Science World Journal Vol 10 (No 2) 2015
www.scienceworldjournal.org
ISSN 1597-6343

Full Length Research Article

CHANGES IN INDICES OF DAILY TEMPERATURE AND PRECIPITATION EXTREMES IN NORTHWEST NIGERIA

Auwal F. Abdussalam

Department of Geography, Faculty of Science, Kaduna State University, PMB 2339, Tafawa Balewa Way, Kaduna.

Email: abdussalamauwal@gmail.com

ABSTRACT
It's a known fact that climate change will bring about increases in the occurrence of weather extreme events such as elevated temperature, drought, and floods; most especially in areas classified as hotspots to climate change – such as northwest Nigeria. This study investigates trends in extreme temperature and precipitation indices between 1971 and 2010 for six synoptic weather stations in northwest Nigeria. Results indicate that there have been statistically significant, spatially coherent trends in temperature indices that are related to temperature increases in the region. Significant, increasing trends have been found in the annual minimum of daily maximum and minimum temperature, the annual maximum of daily maximum and minimum temperature, the number of summer nights, and the number of days where daily temperature has exceeded its 90th percentile. Significant negative trends have been found in the number of days when daily temperature is below its 10th percentile and daily temperature range. Trends in precipitation indices, including the number of days with precipitation, the average precipitation intensity, and maximum daily precipitation events, are weak in general and do not show spatial coherence, with Kaduna showing decreasing trend.

Keywords: *Climate, Extremes, Trends, Temperature, Precipitation*

INTRODUCTION
The Intergovernmental Panel on Climate Change (IPCC, 2007) Assessment Report Four (AR4) states that there will be an increased risk of more intense, more frequent and longer-lasting heat waves in a warmer future climate, and that events such as the European heat wave in 2003 would be more common (Meehl et al., 2007). Meehl and Tebaldi, (2004) estimated that many of the areas that receive the most severe heat wave events in the present climate will experience the greatest increase in heat wave severity in the second half of the twenty-first century.
Extreme temperature events, through the occurrence of prolonged hot or cold spells, can have serious impacts on our environment and society. In recent years investigations of observed temperature in many regions of the world have already shown some important changes in the extremes. This warming may not be spatially or temporally uniform, but it is projected to continue and will likely be accompanied by more extreme climate events (Folland et al., 2001). Population and infrastructure are becoming more vulnerable to severe and intense weather and it is essential to closely monitor the extreme events and to continue to search for evidence of changes in climate extremes. Recent investigation of the trends in temperature indices over Europe has indicated a symmetric warming of the cold and warm tails of the daily minimum and maximum temperature distributions during 1946–99 (Klein Tank and Können, 2003). The frequency of cold days has decreased in northern China while the number of hot days has also decreased in the eastern part of the country over the past 40 years (Zhai et al., 1999).
There is increasing evidence that extreme heat events have become more prolonged with climate change and that these events will increase in frequency, duration and intensity (Solomon et al., 2008). Extreme heat events have a significant impact on human health both directly through dehydration, and indirectly through a number of other health conditions including cardiovascular collapse and respiratory distress (Solomon et al., 2008). Prolonged exposure to high temperature can cause heat-related illness, including heat cramps, heat syncope, heat exhaustion, heat stroke and death (Kilbourne, 1999). Heat events can result in increased deaths and emergency hospital admissions, especially among vulnerable groups such as elderly people, young children and patients with chronic diseases. Elevated temperatures also have major consequences on livestock, and terrestrial biota generally (Basu and Samet, 2002; Argaud et al., 2007).
Precipitation extremes may cause serious effects on human population. History has shown that disasters like famines and diseases outbreaks are caused by droughts and flooding respectively. Extreme precipitation may result in flooding which often cause population displacement, and diseases outbreaks are very peculiar with displaced population in temporary camps due to poor water supply, sanitation, and overcrowding. Flooding caused by heavy rainfall may induce water related illness like cholera and typhoid, if the flood water becomes contaminated with human and animal waste. Under extreme precipitation, water and waste-water services may be damaged or failed, resulting in service breakage or contaminations of drinking water with severe impacts to population health. After heavy precipitation, storm water washes human, animal, and other waste into unprotected water sources, thereby chemically or biologically polluting the water at the point of consumption.
Any change in the frequency or severity of extreme climate events could have profound impacts on nature and society. It is thus very important to analyse extreme events. Populations in developing countries are likely to be particularly vulnerable to floods (Haines and Patz, 2004) induced by extreme precipitations due to population growth, concentration of population in high-risk areas, and poor public health infrastructures. Particular example is northwest Nigeria; in this region flooding has recently become an annual problem in states like Kano, Kaduna, Katsina, Sokoto, Kebbi and Zamfara with outbreaks of diseases and the loss of

lives and properties.

