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Spatial and Temporal Trends in Diurnal Temperature and Precipitation Extremes in North Central Nigeria

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Abstract. Global warming and changes in precipitation patterns are among the major effects of climate change. In this study, the long-term variability in ambient surface temperature and precipitation were evaluated in the north central region of Nigeria (Abuja, Kogi, Kwara, Niger, and Plateau) using meteorological observations obtained from 1975 to 2008. Daily precipitation data from synoptic weather stations were carefully quality-controlled using the RCLimindex 1.1 developed by Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI). The quality-controlled dataset were homogenized using RHtestsV4 and the detected change points were adjusted. Results showed a decrease in cool nights and cool days (TN10P, TX10P), and increasing trend in warm nights and days (TN90P, TX90P). The trend in rainfall is variable compared to changes in temperature. The precipitation indices indicated increasing trend in total annual precipitation (PRCPTOT), and a significant decrease in the number of consecutive wet days (CWD) in this region. In general, regional changes in climate temperature and precipitation extremes were significant ($p < 0.05$) and could result in serious climate induced effects.

Keywords: Climate change; RCLimindex; RHtests; daily precipitation; daily temperature

1. Introduction

The Earth's climate is changing largely in response to increased atmospheric concentrations of greenhouse gases (GHGs) (carbon dioxide, methane, halocarbons, nitrous oxide, sulfur hexafluoride) and particulate matter influenced majorly by anthropogenic emissions from fossil fuel and cement production [1–8]. In recent years, there has been heightened concerns about unmitigated alteration of our climate system which has exacerbated extreme weather events, accelerated sea level rise, desertification, coastal erosion, droughts, unprecedented rise in ambient temperature, flooding causing property damage and population displacement, and socioeconomic burdens [1]. Uncontrolled climate change will continue to deplete our natural resources and threatens our health and the environment. The intensity and recurrence of extreme climatic changes have more impact on nature and humans especially in developing countries [9–14].

Changes in surface temperature otherwise known as global warming has attracted the attention of the researchers, world leaders and policy makers due to increasing magnitude and frequency of extreme



precipitation events [15,16]. Populations in less developed countries are more likely to be in danger due to floods as a result of extreme precipitations [17]. On a global scale, extreme precipitation events filliped by thunderstorm activity, increased moisture levels in the atmosphere, and flash flooding appear to occur more frequently and these extreme events have been widely reported [16,18–24]. Due of the excess water vapor in the atmosphere, increase in temperature is reported to be associated with the current increment in extreme precipitation events [7]. A large number of comprehensive studies on changes in daily extreme temperature and precipitation events have been conducted at local, regional and global scales [25–31]. A few reviews have also indicated that these temperature and precipitation extreme events vary spatially [7,8,32–35]. Other documented reports have considered changes in climate extremes across different geographic regions and timescales [36,37].

Evidence of significant changes in the annual precipitation intensity and frequency of daily precipitation in West Africa have been documented [10,38,39]. It has been reported that minimum temperature increased more than maximum temperature, thereby, narrowing the diurnal temperature range [40,41]. Amongst the most vulnerable regions to climate change is the Sahelian region of West Africa [42]. Following the drought in 1970 till the mid-1980s, the Sahelian district has been a zone of extreme precipitation and temperature research [43,44]. Thus, this study was needed to evaluate the long-term variability in ambient surface temperature and precipitation in north central region, situated in the Sahelian region of Nigeria. Although a few studies on changes in precipitation and temperature extremes have been reported in Nigeria, most reports considered meteorological data that were restricted to very limited local weather stations [45–48]. Research on climate changes in extremes across different geographic regions and timescales in the country is sparse. For effective mitigation and adaptation, understanding how global warming alters and responds to extreme events in Nigeria is needed.

The objective of this study is to provide a regional-scale statistical analysis of observed changes in temperature and precipitation extremes over the north central region of Nigeria. The study reviews variations and trends of climate change extremes over the region using absolute, threshold and percentile-based climate indices. The current study is focused on a 33-year daily-observed meteorological temperature and precipitation data from six weather stations across the region.

2. Data and method

2.1 Study area

The area of study is the North-central region of Nigeria. It consists of 7 states (Figure 1). The size of the region is 242,425 sq. km. It has a population of over 20 million people. The meteorological stations considered include Abuja (9.0765° N, 7.3986° E), Bida (9.0797° N, 6.0097° E), Ilorin (8.4799° N, 4.5418° E), Jos (9.8965° N, 8.8583° E), Lokoja (7.8023° N, 6.7333° E), and Minna (9.5836° N, 6.5463° E). The Sahel climate or tropical dry climate is the predominant climate type in the northern part of Nigeria. Annual rainfall totals are lower compared to the southern part of Nigeria. Rainy season in the northern part of Nigeria last for only three to four months (June–September). Flooding occurs annually. The rest of the year is hot and dry with temperatures climbing as high as 40 °C (104.0 °F).

