Global and Planetary Change 162 (2018) 252–265

Contents lists available at ScienceDirect

Global and Planetary Change

journal homepage: www.elsevier.com/locate/gloplacha

Observed climate variability over Chad using multiple observational and reanalysis datasets

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ARTICLE INFO

Keywords:
Chad
Climatology
Interannual variability
Trend
Land-cover

ABSTRACT

Chad is the largest of Africa's landlocked countries and one of the least studied region of the African continent. The major portion of Chad lies in the Sahel region, which is known for its rapid climate change. In this study, multiple observational datasets are analyzed from 1950 to 2014, in order to examine the trend of precipitation and temperature along with their variability over Chad to understand possible impacts of climate change over this region. Trend analysis of the climatic fields has been carried out using Mann-Kendall test. The precipitation over Chad is mostly contributed during summer by West African Monsoon, with maximum northward limit of 18° N. The Atlantic Ocean as well as the Mediterranean Sea are the major source of moisture for the summer rainfall over Chad. Based on the rainfall time series, the entire study period has been divided in to wet (1950 to 1965), dry (1966 to 1990) and recovery period (1991 to 2014). The rainfall has decreased drastically for almost 3 decades during the dry period resulted into various drought years. The temperature increases at a rate of 0.15 °C/decade during the entire period of analysis. The seasonal rainfall as well as temperature plays a major role in the change of land use/cover. The decrease of monsoon rainfall during the dry period reduces the C4 cover drastically; this reduction of C4 grass cover leads to increase of C3 grass cover. The slow revival of rainfall is still not good enough for the increase of shrub cover but it favors the gradual reduction of bare land over Chad.

1. Introduction

Africa is the second largest continent as well as the second populous place of the world. Because of its vastness, Africa incorporates eight different climatic zones according to Koppen climate classification system (Köppen, 2011, 1884; Rubel and Kottek, 2011). These includes the desert, arid regions in the north, rain forest in the south, cross-savanna in the central region and many more. All these climate zones in Africa are particularly vulnerable or sensitive to climate variability and climate change (Olago and Odada, 2005). One of the interesting geographical features of Africa is its position with respect to the equator, which almost divides Africa into two halves such as the northern and southern part, which have their own climatic influences.

The regional climate analysis over Africa shows that 2013 was the warmest year on the African continent (IPCC, 2013) with the observed temperature much higher as compared to the average of 1961 to 1990 in most part of Africa. Another report from World Meteorological Organisation (WMO) on global climate shows that, 2011 to 2015 is the warmest period for all continents except for Africa. More recently, WMO confirms 2016 as the hottest year on record, about 1.1 °C above pre-industrial era. The warming of climate system was unequivocal since 1850 (IPCC, 2007), which reported that the increase in global temperature is 0.75 °C from the period between 1850–1899 to 2001–2005 (Trenberth et al., 2007). All these reports clearly indicate the rise of temperature along the African continent with a positive temperature trend. In terms of precipitation, there exists a large regional variability within Africa (IPCC, 2007). However, the largest negative trend in annual precipitation is observed over western Africa and the Sahel region whereas a drying trend is also evident over southern Africa since 1901 (Trenberth et al., 2007). Rainfall over the Sahel region of western and central Africa was generally close to or above normal during the period 2011 to 2015, except in 2011.

Several studies have been carried out over Africa to understand the climatic variability of temperature, such as the increasing warming (Collins, 2011; Hulme et al., 2001); coherent warming of both maximum and minimum temperature especially during winter (Caesar et al., 2006); gradual decrease of cold climate extreme during the second half of 20th century (Frich et al., 2002; New et al., 2006) and

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https://doi.org/10.1016/j.gloplacha.2018.01.013
Received 31 May 2017; Received in revised form 10 December 2017; Accepted 10 January 2018
0921-8181/

increase of extreme hot days and nights (New et al., 2006). In addition, various studies try to find the behavior of rainfall over African continent. The oscillatory behavior of rainfall (Ogallo, 1979) and climate extremes (New et al., 2006) without any particular trend have been reported. The decrease of rainfall over Sahel region after 1970 is reported using long-term rain gauge data (Le Barbé et al., 2002). Most of the years during 1950s (1970s) are found to be wet (dry) years (Nicholson, 2000, 2001). They further analyzed the land surface-atmospheric interaction to understand the interannual variability of rainfall and found that the recovery from the dry state to normal is slower than the wet state and hence the dry condition persist over Sahel region of Africa. The inter-decadal variability of rainfall over Sahel region along with a relatively rainfall stable period is observed during 1961 to 1990 (Hulme et al., 2001). Several regional climate analyses were also conducted over specific zones; for e.g. study of the rainfall variability over southern and west Africa does not show any statistical significance (New et al., 2006); whereas the rainfall extremes have increased over the eastern part of south Africa (Kruger, 2006) and the warming/cooling over the western Indian Ocean modulates the rainfall over Namibia and south Africa (Landman and Mason, 1999). Rowell et al. (1995) represents the global SST pattern and its influence on rainfall variability over northern Africa or over semi-arid region of west Africa (Nicholson, 2000, 2001).

