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# Changes in Diurnal Temperature Range Over Nigeria from 1960 to 2019

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## Abstract

*Diurnal temperature range (DTR) is an important derived variable used in detecting signature of observed climate changes. Understanding its changes in recent time is important for managing and coping with climate change induced risks. This study analysed the long term trend and abrupt changes in diurnal temperature range over Nigeria from 1960 to 2019. Descriptive statistics, Mann-Kendall trend test, Sen's slope and Pettit's tests were used to assess the characteristics, trend, abrupt change and significance in annual DTR time series. Pearson correlation was used to examine the spatial relationship between DTR and minimum temperature, maximum temperature, precipitation and cloud cover. Results showed that mean DTR amount varied across spatio-temporal scales with steady increase from the coastal region, coupled with a weak inter-annual variability (CV < 3%). The trend analysis showed a significant decreasing DTR in most grid points (GP) and regions of Nigeria, with the exception of Enugu, Ado-Ekiti and Warri. Also a significant negative trend was observed at the Guinea, Sudan and Sahel savanna regions. Abrupt changes occurred in the 1970s in the entire regions and most of the GPs with Ado-Ekiti, Calabar, and Enugu occurred in 1991 while Maiduguri and Jos experienced such changes in 2011. Furthermore, significant abrupt changes were observed at the following GPs and regions; Ikeja, Kaduna, Kano, Katsina, Sokoto, Yelwa, Yola, Guinea, Sudan and Sahel Savannas. This decrease in DTR over most of the GP and the entire region indicate that the climate of Nigeria is becoming warmer possibly due to environmental changes with precipitation and cloud cover being the major drivers of DTR variability in Nigeria. Thus, proper climate actions should be taken through adaptation and resilient planning for the sustainable development of socio-economic and natural systems.*

**Keywords**: CRU TS v4.04, Climate Change, Diurnal Temperature Range, Trend Analysis, Pettit test, Nigeria

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## INTRODUCTION

Temperature is a basic climatic element that defines the atmospheric condition of a given place as it depicts the degree of hotness or coldness of a particular region. Although, mean temperature is the major variable for such definition, it has been observed that it solely cannot be used to sufficiently analyse the process of climate variability and change (Barkan, Shafir and Alpert, 2020). Owing to this, the diurnal temperature range (DTR) which is a derived variable representing the difference between daytime maximum temperature and night-time minimum temperature is preferred to mean temperature as an indicator of climate change in a region (Karl *et al*., 1991; Braganza *et al*., 2004) and has been used in climatic extremes researches. Also, DTR is used to investigate the counteracting effects of long wave and shortwave radiative forcing, because the diurnal minimum and maximum temperature is closely related to the long wave and short wave radiative flux (Makowski, Wild and Ohmura, 2008).

Based on the various assertions of some researchers, there has been steady decline in DTR globally since the 1950s (Easterling *et al.,* 1997, Price *et al.,* 1999, Dai *et al.,* 1999, Qu *et al.,* 2014, Sun *et al*., 2019). Others (Makovsky *et al.,* 2008; Rhode *et al.,* 2013) found an increasing DTR trend in some locations, while Samba and Nganga (2014) reported insignificant change in DTR in Congo-Brazzaville.

Consequently, several studies tried to establish the mechanisms influencing DTR variability (e.g. Price *et al.,* 1999) at various time scales. Other studies affirmed that the inter-annual variation of DTR responds strongly to forcings from cloud cover (Price *et al.,* 1999; Stone and Weaver, 2003; Xia, 2013; Dike, Lin, Wang and Nnamchi, 2019), soil moisture (Wu, 2010; Dai *et al.,* 1999), precipitation (Shahid, Harun, and Katimon 2012; Dike *et al.,*2019; Sun *et al.,* 2019), relative humidity (Barkan, Shafir and Alpert, 2020), land use changes (Scheitlin and Dixon, 2010), fluctuations in the planetary boundary layer depth (Davy *et al.,* 2017) and atmospheric large scale teleconnections (Wu, 2010).

In contrast to these findings, Easterling *et al.,* (1997) concluded that neither of these factors alone can provide unique explanation to the observed changes in DTR as different regions are affected by different factors.

Changes in DTR has significant relationship to human and ecological health, comfort and on many environmental aspects, especially on water requirement calculation, planting time determination, crop growth and even on human mortality ratio (Battisti and Naylor, 2009; Lim *et al., 2015*). In consonance with these reports, Cao *et al.,* (2009) identified DTR as an independent risk factor for coronary heart disease (CHD) mortality, through its ability to induce additional environmental stress to the human cardiovascular system. In addition, Wang and Shilenje (2017) reported a link between low DTR values with an increase in malaria cases in East Africa. Therefore, this information is very relevant to the health professionals as it serves as an input in their health awareness campaigns, disease preparedness and planning. Due to devastating effects of climate change as observed in different parts of the country which ranges from increased vulnerability to temperature-induced hazards, infrastructural development, policy formulation and implementations, health issues amongst others, there is need to understand DTR in the context of climate change as it will assist in adaptation and resilience planning through purposeful climate actions that will promote sustainable socio-ecological development.

