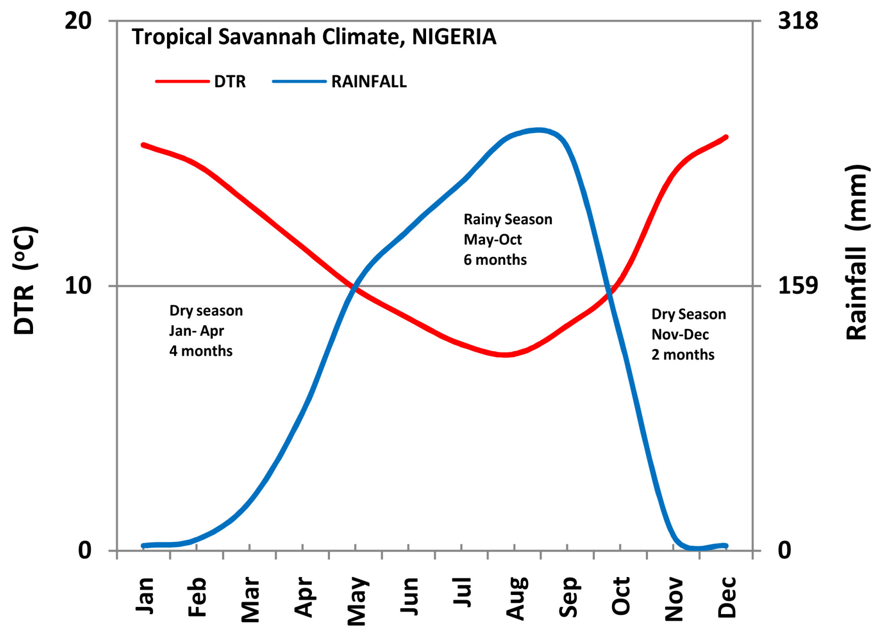


Figure 6. 41-Years' (1981-2021) average monthly DTR vs. rainfall, tropical savannah climatic zone NIGERIA.

approached and increased as the rainy season departed ushering-in the dry season. This resulted to the rough parabolic pattern of DTR and an equally rough but inverted parabolic pattern of rainfall.

2) The DTR trough or least value corresponds to the rainfall peak period while the highest value (peak) of DTR occurs at least or no rainfall (rainfall trough).

3) There was an average of six months rainfall starting in May and ending in October with a 41-years' average volume of 1327 mm, which peaked in August with 247 mm of rainfall. These values are less compared to those obtained from the tropical monsoon climatic zone of the south of Nigeria.

4) The lowest 41-years' average monthly DTR is 7.4˚C in August corresponding to the rainfall peak of 247 mm while the maximum DTR during the dry season was 15.6˚C in December corresponding to a little or no rainfall of 2.9 mm.

5) There was no double rainfall peaks in the central part of Nigeria with a tropical savannah climate as experienced in the tropical monsoon climate of the south.

The seasonal plot of the response of DTR to rainfall is shown in Figure 7 where the horizontal axis started with the onset of rainy season in April and ended with departure of dry season in March.

Continuing with the listing of results from above, it can further be inferred from Figure 7 that:

6) the season on season pattern of Rainfall and DTR exhibited rough sinusoids with DTR pattern been 180 degrees out of phase with Rainfall, which is due to the inverse relationship between DTR and rainfall (an increase in rainfall led to a decrease in DTR and vice versa).

7) In the rainy season, the peak of rainfall coincided with the trough of DTR and in the dry season, the peak value of DTR coincides with the trough of rainfall.

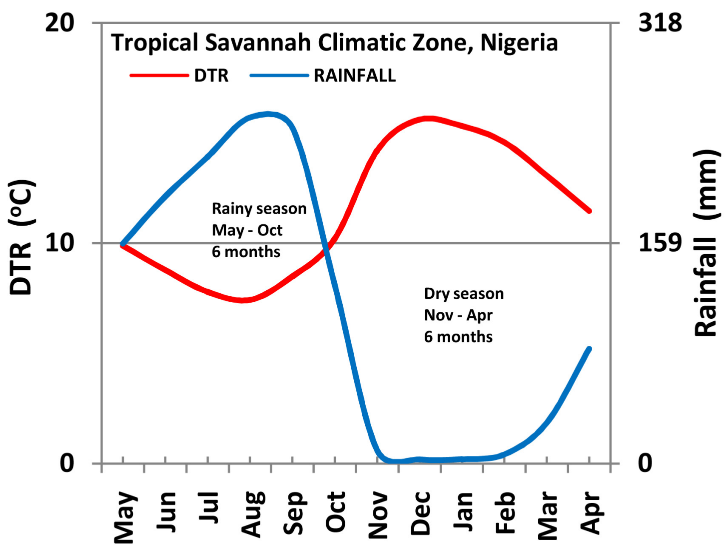


Figure 7. Seasonal plot of Years' (1982-2021) average monthly DTR and rainfall, Tropical savannah climatic zone, NIGERIA.

