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Analyses of Spatial Distribution and Temporal Trends of Temperature and Its Extremes over Nigeria using Climate Indices

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Abstract

Climate change and its associated extreme climate and extreme events are threat to man and his environment. Over the years, climatic parameters have been used as climate change indicators to study climate change. In order to access extreme climate due to climate change in Nigeria, this paper attempt to evaluate spatial distribution and temporal trends of temperature and its extremes over Nigeria for 35 years (1979 - 2013). Daily temperature data used were obtained from the Nigeria Meteorological Agency (NIMET), Lagos. The data was subjected to quality checked and homogenization. Climate extreme indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) was adopted in this study. The data were analysed employing Sen's slope estimator and Mann-Kendall test. Results revealed that spatial distribution of temperature and its extremes over Nigeria varied across the country, increasing/decreasing mostly towards the northern or the coastal regions. Significant increase was observed at $p < 0.05$ in the temporal trends of averages of yearly maximum and minimum temperature and hot temperature indices in all the regions in line with the global warming trend. The increase in warm days and warm nights doubled the rate at which cold days and cold nights decreased in most of the study areas. The annual and decadal changes in temperature and its extremes as well as the period under investigation (35 years) were determined. Our findings depict that the country is trending towards a drier and warmer climate which are clear evidence of climate change. The results further suggest that the Atlantic Ocean and the Sahara Desert which control the atmospheric condition of the country may be promoter of the observed extreme events caused by climate change in Nigeria. This study discussed contemporary issues in our society which are useful to the general populace, researchers, and policy makers among others.

Keywords: Climate indices, Climate change, Global warming, Nigeria, Spatial distribution, Temporal trends

Introduction

One of the major challenges facing the world and developing nations like Nigeria in particular is climate change. The effects of these changes may be more pronounced in this 21st century than ever before due to the increasing reports on the impacts of climate change globally. Climate change is believed to lead to increase in climate variability and in the frequency and intensity of extreme events [1]. Extreme events such as floods, droughts, heat waves, etc. have significant impacts on humanity and the society as a whole. It therefore attracts worldwide attention.

According to the world meteorological organization (WMO), climate extremes are rare meteorological and climatological phenomena that surpass a defined threshold. Climate extremes usually lead to extreme events which fall in the tails of probability distribution of climate parameters like rainfall and temperature [2,3]. Changes in extreme temperature indices due to global warming vary from one place to another and from day to night.

Different researchers have used different temperature and precipitation indices for studying extreme events [4]. The Expert Team on Climate Change Detection and Indices (ETCCDI) has recommended 27 climate indices (for temperature and precipitation) which have been used by several authors [3,5]. The temperature indices defined by the ETCCDI are shown in **Table 1**. See [11,12] for detail on the recommended 27 climate indices.

Several research works have been carried out on variability of temperature [6,7], extreme temperature trends [8], characteristic of extreme temperature [9,10], climate variability, extreme rainfall and temperature events [1,11,12], trends of extreme climate [1,5,13], and extreme weather events [14].

Rehman and Al-Hadhrami [8] reported significant increase in hot days per year and insignificant decrease in hot nights from their study in West Coast of Saudi Arabia. Manton *et al.* [4] also observed significant increase in the annual number of hot days and warm nights with significant decrease in the annual number of cool days and cool nights. They also reported that the frequency of extreme rainfall events has declined. Chen *et al.* [10] had similar results from their study.

Soltani *et al.* [2] noted from their study in Iran from 1995 - 2010 that the rate of annual minimum temperature increased nearly twice the annual maximum temperature over the country (i.e. 0.31 and 0.59 °C/decade, respectively). They also reported that the annual frequency of warm days and warm nights has increased by 12 and 14 days/decade, while the number of cold days and nights has decreased by 4 and 3 days/decade.

The findings of Khan *et al.* [3], using temperature indices show increasing warming trend. Report by the Intergovernmental Pane of Climate Change (IPCC) shows that from 1880 to 2012, the mean global surface temperature has risen by 0.85 °C [10]. Also, between 1901 and 2010, the global average sea level has risen by 19 centimeters. These are evidences that the globe has warmed.

Akande [14] in their work on geospatial analysis of extreme weather events in Nigeria reported high and low precipitation intensity, frequency and duration in region close to the Atlantic Ocean and the Sahara Desert, respectively.

Working on observed changes in climate extremes in Nigeria over 3 climatic zones (Guinea coast, Savannah and Sahel) of the country, Britannica [15] reported significant increase in the number of warm spell, warm days/nights and decrease in cold spell, cold days/nights for the period under study. Despite the numerous works, there is no recent study in this area in Nigeria. Therefore, this study will complement as well as extend the works by earlier researchers by providing more useful information on changes in the characteristic of extreme climate in Nigeria.

Nigeria is located on latitude 4° N and 14° N and longitude 2° E and 15° E in West Africa. The country occupies an approximate area of about 923,770 km^2. It is located about few kilometers to the Atlantic Ocean in the south and to the Sahara Desert in the north. The interplay of the air masses from the Atlantic Ocean and the Sahara Desert greatly influenced the atmospheric conditions of Nigeria. Rainy and dry seasons are the 2 seasons observed in the country. The rainy season decreases progressively from the south to the far northern region. The south, southwest and far north receives about 3,000, 1,800 and 500 mm of rain a year, respectively [16]. In most of the year, the south western region and farther inland are dry while the south eastern region is hot and wet.

The country has experienced several extreme events such as floods, droughts etc almost on a yearly basis; leading to loss of lives and properties [17]. However, most people assumed this as normal re-occurring events in Nigeria. This depicts that there is a knowledge gap between average climate and climate extremes among the general populace in Nigeria. This may be an indication of low climate change perception among the populace, which may implies that studies on climate change and its effects are still limited in Nigeria. Thus, an indication for more researches in this area. Hence, this study is aimed at investigating the spatial distribution and temporal trends of temperature and its extremes over Nigeria from 1979 - 2013 using climate indices.