2.2 Data Source

The observed meteorological data, including records of daily maximum temperature, minimum temperature and precipitation between 1975 and 2008, were obtained from the Nigerian Meteorological Agency (NIMET) and used in this study. The data obtained was split into two base periods 1976–1991 and 1992–2007 in order to assess the observed changes of extreme climate over the stations with the exceptions of Abuja that the base periods 1983–1997 and 1998–2007 were adopted because the station's meteorological data started from 1982. The data from the 6 synoptic weather stations were subjected to quality control using RClimdex 1.1 developed by Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) which can be downloaded freely online from the ETCCDMI website <http://etccdi.pacificclimate.org/indices.shtml> [49]. In the quality

control process, the dataset went through the following procedures; all missing values were coded as -99.9 which were replaced into an internal format that RCLimDex software package recognized (like NA, not available) to avoid errors in the computation; and all unnecessary values were also replaced as NA. These values include daily precipitation less than zero, daily minimum temperature greater than daily maximum temperature, and minimum and maximum temperatures greater than 6 standard deviations from the long-term (full dataset) mean value. Also, the quality control process detected outliers in daily minimum and maximum temperature, which were removed. According to the Joint World Meteorological Organization Commission for Climatology (CCI)/World Climate Research Programme (WCRP) project on the CLIVAR Expert Team on Climate Change Detection and Indices (ETCCDI) guidelines for climate change detection in climatic indices, a threshold can be calculated for threshold indices if at least 70% of data are present. The stations, as shown on Table 1, had more than 70% daily data, hence, they were retained for indices calculation in this study.

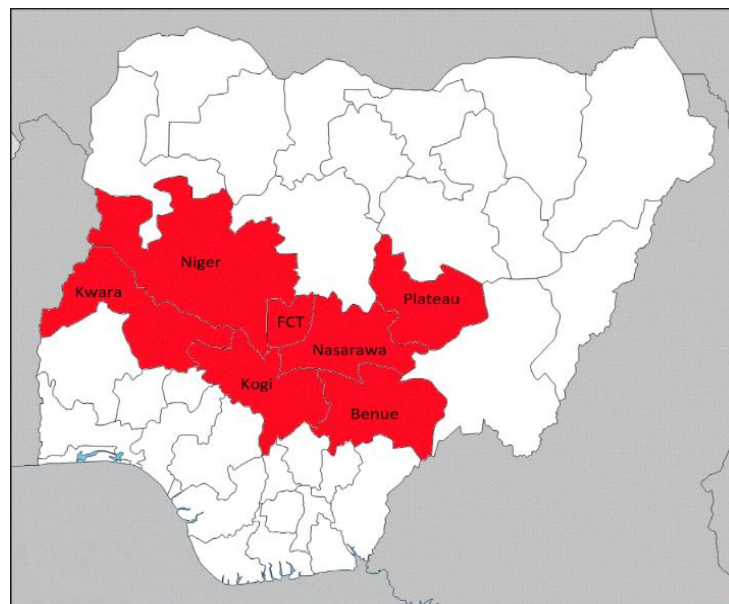


Figure 1. The approximate topography of Nigeria and the location of the states in the North central region highlighted in red.

2.3 Data Quality Control and Homogeneity

In this study, data quality control was considered as a prime prerequisite for subsequent climate indices analysis. A simple data quality control and homogenization was performed using the RCLimDex [49] and RHtestsV4 [50] (available from <http://etccdi.pacificclimate.org/software.shtml>). The software checks for non-climatic shifts that may exist in daily, monthly, and annual time series. There are many approaches and techniques developed to adjust non-climatic shifts in data time series [51–54]. However, RHtestsV4 is based on the transPMFred algorithm [55], which integrates a data adaptive Box-Cox transformation procedure into the PMFred algorithm [56]. This software performs four statistical tests: (i) The Penalized Maximum T (PMT) test for detection of unknown change points [57]; (ii) The Student T test for determining the statistical significance of known change points [57]; (iii) The Penalized Maximum F (PMF) test for detection of unknown change points [56]; (iv) The regular F test for determining the statistical significance of known change points [58]. The software can also make Quantile-Matching (QM) adjustments to daily or sub daily (up to hourly) data series for the change points already identified in the corresponding annual or monthly data series. The detected

change points were adjusted and the homogenized datasets were then loaded into the RCLimDex software for computation of the climate indices.