Some earlier studies depicts that there is no trend in annual rainfall over Africa (Bunting, 1975; Landsberg, 1975; Rodhe and Virji, 1976) during the period 1935 to 1975. Four years later, Ogallo (1979) reported that there is no significant trend in rainfall over Africa for the same period however, they have also mentioned that most of the annual rainfall series indicated an oscillatory characteristics except over 4 stations where increase in rainfall pattern is observed and that have been attributed to the local factors. In contrast, IPCC indicates a clear change in rainfall trends (IPCC, 2007). In terms of temperature, a significant increasing trend over all of Africa and its sub-regions (such as northern Hemisphere Africa, southern Hemisphere Africa, tropical Africa, and subtropical Africa) is reported (Collins, 2011). They found both northern and southern parts of Africa have a significant warming during summer in the most recent period 1995 to 2010 as compared to the earlier period 1979 to 1994. However, during winter, the significant warming is only concentrated over north of Africa. The comparison of the two most recent decades depicts that the warming is observed over the above-mentioned regions during 2001 to 2010 as compared to 1979 to 1990. Many studies focus to understand more precisely the inter-seasonal variability of the west African monsoon (N'Datchoh et al., 2017; Paxian et al., 2016; Poan et al., 2016; Roehrig et al., 2013) because of its huge socio-economic impacts on local populations. Few researches are dedicated to identify dust sources in the Namibia desert (Eckardt and Kuring, 2005) or in Bodélé depression (Washington et al., 2006) and their implications to climate change, shifting of ITCZ and its impact on rainfall in Sahel and even more aspects of climate. As mentioned earlier, each climate zone will have their own peculiar/signature response to the climate change. For this purpose, it is very necessary to provide the details about each regions of Africa. Further studies over different sub-regions of Africa will be helpful to get an idea about the change in temperature and precipitation trends over these sub-regions. This information will be an important contribution to make strategy for water resource management (both collection and storage), seasonal agriculture and food production to counter the ill effects of climate change by proper adaptation mechanism, sustainable development of different sub-regions.

Although several studies have been conducted over the Sahel region, the study of climate variability over some countries like Chad have either least or no focus in the past. The major earlier climatic studies over Chad involve the Saharan dust in north and change in micro-climate due to the presence of Lake-Chad (Bastola and François, 2012; Coe and Foley, 2001; Delclaux et al., 2008; Nilsson et al., 2016). Therefore, this study aims to examine

- the under-focused climate variability over Chad from 1950 to 2014.
- the changes in temperature and precipitation pattern and their trend within the study period.
- the changes in land use/land cover (hereafter, LULC) with special focus on C3 and C4 type of grass covers.

These analyses will provide an indication of changing climate patterns over Chad, which may form basis for other studies on future climate change. The change in LULC will further induce changes in ecological systems (biogeochemistry of ecosystems, nitrogen and carbon cycles), animal productivity and agronomic output. In addition, the change in temperature/precipitation and land LULC will have its socio-economic impact on the country. These impacts of slowly changing climate in this study would help for developing mitigation and adaptation strategies. Below, Section 2 deals with the datasets used and methodology adopted for this study. Section 3 discusses about the geographical location and LULC pattern over Chad. Section 4 describes the results and discussion while Section 5 summarizes the main findings followed by the concluding remarks.

2. Data and methodology

Multiple monthly datasets are used for the analysis of spatial pattern of seasonal and annual climatology of various meteorological parameters over Chad from 1950 to 2014, listed below

- University of Delaware (hereafter, UDEL) at $0.5^{\circ} \times 0.5^{\circ}$ horizontal resolution for the analysis of temperature and precipitation (Willmott et al., 2001).
- Climate Research Unit (hereafter, CRU) at $0.5^{\circ} \times 0.5^{\circ}$ horizontal resolution for the analysis of temperature and precipitation (Harris et al., 2014).
- Global Precipitation Climatology Center (hereafter, GPCC) at $0.5^{\circ} \times 0.5^{\circ}$ horizontal resolution for the analysis of precipitation (Schneider et al., 2011).
- National Center of Environmental Protection (hereafter, NCEP) at $1.5^{\circ} \times 1.5^{\circ}$ horizontal resolution for the analysis temperature and vertically integrated moisture flux and transport (Kalnay et al., 1996).
- LULC data (developed by Meiyappan and Jain) at $0.5^{\circ} \times 0.5^{\circ}$ horizontal resolution for the analysis of land use and land cover change (Meiyappan and Jain, 2012).
- United State Geological Survey Global Land Cover Characterization (hereafter, USGS GLCC) at $0.5^{\circ} \times 0.5^{\circ}$ horizontal resolution for the analysis of topography (Brown et al., 1999).

The study has been conducted for 65 years ranging from 1950 to 2014, in order to understand the mean behavior of these meteorological parameters and their trends over Chad. The area-averaged temperature over Chad (the grid points lie within the political boundary of Chad) is considered for the present analysis. It is observed that the rainfall over Chad is not uniform; the northern part of the country does not receive rainfall throughout the year as it belongs to the great Sahara Desert. The area-averaged rainfall is computed like the temperature but over a region where longitude ranges from 13.5° E to 24° E and latitude varies from 7.5° N to 16.5° N. The careful removal of grid points over Sahara will provide robust result in terms of rainfall trend and variability over Chad. The standardized precipitation and temperature anomaly is computed by dividing the anomaly (difference of the corresponding seasonal and annual value with respect to long-term seasonal and annual mean) with the corresponding standard deviation value of temperature and rainfall respectively during the period considered for the study. The standardized value greater than $+1$ (-1) implies the excess (deficit) year in terms of rainfall and warm (cold) year in terms of temperature.

The annual, seasonal (December–February(DJF), Pre-monsoon: