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RESEARCH ARTICLE

Observed changes in climate extremes in Nigeria

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The study presents observed changes in climate extremes using daily precipitation and temperature data over 24 stations, covering the three climatic zones (Guinea coast, Savannah and Sahel) of Nigeria for the period 1971–2013. The data were homogenized with Expert Team on Climate Change Detection Indices (ETCCDI) RHtests version 4 software. RClimDex version 1.0 software was used to calculate 17 of the ETCCDI recommended precipitation and temperature extreme indices. The spatio-temporal variation in the observed trends was analysed over each of the climatic zone. Results show a significant increase in the frequencies of warm spell, warm days and nights and decreasing cold spell, cold days and nights over the three climatic zones. A significant increase in annual total precipitation was found in some stations across the Guinea coast and Sahel zones. Changes in consecutive dry days and consecutive wet days are non-significant in most stations. Also, a significant increase in extremely wet days was observed in a few stations across the three climatic zones. The implication of the observed warming could, however, result in thermal discomfort of lives in areas with significant positive trends. This could also exert pressure on the economy's power sector, as energy demand for cooling will increase. The increase in total annual precipitation will potentially be favourable for hydropower generation and increase the availability of the potable water supply for both industrial and domestic uses in the country. However, the increase in consecutive dry days and the decrease in consecutive wet days are dangerous for agricultural practices and, hence, food security.

KEYWORDS
climate extreme indices, climatic zones, Nigeria, precipitation, temperature, trends

1 | INTRODUCTION

Extreme weather and climate events most often have damaging impacts on human communities, environment and economy. For instance, in August and September 2013, northern and southwestern Nigeria experienced persistent torrential rainfall that led to destructive floods and claimed human lives (WMO, 2015). Considering the societal importance of the impacts of weather and climate extremes, the Intergovernmental Panel on Climate Change (IPCC), in addition to addressing climate extremes in its last assessment report (Hartmann *et al.*, 2013), has also produced a special report on climate and weather extremes (e.g. Seneviratne *et al.*, 2012). Both reports agree that extreme warming trends, in most parts of Africa, have increased in the 20th century, despite data limitations. Although extreme precipitation in Africa does not show a coherent spatial trend, the degree of dryness (droughts) has increased (Hartmann *et al.*, 2013). The changes in most of these extremes have been attributed to anthropogenic increases in concentrations of the greenhouse gases (Seneviratne *et al.*, 2012).

Monitoring the global trends and variability of climate and climate extremes has mainly been hampered by the lack of quality data in many parts of the world, especially in some parts of Africa, Asia and South America (Alexander *et al*., 2006; Donat *et al*., 2014). This is partly due to data-sharing policy in many national meteorological and hydrological agencies. In order to remedy this situation, the joint World Meteorological Organization (WMO) Commission on Climatology (CCl), World Climate Research Program (WCRP) Climate Variability and Predictability project (CLIVAR), and Joint Commission on Marine Meteorology (JCOMM) Expert Team on Climate Change Detection Indices (ETCCDI) has organized series of scientific workshops (Karl *et al*., 1999; Peterson and Manton, 2008; Alexander, 2016) for data-sparse regions, including Nigeria (New *et al*., 2006). In each workshop, daily maximum and minimum temperatures and precipitation data brought by the local meteorologists were quality controlled, tested for homogeneity and analysed for climate extremes. The ETCCDI recommended that the precipitation and temperature extreme indices obtained from these data (e.g. Peterson and Manton, 2008; Klein Tank *et al*., 2009) be made available to the public by the participants, thus bypassing certain restrictions on data sharing by some national meteorological and hydrological services.

Many studies have analysed trends in the mean and climate variability (mostly rainfall) over West Africa in general and Nigeria in particular (e.g. Hulme *et al*., 2001; Mahe *et al*., 2001; Malhi and Wright, 2004; Ekpoh and Nsa, 2011; Oguntunde *et al*., 2011; Akinsanola and Ogunjobi, 2014, 2015). However, in Nigeria, analyses of precipitation and temperature extremes have not been given much attention compared with studies of trends in average precipitation and temperature. In addition to New *et al*. (2006), Gbode *et al*. (2015) analysed precipitation and temperature extreme indices from 1960 to 2007 in Kano, northern Nigeria. Although Gbode *et al*. did not test for any homogeneity in the data sets, findings from both studies agree that there is warming in the region. Also observed from precipitation indices is a decrease in the number of consecutive wet days (CWD), a slight increase in annual total precipitation and an increase in extremely wet days. In a recent study, Abatan *et al*. (2017b) examined trends in mean and extreme temperatures over Ibadan, southwest Nigeria, using the ERA-20C gridded data set. They found an increase in seasonal and annual mean minimum temperature, a non-significant decrease in annual mean maximum temperature, warming in annual cold nights and cold days, as well as a mix of positive and negative trends in absolute extreme temperature at seasonal scale. However, these studies were geographically limited because New *et al*. (2006) used data from four stations only, Gbode *et al*. (2015) used data from only one station and Abatan *et al*. (2017b) relied on reanalysis data over Ibadan alone.

The only nationwide study of climate extremes in Nigeria is that recently carried out by Abatan *et al*. (2016, 2017a). Abatan *et al*. (2016) used daily station temperature data from 1971 to 2012 with focus on percentile-based temperature extreme indices to show that there is a significant increase in the fraction of hot extremes and a decrease in the fraction of cold extremes at seasonal and annual timescales. On the other hand, Abatan *et al*. (2017a) used both an observed and an ERA-20C gridded temperature data set to study trends in absolute temperature extreme indices from 1971 to 2012. Their analysis showed that the frequency and intensity of extreme temperature events over Nigeria are more pronounced during the dry season months (November–February). Abatan *et al*. also observed significant teleconnection patterns between extreme temperature and the large-scale North Atlantic Oscillation (NAO). This link was found to be consistent with both data sets.

Extreme analyses by Abatan *et al*. (2016, 2017a) considered 21 stations distributed across all the climatic zones in Nigeria, but these studies are limited to trends in extreme temperature indices. A further limitation of their studies is that only trends in percentile-based threshold and absolute extreme temperature indices were analysed. This excludes the important extreme temperature duration index, as well as extreme precipitation indices. Thus, there is also the need to address these other extreme indices in order to improve the understanding of trends in extreme precipitation and temperature in Nigeria. In addition, 12 of the 24 selected stations used in the current study (Table 1) were not among stations considered by Abatan *et al*. (2016, tab. 1; 2017a, tab. 1). Additionally, there is a difference in the timescale of the other stations analysed in the present study compared with those in Abatan *et al*. (2016, 2017a).

In the present study, observed daily precipitation and temperature data are analysed to study trends in the relevant ETCCDI-recommended extreme climate indices over Nigeria from 1971 to 2013. The study examined trends in the absolute, duration and threshold of extreme temperature indices as well as extreme precipitation indices over the three climatic zones in Nigeria. These analyses were carried out using ETCCDI RClimDex version 1.0 software. Thus, the present paper complements and extends the work of Abatan *et al*. (2016, 2017a) by further robust investigation of recent extreme climate events in Nigeria. The present paper will, therefore, provide additional information to further describe the state of the climate system in Nigeria by using daily precipitation and temperature data covering a 43-year period (1971–2013).

The paper is structured as follows. Section 2 describes the study area, source of data and analysis methods used. The results are presented and discussed in Section 3. Section 4 concludes.

2 | DATA AND METHODS

2.1 | Study area

Nigeria is a West African country lying between 4–14 ° N and 3–14 ° E (Figure 1). It covers an approximate area of about 923,770 km^2 and is bordered to the north by the Republic of Niger, to the south by the Atlantic Ocean, to the west by the Republic of Benin and to the east by Cameroon. The country can be divided into three different climatic zones (Figure 1); Guinea coast (4–8 ° N), Savannah (8–11 ° N) and Sahel (11–14 ° N), based on similarities in land-use/land-cover, climate and ecosystems (Iloeje, 1981; Omotosho and Abiodun, 2007; Abiodun *et al*., 2013). These zones are strongly influenced by the West African monsoon, which provides most of the precipitation for agricultural and other sectors of the country's economy.