Table 1. Meteorological station data.

Station Name	States	Period	Latitude	Longitude
Abuja	FCT	1982–2008	9.0765	7.3986
Bida	Niger	1975–2008	9.0797	6.0097
Ilorin	Kwara	1975–2008	8.4799	4.5418
Jos	Plateau	1975–2008	9.8965	8.8583
Lokoja	Kogi	1975–2008	7.8023	6.7333
Minna	Niger	1975–2008	9.5836	6.5463

2.4 Climate Indices

Climate indices are used for statistical study, analysis and comparison of time series, means, extremes and trends variations [59]. There are 27 indices computed and recommended by the ETCCDI for trend analysis and they can be categorized into four: (i) percentile-based indices (e.g., warm days; TX90p, warm nights; TN90p, cold days; TX10p, cold nights; TN10p, wet days; R95p, extremely wet days; R99p); (ii) absolute indices (coldest day; TXn, coldest night; TNn, warmest day; TXx, warmest night; TNx, maximum 1-day precipitation; RX1day, maximum 5-day precipitation; RX5day); (iii) duration indices (cold spell duration indicator; CSDI, warm spell duration indicator; WSDI, growing season length; GSL, consecutive dry days; CDD, consecutive wet days; CWD); and (iv) threshold indices (summer days; SU25, tropical nights; TR20, heavy precipitation days; R10, very heavy precipitation days; R20). Other indices that do not fall into any category but equally important are: annual precipitation total; PRCPTOT, diurnal temperature range; DTR, and simple daily intensity index; SDII. Available online at ETCCDI [49] are the detailed definitions of the indices. Global and regional studies have used these indices for analyzing extreme changes [10,16,26,29]. Twenty four out of the twenty seven climate indices were used in this study and are presented in Tables 2 and 3:

Table 2. List of ETCCDI temperature indices used in this study.

Index	Indicator Name	Definition	Units
SU25	Summer days	Annual count when TX(daily maximum) > 25 °C	Days
TR20	Tropical nights	Annual count when TN(daily minimum) > 20 °C	Days
GSL	Growing season length	Annual (1 January to 31 December in NH, 1 July to 30 June in SH) count between first span of at least 6 days with TG > 5 °C and first span after 1 July (1 January in SH) of 6 days with TG < 5 °C	Days
TXx	Maximum Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Maximum Tmin	Monthly maximum value of daily minimum temp	°C
TXn	Minimum Tmax	Monthly minimum value of daily maximum temp	°C
TNn	Minimum Tmin	Monthly minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
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

Table 3. List of ETCCDI precipitation indices used in this study.

Index	Indicator Name	Definition	Units
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	Mm

RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	Mm
SDII	Simple daily intensity index	Annual total precipitation divided by number of wet days (defined as PRCP \geq 1.0 mm) in the year	Mm/days
R10	Number of heavy precipitation days	Annual count of days when PRCP \geq 10 mm	Days
R20	Number of very heavy	Annual count of days when PRCP \geq 20 mm	Days
CDD	Consecutive dry days	Max. number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	Max. number of consecutive days with RR \geq 1 mm	Days
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	Mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	Mm
PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR \geq 1 mm)	Mm

2.5 Trend Analysis

Statistical analyses were done for 33 years with the base periods 1976–1991 and 1992–2007 as defined in the source code of RCLimDex. Plots and tables of trends were generated using the RCLimDex. The significance of the trends was done using Student t-test. The p-value resulting from the student t-test is the criterion to define the class boundary. It is used to analyze that the trend is equal to 0. The trends that were less than 5% i.e., p-value \leq 0.05, were considered to be significant and less significant when the p-value \geq 0.05. The regional average time series was computed by adding the indices values of the stations in the North central region and dividing by the number of stations.

3. Results and discussion

The twenty-four climate indices selected for precipitation and temperatures based on ETCCDI definitions are computed for each station as well as the regional trends, and are summarized in Table 4. The results obtained after computing the time series for indices trends are presented in Figure 2.

3.1 Temperature Indices

Abuja is observed to have increased in temperature with the warm night trend as high as 1.328. Correspondently, the cool days and nights show decreasing trends. Tropical nights are nights when daily minimum temperature stays above 20°C, it is observed that such nights have increased in this area, which is very harmful especially for the elderly and sick people. In Bida, the temperature increased therefore, this area can be said to be warming. Cool days and nights have reduced, warm days and nights have increased. Nights that temperature is above 20°C (TR20) have increased as well. In Ilorin the warm days and nights are increasing steadily, while the cool nights and days are decreasing. There was a slight increase in the growing season length of this area.