8) The intersection marks the departure of rainy season and onset of dry season.

9) Each half cycle of the rough sinusoid represents a season – rainy and dry season.

10) The 41 years' average highest peak rainfall was 247 mm in August which corresponded with the lowest DTR value of 4.4˚C also in August while the highest DTR of 15.6˚C occurred in December with a corresponding low rainfall of 29 mm in December.

Rainfall is characterized by thick rain cloud cover while dry season, in contrast is characterized by clear skies. Rainfall also increases soil moisture content. The two plots above therefore indirectly showed the influence of rain cloud cover, precipitation and soil moisture on DTR and proved that an increase in these factors leads to a decrease in DTR and vice versa. It further reinforced the result that DTR in Tropical Savannah climatic zone is season forcing. To further underpin the above results, the Comparison of the patterns of DTR and Difference plot between 1981 and 2021 DTR are shown in Figure 8.

Continuing with the listing of results for the Tropical savannah from above, the results from Figure 8 are summarized below:

11) The patterns of DTR in 1981 and in 2021 are similar as described in item (2) above implying that it is season forcing but climate change affected the magnitudes.

12) In the rainy season, the lowest value of average monthly DTR in 1981 was 6.8˚C in July compared to 7.2˚C also in July 2021 while the 41-years' average was 7.4˚C in August.

13) In the dry season, the maximum value of average monthly DTR was

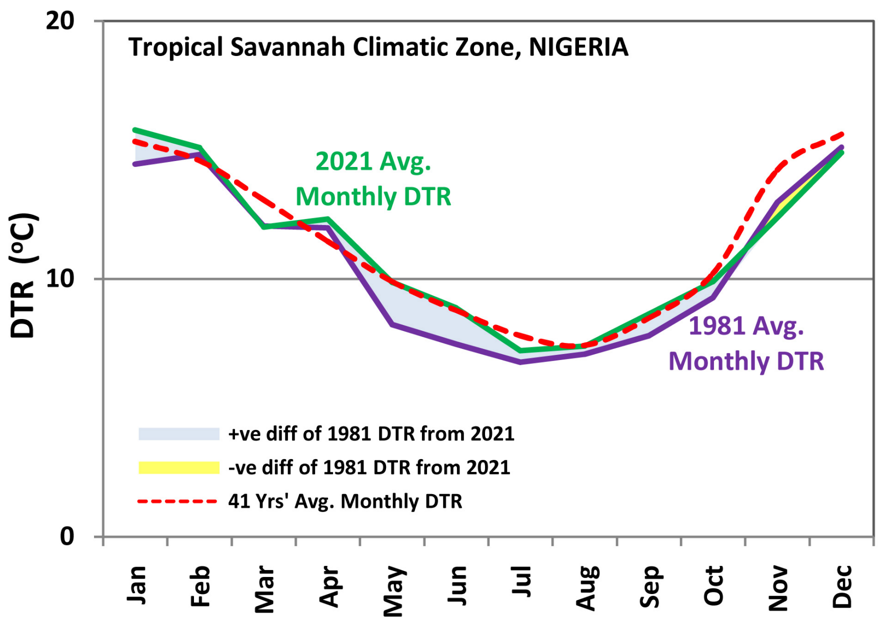


Figure 8. Comparison of DTR pattern and difference plot of 1981 and 2021 DTRs, Tropical savannah climatic zone, NIGERIA.

15.1˚C in December 1981 and 15.8˚C in January 2021 while the 41-year maximum average value was 15.6˚C in January.

From the foregoing, it is deduced that there is no broad difference in the DTR of 1981 and 2021, a difference of 0.4˚C, and also with the 41 years' average. The differences seen are due to climate change that affected the duration and intensity of rainfall which also affected DTR. This reinforced the opinion that DTR in the Tropical Savannah Climatic zone of Nigeria is season dependent or season forcing.