Despite the threats extreme events poses to population health, In Nigeria, cases of extreme weather events are only reported by the media. An example is the heat event reported by BBC Africa in 2002 where many people lost their lives in Maiduguri when the temperature rose above 50° Celsius. Hence there is so far no quantitative research that studied the frequency and magnitude of these extreme events in northern Nigeria. The current study intends to investigate extreme indices in 40 years of daily temperature and precipitation data from six weather stations in northwest Nigeria.

MATERIALS AND METHOD

Meteorological Data

Digital records of daily precipitation amounts and daily maximum and daily minimum temperatures from the six available meteorological stations in northwest region of Nigeria (see Table 1) were obtained for the period 1971 to 2010. Although the data was obtained from the Nigerian Meteorological Agency (NIMET) – a government organisation in charge of all weather stations across the country - the metadata of two of the selected stations (Kano and Kaduna) were further scrutinised by visiting them in order to ascertain the specific measurement techniques. Quality control (QC) was carried out for all variables, specifically maximum and minimum temperatures and rainfall were checked using an R-based software tool *Rclimdex.r 1.0*. This has been developed and maintained by the Climate Research Division (CRD) of the Meteorological Service of Canada on behalf of the Expert Team on Climate Change Detection and Indices (ETCCDI). This tool is capable of identifying duplicate dates, out-of-range values based on a defined threshold, outliers, coherence between maximum and minimum temperatures (Tmax > Tmin), and consecutive days with equal values. These are daily values outside a threshold defined by the user. In this study, this threshold is defined as the mean of the value for the day plus or minus four times the standard deviation of the value for the day standard deviation.

Data homogeneity is assessed using an R-based program, RHtest, also developed by ETCCDI. This program is capable of identifying multiple step changes at documented or undocumented change points. It is based on a two-phase regression model with a linear trend for the entire base series (Wang, 2003). The data quality control (QC) and homogeneity test procedures identified some apparent problems in the data. Each potential outlier was manually validated using information from the days before and after the event along with expert knowledge about the climate (for example, Aguilar et al., 2009). Stations information, including names and coordinates are shown in Table 1.

Table 1 Summary of station characteristics and meteorological data at six stations in Northwest Nigeria

City	Station ID	Lat	Lon	Elev. (m)	Variables obtained from all stations
					Maximum Temperature (°C) Minimum Temperature (°C) Rainfall (mm/day)
Kano	65 0460	12° 03'	08° 32'	476	
Sokoto	65 0100	12° 55'	05° 12'	351	
Gusau	65 0150	12° 10'	06° 42'	463	
Kasina	65 0280	13° 01'	07° 41'	427	
Kaduna	65 0190	10° 02'	07° 19'	645	
Yelwa	65 0010	10° 53'	04° 45'	244	

Extremes indices computation

The ETCCDI recommended a total of 27 core indices with primary focuses on extremes to be derived from station daily data. They are a part of a larger list defined by the World Meteorological Organization Working group on Climate Change Detection (Folland et al., 2001; Jones et al., 1996; Peterson et al., 2002). Most of the definitions for the indices were presented in the work of Peterson et al. (2002), and have been computed for other regions (for example, Aguilar et al., 2009; Haylock et al., 2006; Vincent et al., 2011).

Twenty indices of temperature and precipitation were selected to investigate extreme climate conditions for the six meteorological stations in northwest Nigeria between 1971 and 2010 (Table 1). The indices were computed using RClimDex, an R-based software package developed by ETCCDI. This software along with documentation is available at p://cccma.seos.uvic.ca/ETCCDMI. The bootstrap procedure of Zhang et al. (2005) has been implemented in RClimDex to ensure that the percentile-based temperature indices do not have artificial jumps at the boundary of the in-base and out-of-base periods. Apart from the trends for individual stations, trends are also calculated for the region as a whole. The regional temperature (precipitation) trends are obtained from regional average indices series calculated as the arithmetic average of the annual indices values at all the six stations for 1971–2010. Trends were computed using Wang and Swail (2001) method, taking account of a lag-1 autocorrelation effect. Details of the trend estimation and significance testing are explained in the work of Wang and Swail (2001).