The temperature indices in Jos indicated a significant decrease. This area is known to be cool which explains increase in number of cool nights although cool days decreased. Warm days increased while warm nights decreased. The temperature in this area fluctuates. The monthly maximum daily values of minimum temperature (TNx) and monthly minimum daily values of minimum temperature (TNn) both decreased in trend. Growing season length slightly increased but it is not safe to conclude that this area's agricultural activities will be effective. The temperature indices in Lokoja show increase in warm nights and days and decrease in cool nights and days. Tropical nights have increased which is a risk to health. The diurnal temperature range decreased. The temperature in Minna is increasing. Warm nights and days have significantly increased while cool nights and days decreased significantly, all within the acceptable confidence level <0.05. Growing season length has increased slightly. This region shows a decrease in cool nights and cool days (TN10P, TX10P) while increasing trend in warm nights and days (TN90P, TX90P) indicating that the region is getting warmer, especially warm nights, with a high positive slope of 0.273 showing the nights have been very warm. The diurnal temperature range (DTR) shows a slight increase in trend. Warm spell duration indicator (WSDI) also shows that warm days have increased annually which confirms the TX90P positive trend.

3.2. Precipitation Indices

The amount of precipitation in Abuja decreased and the total annual precipitation is on a low range. Consecutive wet days have shortened. All the precipitation indices in Bida decreased showing there is limited rainfall but except for consecutive wet days, which slightly and non-significantly increased. Total annual precipitation dropped significantly to a negative slope of -3.331 . The precipitation in Ilorin is quite adequate. The total annual precipitation has increased, heavy precipitation days (R95p) and very heavy precipitation days (R99p) also increased significantly. Consecutive wet days decreased alternatively. In Jos, the precipitation indices in this area all decreased with the total annual precipitation of -0.608 . Heavy and very heavy precipitation also decreased. Consecutive wet days as well decreased. In Lokoja, heavy precipitation days and very heavy precipitation days have increased as well as the total annual precipitation which indicate an adequate amount of rainfall in this region. The growing season length decreased indicating that this area can only grow crops that require short growing seasons. Conversely, the precipitation in Minna decreased with the total annual precipitation negative slope trend of -1.253 (Figure 2). The rainfall here is limited. Consecutive wet days decreased while the consecutive dry days increased significantly. Regionally, the total annual precipitation (PRCPTOT) indicated an increase in trend and decrease in number of consecutive wet days (CWD). The accumulated rainfall of extremely wet days (R99P) shows a highly increasing trend. It is also observed that the maximum 1-day rainfall amount (RX1day) increased but not as much as maximum 5-day (RX5day) which has a slope of 0.193 (Table 4). Hence, the trend in rainfall is variable compared to temperature.

Regional studies have shown similar trends in temperature indices with this study. A general warming trend was found throughout the Guinea, Savannah, and Sahel region of Nigeria from 1971 to 2012 [45,47,51] as there were more frequent warm nights and days and less cool nights and days. Also the precipitation trend increased but not as significant as temperature indices. Total annual total rainfall and all precipitation indices indicated a positive trend in most stations except for the number of consecutive wet days. Studies in some parts of Africa including Nigeria support the results in this study that there is increased warming in across major regions in Africa [10]. All the precipitation indices showed slightly significant increase. Number of consecutive wet days decreased by -0.029 days per year, total annual rainfall increased by 1.101 mm per year, and extremely wet days slightly increased by 0.090 days per year. These results do not differ from the data reported globally [6]. The changes observed in the climate calls for the use of renewable energy tools to reduce the amount of greenhouse gases in the atmosphere and a means of dissipating water bodies.