In a similar fashion, the comparison of patterns of rainfall and difference plot between 1981 and 2021 rainfall for the Tropical Savannah climatic zone is shown in Figure 9.

The results from Figure 9 (and continuing with the listing of results) are summarized thus:

14) The patterns of Rainfall in 1981 and in 2021, a lapse of four decade are similar as described in item (2) above which is a response to the season at hand but the differences in the volumes of rainfall were due to climate change. The total average annual volume was 1336 mm in 1981 compared to 1366 mm in 2021 while the 41 years' total annual average rainfall was 1327 mm, all figures within same range.

15) During the rainy season, the 1981 average monthly peak rainfall was 267 mm in September compared to 262 mm also in September recorded in 2021 while the 41-year average had a peak in August of 250 mm.

16) In comparison with the tropical monsoon, it is observed that the volume of rainfall is higher in the tropical monsoon than in the tropical savannah but conversely, the values of DTR is lower in the tropical monsoon than in the tropical savannah, implying that in the northward direction, rainfall decreases but

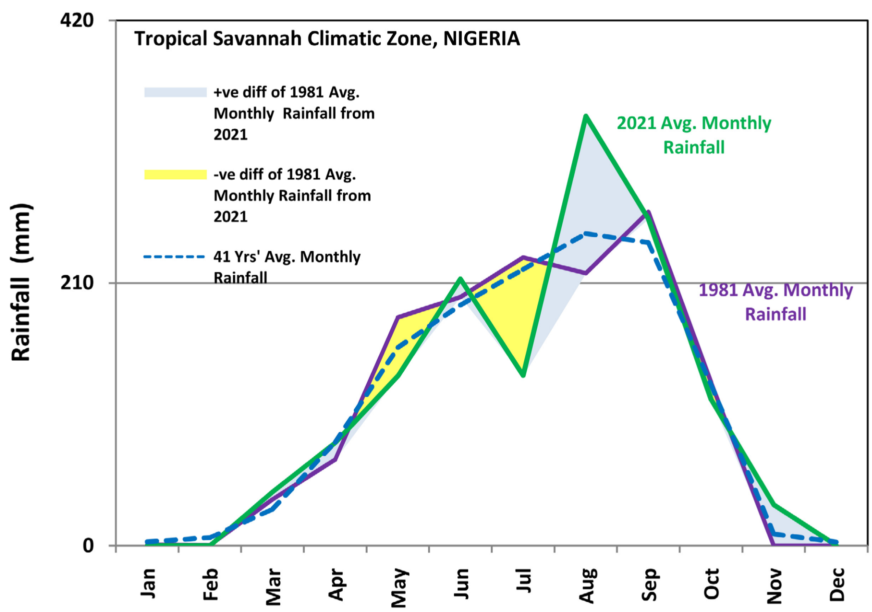


Figure 9. Comparison of rainfall pattern and difference plot of 1981 and 2021 Rainfall, Tropical savannah climatic zone, NIGERIA.

DTR increases.

It can be inferred that the dry and rainy seasons still prevailed in tropical savannah climatic zone of Nigeria within the four decades studied. The differences in the onset, intensity and departure of the events within them were due to the impacts of climate change.

### 4.3. Semi-Arid (Steppe) Climatic Zone, NIGERIA

The yearly average response of DTR to rainfall is shown in the plot of Figure 10 for the 41-years' average monthly of DTR and Rainfall.

From Figure 10, the results are summarized as follows;

1) The inverse relationship between DTR and rainfall is obvious with a decrease in DTR associated with an increase in rainfall, leading to a u-shaped curve (parabola) of DTR pattern and down facing inverted parabolic curve for the Rainfall pattern, where the trough of the DTR corresponds to the peak in rainfall.

2) There was an average of four months of rainfall starting in June and ending in September with a peak average monthly rainfall of 234 mm in August and a 41-years' average total volume of 726 mm. These values are far less than those obtained from the Tropical monsoon climatic zones for the reason of its proximity to the desert while the tropical monsoon is proximate to the coast, delta and rainforest.

3) The lowest average monthly DTR is 8.2˚C in August and the maximum average monthly volume of rainfall is 234 mm also in August while maximum average monthly DTR is 16.6˚C in November corresponding to the minimum average monthly volume of rainfall is 0.1 mm also in November.