All the indices have been calculated as annual values and a subset of them were also calculated as quarterly values for standard 3-month seasons; that is., March–April–May (MAM), June–July–August (JJA), September-October-November (SON), and December-January-February (DJF). Both trends and indices results are presented at 95% significance level.

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Table 2: List of the ETCCDI indices investigated in this study

Element	ID	Indicator name	Definitions	Units
Temperature	SU25	Summer days	Annual count when TX(daily maximum)>25ºC	Days
	TR20	Tropical nights	Annual count when TN(daily minimum)>20ºC	Days
	TXx	Max Tmax	Monthly maximum value of daily maximum temp	ºC
	TNx	Max Tmin	Monthly maximum value of daily minimum temp	ºC
	TXn	Min Tmax	Monthly minimum value of daily maximum temp	ºC
	TNn	Min Tmin	Monthly minimum value of daily minimum temp	ºC
	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
	DTR	Diurnal temperature range	Monthly mean difference between TX and TN	ºC
Precipitation	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 the number of wet days (defined as PRCP>=1.0mm) in the year	Mm/day
	R10	Number of heavy precipitation days	Annual count of days when PRCP>=10mm	Days
	R20	Number of very heavy precipitation days	Annual count of days when PRCP>=20mm	Days
	CDD	Consecutive dry days	Maximum number of consecutive days with RR<1mm	Days
	CWD	Consecutive wet days	Maximum number of consecutive days with RR>=1mm	Days
	PRCPTOT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR>=1mm)	Mm

RESULTS

Twenty selected climate indices for temperatures and rainfall based on CLIVAR/ETCCDI definitions (Table 2) are computed for both regional and individual station's time series.

Temperature Indices

Both regional and individual's station trends of twenty selected climate indices are presented in Table 2. A decreasing trend is apparent for both TX10p and TN10p since the beginning of data (1970s), suggesting a decrease in the number of cold days. Regional anomalies of annual series of percentage of days when daily maximum or daily minimum temperature is above its 90th percentile (TX90p and TN90p, respectively) displayed sharp increases in the 1990s contrasting with the more gradual trends in TX10p and TN10p. Statistically significant and spatially coherent decreasing trends are also observed in the six investigated stations, the spatial patterns of the TX90p trend are similar to those of the TN90p trend showing a statistically significant trend. The trends in TN10p are typically stronger than those of TX10p. Significant trends have only been observed in MAM and JJA for the latter index. The spatial distribution of trends for 1971–2010 is similar to those investigated sub-periods of 1971–1990 and 1991–2010, with trends of 19710–1990 being weaker. Generally there have been significant increases in the number of warm days, and significant decreases in the number of cold days. The increasing trends in the number of warm days are much stronger than the decreases in the number of cold days. Changes in the frequencies of cold days and warm days do not occur at the same time, that is, decreases in the number of cold days are more gradual and started in the 1970s, while increases in the number of warm days mainly occurred in the 1990s.

Table 3: Temperature and rainfall trends (per decades) for various ETCCDI indices for the six stations in northwest Nigeria between 1971 and 2010