The Guinea coast zone is located in the southern part of the country (4–8 ° N) and is characterized by a sub-humid climate with average annual rainfall ranging from about 1,575 to 2,533 mm (Oguntunde *et al*., 2011). To the north, from 8 ° to 11 ° N, is the Savannah zone, which is a semi-arid region with average annual rainfall of about 897–1,535 mm. The reduction in rainfall in this zone is mainly due to the monsoon jump, which is the observed abrupt latitudinal shift of maximum precipitation from the Guinea coast into the Sahel region around June (Sultan and Janicot, 2000; Le Barbe *et al*., 2002; Lebel *et al*., 2003; Hagos and Cook, 2007). This phenomenon thereafter enhances the appearance of the "little dry season" between July and August along the Guinea coast. The Sahel zone covers the northern part of the country (11–14 ° N) and is characterized by a unimodal rainy season between July and September, with a pronounced pick in August which coincides with the northernmost position of the intertropical discontinuity (ITD) at about 21°–22 ° N latitudes (e.g. Nicholson, 2013). The average annual rainfall over the region ranges between about 434 and 969 mm (Oguntunde *et al*., 2011).

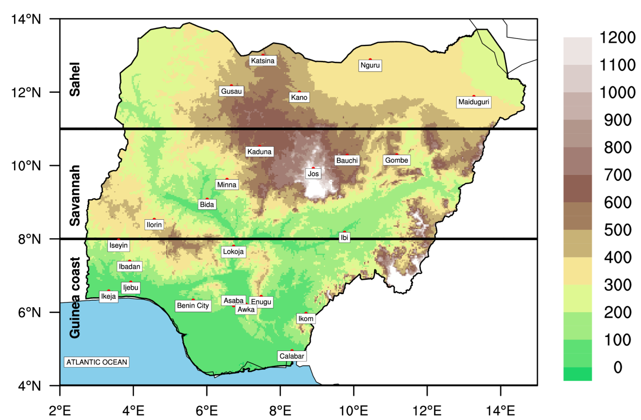

FIGURE 1 Geographical location of stations used and the three different climatic zones in Nigeria: Guinea coast (4–8 ° N), Savannah (8–11 ° N) and Sahel (11–14 ° N), with elevation at an interval of 100 m [Colour figure can be viewed at wileyonlinelibrary.com]

2.2 | Daily data

The study investigates changes in the characteristics of extreme climate events using daily precipitation, minimum and maximum near-surface temperatures from 24 synoptic stations across the three climatic zones of Nigeria. Table 1 and Figure 1 show the distribution of the selected stations and some characteristics of the data used over each climatic zone. Both the Guinea coast and Savannah have more stations than the Sahel, which has five stations. These data were extracted from the archive of the Nigerian Meteorological Agency (NiMet) and covered the period 1971–2013. Note that the daily data series in some stations starts from either 1972, 1974, 1975 or 1982 (Table 1).

2.3 | Quality control

The data were quality controlled using the standard RClimDex version 1.0 software package developed and freely made available, upon request, by the ETCCDI (Zhang and Yang, 2004; see http://etccdi.pacificclimate.org/software.shtml). During quality control, erroneous data, such as negative precipitation or days with precipitation > 200 mm, minimum temperature > maximum temperature, and minimum and maximum temperatures > 6 SD (standard deviation) from the long-term mean (Gbode *et al*., 2015), were replaced with −99.9, which is recognized as missing data by RClimDex in order to avoid erroneous computation. The SD of 6 was used to reduce the number of outliers in the data series, which may not necessarily be an outlier mostly due to some extreme events in the highly variable precipitation data.

Next, the data were tested for homogeneity using ETCCDI RHtests version 4 software: one for temperature and another for the precipitation series (Wang *et al*., 2010). This software can also be freely downloaded, with permission, from http://etccdi.pacificclimate.org/software.shtml.

Using the RHtests version 4 software package, homogeneity tests were performed on each time series to ensure homogeneity in the whole data set (Wang and Feng, 2009). Generally, the penalized maximal *F*-test (e.g. Wang, 2008a) was used to identify potential change points in the time series. This test is based on two-phase regression models for the detection of shifts in individual station time series (Wang, 2008b). The procedure was applied to the daily maximum and minimum temperatures and to monthly total precipitations. Some change points were identified during the homogeneity test. These change points could be as a result of either a change in station location, faulty instruments or natural shifts in climate. In the absence of reference data, the change points were, however, automatically homogenized. It was found that the time series of precipitation for Kaduna,

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TABLE 1 Stations used in the study

Station	Longitude (° E)	Latitude (° N)	Elevation (m a.s.l.)	Period	Climatic zone
Asaba	6.73	6.18	60	1975–2013	Guinea coast
Awka	7.07	6.22	100	1975–2013	
Benin City	5.63	6.33	80	1971–2013	
Calabar	8.32	4.95	80	1971–2013	
Enugu[b]	7.48	6.43	300	1971–2013	
Ibadan	3.90	7.39	200	1971–2013	
Ijebu	3.93	6.82	60	1974–2013	
Ikeja	3.33	6.58	40	1971–2013	
Ikom	8.70	5.97	100	1972–2013	
Iseyin	3.60	7.97	300	1982–2013	
Lokoja	6.73	7.80	180	1971–2013	
Bauchi	9.82	10.28	600	1971–2013	Savannah
Bida	6.01	9.08	140	1971–2013	
Gombe	11.17	10.29	440	1972–2013	
Ibi	9.75	8.18	120	1971–2013	
Ilorin	4.57	8.53	280	1971–2013	
Jos	8.90	9.92	1,160	1971–2013	
Kaduna[a]	7.44	10.52	580	1971–2013	
Minna	6.55	9.62	280	1971–2013	
Gusau	6.67	12.17	420	1971–2013	Sahel
Kano[c]	8.52	12.00	460	1971–2013	
Katsina	7.53	13.00	440	1971–2013	
Maiduguri	13.27	11.88	280	1971–2013	
Nguru	10.45	12.88	340	1971–2013	

Notes: The time period considered is based on the data made available to the authors and the start year of operations of the station.
[a]Precipitation;
[b]maximum; and
[c]minimum temperature series are not homogenous.

maximum temperature for Enugu and minimum temperature for Kano were not homogenous (Table 1). At the end of the homogeneity test, > 90% of the time series was consistent in all stations. Only the homogenized data sets were used to calculate the indices analysed in the present study. Indices corresponding to inhomogeneous variables were excluded from data analysis.

2.4 | Calculation of indices, trend analysis and zonal averaging

The homogenized data series of the individual stations within the same climatic zones were averaged to generate the zonal time series used for the zonal statistics. Thereafter, RClimDex version 1.0 software was used to calculate the extreme precipitation and temperature indices for each homogeneous time series. A total of 17 of the 27 indices recommended by the ETCCDI (e.g. Zhang *et al.*, 2011) were considered relevant to the study area of the present paper (Table 2). To compute the percentile-based indices, the first 30 years of each time series were used as the base period. The statistical significance of the trends was determined using the Mann–Kendall test, which tests for monotonic trends in a time series based on the Kendall rank correlation of the series and time (Mann, 1945). The *p*-value derived from the test, which serves as a criterion to define the class boundary, was used to analyse the null hypothesis that there is no trend in the data series and to determine if the trends in the extreme indices are significant. The change in trend is considered significant when the obtained $p \leq 0.05$, otherwise it is not significant.

The zonal extreme indices were determined from the average of individual station data within each climatic zone. A further statistical significance test was carried out on the new series. The statistical significance of the trends for each series was also performed using the Mann–Kendall test at a 95% confidence interval ($p \leq 0.05$).

3 | RESULTS AND DISCUSSION

The zonal trends and statistical significance of all extreme precipitation and temperature indices analysed are summarized in Table 3. Statistically significant trends are indicated by bold font.

TABLE 2 The Expert Team on Climate Change Detection Indices (ETCCDI) indices used to analyse climate extremes

Index	Indicator	Definitions	Unit
TminMean	Mean T_{min}	Annual mean daily minimum temperature	°C
TmaxMean	Mean T_{max}	Annual mean daily maximum temperature	°C
TXx	Maximum T_{max}	Monthly maximum daily maximum temp	°C
TNn	Minimum T_{min}	Monthly minimum daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	%
TX10p	Cool days	Percentage of days when TX < 10th percentile	%
TN90p	Warm nights	Percentage of days when TN > 90th percentile	%
TX90p	Warm days	Percentage of days when TX > 90th percentile	%
WSDI	Warm spell duration indicator	Annual count of days with at least six consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least six consecutive days when TN < 10th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
R10mm	Heavy precipitation days	Annual count of days when RR ≥ 10 mm	Days
R20mm	Very heavy precipitation days	Annual count of days when RR ≥ 20 mm	Days
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	Days
PRCPTOT	Annual total wet day precipitation	Annual total precipitation in wet days (RR ≥ 1 mm)	mm
R99p	Extremely wet day precipitation	Annual total precipitation due to extremely wet days when RR > 99th percentile	mm

Note: The first 30 years of each time series were used as the reference period in order to calculate percentile-based indices.