4) There was no "August Break" in the Semi-Arid climatic zone as expected.

The seasonal plot for the 41-years' average of monthly DTR versus Rainfall is

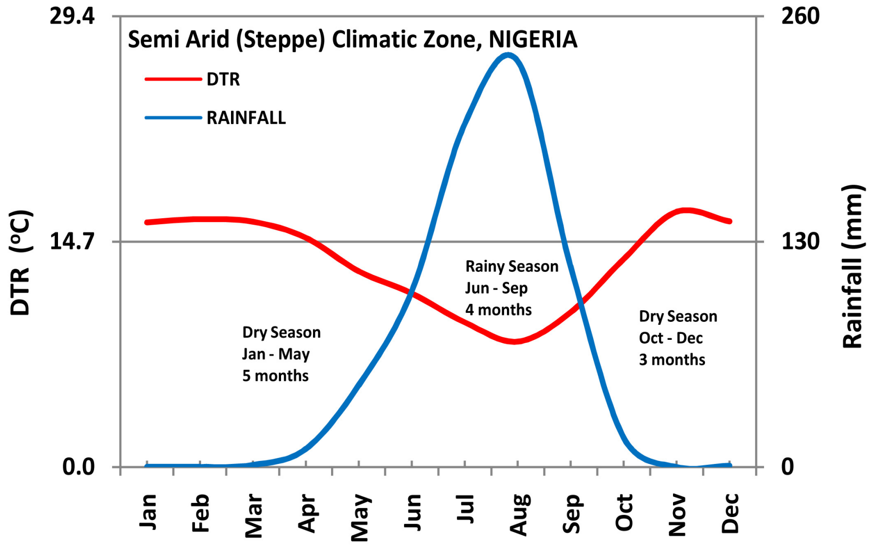


Figure 10. 41-Years' average monthly DTR vs. 41-Years' average monthly rainfall. Semi-Arid climatic zone, NIGERIA.

shown in Figure 11 with the time x-axis starting with the onset of rainy season in June.

It is inferred from Figure 11 (and continuing with the numbering from above) that;

5) The season on season pattern of Rainfall and DTR exhibited roughly shaped sinusoids with the DTR pattern been 180 degrees out of phase with Rainfall, which is due to the inverse relationship between DTR and rainfall (viz., an increase in rainfall leads to a decrease in DTR and vice versa).

6) In the rainy season, the peak of rainfall coincided with the trough of DTR and in the dry season, the peak value of DTR coincides with the trough of rainfall.

7) The intersection of the two plots marked the departure of rainy season and onset of dry season.

8) Each half cycle of the rough sinusoid represents a season – rainy or dry season.

9) The 41-years' average monthly rainfall peaked in August with of 234 mm of rain with a corresponding lowest 41 years' average monthly DTR of 8.2˚C also in August while the highest DTR of 16.6˚C occurred in November with a corresponding lowest rainfall of 0.1 mm.

10) Rainfall is mostly preceded by thick rain-cloud cover while dry season in contrast is characterized by clear skies. Soil moisture increases with precipitation The plot of Figure 11 therefore showed the influence of cloud cover, precipitation and soil moisture on DTR (since thick rain cloud cover is associated with rainfall) and proved that an increase in those factors leads to a decrease in DTR and vice versa.