Elements	ID	Kaduna	Gusau	Kano	Katsina	Sokoto	Yelwa	Regional	Units
Temperature	SU25	2.65	**3.77**	3.81	3.45	**4.16**	2.98	3.47	days
	TR20	**3.11**	**4.23**	**4.60**	3.93	**5.14**	**3.37**	**4.06**	days
	TXx	0.24	**0.27**	**1.03**	**1.22**	1.65	**0.39**	**0.80**	ºC
	TNx	**0.26**	**0.43**	**0.32**	**0.38**	**0.67**	**0.49**	**0.43**	ºC
	TXn	**0.19**	**0.17**	**0.21**	**0.14**	**0.26**	0.19	0.19	ºC
	TNn	0.20	**0.31**	**0.36**	0.28	**0.41**	**0.24**	0.30	ºC
	TN10p	**-1.38**	**-2.03**	-2.67	-2.89	**-2.93**	**-1.96**	**– 2.64**	days
	TX10p	-1.30	**-1.87**	**-2.01**	**-1.98**	-2.37	**-1.36**	– 1.82	days
	TN90p	**3.72**	4.01	**5.17**	**4.39**	**5.47**	**3.78**	**4.42**	days
	TX90p	**4.16**	5.28	**6.01**	**5.55**	6.23	4.91	**5.36**	days
	WSDI	**5.21**	6.02	6.74	**7.11**	**7.54**	**5.43**	6.34	days
	DTR	**-0.12**	**-1.25**	**-1.30**	**-1.28**	**-1.03**	**-.1.32**	**– 1.00**	ºC
Precipitation	RX1day	-0.65	0.24	0.31	-0.04	0.29	0.11	0.06	mm
	Rx5day	-0.06	0.31	0.28	**0.07**	0.31	**0.02**	0.16	mm
	SDII	**-0.02**	**0.36**	0.32	0.26	0.31	0.11	**0.22**	mm/day
	R10	-0.09	**0.13**	0.34	-0.37	0.91	0.08	0.29	days
	R20	-0.71	0.06	0.41	**0.35**	0.53	-0.11	**0.09**	days
	CDD	**0.68**	-0.12	**-0.42**	**-0.227**	-0.04	0.55	**0.22**	days
	CWD	**-0.02**	0.06	0.14	0.16	0.12	**-0.06**	0.09	days
	PRCPTOT	-2.23	**3.05**	5.38	1.58	5.11	**2.87**	2.63	mm

Values for trends significant at the 5% level are shown in boldface.

The regional averages for annual maximum and minimum values of daily maximum temperatures (TXx and TXn respectively) are displayed in Figure 1. The long-term changes in the annual maximum and minimum values of daily minimum temperatures (TNx and TNn) are similar to those of TXx and TXn, but the trends are stronger. Upward trends in the highest and lowest daily minimum temperatures in the year are significant at all stations; there exist more significant trends in the MAM and JJA than in the DJF.

Other additional temperature indices have been computed. They include the number of summer days (SU25), the diurnal temperature range (DTR), and the number of tropical nights (TR20). Trends for regional averaged time series for SU25, DTR, and TR20 are presented in Table 3. The long term changes of SU25 are very similar to that of TX90p and TN90p in that there is little trend prior to 1990, but it has sharply increased during the past one and half decades. These results correspond very well to the findings that most of upward trend in the TX90p and TN90p is attributable to the increase in temperatures during warmer seasons in more recent years. Similar to findings in other parts of the world (for example, Frich et al., 2002), the daily temperature range has significantly decreased in the region (Figure 1). The number of tropical nights has increased significantly, with the increase occurring more in the recent decades, due to sharp increases in the MAM and JJA temperatures during the period.