3.1 | Temperature indices

Figure 2 shows the annual averages of daily maximum and minimum temperature (TmaxMean and TminMean). The size of the triangles depicts the magnitudes of the trends; whether they are upward pointing or inverted depicts increasing or decreasing trends, respectively; and filled or empty symbols depict significant or non-significant trends at a 95% confidences interval, respectively. Significant warming trends were observed over most stations in the three climatic zones of the country (Table 3). It can be deduced from the TmaxMean index that about 75% of the stations have significant warm trends; and from the TminMean that about 33% have significant cold trends. Both annual mean maximum and minimum temperatures are found to decrease in Ilorin. The decrease is only found to be significant with TmaxMean. Also, in Ikeja, both TmaxMean and TminMean indices

TABLE 3 Summary of trends of the indices and their statistical significance for the period 1971–2013

	Zones								
	Guinea			Savannah			Sahel		
Indices	Trend	Tau	*p*-value	Trend	Tau	*p*-value	Trend	Tau	*p*-value
TminMean	**0.034**	0.824	0.000	**0.018**	0.572	0.000	**0.015**	0.378	0.000
TmaxMean	**0.019**	0.625	0.000	**0.007**	0.318	0.003	**0.053**	0.839	0.000
TXx	**0.043**	0.614	0.000	**0.021**	0.296	0.005	**0.024**	0.309	0.005
TNn	**0.042**	0.368	0.001	0.014	0.158	0.140	**0.058**	0.461	0.000
TN10p	**−0.145**	−0.426	0.000	**−0.105**	−0.259	0.015	**−0.221**	−0.368	0.001
TN90p	**0.223**	0.373	0.000	**0.094**	0.246	0.021	**0.342**	0.492	0.000
TX10p	**−0.271**	−0.649	0.000	**−0.095**	−0.325	0.002	**−0.059**	−0.248	0.020
TX90p	**0.355**	0.493	0.000	**0.183**	0.411	0.000	0.152	0.349	0.152
WSDI	**0.300**	0.323	0.004	**0.114**	0.256	0.023	**0.202**	0.294	0.009
CSDI	**−0.110**	−0.319	0.004	−0.098	−0.135	0.235	**−0.200**	−0.270	0.015
DTR	**0.007**	0.232	0.020	**0.011**	0.408	0.000	**−0.038**	−0.575	0.000
PRCPTOT	**8.032**	0.342	0.001	2.249	0.155	0.146	**7.042**	0.437	0.000
R99p	1.354	0.205	0.054	0.886	0.187	0.079	**1.330**	0.323	0.002
R10mm	**0.208**	0.366	0.001	0.016	0.048	0.671	**0.136**	0.363	0.001
R20mm	**0.169**	0.415	0.000	**0.064**	0.286	0.011	**0.147**	0.480	0.000
CWD	−0.080	−0.132	0.255	−0.030	−0.222	0.065	0.000	0.019	0.884
CDD	0.228	0.114	0.290	0.485	0.162	0.131	0.315	0.015	0.899

Note: Significant trends are shown in bold.

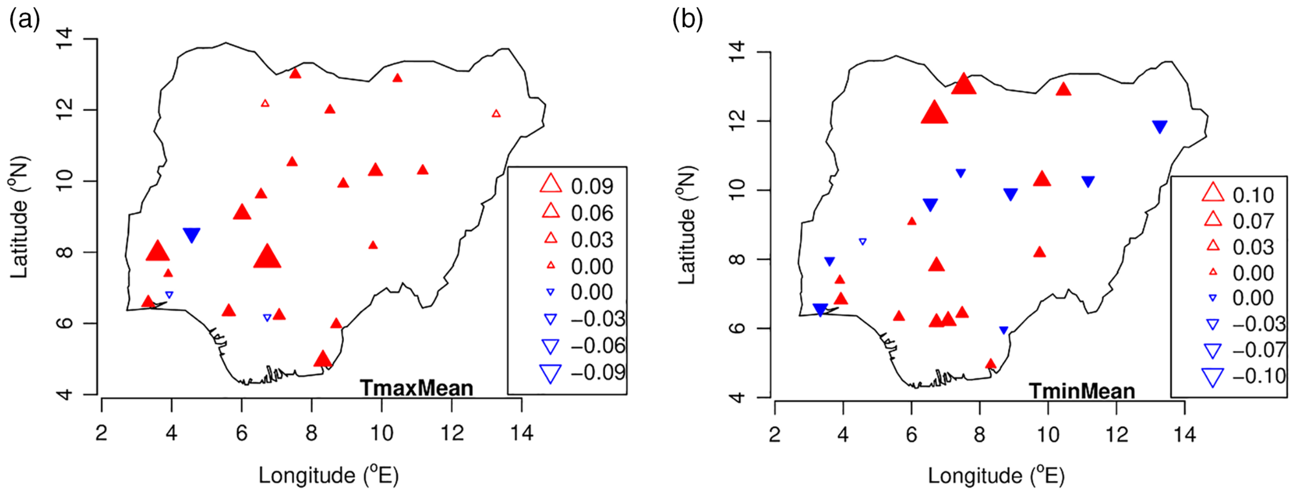

FIGURE 2 Changes in annual mean maximum and minimum temperature: (a) TmaxMean; and (b) TminMean (°C/year). In this and Figures 3–7, the annual values were plotted against time (year) to determine the trends in units of indices *per* time. The size of triangles represents the magnitude of the trend; whether they are upward pointing or inverted shows positive or negative trends, respectively; and a filled symbol depicts significant trends at the 95% confidence level [Colour figure can be viewed at wileyonlinelibrary.com]

significantly increase and decrease, respectively. The reasons for these temperature signals in Ikeja could be explained by the increasing rate of anthropogenic activities as well as its proximity to the Atlantic Ocean.

Table 3 and Figure 3 show that there are significant increasing trends in the frequencies of warm days and nights, and significant decreasing trends in cool days and nights. On average, there were decreasing numbers of cool nights and