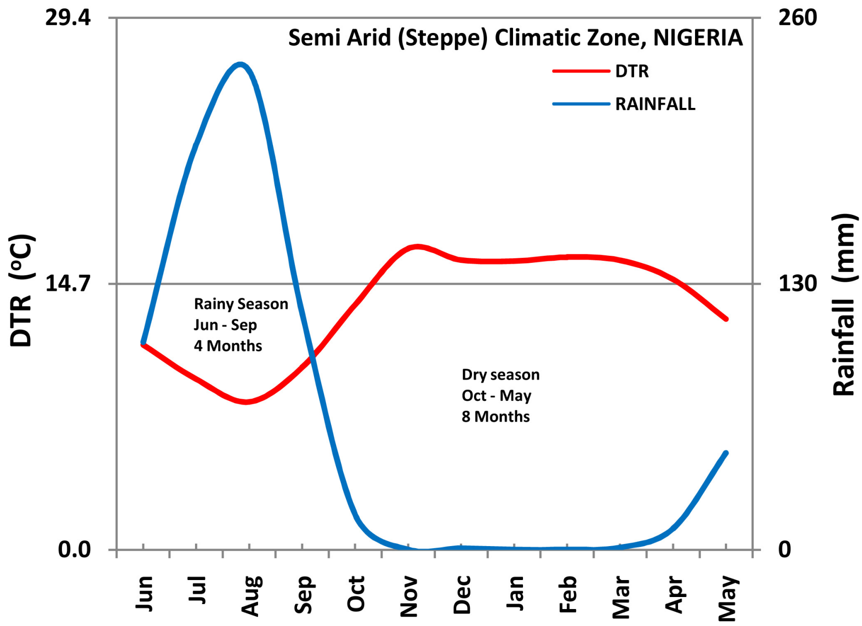


Figure 11. Seasonal plot of 41-Years' average monthly DTR and rainfall (1981-2021), Semi-Arid (steppe) climatic zone, NIGERIA.

To reinforce the seasonal dependence of DTR, further comparisons were made between the DTR of 1981 and 2021 and Rainfall patterns of 1981 and 2021 to underpin the above results.

The results are shown in Figure 12 and Figure 13.

Continuing with the listing of results from above, the results from Figure 12 are summarized below:

11) The patterns of DTR in 1981 and in 2021, four decades apart are similar as described in item (2) above implying that DTR is season forcing but climate change affected its magnitudes.

12) The lowest average monthly of DTR in 1981 was 10.3˚C in August compared

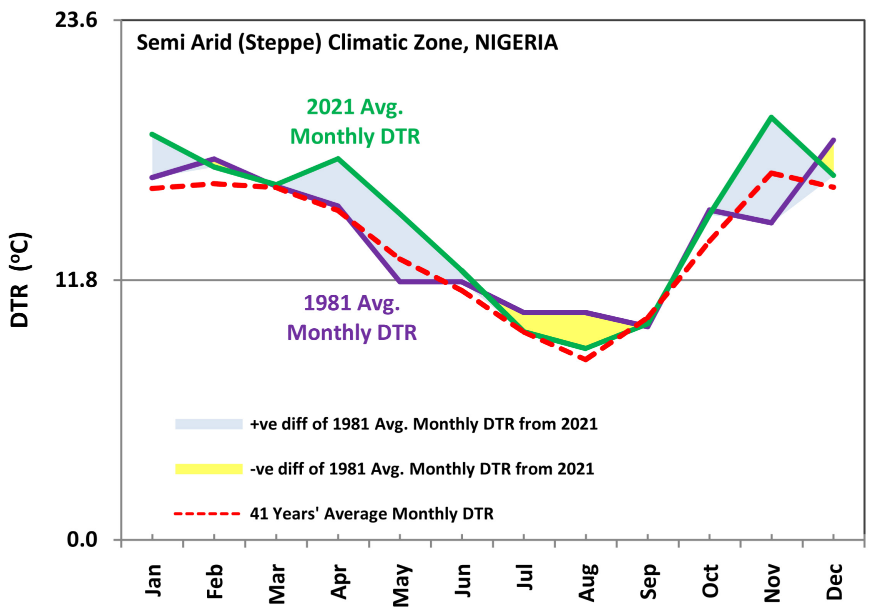


Figure 12. Comparison of DTR pattern and difference plot of 1981 and 2021 DTRs. Semi-Arid (steppe) climatic zone, NIGERIA.