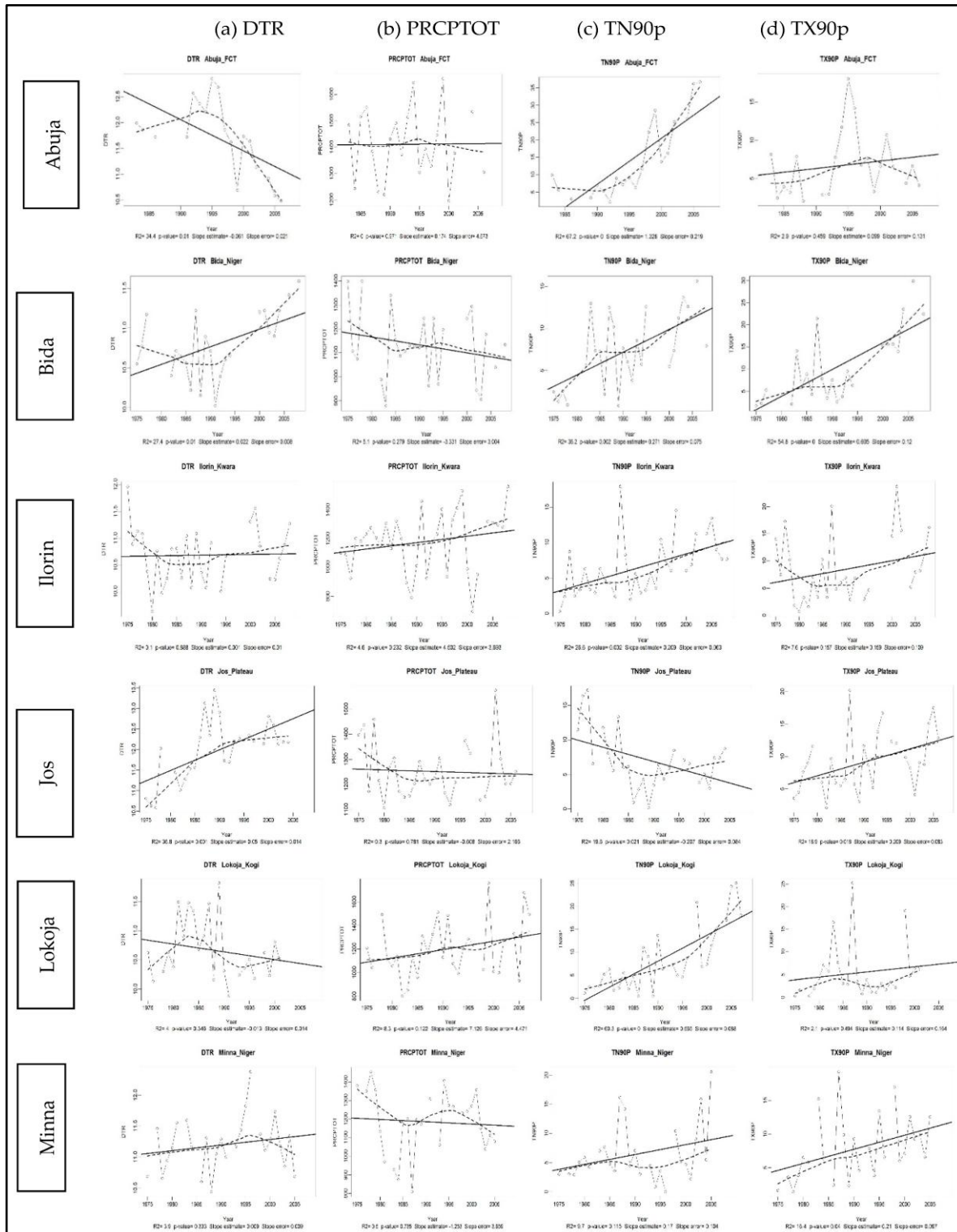


Figure 2. Time series of climate indices for the six stations in north central Nigeria (1976–2008): (a) diurnal temperature range (b) total annual precipitation (c) warm nights, and (d) warm days.

4. Conclusions

It is no news that the climate is changing significantly with time and the impact of this change may portend negative consequences on agriculture, the environment, human health and economy of Nigeria. This study has shown the trends in 24 climate indices in north central Nigeria using daily

precipitation and temperature data from six meteorological stations for the period 1975 to 2008 and comparing two base periods 1976–1991 and 1992–2007. The results show significant trends in the temperature indices, which corresponds to the warming trend in this region in Nigeria. The frequency of warm days increased while the frequency of cold days decreased on the other hand. The precipitation indices, consisting of annual total precipitation, number of wet days, monthly maximum 1-day precipitation, monthly maximum consecutive 5-day precipitation, annual number of days when precipitation is greater than 10 mm, annual number of days when precipitation is greater than 20 mm increased while consecutive wet days decreased. These findings correspond with other observed climate extremes reported in similar studies [38,45–47]. The use of renewable energy tools to reduce the amount of greenhouse gases in the atmosphere and a means of dissipating water bodies. With good management of irrigation systems, agricultural activities can still be effective in this region.

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Conflicts of Interest: The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

ETCCDI	Expert Team on Climate Change Detection and Indices
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
Mm	Millimeter
NIMET	Nigerian Meteorological Agency
PMF	Penalized Maximum F
PMT	Penalized Maximum T
QM	Quantile-Matching

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