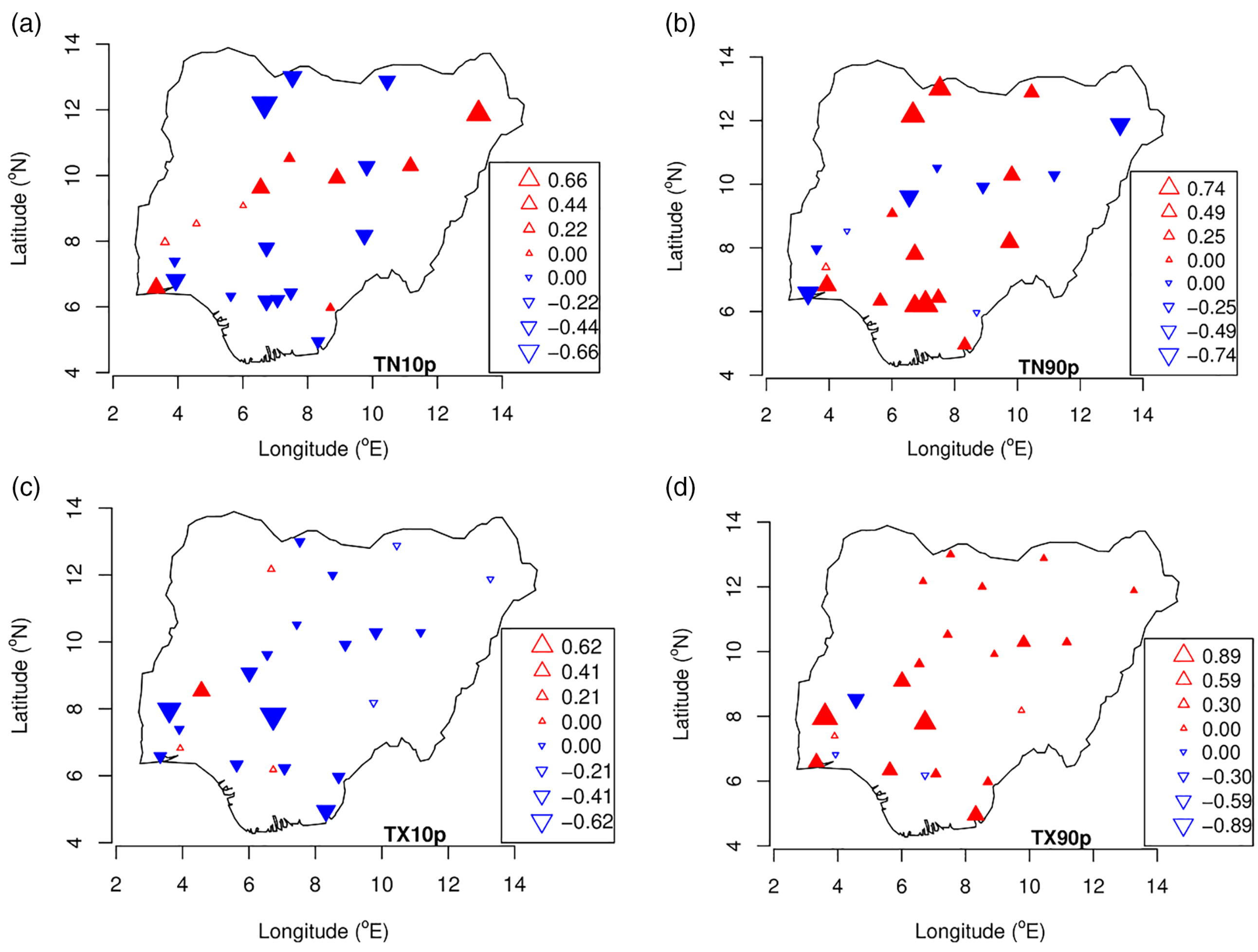

FIGURE 3 Frequency of (a) cool nights (TN10p); (b) warm nights (TN90p); (c) cool days (TX10p); and (d) warm days (TX90p) (days/year) [Colour figure can be viewed at wileyonlinelibrary.com]

days and increasing numbers of warm nights and days in the three climatic zones. These trends are significant for most stations at a 95% confidence level (i.e. $p \leq 0.05$). In the Guinea coast and Savannah region, the observed magnitudes of the warming and cooling trends are smaller in some stations and greater elsewhere. Also, the magnitudes of the trends of warm night- and daytime extremes are higher than those of cool night- and daytime extremes. These results are consistent with Alexander *et al*. (2006) who reported a significant increase (decrease) in the occurrence of annual warm nights (cold nights) over 70% of the globe. Similarly, Donat and Alexander (2012), using climate indices, showed regions of the globe with a significant shift from the upper and lower tails day- and night-time temperature distribution. Using data from selected stations over Nigeria, Abatan *et al*. (2016) obtained similar results. However, note that stations such as Ikeja, Minna, Jos, Gombe and Maiduguri have a significant decrease in warm nights and increase in cool nights trends. The results could be associated with local effects such as the ocean (Ikeja) and plateaus (Minna, Jos, Gombe and Maiduguri) that act to control temperature over the stations. Night-time cloudless conditions, which oftentimes cause strong radiative cooling, could also be responsible for the increasing cool nights in some stations.

The monthly maximum daily maximum temperature (TXx) (Figure 4a) shows a general trend increase across the three zones, but with smaller magnitudes in most stations. However, some stations such as Asaba and Ilorin have a decreasing trend in TXx with smaller magnitudes. The positive trend in this index is significant at 14 of the selected stations across all climatic zones. Among others, Ikeja and Benin City in the Guinea coast, Bida and Bauchi in the Savannah, and Kano and Katsina in the Sahel constitute about 43% of stations with significant positive trends. Similarly, Table 3 and Figure 4b also show an increasing trend in the coldest daily minimum temperature (TNn). Stations in the extreme north of the Sahel appear to have significant positive trends in TNn with higher magnitudes, except for Maiduguri, which has a small magnitude of a significant decrease in the index. The TNn of 62% for the stations in Savannah show a general significant decrease with weaker magnitudes, but the index increases significantly in Bauchi. In the Guinea coast, the index is positive at 73% of the stations, that is, eight stations, in the zone. The increasing trend is significant at seven of the stations. The reasons for the significant trends in TNn, most especially in the Sahel, could be associated with the fact that during the periods December–February and March–May stations in the region are found to the north of the ITD. During this period, a predominantly daytime clear-sky condition, which allows more insolation reaching the Earth's surface, prevails, thus increasing the daytime temperature. Also, at night, the clear-sky situation allows more terrestrial radiation to escape into space, thereby causing strong radiative cooling as well as decreasing night-time temperature.

As shown in Table 3, the cold and warm spells indices show changes in most stations across all the climatic zones, especially in the Sahel. A significant increasing trend of the warm spell duration index (WSDI) was found in three of five stations in the Sahel as well as in some stations in the other two zones; Asaba, Ijebu, Ibadan in the Guinea coast and Ilorin in the Savannah have significant decreasing trends (Figure 5a). Simultaneously, significant decreasing trends of the cold spell duration index (CSDI) was observed over three stations in the Sahel region and in the majority of stations in the Guinea coast (Figure 5b). The CSDI increased significantly in Ikeja, Jos and Maiduguri. On average, there were significant decreasing (increasing) trends in CDSI (WSDI) over the three climatic zones. According to Seneviratne *et al*. (2012), the increasing frequencies of warm spell duration and decreasing cold spell duration could be because of the global rise in anthropogenic activities, which is responsible for the increase in greenhouse gases

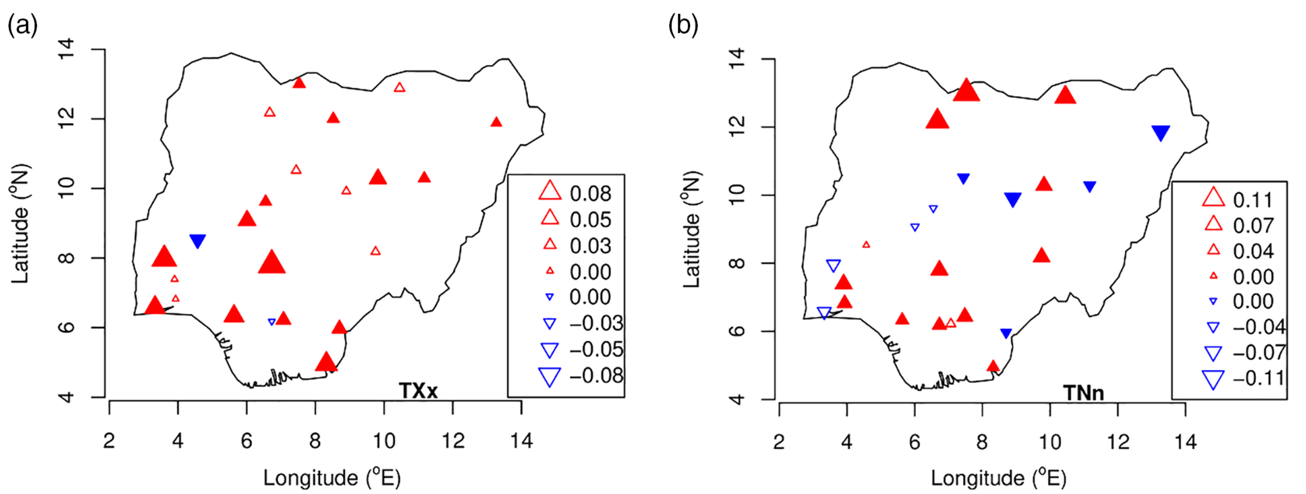

FIGURE 4 Annual trend of monthly (a) maximum daily maximum temperature (TXx); and (b) minimum daily minimum temperature (TNn) (°C/year) [Colour figure can be viewed at wileyonlinelibrary.com]