Recently, there is an increasing interest in DTR studies in Nigeria as an important index in extreme climate research (e.g. Benson, Nwokike, Williams, Adedapo and Fred-Ahmadu, 2019;

Gbode *et al.,* 2019; Dike *et al.,* 2019). For example, Benson *et al.,* (2019) reported an increase in DTR in Minna, Jos, Bida, Ilorin and a decrease in Lokoja and Abuja from 1976 to 2008 period, while Dike *et al.,* (2019) examined DTR trend over the Guinea and Sahel regions of Nigeria using station data for the period 1971 to 2013.

Change point analysis has in recent time been used to detect structural changes in historical data such as hydro-meteorological data, economic data, bioinformatics, image analysis, speech recognition and so on (Aminikhanghahi and Cook, 2017). There can also be unexpected, structural changes in time series data properties such as the mean or variance (Sharma, Swayne and Obimbo, 2016). Moazed *et al.,* (2012) noted that analysis of time series without considering the change point may lead to misunderstanding the time series trend. Similarly, analyzing only change point and overlooking trend or vice versa may mislead the calculation (Sharma *et al.*, 2016).

In order to avoid this challenge, analysing both trend and change points leads to an improved understanding and prediction of the historical and future diurnal temperature range. Change points are also known as breakpoints, segmentation, and structural break in statistical literature (Aminikhanghahi and Cook, 2017). Change points seek to answer the following questions: Did a change occur? When did the changes occur? Despite its importance, no study has been conducted on change point detection in DTR over Nigeria.

For this study, a comprehensive analysis was conducted on the characteristics, variability, trend and abrupt changes in DTR at station and climatic regions of Nigeria using CRU TS4.04 gridded data set from 1960 to 2019. This work attempted to (1) investigate the temporal and spatial variations of DTR in 16 GPUs and 5 climatic regions, (2) identify gradual trends and abrupt shifts at various temporal scales (annual) in DTR data series and (3) the spatial association between DTR and other climatic elements such as minimum and maximum temperature (Tmin, Tmax), Precipitation and cloud cover. The findings will advance the understanding of the structural changes in DTR climatology in Nigeria because of its significant influences on human and animal health, energy demand, food security, economic activities and occurrence of extreme events.

## MATERIALS AND METHODS

### The study area

Nigeria is a tropical country located between latitudes 4°N and 14°N and between longitudes 2.8°E and 14.7°E of the Greenwich Meridian. It is bounded to the north by Niger Republic, northeast by Chad, to the east by Republic of Cameroun, Benin Republic to the west and the Gulf of Guinea in the south (Figure 1). It has an area of 923,768 km$^2$ comprising of thirty-six (36) states and a Federal Capital Territory which serves as its administrative capital. The relief of the country comprises generally of highlands and lowlands. The climate is characterized by abundant insolation, high temperatures and with two marked seasons- dry and wet. The country has a projected population of 200,963,599 persons in 2019 (Worldometre, 2020), with a population density of 221 person per square kilometre and an urban population of 102,805,995 accounting for 51.2 % of the total population. The country's share of world population is 2.61 % with a median age of 18.1 years (Worldometre, 2020). This shows that the country has more of young people with increasing urban population.