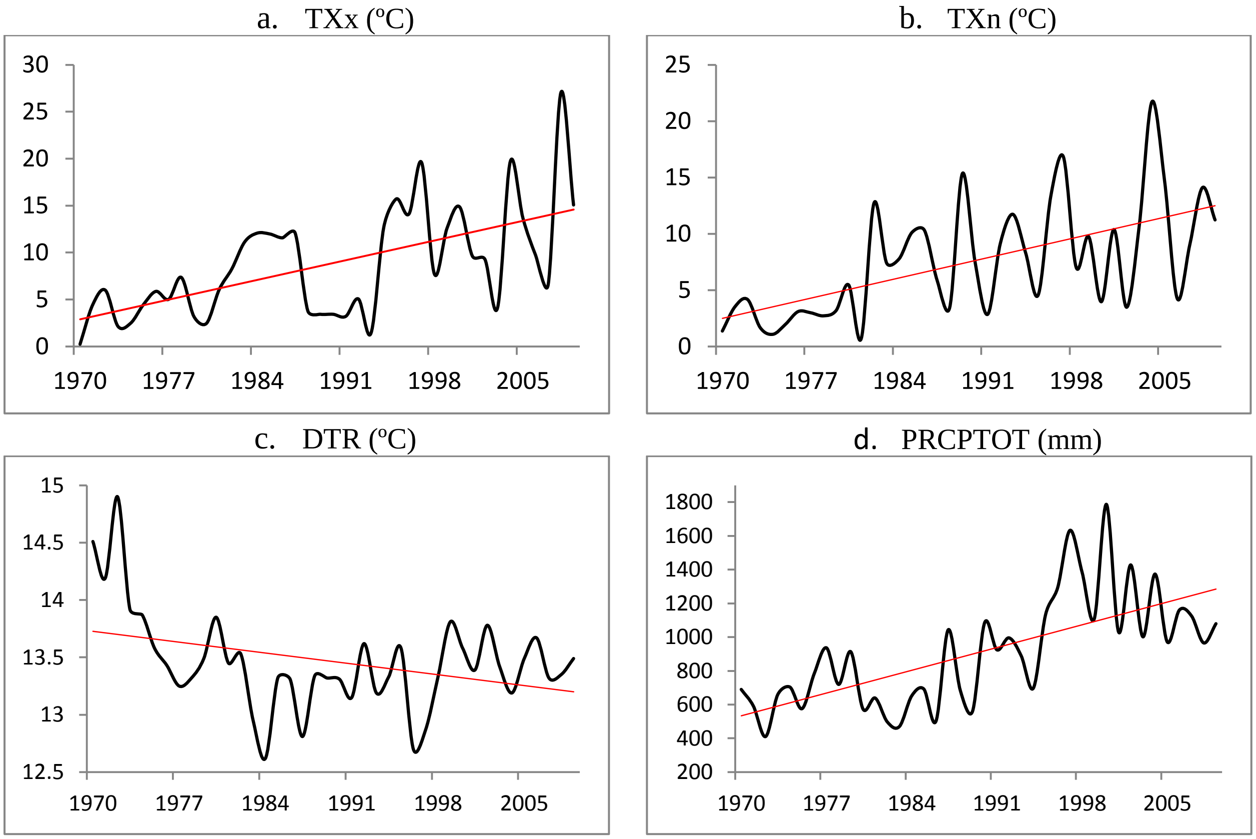

Figure 1: Regional time series of the six stations in northwest Nigeria averaged over the period of 40-years (1970 – 2010) for (a) monthly maximum value of daily maximum temperature (b) monthly maximum value of daily minimum temperature (c) diurnal temperature range, and (d) annual total wet-day precipitation. Red line indicates ordinary least square fit.

PRECIPITATION INDICES

Precipitation variation is characterized by strong interannual variability with less significant trend in all the precipitation indices calculated (Table 3). As an example, regional average and individual station's precipitation totals are plotted in Figures 1 and 2 respectively. Because precipitation climatology varies considerably from one place to another place, the time series of precipitation anomalies shown in Figure 1 are more representative for the wetter region. Figure 2 shows the trend of the total precipitation for the six investigated stations; the plot reveals an increasing trend (for example, Sokoto and Kano) and decreasing one (as in the case of Kaduna).

The trends calculated for precipitation indices are shown in Table 3. First and foremost, both the regional and individual station's time series show increases (though not significant) in total precipitation with only Kaduna showing otherwise. The maximum number of consecutive dry days is increasing in Kaduna and the length of the maximum number of consecutive wet days shows a significant in other stations. The measures of heavy precipitation are increasing in all stations except Kaduna and Katsina. This includes both percentile measures (that is, rainfall above the 95th (very wet) and 99th (extremely wet) percentiles), as well as the maximum one and five day precipitation amount recorded in a year. However, few indices show statistically significant trend, and less spatial coherency if compared with that for temperature indices.