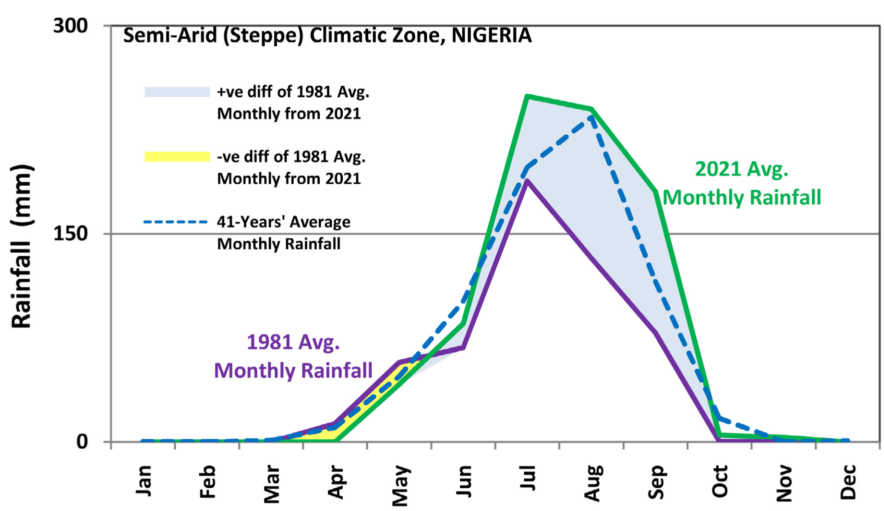


Figure 13. Comparison of pattern and difference plot of 1981 and 2021 average monthly rainfall, Semi-Arid (steppe) climatic zone, Nigeria.

to 8.7˚C also in August 2021 while the lowest 41-years' average monthly DTR was 8.2˚C in August, all during the peak of rainy season as **Figure 13** will show.

13) In the dry season, the maximum average monthly DTR was 18.2˚C in December 1981 and 19.2˚C in November 2021 while the 41-years' maximum average monthly DTR was 16.4˚C in November.

14) From the foregoing, the patterns of DTR are the same, four decades apart and even with the 41 years' average, implying the seasonality of DTR. The differences in the magnitude of the values of DTR were due to climate change that affected the duration and intensity of rainfall and by extension the cloud cover, precipitation and soil moisture.

In similar fashion, the comparison of rainfall patterns and difference plot for 1981 and 2021 rainfall is shown in **Figure 13** for the semi-arid (steppe) climatic zone of Nigeria.

From **Figure 13** and continuing the listing of results from above, the results are as follows:

15) The patterns of Rainfall in 1981 and in 2021, a lapse of four decade are similar as described in item (2) above which is a response to the season at hand. However, the differences observed in the volumes of rainfall were due to climate change, with the total average annual volume of 537 mm in 1981 compared to 804 mm in 2021 while the 41 years' average total rainfall was 726 mm.

16) During the rainy season, the 1981 average monthly rainfall peaked in July with 188 mm compared to the 2021 peak of 249 mm also in July while the 41-years' average had a peak of 234 mm in August.

In comparison with the tropical monsoon climatic zones, it is observed that the volume of rainfall is very much lower while conversely the values of DTR is much higher, confirming that DTR increases in the northward direction while rainfall decreases accordingly.

It can be inferred that the dry and rainy seasons still prevails in the semi-arid (steppe) climatic zone of Nigeria within the four decades studied, but their onset, intensity, departure are impacted by climate change.

## 5. Conclusions

DTR is season forcing in Nigeria irrespective of the climatic zone of any part of the country and the year-on-year and season-upon-season patterns of DTR are the same shape and cyclic due to the cyclic nature of the rainy and dry seasons.

There is an inverse relationship of DTR with rainfall whereby DTR decreases with an increase in rainfall during the rainy season (by extension, increase in cloud cover, precipitation, soil moisture and humidity) and increases with a decrease or no rainfall during the dry season (and by extension, clear skies).

Due to the inverse relationship of DTR with rainfall in each climatic zone, the year-on-year patterns of DTR and rainfall approximate to roughly-shaped parabolas (facing each other), with the DTR trough (lowest value) corresponding to the rainfall peak in the rainy season and DTR peaks/highs coincides with least or no rainfall in the dry season.

Within a climatic zone and also due to the inverse relationship of rainfall with DTR, the season-on-season patterns of rainfall (and correspondingly of DTR) have the same respective shapes which approximate a rough sinusoid with the DTR pattern being 180 degrees out of phase with the rainfall pattern, and each half cycle of the sinusoid represents a (dry or rainy) season while the intersection of the two sinusoids marks the onset of one season and the departure of the other season, and the peaks/trough of DTR corresponds to the troughs/peaks of rainfall respectively.

Amongst the climate zones, DTR value towards the coastal south that experiences intense and longer duration of rainfall with high humidity and vegetal cover is relatively much lower in magnitude compared to the higher DTR values towards the arid North which has sparse and shorter duration of rainfall with dry, less humid and savannah environment.

## Recommendations

Efforts should be geared towards capturing weather data in specific climatic-zones for future research purposes.

More climate studies in specific climatic zones are recommended in order to fully understand the response of climatic zones to climate change.

There should be global effort to improve vegetation is arid and semi-arid land (ASAL) areas to help mitigate climate change.

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## Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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