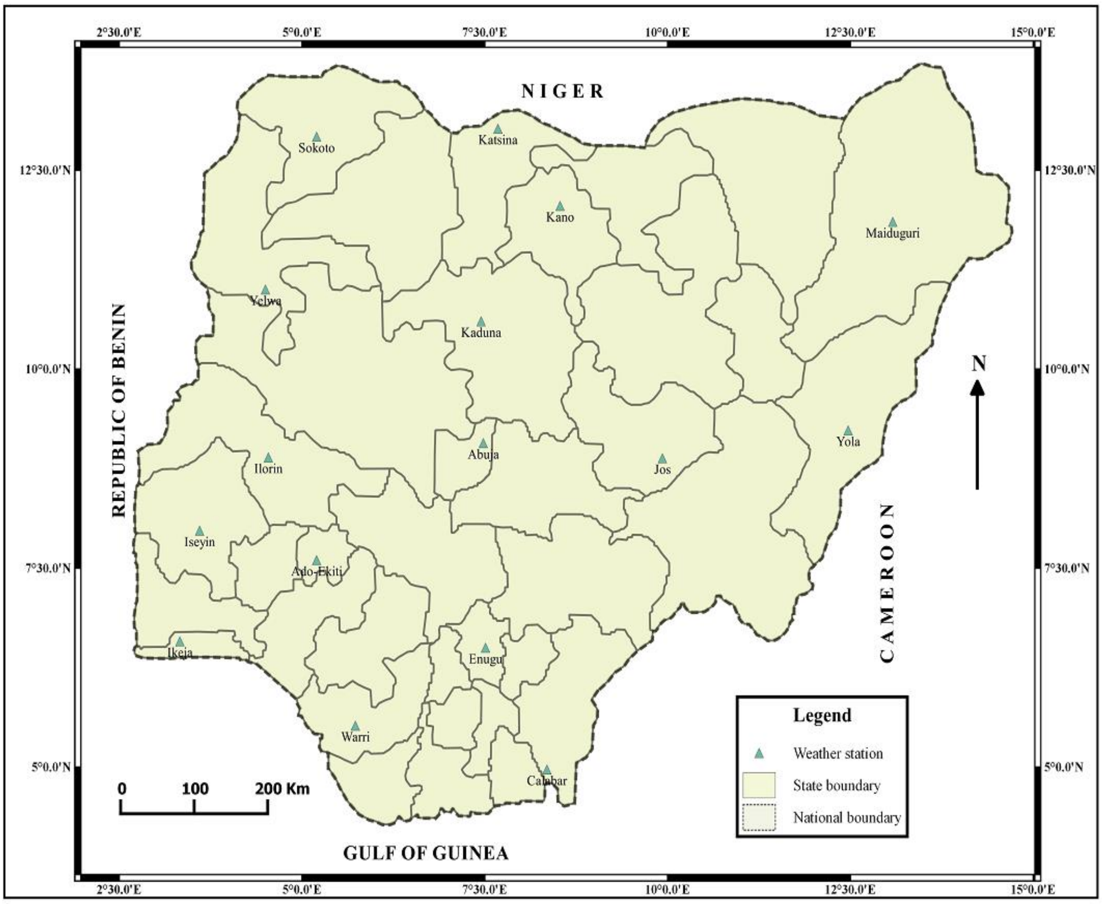


Figure 1: Nigeria showing the selected weather stations / grid points

**Source of data**

The analysis is based on widely used minimum and maximum temperature, precipitation, cloud cover fractions and DTR data from the Climatic Research Unit (CRU TS4.04). The gridded Time-series (TS) data version 4.04 data are month-by-month variations in climate over the period 1901-2019, provided on high-resolution (0.5 x 0.5 degree) grids (Harris, Jones and Osborn, 2020). The CRU TS4.04 data were produced using angular-distance weighting (ADW) interpolation. CRU DTR data has been used in several DTR studies (e.g. Lauritsen and Rogers, 2012; Ionita *et al.,* 2012; Wang and Shilenje 2017; Ongoma *et al.,* 2020). The minimum and maximum temperature, precipitation and cloud cover fractions were used to ascertain the relationship between DTR and these factors. We considered the 1960–2019 period which has been reported to depict significant changes in earth's climate due to anthropogenic induced global warming (Intergovernmental Panel on Climate Change (IPCC), 2013) in addition to generally improved observations.

**Data analysis**

DTR for sixteen grid points (GP) corresponding to sixteen weather stations in five climatic regions reported by Akinsanola and Ogunjobi (2014) were extracted and used for the analysis (Table 1).

**Table 1: Grid points of stations and their corresponding climatic regions**

| Station (GPs) | Latitude | Longitude | Climatic Region |
|---|---|---|---|
| Calabar | 4.97 | 8.35 | Coastal |
| Ikeja | 6.58 | 3.33 | Coastal |
| Warri | 5.52 | 5.73 | Coastal |
| Ado-Ekiti | 7.6 | 5.2 | Rainforest |
| Enugu | 6.5 | 7.51 | Rainforest |
| Iseyin | 7.97 | 3.6 | Rainforest |
| Abuja | 9.07 | 7.48 | Guinea savanna |
| Ilorin | 8.89 | 4.54 | Guinea savanna |
| Jos | 8.88 | 9.93 | Guinea savanna |
| Kaduna | 10.6 | 7.45 | Guinea savanna |
| Kano | 12.05 | 8.53 | Sudan savanna |
| Yelwa | 11 | 4.5 | Sudan savanna |
| Yola | 9.23 | 12.47 | Sudan savanna |
| Katsina | 13.02 | 7.68 | Sahel savanna |
| Maiduguri | 11.85 | 13.08 | Sahel savanna |
| Sokoto | 12.92 | 5.2 | Sahel savanna |

Descriptive statistics such as the minimum, maximum, mean, standard deviation (SD) of DTR in the different stations were calculated. In addition, the coefficient of variation (CV) was used to determine interannual variability in the DTR time series.

Furthermore, trend analysis was performed to detect gradual changes or tendencies in the time series data. Non parametric Mann–Kendall (MK) test (Mann, 1945; Kendall, 1975) and Sen's slope estimator (Sen, 1968) were used to investigate the direction and magnitude of trends in DTR at the interannual scale in different stations and regions. The 95% confidence level was used to estimate the statistical significance of each of the trend.
The Mann–Kendall test statistics S was calculated using the following equation:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} sign(x_j - x_k) \dots\dots\dots\dots (1)$$

Where xi is the data value at time i, n is the length of the dataset and sign ( ) is the sign function which can be computed as:

$$Sign(x_i - x_j) = \begin{cases} 1 \ if \ (x_i - x_j) > 0 \\ 0 \ if \ (x_i - x_j) = 0 \\ -1 \ if \ (x_i - x_j) < 0 \end{cases} \dots\dots\dots\dots (2)$$

For n > 10, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} & if \ S > 0 \\ 0 & if \ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}} & if \ S<0 \end{cases} \dots\dots\dots\dots\dots (3)$$

Where, Var(S) is the variance of statistic S.
Sen's slope estimator (Sen, 1968) uses the median value over all possible combination of the pairs in a time series for estimation of true slope of a linear trend. The Slope (β) estimator is given as:

$$\beta = median \frac{(X_j - X_i)}{j - i} (k = 1, \dots, N) \dots\dots\dots (4)$$

Where, xj and xi are considered as data values at time j and i (j > i), respectively.

Parametric ordinary least square method was also used to estimate the linear trend in the time series. The simple linear regression model involves a single predictor variable and is written as:

$$Y = \beta 0 + \beta 1x + \varepsilon \dots \dots \dots \dots (5)$$

Where Y is the response or dependent variable (DTR), x is the predictor or independent variable (year), $\beta 0$ and $\beta 1$ are model parameters or regression coefficients that have a physical interpretation as the intercept and slope of a straight line, respectively. The slope $\beta 1$ measures the change in the mean of the response variable y for a unit change in the predictor variable x.

The Non parametric Pettit test (Pettit, 1979) was used to detect a single change-point in the DTR series. It tests the $H_0$: The T variables follow one or more distributions that have the same location parameter (no change), against the alternative $H_1$: a change point exists. It is defined as:

$$K_T = max|U_t, T| \dots \dots \dots \dots (6)$$

Where

$$U_t T = \sum_{i=1}^{t} \sum_{j=t+1}^{T} sign(X_i - X_j) \dots \dots \dots \dots . (7)$$

In addition the Pearson correlation method was used to determine the degree of spatial association between DTR and other meteorological elements identified to exert influence on DTR. They include: minimum temperature, maximum temperature, precipitation and cloud cover.

## RESULTS

### Diurnal temperature range characteristics over Nigeria

#### *Descriptive statistics of DTR climatology at different grid points*

The descriptive statistics of DTR climatology in different stations of Nigeria are depicted in Table 2. Ikeja had the minimum DTR of 7.65°C; while Maiduguri had the maximum of 15.66°C. The mean DTR increased from the coastal station to the Sahelian station with Ikeja and Maiduguri having the lowest (8.25°C) and Highest (15.01°C) mean DTR values respectively. The coefficient of variation showed a distinct pattern across the stations with the highest and lowest variability of 3.68% and 2.16% observed at Warri and Ilorin stations. Two coastal stations; Warri and Ikeja had the highest amount of variability while the Guinea savanna stations of Abuja, Jos and Ilorin had the least of amount of variability at inter-annual basis.

Generally, the standard deviation showed deviations from 0.22 °C to 0.44°C across the 16 GPUs. However, it was observed that greater deviation occurred at the Sahel savanna GPUs of Sokoto, Katsina and Maiduguri, while Calabar, Ilorin and Abuja had the lowest amount of deviation from the mean.

**Table 2: Descriptive statistics of DTR in the Nigerian stations**

| Station | Minimum (°C) | Maximum (°C) | Mean (°C) | STD (°C) | CV (%) |
|---|---|---|---|---|---|
| Abuja | 10.48 | 11.65 | 11.14 | 0.25 | 2.24 |
| Ado-Ekiti | 9.24 | 10.48 | 9.79 | 0.28 | 2.86 |
| Calabar | 7.83 | 8.98 | 8.51 | 0.22 | 2.59 |
| Enugu | 8.81 | 10.13 | 9.46 | 0.27 | 2.85 |
| Ikeja | 7.65 | 9.03 | 8.25 | 0.27 | 3.27 |
| Ilorin | 10.51 | 11.62 | 11.10 | 0.24 | 2.16 |
| Iseyin | 9.16 | 10.51 | 9.77 | 0.27 | 2.76 |
| Jos | 10.84 | 12.29 | 11.62 | 0.28 | 2.41 |
| Kaduna | 11.78 | 12.94 | 12.36 | 0.29 | 2.35 |
| Kano | 12.91 | 14.48 | 13.77 | 0.37 | 2.69 |
| Katsina | 13.53 | 15.51 | 14.49 | 0.43 | 2.97 |
| Maiduguri | 13.98 | 15.66 | 15.01 | 0.40 | 2.66 |
| Sokoto | 12.68 | 14.54 | 13.55 | 0.44 | 3.25 |
| Warri | 7.71 | 9.07 | 8.27 | 0.30 | 3.63 |
| Yelwa | 11.76 | 13.10 | 12.45 | 0.33 | 2.65 |
| Yola | 11.66 | 13.49 | 12.79 | 0.38 | 2.97 |

***DTR characteristics at different climatic regions***

Table 3 shows the DTR characteristics at the various climatic regions. On the average, DTR increased from the coast to the Sahel savanna region. The coastal and Guinea savanna region had the highest and lowest variability of 2.99 % and 2.08% respectively. The Sahel region had the highest deviation from the mean.

**Table 3: Descriptive characteristics of DTR at different climatic regions of Nigeria**

| Regions | Minimum (°C) | Maximum (°C) | Mean (°C) | STD (°C) | CV (%) |
|---|---|---|---|---|---|
| Coastal | 7.86 | 9.02 | 8.35 | 0.25 | 2.99 |
| Rainforest | 9.16 | 10.37 | 9.67 | 0.26 | 2.69 |
| Guinea | 10.93 | 12.00 | 11.55 | 0.24 | 2.08 |
| Sudan | 12.31 | 13.57 | 13.00 | 0.31 | 2.38 |
| Sahel | 13.45 | 15.10 | 14.35 | 0.36 | 2.51 |

The difference between the coastal region and the others was very evident, as its DTR mean values were considerably smaller than that of other regions.

**Trend in diurnal temperature range over Nigeria**

Table 4 presents DTR trend and its significance for all GPs and regions. It was observed that almost all the GPs experienced a decrease in amount of DTR except Ado-Ekiti, Warri, Enugu, Calabar and Maiduguri where a zero trend was recorded. Similar results were obtained when we used the ordinary least square method with slight variations in some GPUs. We further examined the significance of the obtained trend at 95% confidence level. The following stations; Yelwa, Sokoto, Kaduna, Kano, Katsina, Jos, Abuja, Yola and Ilorin recorded significant changes in the inter-annual values of DTR. However, no change was observed in Iseyin, Ikeja, Warri, Calabar, Enugu, Maiduguri and Ado-Ekiti.

**Table 4: Parametric and non Parametric trend test for diurnal temperature range in different GPs and climatic regions of Nigeria (1960– 2019)**

| Station/Region | OLS | Sen's slope | Z value | MK (Tau) | P value |
|---|---|---|---|---|---|
| Abuja | -0.004 | -0.005 | -2.438 | -0.218 | 0.015* |
| Ado-Ekiti | 0.001 | 0.000 | 0.038 | 0.004 | 0.969 |
| Calabar | 0.000 | 0.000 | -0.249 | -0.023 | 0.803 |
| Enugu | 0.000 | 0.000 | -0.230 | -0.021 | 0.818 |
| Ikeja | -0.002 | -0.003 | -1.372 | -0.123 | 0.170 |
| Ilorin | -0.003 | -0.003 | -1.813 | -0.162 | 0.070 |
| Iseyin | -0.002 | -0.003 | -1.512 | -0.135 | 0.130 |
| Jos | -0.007 | -0.006 | -2.795 | -0.250 | 0.005* |
| Kaduna | -0.007 | -0.008 | -3.120 | -0.278 | 0.002* |
| Kano | -0.008 | -0.008 | -2.935 | -0.261 | 0.003* |
| Katsina | -0.010 | -0.010 | -2.935 | -0.262 | 0.003* |
| Maiduguri | -0.001 | 0.000 | 0.153 | 0.014 | 0.878 |
| Sokoto | -0.013 | -0.013 | -3.821 | -0.340 | 0.000* |
| Warri | 0.000 | 0.000 | -0.262 | -0.024 | 0.794 |
| Yelwa | -0.010 | -0.011 | -4.453 | -0.396 | 0.000* |
| Yola | -0.008 | -0.006 | -2.208 | -0.197 | 0.027* |
| Coastal | -0.001 | -0.001 | -0.753 | -0.068 | 0.451 |
| Guinea | 0.000 | -0.006 | -2.935 | -0.262 | 0.003* |
| Rainforest | -0.005 | -0.001 | -0.657 | -0.059 | 0.511 |
| Sudan | -0.009 | -0.009 | -4.121 | -0.366 | 0.000* |
| Sahel | -0.008 | -0.008 | -3.350 | -0.299 | 0.001* |

*Signifies trends that are statistically significant at the 95% confidence level.

Furthermore, at the regional level, decrease in DTR was observed in all the regions. Nevertheless, only the Guinea, Sudan and Sahel savanna regions recorded a significant decrease.

**Change point analysis of DTR over Nigerian stations and regions**

The position of a possible change point and its significance across the different stations and regions in Nigeria is shown in Table 5. Changes in DTR series were observed in the following years; 1973 (7), 1974 (1), 1975 (7), 1991 (3), 2009 (1) and 2011 (2). Furthermore, statistically significant changes were observed in the following stations and regions; Ikeja, Kaduna, Kano, Katsina, Sokoto, Yelwa, Yola, Guinea savanna, Sudan savanna and Sahel savanna. Most of the significant changes occurred in the 1970s.

**Table 5. Petitt test estimated change point (year of CP) and their P values**

| Station/Region | Year of Change Point | P value | Remark |
|---|---|---|---|
| **Abuja** | 1974 | 0.1767 | Insignificant change |
| **Ado-Ekiti** | 1991 | 0.4954 | Insignificant change |
| **Calabar** | 1991 | 0.7693 | Insignificant change |
| **Enugu** | 1991 | 0.5723 | Insignificant change |
| **Ikeja** | 1975 | 0.03202* | Significant change |
| **Ilorin** | 1975 | 0.1916 | Insignificant change |
| **Iseyin** | 1975 | 0.07174 | Insignificant change |
| **Jos** | 2011 | 0.09491 | Insignificant change |
| **Kaduna** | 1973 | 0.0008268* | Significant change |
| **Kano** | 1973 | 0.0002039* | Significant change |
| **Katsina** | 1973 | 0.00009074* | Significant change |
| **Maiduguri** | 2011 | 0.1002 | Insignificant change |
| **Sokoto** | 1973 | 0.00006724* | Significant change |
| **Warri** | 1975 | 0.3676 | Insignificant change |
| **Yelwa** | 1975 | 0.00003771* | Significant change |
| **Yola** | 2009 | 0.03271* | Significant change |
| **Coastal** | 1975 | 0.2312 | Insignificant change |
| **Guinea** | 1973 | 0.02365* | Significant change |
| **Rainforest** | 1975 | 0.4311 | Insignificant change |
| **Sudan** | 1973 | 0.0002387* | Significant change |
| **Sahel** | 1973 | 0.0006933* | Significant change |

*Statistically significant at the 95% confidence level.

From Table 5 it can be deduced that significant abrupt change in DTR occurred most at the Sudan and Sahel savanna region while no significant change occurred at the Coastal and Rainforest regions. During the period of this study, despite this wide observation, Ikeja which is a station located within the coastal region experienced a significant abrupt change in DTR series starting from 1973.

**Relationship between DTR and other meteorological elements in Nigeria**

The spatial relationships between DTR and meteorological elements such as minimum temperature, maximum temperature, precipitation and cloud cover are presented in Figures 2a-d. Figure 2(a) shows a weak positive relationship between DTR and Tmin at the coastal stations while towards negative relationship was observed from the Sahel to the Guinea region. However the degree of association became stronger towards the Sahel savanna region and some parts of the Sudan region. In Figure 2(b), there is a general positive almost zonal association between DTR and Tmax. The strongest association occurred at the coastal stations and decreased towards the Sahel. Figure 2(c) shows the relationship between DTR and precipitation, wherein strong negative association ($r > -0.7$) was observed over most parts of Nigeria. The relationship between DTR and cloud cover is shown in Figure 2(d) wherein very strong negative association ($r>-0.8$) was observed within Nigeria.

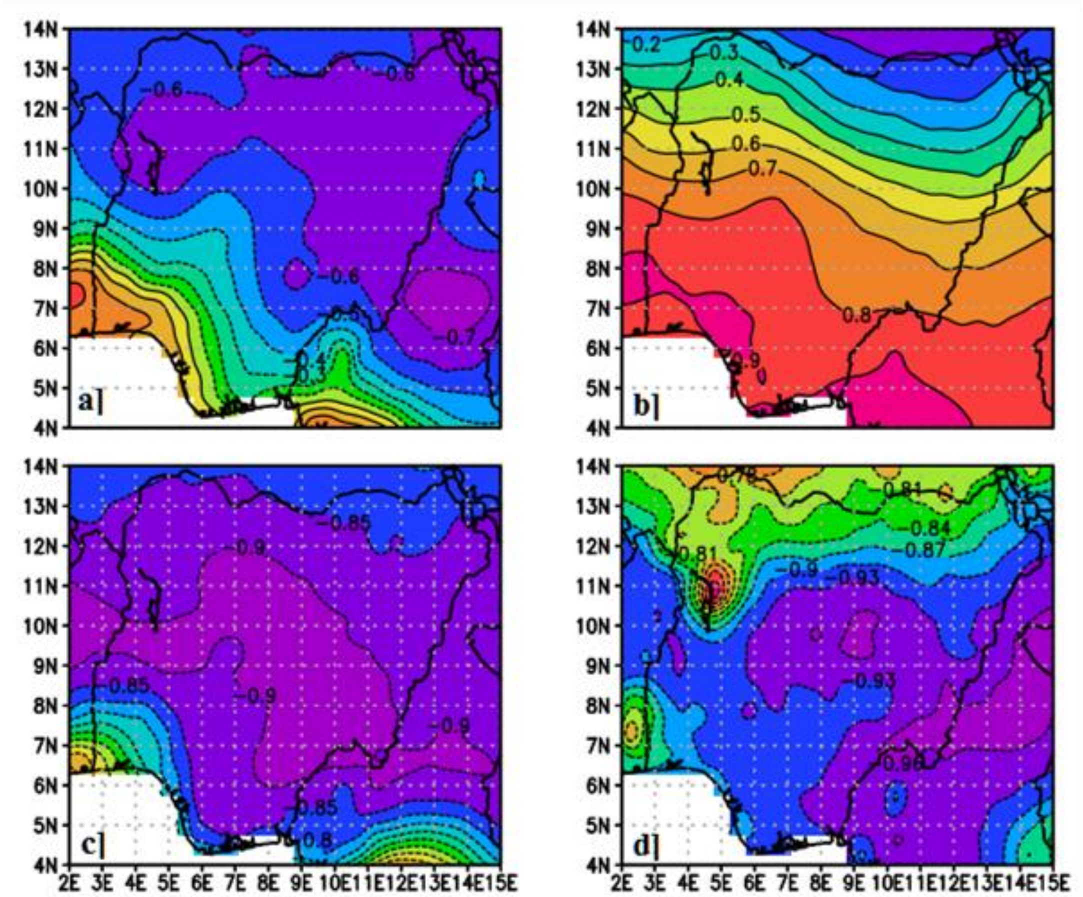


Figure 2: Relationship between DTR and other meteorological elements a] Minimum Temperature, b] Maximum Temperature, c] Precipitation and d] Cloud cover fraction

From Figure 3 above, it can be deduced that precipitation and cloud cover exerted more influence on DTR changes than minimum and maximum temperatures. Although the association between DTR, Tmin and Tmax showed both an inverse positive and negative relationships pattern from the coastal region to the Sahel savanna region with DTR variability in the Sudan-Sahel regions negatively associated with increase in Tmax while a positive relationship was observed between DTR and Tmin at the coastal and rainforest regions. From the above pattern, it can be inferred that the observed changes in the DTR variability over Nigeria reflect the variations in Tmin and Tmax. This is often being moderated by the prevailing condition of cloud cover and precipitation as these two tend to moderate the radiation budget of a given location.

## DISCUSSION

The DTR being an important index for climate change detection (Braganza *et al.*, 2004; Dike *et al.*, 2019) has shown spatial variations across different GPs and climatic regions of Nigeria. DTR variations is characterised by weak interannual variability in most of the GPs and regions especially around the coastal and Guinea savanna regions. The pattern of variability does not follow the distribution in the mean value of DTR in Nigeria. This implies that DTR variations and changes differ from one GP (region) to the other.

Furthermore, the obtained general decrease in DTR trend over Nigeria for the period 1960 to 2019 are consistent with results obtained from other global, regional and national studies (Dai *et al.*, 1997; Braganza *et al.*, 2004; Dike *et al.*, 2019). However, Sun *et al.*, (2019) reported an increasing DTR trend in most parts of Europe and a significantly decreasing trend over the global land surface during the 1901 to 2014 period. Ongoma *et al.,* (2020) reported increase in DTR over Fiji and surrounding Pacific Islands. Braganza *et al.,* (2004) argued that if global warming has been implicated to be responsible for the decrease in global DTR, both Tmax and Tmin should have equally increased due to increasing global warming as predicted by climate models. What this means is that what is driving the observed changes in mean temperature and DTR is actually increase in minimum temperature (Walters *et al.,* 2007; Qu *et al.,* 2014). Although the declining trend of DTR was observed in the entire region with significant warming at all the Savanna regions, the obtained value differed slightly from studies by Dike *et al.,* (2019); Gbode *et al.,* (2019) in Nigeria. Comparatively, Dike et al., (2019) opined that the domain averaged DTR has increased marginally over the Guinea coast at a rate of 0.01°C per decade during the period 1971 to 2013, while Gbode *et al.,* (2019) reported a significant increase (0.007and 0.011°C) over the Guinea and Savanna regions respectively and a decrease of -0.038°C over the Sahel region. The variations observed in studies by these authors may be due to difference in domain delineation, dataset and period applied in their respective studies. This calls for further studies as the contrasting trend signal in DTR over Nigeria. Also, comparism between parametric and non-parametric trend shows that OLS method shows different trend magnitude at Guinea savanna and Rainforest region.

In order to account for the obtained variations in DTR over the different climatic regions of Nigeria, the influences of atmospheric elements (Tmin, Tmax, precipitation and cloud cover) on DTR distribution was examined using correlation analysis. This method has been applied in similar studies (e.g. Dike *et al.,* 2019; Xue *et al.,* 2018; Shahid, *et al.,* 2012). Changes in these elements have been identified as an important driver of observed variations in DTR (Wu, 2010). Cloud cover and precipitation influenced DTR through the differential impact of clouds on radiative balances during the day and night times which resulted in changes in maximum and minimum temperature (Dai *et al.,* 1997; Zhou *et al.,* 2009; Shahid, *et al.,* 2012; Sun *et al.,* 2019). Decrease in DTR has been attributed to increase in minimum temperature rather than maximum temperature, thus contributing to narrow the diurnal temperature range (Easterling, 1997; Walters *et al.,* 2007; Qu *et al.,* 2014).

The association between cloud cover and DTR has widely been recognized (Price *et al.,* 1999; Stone and Weaver, 2003; Xia, 2013; Dike *et al.,* 2019). The spatial correlation between cloud cover and DTR during the study period illustrates a very strong negative association with most parts of Nigeria having a correlation coefficient (R) of -0.8 and above. This implies that the higher the total cloud cover, the less the amount of DTR. Similar result was obtained by Xue et al., 2018 where they opined that the negative correlations suggest that the increase in amount of cloud cover amplifies the radiative flux thereby resulting to a decreasing DTR. This result partially corroborates that of Dike *et al.,* (2019) in the same study area, however we differ in the strength of the correlation between DTR and Precipitation and cloud cover where our result shows a strong negative association. This implies that when DTR is high (low), cloud cover and precipitation are low (high) respectively.

The implication of the decreasing DTR trends on sensitive socio-ecological and socio-economic systems will likely vary across different stations and regions. As areas that rely more on climate sensitive sectors. This is because increase in temperature may have a large bearing on agriculture and water availability besides human health and energy demand. Furthermore, high temperatures are a major constraint to crop productivity, especially when temperature extremes coincide with critical stages of the plant development. This will compound the already vulnerable population (because more than 80% of Nigerian populations are regarded to be living under an extreme poverty condition) as their ability to cope and recover from shocks is limited. It will also aversely lead to depletion of ecosystem capital, as natural resources form the basis for sustainable development of majority of the Nigerian populace. The greatest risk will be its impact on the health of the populace as it will threaten the health of the vulnerable people most significantly the very young and old individuals.

**CONCLUSION**

The aim of this work was to identify the characteristics, variability and trend of DTR over Nigeria using 60 years (1960–2019) data from CRU Ts4.04 gridded datasets. The main findings of our study are summarized as follows. Results obtained in this study have indicated that there was obvious spatial and temporal variation of DTR in Nigeria with significant decrease over large parts of Nigeria during the study period. The regions with significant decrease are the Guinea, Sudan and Sahel savanna. There was a significant change point ($p < 0.05$), mainly during the 1970s in most of the stations and regions particularly over the Savanna climatic region. The changing characteristics, fluctuations and trend in DTR observed during this study have clearly indicated changing climate in Nigeria. Consequently there is need to proactively implement policies that will reduce the vulnerability of socio-ecological systems to the adverse impacts of significant decrease in DTR in most parts of Nigeria especially over the Savanna region. Furthermore, changes in minimum temperature, cloud cover and precipitation have been identified to exert more influence on DTR variability in the study area as other factors either amplified or dampened their effect. The above findings on the changing climate of Nigeria are of significant practical importance for adaptation and resilient planning for the sustainable development of socio-economic and natural systems globally. Based on the findings in this study, studies should be conducted on the impact of DTR variability on socio-ecological systems such as health, agriculture, infrastructure development, governance and planning in Nigeria.

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