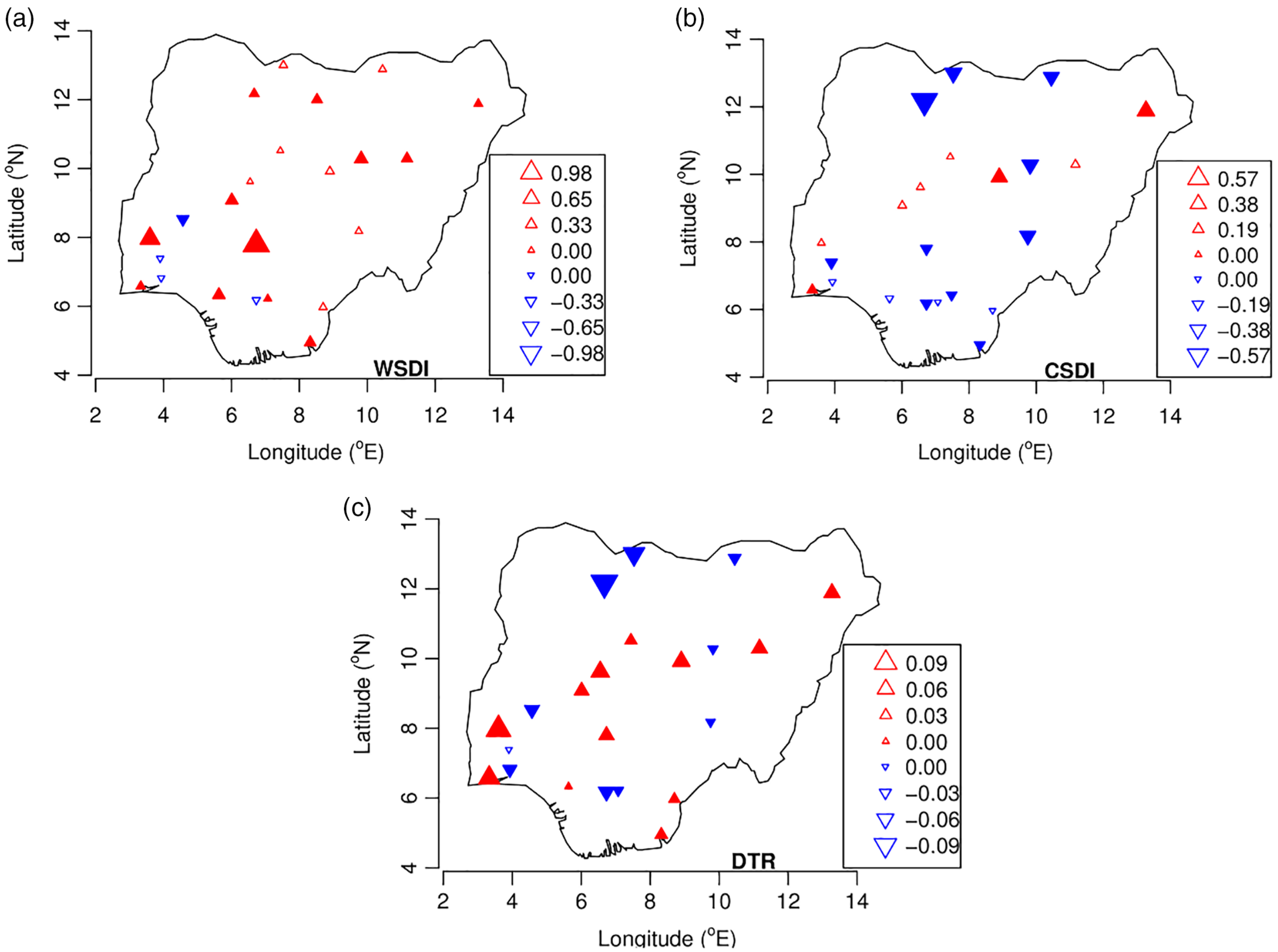

FIGURE 5 Trend of (a) consecutive warm spell (WSDI); (b) consecutive cold spell (CSDI) (days/year); and (c) diurnal temperature range (DTR) (°C/year) [Colour figure can be viewed at wileyonlinelibrary.com]

concentrations in the atmosphere and thus result in a warming of the Earth's surface.

Trends in the diurnal temperature range (DTR) are significant with a decreasing trend in 40% of the stations, and another 54% show an increase in this index (Figure 5c). Of all the stations, only Ibadan in the Guinea coast has an insignificant decreasing trend. At the zonal level, the DTR has significant increasing trends over the Guinea coast and Savannah, but significant decreasing trends over the Sahel. These changes are consistent with the findings of Alexander *et al*. (2006), that there has been a consistent global increase in the observed daily maximum temperature and an increasing shift in daily minimum temperature in the past 30–40 years. The negative DTR in the Sahel could be because both maximum and minimum temperatures have increased during the period and that the warming has been faster with minimum temperature (Mouhamed *et al*., 2013).

The consequences of the observed persistent warming could result in the thermal discomfort of lives in areas with significant trends. This could also exert pressure on the economy's power sector, as energy demand for cooling will increase. For example, Aebischer *et al*. (2007) examined the connection between changing summer weather conditions, thermal comfort and energy demand for cooling in Europe and found an increase electricity demand for cooling of 10–30 MJ/m due to a warmer climate. They also emphasized the role of warmer temperature on indoor temperature and thermal comfort conditions, and the increase of cooling energy requirements due to a decrease in heating requirements for individual buildings.

3.2 | Precipitation indices

The annual total precipitation (PRCPTOT) index has a significant increasing trend over most stations in the Guinea coast, Bauchi in the Savannah, and Kano and Maiduguri in the Sahel (Table 3 and Figure 6a). The significant positive trend in the PRCPTOT over Kano was previously reported by Gbode *et al*. (2015). This could be associated with the influence of localized rainfall and convective activities generated due to the presence of catchment wetlands of the Hadejia and Jama'are rivers (Adeyeri *et al*., 2019). This association has been established in other regions (Krinner, 2003; Bai *et al*., 2013). There are three stations in the Savannah with weaker and insignificant negative trends in the PRCPTOT. In general, the result indicates increasing trends in the PRCPTOT in Nigeria, except for stations in the Savannah region and a selective few in the other two zones (Table 3).

The observed trends in annual total precipitation due to extremely wet days (day with rainfall > 99th percentile of daily rainfall) has significantly increased in Asaba, Ibadan, Bauchi, Gombe and Kano (Figure 6b). Other stations with positive trends in the index are Ikeja, Ijebu, Benin City, Ikom and Maiduguri, but their magnitudes are weaker. A few stations including Ilorin, Bida, Jos and Nguru had negative trends. The R99p trend in the Sahel, however, increases significantly.

Figures 6c,d present trends in days with daily precipitation ≥ 10 mm (R10mm) and 20 mm (R20mm), respectively. There is a higher magnitude of the positive trend for the R10mm index than for R20mm. For instance, in the Guinea coast zone, Ikeja, Ijebu, Awka and Calabar show significant positive trends in R10mm with a higher magnitude. Of these four stations, Ikeja and Calabar have higher trends in the number of days with precipitation > 10 mm. The high positive trend observed in these two locations could be a result of their proximity to the Atlantic, a major source of moisture transported inland by the monsoon flow. There are no observed significant trends in R10mm in the Savannah zone. A positive significant trend was observed in Katsina, Kano and Maiduguri in the Sahel. This could be evidence of rainfall recovery from the drought period over the region between 1970 and the 1980s (Thompson and Polet, 2000). Significant trends with a lower magnitude were found for the R20mm index over some stations in all zones (Figure 6d). The trend decreases in Ikom and Jos in the Guinea coast and Savannah, respectively. However, some stations in the Guinea coast also show a significant increase in R20mm, but with a lower magnitude than R10mm. In the Savannah zone, a significant positive trend was observed only in Bauchi, while other stations in the zone show an insignificant increase. Similarly, Katsina, Kano and Maiduguri in the Sahel zone also show a significant increasing trend in R20mm compared with that of R10mm.