This study is very significance as it hopes to give information about the extreme climate observed in Nigeria, due to the impact of climate change; thereby increasing the understanding of climate change perception in Nigeria. This study will be useful to climate scientists, policymakers, general populace, system planners, and resource managers; since climate extreme affects agriculture, human's health, energy, water resources, and ecosystem among others. Therefore, the results from this research will interestingly bring more attention to climate change and the associated extreme climate and extreme events in Nigeria.

Materials and methods

Daily maximum and minimum temperature data from 1979 to 2013 (35 years) for 21 meteorological stations located across the country were used for this study (**Figure 1(a)**). This study spanned for 35 years due to limitation in accessing daily temperature data. The data used were the readily available data to the authors. The data were obtained from the Nigeria Meteorological Agency (NIMET), Lagos.

Stations in each zones of Nigeria denoted as northwest (Zone 1), northeast (Zone 2), north central (Zone 3), southwest (Zone 4), southeast (Zone 5), and south-south (Zone 6) were averaged to assess temporal trends of temperature and its extremes in each of the zone shown in **Figure 1(b)**.

RClimDex 1.1 developed by the ETCCDI was employed in data quality control and homogenisation. These datasets was then used in the computation of climate indices developed by the ETCCDI employing RClimDex software [18].

Based on the location of Nigeria, 13 temperature indices were selected for this study. This is because indices such as Frost days (FDo), Ice days (IDo), are removed from the analysis as they are not observed in the country. Non-parametric Sen's slope estimator was used for the estimation of changes in annual temperature and its indices, while Mann-kendall test was employed in assessing significance of the changes based on the recommendation by the World Meteorological Organisation [19]. For the mathematical expression of Sen's slope estimator and Mann-kendall test, see [10] for more information. The statistical analysis was performed at 0.05 significant level using the software R. Inverse weighting method (IWM) for interpolation was used in the analysis of spatial distribution of temperature and its extremes across Nigeria using ArcGIS 10.3 software.

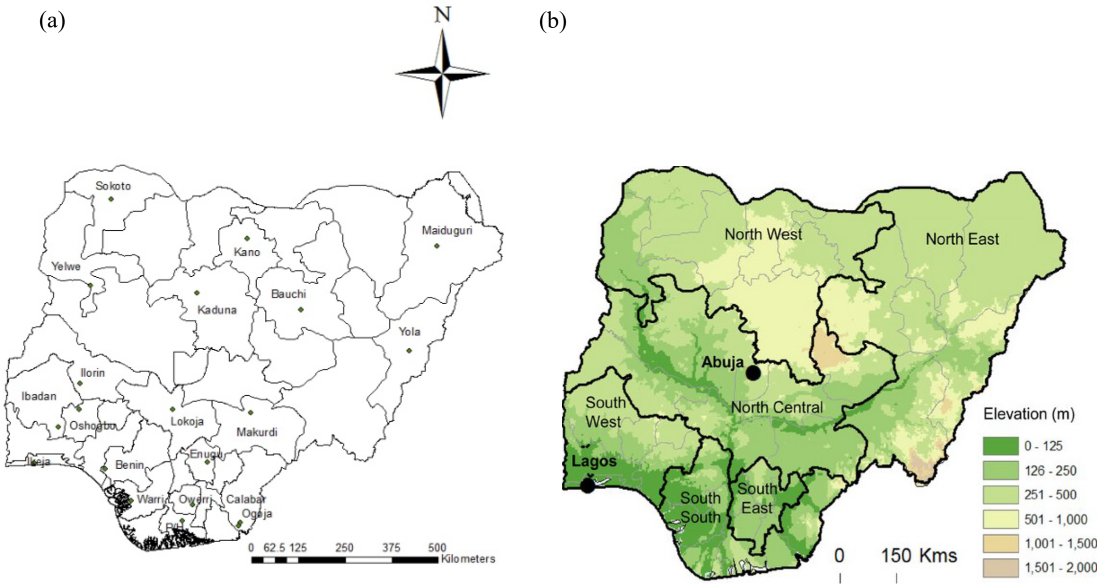


Figure 1 Map of Nigeria showing (a) the meteorological stations and (b) different zones in Nigeria [20].

Results and discussion

Spatial distribution of Tmax, TXx, and TNx

It could be observed from **Figure 2(a)**, that maximum temperature (Tmax) over the country increased steadily from the coastal area to the north eastern and north western regions of the country. The lowest and highest values of maximum temperature for the period under study are 29.72 - 32.07 °C and 36.46 - 38.53 °C, respectively. Similarly, maximum of maximum temperature (TXx) and minimum of maximum temperature (TXn) have similar variation patterns with the maximum temperature (Figures not shown). The TXx ranges between 39.99 and 42.97 °C, 47.70 and 49.59 °C, while TXn ranges between 21.36 and 22.52 °C, 24.54 and 25.76 °C.

Spatial distribution of Tmin, TNx, and TNn

On the other hand, minimum temperature (Tmin) decreased steadily from the coastal area to the north eastern region of the country (**Figure 2(b)**). For the period under investigation, the value of the minimum temperature ranges between 18.30 - 20.45 °C and 27.18 - 31.70 °C. Similarly, maximum of minimum temperature (TNx) and minimum of minimum temperature (TNn) also varies across the country (Figures not shown). The TNx ranges between 24.08 - 25.35 °C and 28.33 - 30.07 °C, while TNn ranges between 7.44 - 9.69 °C and 14.65 - 17.01 °C.

The increase in maximum temperature towards the northern region may probably be due to its proximity to the Sahara Desert, thereby making the region to be dry and cloudless. On the other hand, the increase in minimum temperature towards the coastal region may be due to its proximity to the Atlantic Ocean; thereby making the region to be wet and cloudy. Thus, the spatial distribution of maximum and minimum temperature observed in this study may be attributed to the interplay of the tropical-continental and tropical-maritime air masses which control the atmospheric and climatic conditions over Nigeria. This finding is in agreement with the report by other researchers [7,21].