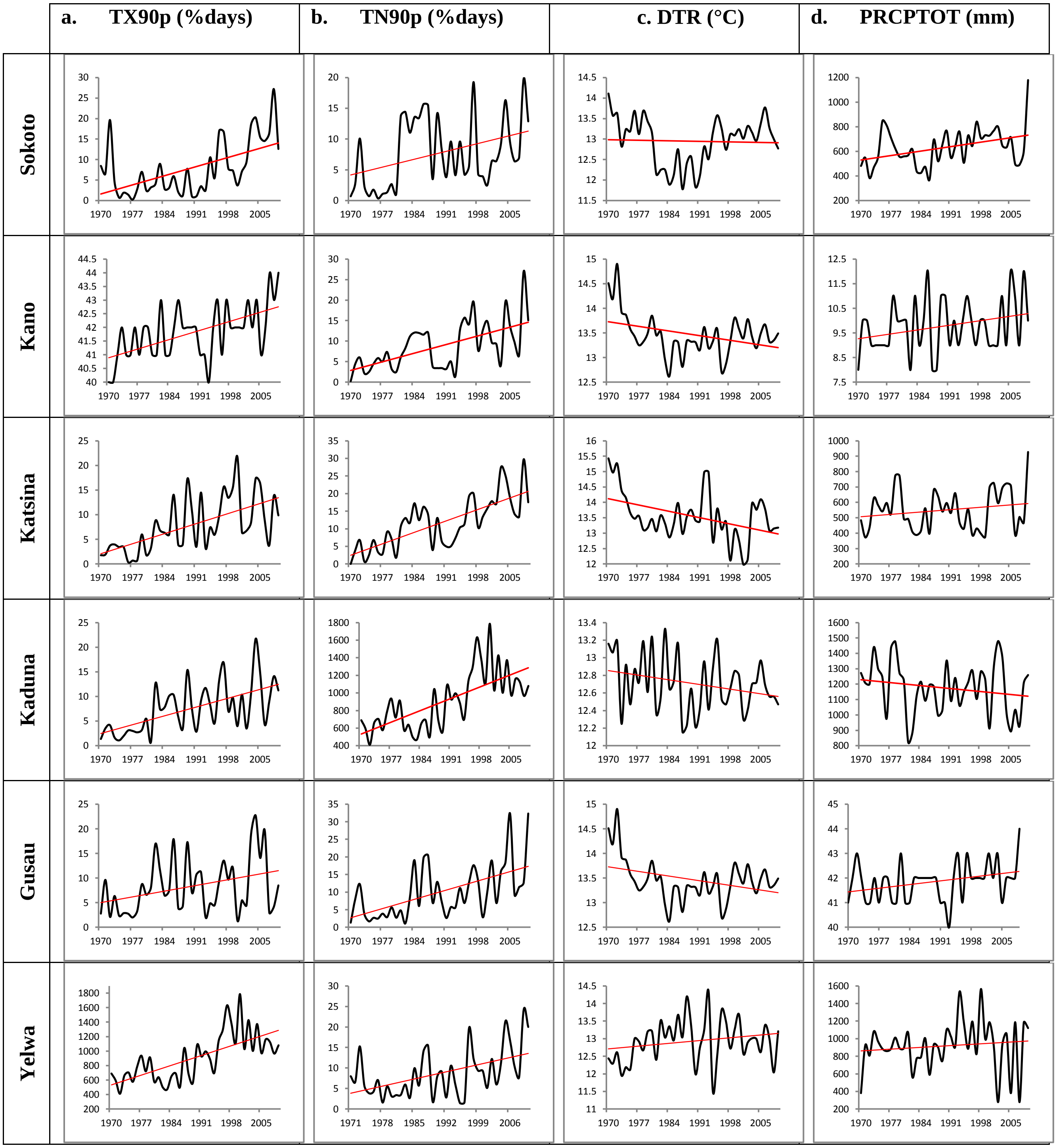

Figure 2: Time series of the six stations in northwest Nigeria over the period of 40-years (1970 – 2010) for (a) warm days (b) warm nights (c) diurnal temperature range, and (d) annual total wet-day precipitation. Red line indicates ordinary least squares fit.

DISCUSSION

Results from the regional time series for DTR, TXx, TXn and PRCPTOT are shown in Figure 1. It is evident from the figure that warmer days and nights have generally increased. Trends in all temperature indices for all the six stations have shown a spatial coherence with mostly statistically significant increases ($p<0.05$). The frequencies of days and nights (Table 3) that are warmer than 90th percentile (TN90p and TX90p) have shown positive significant increases over the long period of data (40-years) and for the two investigated sub-periods, with Sokoto and Kano showing the strongest trend. Other computed temperature indices such as the annual count of days with at least 6 consecutive days when TX>90th percentile (WSDI) also showed statistically significant increases. In terms of diurnal temperature range (DTR) all stations time series for the full study period and for the two different sub-periods have shown a significant negative trend. This is because increase in night temperature tends to be higher than that of day time. Trends for the temperature indices are shown in Table 3, with warm extremes increasing and cold extremes decreasing, these series clearly indicate significant warming. The warmest day and night of the year and the coldest day and night of the year are warming at a rate approximately comparable to the global average. Significant trends are observed in all the calculated temperature indices in all four seasons, with stronger slopes on average during the MAM and JJA seasons. The identified warming in northwest Nigeria matches well with results from various similar studies around the globe, the study by New et al. (2006) in Southern Africa being a very good example. Although the comparison is not straightforward, as the regions studied are largely different, it concurs with what is found in this study of significant increasing (decreasing) trends for warm (cold) days and nights, and absolute daytime and nighttime maximum and minimum temperatures.

Precipitation indices also reveal an increasing trend in all stations (though not statistically significant for some indices) with the exception of Kaduna that reveals a negative trend. In relation to rainfall, a declining trend in the total precipitation amount in Kaduna and to a lesser extent in Yelwa is observed, meanwhile non-significant increases are found in Sokoto and Kano. This is in agreement with Nicholson (2000, 2001). It has been observed that extreme precipitation indices are not significantly increasing in some of the studied stations.

Anecdotal evidence has shown that northwest Nigeria is particularly vulnerable to climate extremes because of its physical and socioeconomic characteristics, such as widespread poverty, desertification, ecological disruption, high population growth rate and extreme weather events. The region lies in areas identified as "hotspots" of climate change (Collier, 2008), and which are projected to be disproportionately affected by an increasing disease burden, and extreme climate events. The region has the highest population in the country (over 41 million), and a large proportion of the area is vulnerable to flooding, desert encroachment, poverty and prevalence of infectious diseases. It has been observed that in past decade extreme weather events were common, and occurred regularly.

There is increasing evidence that, with climate change, climate extremes such as heat events will increase in frequency, intensity, and duration (Solomon et al., 2008). Extreme weather events have both direct and indirect potential impacts. Flooding caused by extreme rainfall may provoke water-related infectious diseases like cholera and typhoid, if the flood water becomes contaminated with human and animal wastes. After heavy precipitation, storm water washes human, animal, and other waste into unprotected water sources, thereby chemically or biologically polluting the water at the point of consumption. Bridgman et al. (1995) report that the outbreak of *cryptosporidiosis* in the United Kingdom was thought to have been triggered by heavy rainfall, leading to water running across the surface of a field where cattle were grazing: this washed the cattle faeces into the water supply. Outbreaks of diarrhoeal diseases associated with water contamination like cholera, typhoid, and viruses such as hepatitis A have been linked with heavy rainfall in the USA (Rose et al., 2000; Curriero et al., 2001). A strong relationship with about one half of waterborne disease outbreaks and extreme rainfall in the United States was reported (Curriero et al., 2001). In the tropics, diarrhoeal diseases typically peak during the rainy season: several cholera outbreaks were reported following heavy rains in 1997 in east Africa. Countries like Tanzania, Kenya, Guinea-Bissau, Chad and Somalia (Kovats, 1999) were severely affected. Contamination events were found to occur when daily rainfall levels exceeded a threshold of about 5–6cm in the Great Lakes region of Africa (Patz et al., 2008). Extreme rainfall in Nigeria will cause population displacement, injuries, mental dislocation, and property loss. In recent years, some areas in the northwest have experienced these impacts, such states included Sokoto and Kaduna.

On the other hand, drought will affect food production and increase stress on water resources, especially in the countries of southern and western Africa (Haines and Patz, 2004). Elevated temperatures will facilitate changes in water bodies' temperature, which may increase the growth of cholera pathogens and the risk of food contamination (Rabbani and Greenough, 1999). This is most true in areas where infrastructure for storage is not available and environmental hygiene is inadequate. Meningitis has also been established to have a significant positive relationship with temperatures (Abdussalam et al., 2014; Dukic et al., 2012). For example, anecdotal information shows that extreme temperature is aggravating the incidence of meningitis in northern Nigeria. The continual increase of warm spell durations (WSDI) may have important effect on the occurrence of some infectious diseases in this region that were established to have correlation with elevated temperature.

CONCLUSION

This study investigates trends in 20 climate extreme indices in northwest region of Nigeria, using daily temperature and precipitation data form six weather stations for the period 1971–2010. The results show statistically significant, and spatially coherent, trends in temperature indices corresponding to a warming trend in the region. It was found that the frequency of warm days has significantly increased while the frequency of cold days has significantly decreased. The reduction in the number of cold days is gradual and started in the 1970s, but the increase in warm days exhibits a sudden increase toward the 1990s. There have been significant increase in the number of summer nights but the daily temperature range has significantly decreased. Trends in precipitation indices, including annual total precipitation, the number of days with precipitation, the average precipitation intensity, and maximum daily precipitation events, are weak and are not very significant in general. Findings correspond well with what has been observed in similar studies (for example, Alexander et al., 2006; Klein Tank et al., 2006; Vincent and Mekis, 2006).

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