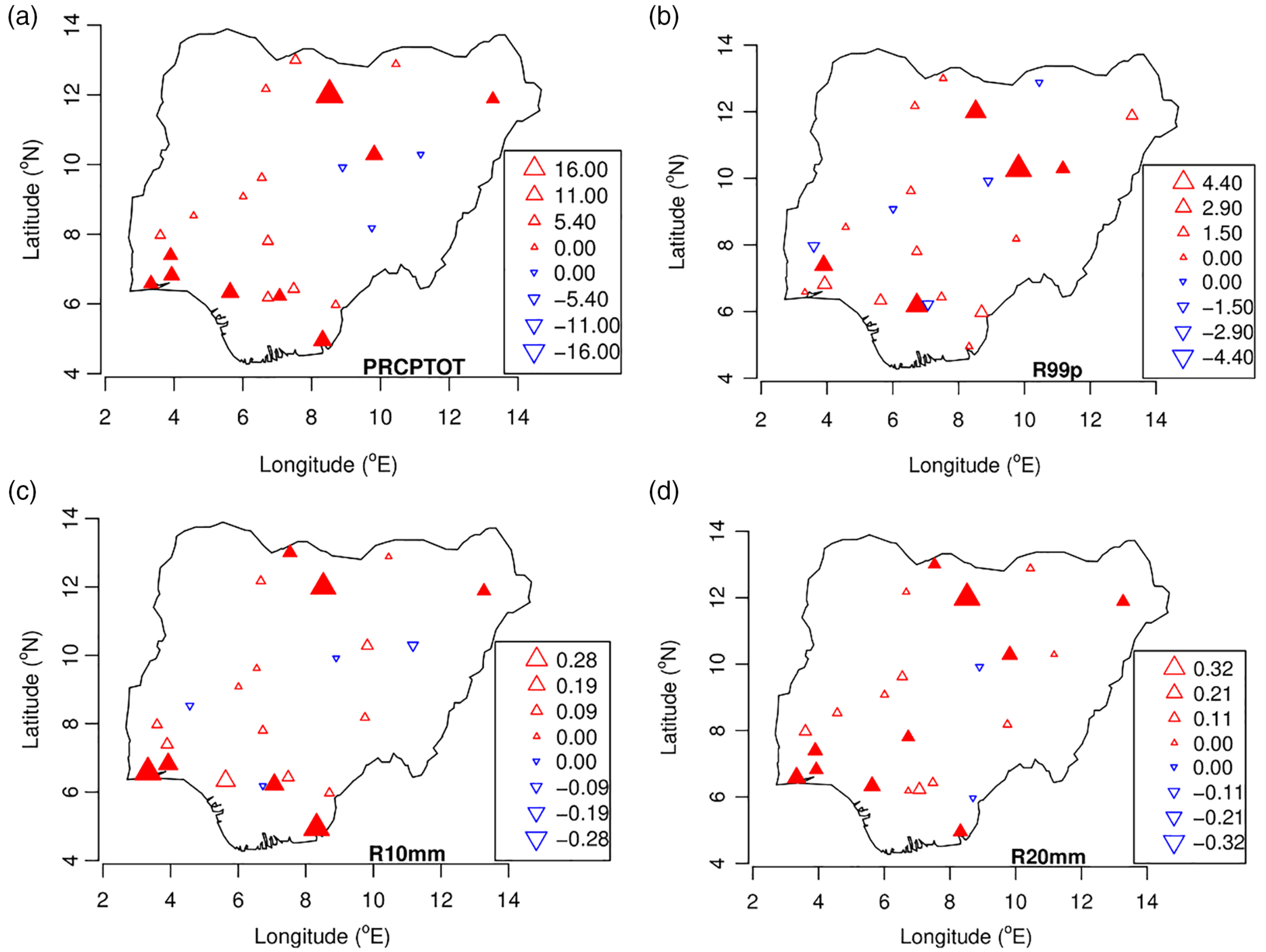

FIGURE 6 Change in (a) annual total wet day precipitation (PRCPTOT) (mm); (b) annual contribution from extremely wet day > 99th percentile (R99p) (mm); (c) days with daily precipitation ≥ 10 mm (10 mm) (days/year); and (d) days with daily precipitation ≥ 20 mm (R20mm) (days/year). As for the temperature plots, the size of triangles represents the magnitude of the trend; whether they are upward pointing or inverted shows positive or negative trends, respectively; and a filled symbol depicts significant trends at the 95% confidence level [Colour figure can be viewed at wileyonlinelibrary.com]

Figure 7a shows that trends in the number of consecutive dry days (CDD) increased over all stations. Though not significant, the CDD depicts trends approaching dryer conditions at most stations. However, an insignificant decreasing trend in the index was observed at Ijebu, Awka, Benin City and Ikom in the Guinea coast zone. In contrast to the CDD index, a decrease in the annual number of days with consecutive wet days (CWD) was observed in most stations (Figure 7b). The negative trends are insignificant over the majority of the stations, except for Ibi and Jos. Stations such as Enugu, Ijebu, Ibadan, Iseyin and Lokoja in the Guinea coast have increasing trends in the CWD, but the trends are insignificant. All stations in the Savannah show a decrease in the CWD, while Maiduguri alone has a significant increasing trend in the CWD in the Sahel.

The observed significant increase of annual precipitation in both the Guinea coast and Sahel could be associated with various environmental and atmospheric factors. For example, in the Guinea coast, the enhanced rainfall could be associated with a longer rainfall period, which varies greatly at both seasonal and interseasonal time scales. Also, the significant increase in annual precipitation in the Sahel is consistent with the results of Lebel and Ali (2009) who noted a 10% increase in precipitation over the central Sahel as well as an unchanged deficit in the western Sahel during the period 1990–2007. In a preliminary analysis (not shown), the present authors computed the annual standardized precipitation index (SPI) over the Sahel derived from the average total annual rainfall of the five stations within the region for the period 1975–2013, which reflects the time series of the PRCPTOT index. The analysis revealed the already established dry years of the early to mid-1970s and those of the 1980s to the mid-1990s, and the posterior recovery of precipitation from the late 1990s. Further, Druyan (2011) found recovery of seasonal precipitation accumulations in the Sahel between the 1990s and the 2000s, but not at levels of the period preceding the observed drought episodes of the 1970s and 1980s. Although the IPCC (2013) reported a drying trend over West Africa from the results of a longer time series from 1951 to 2012, an extensive study by Ibrahim *et al*. (2014) reported both an increasing annual total precipitation and wet days frequency, which contributes to the partial recovery of rainfall in the Sahel. This recovery of precipitation in the Sahel is due not only to the important role of natural variability (Mohino *et al*., 2011) but also, to a greater extent, to anthropogenic greenhouse gas emissions (Haarsma *et al*., 2005; Ackerley *et al*., 2011; Biasutti, 2013; Dong and Sutton, 2015).

Further, it has been reported (e.g. Gong and Eltahir, 1996) that rainfall over any land region is basically supplied by water vapour advected into the region from surrounding areas and water vapour supplied by evaporation from the same region. Increasing surface temperature over the Sahel region, as a result of anthropogenic activities, will lead to an increase in the rate of evaporation, thereby contributing to precipitation increase in the Sahel region. Studies have attempted to explain the possible causes or forcings behind the recovery of precipitation amounts in the Sahel region. For example, Sanogo *et al*. (2015) reported rainfall recovery in the Sahel. This recovery was shown to reflect in more rain days associated with a longer wet spell duration as well as more extreme rainfall events (Adeyeri *et al*., 2019). Most recently, Akinsanola and Zhou (2018) assessed the factors controlling increasing precipitation over the central eastern Sahel of West Africa and attributed this observable increase to enhancement of the vertical moisture flux, which is mainly induced by increasing moisture convergence from remote sources.

The increase in the observed total annual precipitation at some stations will potentially favour hydropower generation and increase the potable water supply for both industrial and domestic uses in the country. On the other hand, an increase in CDD and a decrease in CWD could be dangerous for agricultural practices and food security. According to the

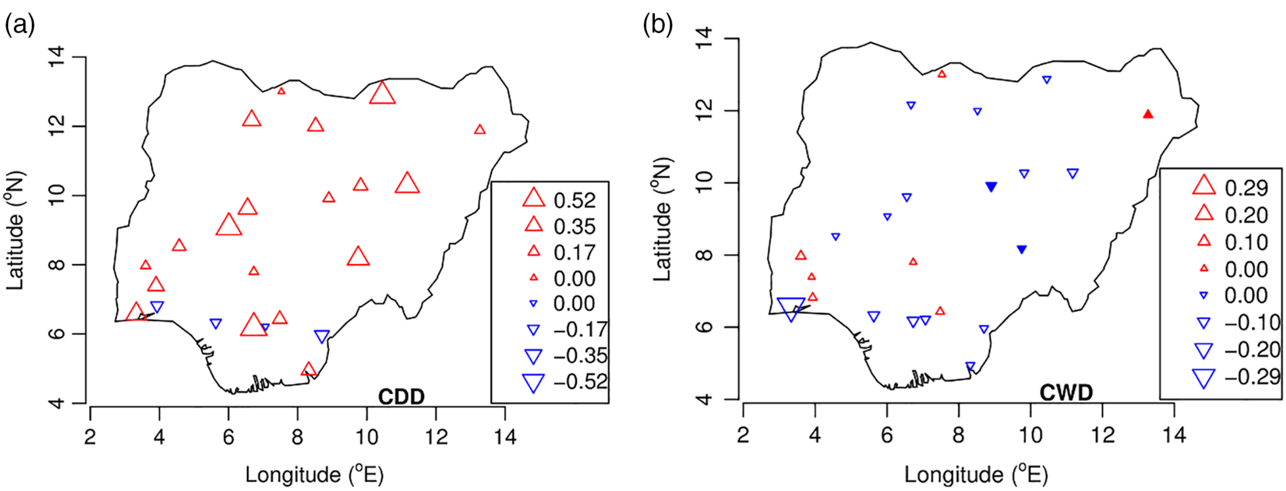

FIGURE 7 Frequency of (a) consecutive dry days (CDD); and (b) consecutive wet days (CWD) (days/year) [Colour figure can be viewed at wileyonlinelibrary.com]

International Food Research Policy Institute and other studies, climate model simulation of projected temperature increases and changing rainfall patterns are expected to contribute to a rise in average food prices (Hertel *et al*., 2010; Nelson *et al*., 2010; van der Mensbrugghe *et al*., 2011). The increase in extreme weather events could exacerbate the situation by causing food shortages, price rises and destabilizing markets in the Nigerian economy.

4 | CONCLUSIONS

The study examined observed changes in daily precipitation and temperature extremes over 24 stations in Nigeria for the period 1971–2013. A homogeneity test was performed on the data series using Expert Team on Climate Change Detection Indices (ETCCDI) RHtest4 software. Observed climate indices were calculated from the homogenized data series with RClimDex version 1.0 software. Results show significant warming trends over most stations in all three climatic zones (Guinea coast, Savannah and Sahel) of Nigeria during the considered period. TmaxMean showed that 75% of the stations have warm extremes; TminMean indicated that 33% had weak cold extremes. Furthermore, an increasing trend of annual averages of daily maximum and minimum temperature was observed in most parts of the country. Significant increasing (decreasing) trends in the frequency of warm days and nights (cold days and nights) are observed over the three climatic zones; while a significant decreasing (increasing) trend in cold spells (warm spells) are also observed in all climatic zones in the country.

In general, trends in precipitation indices show high variability. A significant increase in annual total precipitation was found in some stations across the Guinea coast and Sahel zones. In most stations, non-significant increasing and decreasing trends were found in consecutive dry days (CDD) and consecutive wet days (CWD), respectively. Significant increasing trends in extremely wet days are observed over a few locations, while elsewhere decreasing trends are observed.

The implication of the observed increasing warming may increase the risk of thermal discomfort and heat-related diseases for people living in the affected areas. This would also increase the pressure, already high, on the power sector as the energy demand for cooling would increase. However, the increasing trends in annual total precipitation would potentially contribute to an increase (or at least maintain) in hydropower generation and improve the availability of the portable water supply in the country. However, the increase in CDD and the decrease in CWD could be threatening for agricultural activities, which ensures food security.

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CONFLICT OF INTEREST

The authors declare there is no conflict of interest in any form associated with the publication of this research work.

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REFERENCES

Abatan, A.A., Abiodun, B.J., Lawal, K.A. and Gutowski, W.J., Jr. (2016) Trends in extreme temperature over Nigeria from percentile-based threshold indices. *International Journal of Climatology*, 36, 2527–2540. https://doi.org/10.1002/joc.4510.

Abatan, A.A., Abiodun, B.J., Gutowski, W.J., Jr. and Rasaq-Balogun, S.O. (2017a) Trends and variability in absolute indices of temperature extremes over Nigeria: linkage with NAO. *International Journal of Climatology*, 38 (2), 593–612. https://doi.org/10.1002/joc.5196.

Abatan, A.A., Osayomi, T., Akande, S.O., Abiodun, B.J. and Gutowski, W.J., Jr. (2017b) Trends in mean and extreme temperatures over Ibadan, Southwest Nigeria. *Theoretical and Applied Climatology*, 131, 1261–1272. https://doi.org/10.1007/s00704-017-2049-1.

Abiodun, B.J., Salami, A.T., Matthew, O.J. and Odedokun, S. (2013) Potential impacts of afforestation on climate change and extreme events in Nigeria. *Climate Dynamics*, 41(2), 277–293. https://doi.org/10.1007/s00382-012-1523-9.

Ackerley, D., Booth, B.B.B., Knight, S.H.E., Highwood, E.J., Frame, D.J., Allen, M.R. and Rowell, D.P. (2011) Sensitivity of twentieth-century Sahel rainfall to sulfate aerosol and CO2 forcing. *Journal of Climate*, 24, 499–5014. https://doi.org/10.1175/JCLI-D-11-00019.1.

Adeyeri, O.E., Lawin, A.E., Laux, P., Ishola, K.A. and Ige, S.O. (2019) Analysis of climate extreme indices over the Komadugu-Yobe Basin, Lake Chad region: Past and future occurence. *Weather and Climate Extremes*, 23, 100194. https://doi.org/10.1016/j.wace.2019.100194.

Aebischer, B., Catenazzi, G. and Jakob, M. (2007) Impact of climate change on thermal comfort, heating and cooling energy demand in Europe. *Proceedings ECEEE*, June, 23–26.

Akinsanola, A.A. and Ogunjobi, K.O. (2014) Analysis of rainfall and temperature variability over Nigeria. *Global Journal of Human-Social Science B*, 14 (3), 11–40.

Akinsanola, A.A. and Ogunjobi, K.O. (2015) Recent homogeneity analysis and long-term spatio-temporal rainfall trends in Nigeria. *Theoretical and Applied Climatology*, 128, 275–289. https://doi.org/10.1007/s00704-015-1701-x.

Akinsanola, A.A. and Zhou, W. (2018) Dynamic and thermodynamic factors controlling increasing summer monsoon rainfall over the West African Sahel. *Climate Dynamics*. https://doi.org/10.1007/s00382-018-4394-x.

Alexander, L.V. (2016) Global observed long-term changes in temperature and precipitation extremes: a review of progress and limitations in IPCC assessments and beyond. *Weather and Climate Extremes*, 11, 4–16. https://doi.org/10.1016/j.wace.2015.10.007i.

Alexander, L.V., Zhang, X., Peterson, T.C., Caesar, J., Gleason, B., Klein Tank, A.M.G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F., Tagipour, A., Rupa Kumar, K., Revadekar, J., Griffiths, G., Vincent, L., Stephenson, D.B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. and Vazquez-Aguirre, J.L. (2006) Global observed changes in daily climate extremes of temperature and precipitation. *Journal of Geophysical Research*, 111(D5). https://doi.org/10.1029/2005JD006290.

Bai, J., Lu, Q., Zhao, Q., Wang, J. and Ouyang, H. (2013) Effects of alpine wetland landscapes on regional climate on the Zoige Plateau of China. *Advances in Meteorology*, 2013, Article ID 972430, http://dx.doi.org/10.1155/2013/972430.

Biasutti, M. (2013) Forced Sahel rainfall trends in the CMIP5 archive. *Journal of Geophysical Research: Atmospheres*, 118, 1613–1623. https://doi.org/10.1002/jgrd.50206.

Donat, M.G. and Alexander, L.V. (2012) The shifting probability distribution of global daytime and nighttime temperatures. *Geophysical Research Letters*, 39(14). https://doi.org/10.1029/2012GL052459.

Donat, M.G., Peterson, T.C., Brunet, M., King, A.D., Almazroui, M., Kolli, R.K., Boucherf, D., AlMulla, A.Y., Nour, A.Y., Aly, A.A. and Nada, T.A.A. (2014) Changes in extreme temperature and precipitation in the Arab region: long-term trends and variability related to ENSO and NAO. *International Journal of Climatology*, 34(3), 581–592. https://doi.org/10.1002/joc.3707.

Dong, B.W. and Sutton, R. (2015) Dominant role of greenhouse gas forcing in the recovery of Sahel rainfall. *Nature Climate Change*, 5, 757–760. https://doi.org/10.1038/nclimate2664.

Druyan, L.M. (2011) Studies of 21st-century precipitation trends over West Africa. *International Journal of Climatology*, 31(10), 1415–1424. https://doi.org/10.1002/joc.2180.

Ekpoh, I.J. and Nsa, E. (2011) Extreme climatic variability in Northwestern Nigeria: an analysis of rainfall trends and patterns. *Journal of Geography and Geology*, 3(1), 51–62. https://doi.org/10.5539/jgg.v3n1p51.

Gbode, I.E., Akinsanola, A.A. and Ajayi, V.O. (2015) Recent changes of some observed climate extreme events in Kano. *International Journal of Atmospheric Sciences*, 2015, 1–6. https://doi.org/10.1155/2015/298046.

Gong, C. and Eltahir, E. (1996) Sources of moisture for rainfall in West Africa. *Water Resources Research*, 32(10), 3115–3121. https://doi.org/10.1029/96WR01940.

Haarsma, R.J., Selten, F.M., Weber, S.L. and Kliphuis, M. (2005) Sahel rainfall variability and response to greenhouse warming. *Geophysical Research Letters*, 32, L17702. https://doi.org/10.1029/2005GL023232.

Hagos, S.M. and Cook, K.H. (2007) Dynamics of the west African monsoon jump. *Journal of Climate*, 20(21), 5264–5284. https://doi.org/10.1175/2007JCLI1533.1.

Hartmann, D.L., Klein Tank, A.M.G., Rusticucci, M., Alexander, L.V., Bronnimann, S., Charabi, Y., Dentener, F.J., Dlugokencky, E.J., Easterling, D.R., Kaplan, A., Soden, B.J., Thorne, P.W., Wild, M. and Zhai, P.M. (2013) Observations: atmosphere and surface. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (Eds.) *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York, NY: *Cambridge University Press*, pp. 159–254.

Hertel, T.W., Burke, M.B. and Lobell, D.B. (2010) The poverty implications of climate-induced crop yield changes by 2030. *Global Environmental Change*, 20, 577–585.

Hulme, M., Doherty, R., Ngara, T., New, M. and Lister, D. (2001) African climate change: 1900–2100. *Climate Research*, 17, 145–168. https://doi.org/10.3354/cr017145.

Ibrahim, B., Karambiri, H., Polcher, J., Yacouba, H. and Ribstein, P. (2014) Changes in rainfall regime over Burkina Faso under the climate change conditions simulated by 5 regional climate models. *Climate Dynamics*, 42, 1363–1381. https://doi.org/10.1007/s00382-013-1837-2.

Iloeje, N.P. (1981) *A New Geography of Nigeria*. UK: Longman.

IPCC. (2013) Climate change 2013: the physical science basis. In: Stocker, T.F., Qin, D., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V. and Midgley, P.M. (Eds.) *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge and New York, NY: Cambridge Uni. Press. https://doi.org/10.1017/CBO9781107415324.

Karl, T.R., Nicholls, N. and Ghazi, A. (1999) Clivar/GCOS/WMO workshop on indices and indicators for climate extremes workshop summary. *Climatic Change*, 42(1), 3–7. https://doi.org/10.1023/A:1005491526870.

Klein Tank, A. M. G., F. W. Zweirs, and X. Zhang, 2009: Guidelines on analysis of extremes in a changing climate in support of informed decisions for adaptation. WCDMP-72, WMO-TD/No.1500, 56pp.

Krinner, G. (2003) Impact of lakes and wetlands on boreal climate. *Journal of Geophysical Research: Atmospheres*, 108(D16), https://doi.org/10.1029/2002JD002597.

Le Barbe, L., Lebel, T. and Tapsoba, D. (2002) Rainfall variability in West Africa during the years 1950–90. *Journal of Climate*, 15, 187–202.

Lebel, T. and Ali, A. (2009) Recent trends in the central and Western Sahel rainfall regime (1990–2007). *Journal of Hydrology*, 375(1–2), 52–64. https://doi.org/10.1016/j.jhydrol.2008.11.030.

Lebel, T., Diedhiou, A. and Laurent, H. (2003) Seasonal cycle and interannual variability of the Sahelian rainfall at hydrological scales. *Journal of Geophysical Research*, 108, 8389. https://doi.org/10.1029/2001JD001580.

Mahe, G., L'Hote, Y., Olivry, J.C. and Wotling, G. (2001) Trends and discontinuities in regional rainfall of West and Central Africa: 1951–1989. *Hydrological Sciences Journal*, 46(2), 211–226. https://doi.org/10.1080/02626660109492817.

Malhi, Y. and Wright, J. (2004) Spatial patterns and recent trends in the climate of tropical rainforest regions. *Philosophical transactions of the Royal Society of London B*, 359, 311–329. https://doi.org/10.1098/rstb.2003.1433.

Mann, H.B. (1945) Nonparametric tests against trend. *Econometrica*, 13, 245–259.

Mohino, E., Janicot, S. and Bader, J. (2011) Sahel rainfall and decadal to multidecadal sea surface temperature variability. *Climate Dynamics*, 37(3), 419–440. https://doi.org/10.1007/s00382-010-0867-2.

Mouhamed, L., Traore, S.B., Alhassane, A. and Sarr, B. (2013) Evolution of some observed climate extremes in the West African Sahel. *Weather and Climate Extremes*, 1, 19–25.

Nelson, G.C., M.W. Rosegrant, A. Palazzo, I. Gray, C. Ingersoll, R. Robertson, S. Tokgoz, T. Zhu, T.B. Sulser, C. Ringler, S. Msangi, and L. You, 2010: Food security, farming, and climate change to 2050: challenges to 2050 and beyond. IFPRI Issue Brief No. 66. Washington DC: International Food Policy Research Institute (IFPRI).

New, M., Hewitson, B., Stephenson, D.B., Tsiga, A., Kruger, A., Manhique, A., Gomez, B., Coelho, C.A.S., Masisi, D.N., Kululanga, E., Mbambalala, E., Adesina, F., Saleh, H., Kanyanga, J., Adosi, J., Bulane, L., Fortunata, L., Mdoka, M.L. and Lajoie, R. (2006) Evidence of trends in daily climate extremes over southern and West Africa. *Journal of Geophysical Research*, 111(D14). https://doi.org/10.1029/2005JD006289.

Nicholson, S.E. (2013) The West African Sahel: a review of recent studies on the rainfall regime and its interannual variability. *ISRN Meteorolog*, 2013 (**32** pages), 453521. https://doi.org/10.1155/2013/453521.

Oguntunde, P.G., Abiodun, B.J. and Lischeid, G. (2011) Rainfall trends in Nigeria, 1901–2000. *Journal of Hydrology*, 411, 207–218. https://doi.org/10.1016/j.jhydrol.2011.09.037.

Omotosho, J.B. and Abiodun, B.J. (2007) A numerical study of moisture buildup and rainfall over West Africa. *Meteorological Applications*, 14(3), 209–225. https://doi.org/10.1002/met.11.

Peterson, T.C. and Manton, M.J. (2008) Monitoring changes in climate extremes: a tale of international collaboration. *Bulletin of the American Meteorological Society*, 89, 1266–1271. https://doi.org/10.1175/2008BAMS2501.1.

Sanogo, S., Fink, A.H., Omotosho, J.A., Ba, A., Redl, R. and Ermert, V. (2015) Spatio-temporal characteristics of the recent rainfall recovery in West Africa. *International Journal of Climatology*, 35(15), 4589–4605. https://doi.org/10.1002/joc.4309.

Seneviratne, S.I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C. and Zhang, X. (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Field, C.B., Barros, V., Stocker, T.F., Qin, D., Dokken, D.J., Ebi, K.L., Mastrandrea, M. D., Mach, K.J., Plattner, G.K., Allen, S.K., Tignor, M. and Midgley, P.M. (Eds.) *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*. Cambridge and New York, NY: Cambridge University Press, pp. 109–230.

Sultan, B. and Janicot, S. (2000) Abrupt shift of the ITCZ over West Africa and intra-seasonal variability. *Geophysical Research Letters*, 27, 3353–3356.

Thompson, J. and Polet, G. (2000) Hydrology and land use in a Sahelian flood plain wetland. *Wetlands*, 20, 636–659. https://doi.org/10.1672/0277-5212(2000)020[0639:HALUIA]2.0.CO;2.

van der Mensbrugghe, D., Osorio-Rodarte, I., Burns, A. and Baffes, J. (2011) Macroeconomic environment and commodity markets: a longer-term outlook. In: Conforti, P. (Ed.) *Looking Ahead in World Food and Agriculture: Perspectives to 2050*. Rome: FAO.

Wang, X.L. (2008a) Accounting for autocorrelation in detecting mean shifts in climate data series using the penalized maximal t or F test. *Journal of Applied Meteorology and Climatology*, 47(9), 2423–2444. https://doi.org/10.1175/2008JAMC1741.1.

Wang, X.L. (2008b) Penalized maximal F-test for detecting undocumented mean-shift without trend-change. *Journal of Atmospheric and Oceanic Technology*, 25(3), 368–384. https://doi.org/10.1175/2007JTECHA982.1.

Wang, X.L., Chen, H., Wu, Y., Feng, Y. and Pu, Q. (2010) New techniques for detection and adjustment of shifts in daily precipitation data series. *Journal of Applied Meteorology and Climatology*, 49(12), 2416–2436. https://doi.org/10.1175/2010JAMC2376.1.

Wang, X. L. and Feng, Y. (2009) Published online July 2013, RHtestsV4 User anual. Climate Research Division, Atmospheric Science and Technology Directorate, Science and Technology Branch, Environment Canada. 28 pp. Available at: http://etccdi.pacificclimate.org/software.shtml

World Meteorology Organisation (WMO). (2015) The climate in Africa: 2013. WMO-No. 1147, 32pp, http://www.wmo.int/pages/prog/wcp/wcdmp/documents/1147_EN.pdf. [Accessed on March 22, 2019].

Zhang, X. and Yang, F. (2004) RClimDex (1.0) User Manual, Climate Research Branch Environment, Ontario, Canada. Available at: http://etccdi.pacificclimate.org/software.shtml. [Accessed on March 22, 2019].

Zhang, X., Alexander, L., Hegerl, G.C., Jones, P., Tank, A.K., Peterson, T.C., Trewin, B. and Zwiers, F.W. (2011) Indices for monitoring changes in extremes based on daily temperature and precipitation data. *Wiley Interdisciplinary Reviews: Climate Change*, 2(6), 851–870. https://doi.org/10.1002/wcc.147.

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