Spatial distribution of TX90p, TN90p, TX10p, and TN10p

Figure 3(a) shows that warm days (TX90p) varies spatially across the country. It could be observed that TX90p was low (10.27 - 10.35 %) in the coastal region in stations such as Benin, Warri, while stations such as Ilorin in the north central and Bauchi in the north eastern regions experienced high warm days (10.49 - 10.56 %). Stations in the northern region experienced low warm nights (TN90p) in the range of 10.36 - 10.40 %, while warm nights are high (10.48 - 10.52 %) in stations such as Lagos, Port Harcourt (**Figure 3(b)**).

From **Figure 3(c)**, cold days (TX10p) were observed to be low (10.33 - 10.40 %) in the coastal region in stations such as Lagos and Calabar. Cold days are high (10.51 - 10.57 %) in the north western region in stations such as Sokoto. It could be observed from **Figure 3(d)** that cold nights are low (10.41 - 10.47 %) in stations such as Port Harcourt in the coastal region and Sokoto in the north western region and high (10.62 - 10.71 %) in stations such as Enugu and Imo in the south eastern region. Some parts of Maiduguri also experienced high cold nights for the period under study. The spatial distribution of warm days/nights and cold days/nights across Nigeria for the study period may be attributed to changes in temperature due to global warming [10]. The spatial distribution so observed is in consistency with the results of [17].

Spatial distribution of DTR, SU25, TR20, WSDI, and CSDI

The Diurnal Temperature Range (DTR) has similar spatial distribution with maximum temperature. It increased steadily from the coastal area to the north eastern and north western regions of the country (**Figure 4(a)**). The lowest values (8.09 - 10.87 °C) was observed in the coastal area, while the highest values (16.25 - 18.49 °C) was obtained in the north eastern and north western regions. These spatial patterns could be due to the variations of maximum and minimum temperature across the country, since DTR is the difference between daily maximum and daily minimum temperature.

Figure 4(b) shows that tropical nights (TR20) was low (147.88 - 201.32 days) in stations such as Kano, Kaduna and Bauchi. However, high tropical nights (311.37 - 351.25 days) was recorded in the coastal region. The spatial distribution of warm spell duration indicator (WSDI) depicts that high WSDI (3.14 - 3.62 days) was recorded in stations such as Kano and Kaduna in the northern region with low WSDI (1.65 - 2.16 days) in the coastal area (**Figure 4(c)**). On the contrary, cold spell duration indicator (CSDI) recorded low values (2.05 - 3.00 days) in the northern region and high values (4.99 - 6.08 days) in the coastal region (**Figure 4(d)**).

According to Soltani *et al.* [2], warm and cold spell duration indicators depict long-lasting events of warm and cold days based on 2 different percentiles. From this result, it implies that the northern region experienced long-lasting events of warm and cold days than the coastal region.

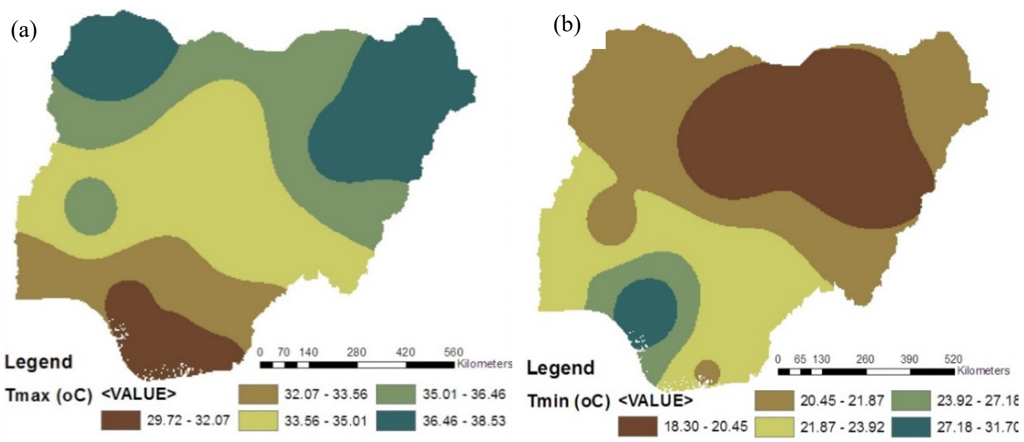


Figure 2 Spatial distribution of overall averages of (a) maximum and (b) minimum temperature over Nigeria (1979 - 2013).

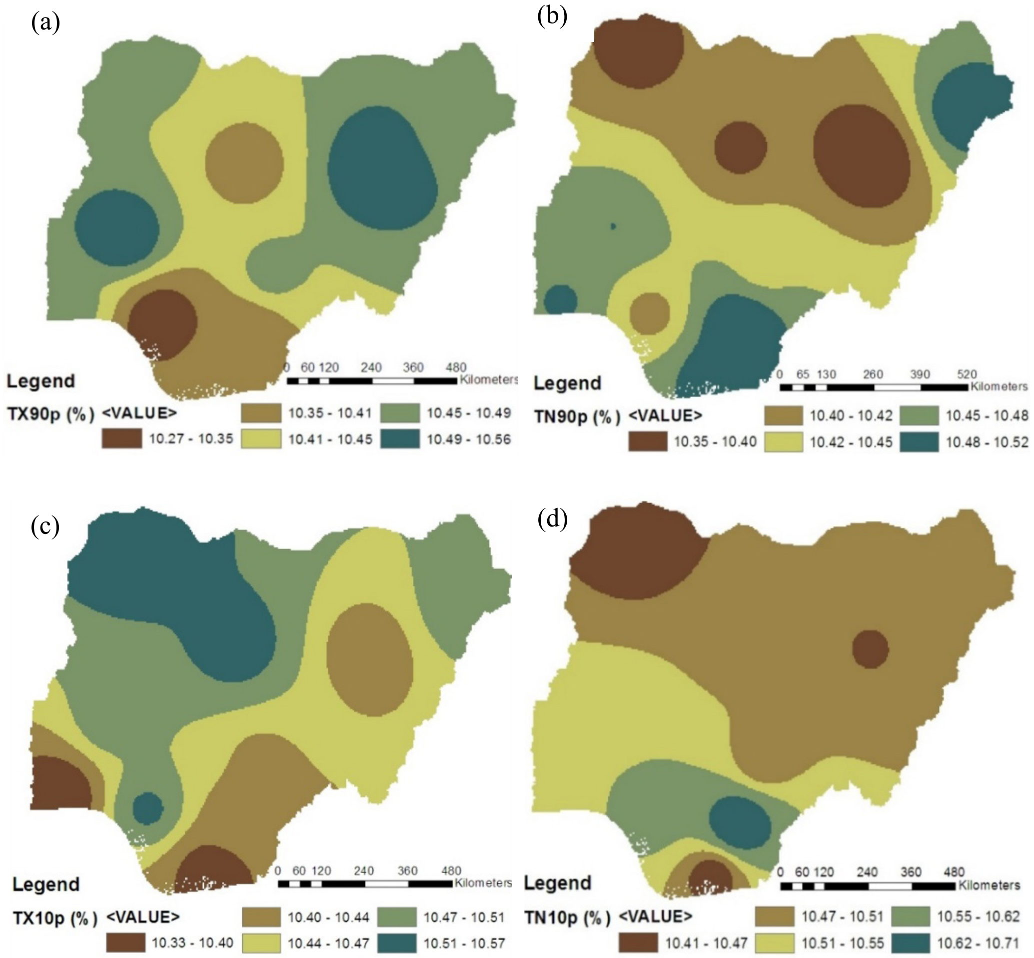
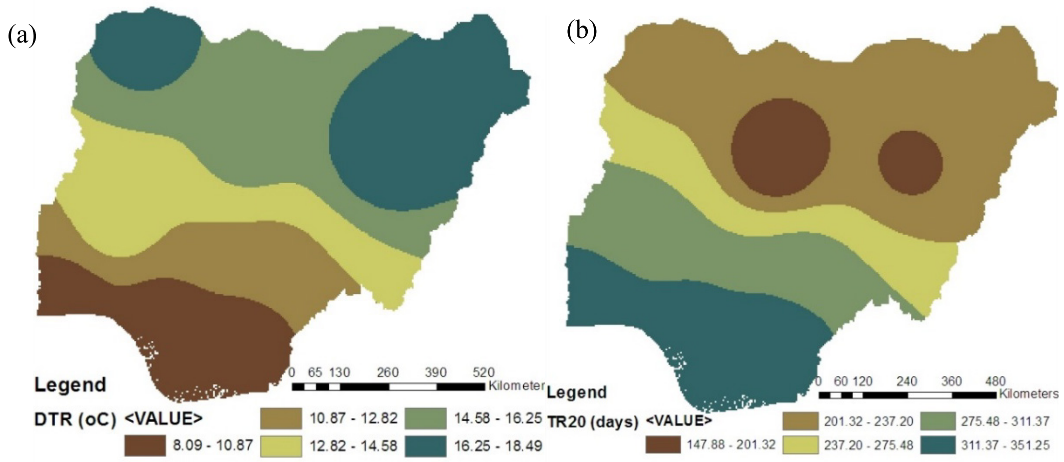


Figure 3 Spatial distribution of overall averages of (a) TX90p (b) TN90p (c) TX10p and (d) TN10p over Nigeria (1979 - 2013).



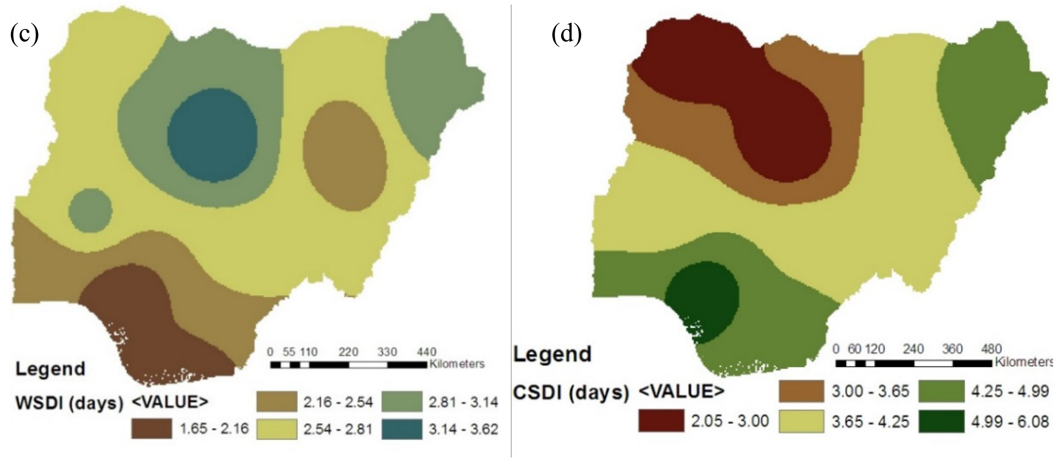


Figure 4 Spatial distribution of overall averages of (a) DTR (b) TR20 (c) WSDI and (d) CSDI over Nigeria (1979 - 2013).

Variation trends of Tmax, Tmin, and DTR

The temporal trends of yearly mean maximum temperature (Tmax), minimum temperature (Tmin), and diurnal temperature range (DTR) in each of the zones of Nigeria from 1979 - 2013 are shown in **Figure 5**. It could be observed that maximum temperature shows positive trends in all the study zones (**Figure 5(a)**). The trends are significant at 0.05 level of significance (**Table 2**). Similarly, from **Figure 5(b)**, the variation trends of minimum temperature (Tmin) show significant positive trend at $p < 0.05$ in all the study areas except in Zone 3 (**Table 2**). This depicts increase in temperature, which may be due to global warming. This is in line with the increasing trend of global surface temperature reported by the IPCC [10].

It is worthy of note that maximum temperature increased by 0.63, 0.34, 0.60, 0.27, 0.48, and 0.20 °C per decade in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Similarly, minimum temperature also increased by 0.16, 0.22, 0.12, 0.20, 0.23, and 0.22 °C per decade. The results of other researchers such as Soltani *et al.* [2], Khan *et al.* [3], Islam [22], Shaid *et al.* [23], show that maximum and minimum temperatures have increased by 0.59 and 0.31 °C, 0.3 and 0.4 °C, 0.06 and 0.15 °C, and 0.11 and 0. 15 °C per decades, respectively.

Interestingly, the change in maximum temperature observed in this study almost doubled that of minimum temperature in most regions. This is in contrast to the findings of some authors. Soltani *et al.* [2] reported that minimum temperature increased twice the maximum temperature (0.59 and 0.31 °C) from their study. This depicts that the rate of change of maximum and minimum temperature could differ from one place to another probably due to difference in geographical location and other factors affecting temperature in the region.

Results further show that for the last 35 years, maximum temperature has increased by 2.20, 1.19, 2.10, 0.94, 1.68 and 0.7 °C in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Similarly, minimum temperature has also increased by 0.56, 0.77, 0.42, 0.70, 0.80, and 0.77 °C, respectively. This is in consistency with the report by Chen *et al.* [10].

Similarly, the variation trends of Diurnal Temperature Range (DTR) show increasing positive trends in all the study areas except Zone 6 that shows non-significant negative trend (**Figure 5(c)**). The trends are significant in Zone 1, Zone 3, and Zone 5 at $p < 0.05$ (**Table 2**). The observed positive trends of DTR indicate that maximum temperature increased faster than minimum temperature. The negative trend observed in Zone 6 implies that minimum temperature increased faster than maximum temperature for the period under study. The decadal changes in DTR from 1979 - 2013 in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, and Zone 6 are 0.46, 0.13, 0.49, 0.08, 0.26, and –0.01 °C per decade, respectively. Both positive and negative trends have been reported by other researchers [3].

Variation trends of TXx, TXn, TNx, and TNn

It could be observed from **Figure 6(a)** that maximum of maximum temperature (TXx) show positive trends in all the study areas except in Zone 6, having non-significant negative trend (**Table 2**). Variation trends of minimum of maximum temperature (TXn) show positive trend in all the study areas

(**Figure 6(b)**). Similarly, positive trends were observed in the maximum of minimum temperature (TNx) as shown in **Figure 6(c)**. However, minimum of minimum temperature (TNn) show positive trends in Zone 1, Zone 3 and Zone 6, while negative trends were observed in Zone 2, Zone 4, and Zone 5 (**Figure 6(d)**). The difference in the trends may be attributed to the geographical locations of the study area and other factors that may directly or indirectly contribute to these variations. Significant positive trends observed in temperature and its indices are in agreement with the results of other scholars [24].

Variation trends TX90p, TN90p, TX10p, and TN10p

From **Figure 7(a)**, warm days (TX90p) show significant positive trends in all the study areas except in Zone 4 and Zone 6 due to their location in the coastal area of the country. The positive trends observed in TX90p depict steady increase in the frequency of warm days. Similarly, positive trends were observed in warm nights (TN90p) in all the study areas (**Figure 7(b)**). This implies increase in the frequency of warm nights. The trends are significant at $p < 0.05$ (**Table 2**). On the other hand, negative trends were observed in the variation trends of cold days and cold nights in all the stations (**Figures 7(c)** and **(d)**). These trends are significant at $p < 0.05$ (**Table 2**).

It is interesting to note that warm days have increased by 0.34, 0.26, 0.31, 0.15, 0.43, and 0.15 % per year in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Warm nights have also increased by 0.20, 0.21, 0.42, 0.46, 0.68, and 0.64 % per year, respectively. On the contrary, cold days (TX10p) have decreased by –0.32, –0.17, –0.31, –0.25, –0.29 and –0.23 % per year in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Cold nights (TN10p) have also decreased by –0.16, –0.17, –0.24, –0.24, –0.37 and –0.38 % per year, respectively. Comparing the rate of increase/decrease of warm days/warm nights with cold days/cold nights, it is pertinent to note that warm days/warm nights have increased twice the rate at which cold days/cold nights decreased in most of the study regions. This may be an indication that the climate of the study area is warming. According to Khan [3], in a warming climate the frequency of cold days/cold nights are relatively low, as observed in this study. The observed variation trends are in conformity with [2,15].

Variation trends of SU25, TR20, WSDI, and CSDI

The variation trends of SU25 and TR20 showed positive trends in all the study areas (Figures not shown). This implies that SU25 and TR20 increased in the period under investigation. The trends of SU25 are significant in Zone 3, Zone 4, Zone 5 and Zone 6 at $p < 0.05$. Similarly, the trends of TR20 are significant in Zone 2 and Zone 6 at $p < 0.05$ (**Table 2**). The increasing trends of SU25 and TR20 are indication of increasing hot extreme weather [3].

It could be observed that the cold spell duration indicator (CSDI) showed negative trends in all the study areas. On the contrary, positive trends were observed in warm spell duration indicator (WSDI) (Figures not shown). The CSDI decreased at the rate of –0.154, –0.179, –0.154, –0.032, –0.189, and –0.129 per year in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Port-Harcourt, respectively. On the other hand, the WSDI increased at the rate of 0.08, 0.14, 0.11, 0.01, 0.19 and 0.01 per year (**Table 2**). According to Soltani *et al.* [2], WSDI and CSDI depict long-lasting events of warm and cold days based on 2 different percentiles. Thus, the positive and negative trends of WSDI and CSDI imply that warm days are experienced in the study areas which are consistent more than cold days.

Our results have revealed that stations with significant changes in temperature and its extremes are located in the coastal regions and the northern region. This is consistency with the report of Akande *et al.* [14] who studies precipitation extremes over Nigeria. These variations may be due to the proximity of Nigeria to the Atlantic Ocean in the south and the Sahara Desert in the north. Thus, we tend to suggest that the Atlantic Ocean and the Sahara Desert may be promoters of extreme events caused by climate change in Nigeria.

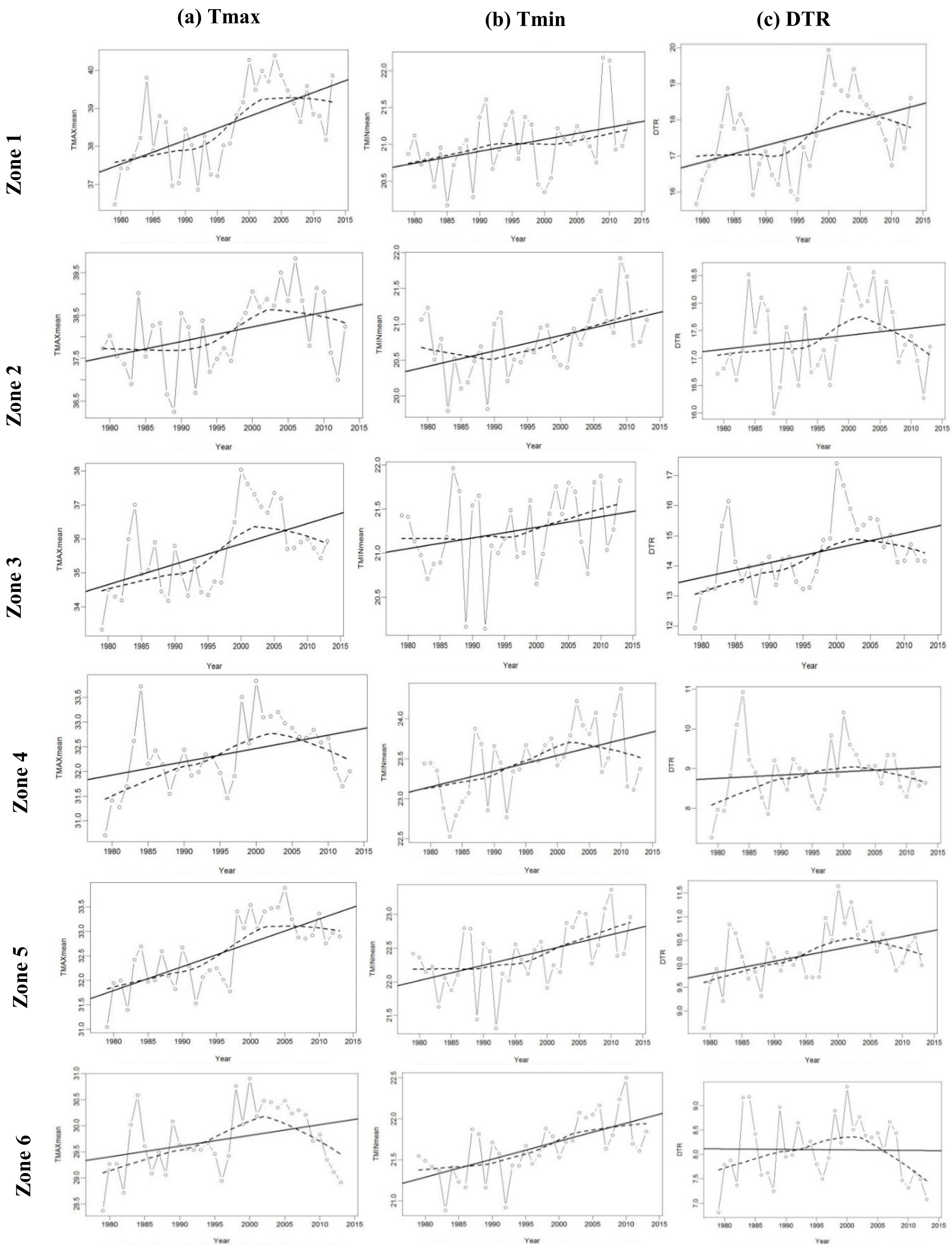


Figure 5 Temporal trends of yearly mean (a) maximum (b) minimum and (c) diurnal temperature range for different zones of Nigeria (1979 - 2013).

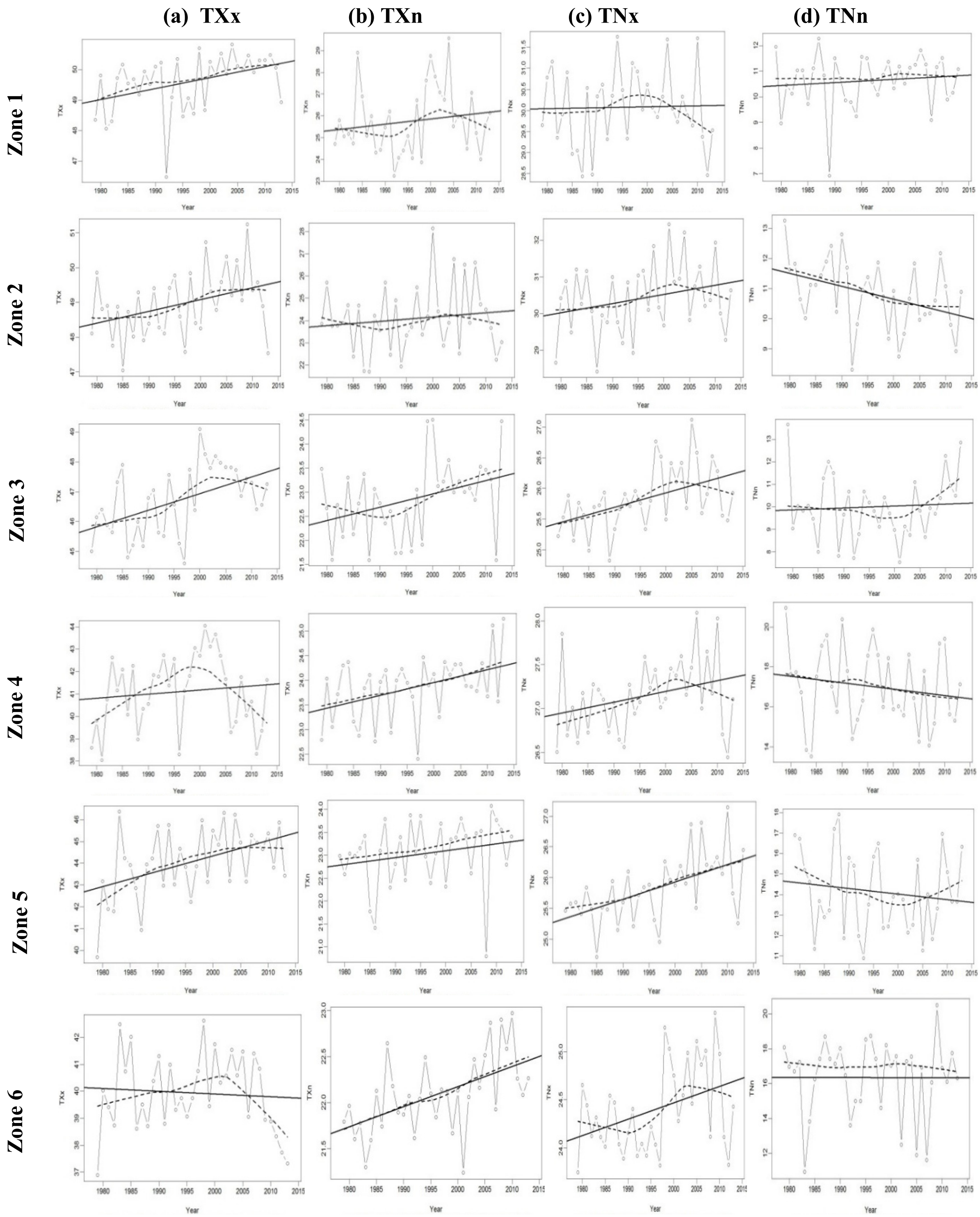


Figure 6 Temporal trends of yearly mean (a) TXx (b) TXn (c) TNx and (d) TNn for different zones of Nigeria (1979 - 2013).

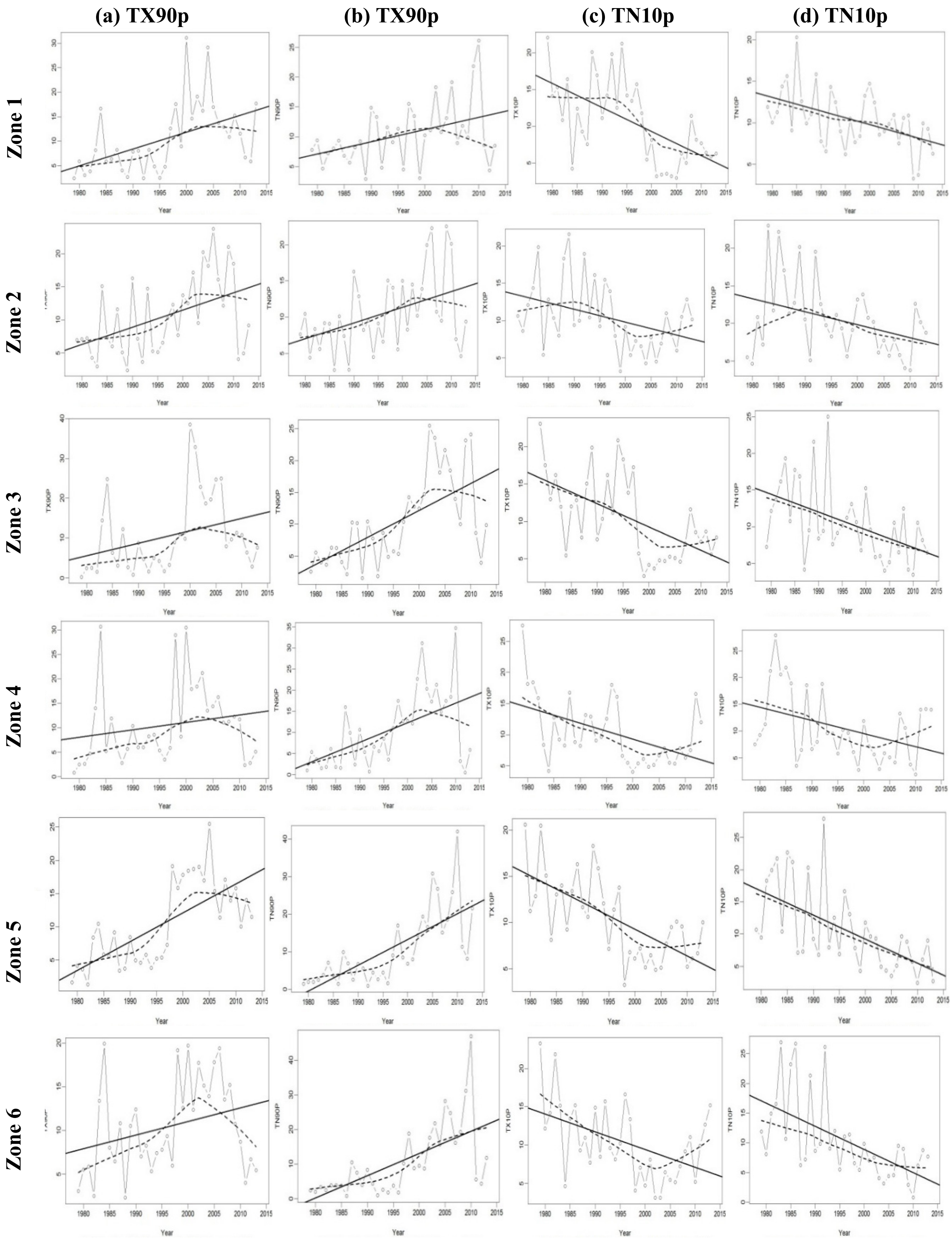


Figure 7 Temporal trends of yearly mean (a) TX90p (b) TX90p (c) TX10p and (d) TN10p for different zones of Nigeria (1979 - 2013).

Table 1 Extreme temperature indices developed by ETCCDI [18].

Index	**Long name**	**Definition**	**Units**
GSL	Growing season length	Annual (1 Jan-31 Dec in NH, 1 Jul-30 Jun in SH) count between 1st span of at least 6 d with TG > 5 °C and 1st span after 1 Jul (1 Jan in SH) of 6 d with TG < 5 °C	Days
SU25	Summer days at 25 °C	Annual count when TX > 25 °C	Days
SU35	Summer days at 35 °C	Annual count when TX > 35 °C	Days
TR20	Tropical nights at 20 °C	Annual count when TN > 20 °C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temperature	°C
TNx	Max Tmin	Monthly maximum value of daily minimum temperature	°C
TN90p	Warm nights	Percentage of days when TN > 90th percentile	% Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	% Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
FD0	Frost days	Annual count when TN < 0 °C	Days
ID0	Ice days	Annual count when TX < 0 °C	Days
TXn	Min Tmax	Monthly minimum value of daily maximum temperature	°C
TNn	Min Tmin	Monthly minimum value of daily minimum temperature	°C
TX10p	Cold days	Percentage of days when TX < 10th percentile	% Days
TN10p	Cold nights	Percentage of days when TN < 10th percentile	% Days

Table 2 Trends of temperature and extreme temperature indices in selected cities over Nigeria from 1979 – 2013.

Index	**Zone 1**		**Zone 2**		**Zone 3**		**Zone 4**		**Zone 5**		**Zone 6**	
	Trends	***p*-value**	**Trends**	***p*-value**	**Trends**	***p*-value**	**Trends**	***p*-value**	**Trends**	***p*-value**	**Trends**	***p*-value**
Tmax	**0.063**	**0.000**	**0.034**	**0.015**	**0.060**	**0.001**	**0.027**	**0.020**	**0.048**	**0.000**	**0.020**	**0.044**
Tmin	**0.016**	**0.028**	**0.022**	**0.004**	0.012	0.114	**0.020**	**0.004**	**0.023**	**0.002**	**0.022**	**0.000**
DTR	**0.046**	**0.009**	0.013	0.290	**0.049**	**0.009**	0.008	0.510	**0.026**	**0.008**	–0.001	0.929
TXX	**0.036**	**0.017**	**0.034**	**0.029**	**0.056**	**0.002**	0.018	0.506	**0.071**	**0.006**	–0.010	0.680
TXN	0.024	0.354	0.019	0.456	**0.027**	**0.038**	**0.026**	**0.012**	0.015	0.218	**0.022**	**0.001**
TNX	0.002	0.889	0.025	0.120	**0.024**	**0.004**	0.012	0.079	**0.028**	**0.001**	**0.017**	**0.022**
TNN	0.012	0.504	**–0.043**	**0.021**	0.009	0.72	–0.032	0.343	–0.027	0.413	**0.000**	**0.991**
TX90p	**0.342**	**0.002**	**0.260**	**0.005**	**0.312**	**0.052**	0.152	0.259	**0.432**	**0.000**	0.155	0.078
TN90p	**0.205**	**0.016**	**0.217**	**0.011**	**0.424**	**0.000**	**0.462**	**0.001**	**0.687**	**0.000**	**0.640**	**0.000**
TX10p	**–0.327**	**0.000**	**–0.173**	**0.022**	**–0.311**	**0.000**	**–0.254**	**0.003**	**–0.290**	**0.000**	**–0.231**	**0.004**
TN10p	**–0.163**	**0.004**	**–0.173**	**0.036**	**–0.241**	**0.004**	**–0.246**	**0.020**	**–0.373**	**0.000**	**–0.389**	**0.000**
SU25	0.043	0.168	0.081	0.114	**0.168**	**0.020**	**0.199**	**0.001**	**0.278**	**0.002**	**0.824**	**0.000**
TR20	0.310	0.215	**0.606**	**0.009**	0.183	0.445	0.036	0.849	0.026	0.925	**0.651**	**0.019**
WSDI	0.086	0.348	0.147	0.059	0.111	0.400	0.013	0.894	**0.199**	**0.016**	0.016	0.810
CSDI	–0.154	0.064	–0.179	0.110	–0.154	0.085	–0.032	0.766	–0.189	0.052	–0.129	0.341

Note: The significant trend at 0.05 level are bold.

Conclusions

Spatial distribution of temperature and its extremes revealed that temperature and its extremes over Nigeria varied spatially across the country from one region to another. The trends of annual mean maximum and minimum temperature for the period under investigation showed significant positive trends ($p < 0.05$). This depicts increase in temperature which may be due to global warming.

Maximum temperature increased by 0.63, 0.34, 0.60, 0.27, 0.48, and 0.20 °C per decade in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Minimum temperature also increased respectively by 0.16, 0.22, 0.12, 0.20, 0.23, and 0.22 °C per decade. The decadal changes in DTR from 1979 - 2013 in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5, and Zone 6 are 0.46, 0.13, 0.49, 0.08, 0.26, and –0.01, respectively. Significant positive trends observed in temperature and its indices are in agreement with the results of other scholars.

Comparing the rate of increase/decrease of warm days/warm nights with cold days/cold nights, it is worthy of note that warm days/warm nights have increased almost twice the rate at which cold days/cold nights decreased in most of the study areas.

The CSDI decreased at the rate of –0.154, –0.179, –0.154, –0.032, –0.189 and –0.129 per year in Zone 1, Zone 2, Zone 3, Zone 4, Zone 5 and Zone 6, respectively. Correspondingly, the WSDI increased at the rate of 0.086, 0.147, 0.111, 0.013, 0.199, and 0.016 per year.

The stations with significant trends appear to be located at the coastal regions close to the Atlantic Ocean or the northern region close to the Sahara Desert. This depicts the influence of the Atlantic Ocean and the Sahara Desert on the weather and climate of Nigeria. Therefore, we tend to suggest that the Atlantic Ocean and the Sahara Desert may be promoters of extreme events caused by climate change in Nigeria.

The implication of the increase in temperature, hot temperature indices and warm days/warm nights observed in this work may likely cause water bodies such as lake, well, stream, and rivers to dry up easily, increase in heat-related diseases, and high demand for electrical appliances in order to make the environment comfortable and habitable. Therefore, more policies and adaptation strategies on how to mitigate the adverse effects due to the extreme climate have to be put in place. We hereby recommend further research on spatial distribution based on the observed seasons in Nigeria. Also, different zones in Nigeria should be study separately for detail information.

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