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Research Article

Intra-Seasonal Variability of Climate Change in Central Burkina Faso

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Abstract

Knowledge of climate variability is relevant and challenging to farmers, decision makers and the population in general. Ninety percent of Burkina Faso working population is engaged in agriculture which accounts for 39% of gross domestic product. Located in central Burkina, the basin has four dams, of which the most important Loumbila is managed for the capital's water supply. A change of climate may affect the water resources most likely and is expected to limit the access to sufficient quality water. In order to characterize climate variability and changes, long-term records of temperature and precipitation (1961 to 2012) were analyzed. By applying R-climdex and R, indices were calculated based on an approach recommended by the World Meteorological Organization Expert Team on Climate Change Detection and Indices. Four indices related to precipitation and other related to temperature were selected. Results show that signs of changing climate in Massili have already emerged including a slight decrease of total precipitation amount and also a delayed rainfall onset along with an earlier cessation resulting to a shorter rainfall period. Although the total precipitation decreased in the basin, occurrence of extremely wet days has slightly increased. The cold spell has decreased while warm spell has increased.

Keywords: *Climate variability, climate change, Burkina Faso, Massilli Basin, climate indices, onset and cessation, dry spells.*

1. Introduction

According to Intergovernmental Panel on Climate Change IPCC (2007), climate change refers to any change in climate over time, whether due to natural variability or as a result of human activities. Climate variability is defined as the variations in term of increase and decrease of climatic patterns (temperature and rainfall) on time scales of months, years, decades, centuries, and millennia. Climate change will affect the entire world and Africa is considered to be "the most vulnerable region to climate change, due to the extreme poverty of many Africans, frequent natural disasters such as droughts, floods, and agricultural systems heavily dependent on rainfall" IPCC (2007). The global climate has changed rapidly with the global mean temperature increasing by 0.7°C within the last century IPCC (2007). Change in climate variability may affect water supply: droughts and lower precipitation reduce water availability, higher temperatures increase the loss of water and increase water demand, droughts and high temperatures combined have the largest impacts on water supply and demand. In other words, the erratic behaviour of rainfall may cause severe hardships including lack of water and reduced vegetation cover with their attendant consequences of famine and death , both to men and animals alike (Oduro-Afriyie, 1989).

However, temperature and rainfall projections show that climate change will impact regions in different ways, with spatiotemporal changes in rainfall pattern, but generally increasing temperatures (IPCC, 2001; Meissner *et al*., 2003; Snyder *et al*., 2004; Tarhule, 2005; Dang *et al*., 2007; Barrios *et al*., 2008;). Indeed, impacts of climate change will vary across regions and populations, through space and time, dependent on myriad factors including non climate stressors and the extent of mitigation and adaptation (IPCC, 2014). Given the uncertainty of global assessments and model efforts, more detailed information about regional patterns of climate change as emphasized by IPCC (2001) would support the development of adaptation and mitigation strategies.

Thus, there is a need to downscale knowledge on temperature and rainfall trends at local scale in order to have relevant and detail information. Indeed, knowledge of climate variability and trend (temperature and rainfall) of a given area is very relevant and challenging to farmers, decision makers

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and the population in general. Most of the world's food is produced under rain-fed systems where climate variability and change play an important role in determining the productivity (Slingo *et al*., 2005). Several authors (Fitter *et al*., 1995; Le Houérou, 1996; Sparks *et al*.,2000; Huang *et al*., 2003; Matsumoto *et al*., 2003;Gordo and Sanz, 2005; Slingo *et al*., 2005; Ahas and Aasa, 2006; Lu *et al*., 2006; Rasul, 2010; Kosa, 2011; Pérez-Sánchez *et al*., 2011) highlighted the effects of increasing temperatures on crop production systems. In addition, Barbier *et al*. (2009); Ouedraogo *et al*. (2010); Zorom *et al*. (2013) showed that extreme climatic conditions, especially droughts, have severely affected crop production and motivated pastoralists to move out of their original agro-ecological zones (FAO, 1997). Lodoun *et al*. (2013) have estimated onset and cessation over the entire Burkina Faso using 39 stations. This study is focus on climate variability in Massili basin (Central Burkina Faso).

2. Data and Methods

2.1 *Study area*

Massili basin is situated between the longitudes 1°15'West and 1°55' West and the latitudes 12°17'North and 12°50' North (figure 1). The basin is drained by The Massili River which originates at about 12 km north of Bousse, a (small village at about 50 km from Ouagadougou). The river drains three departments (Bousse, Ouagadougou and Ziniare) and discharges into the Nakambe River drainage system**.** The basin covers an area of 2612 km² and stretches on a perimeter of 188 km. The natural vegetation is dominated by tree and shrub savannas which represent 27% of the territory while farm land occupied 59%. Massilli Basin belongs to bioclimatic zone within the North type Sudanese where mean annual rainfall varies between 700 and 900 mm/year with a dry season lasting from 6 to 7 months (Fontès and Guinko, 1995). The rainy season starts in mid-May and ends in late September. Highest rainfall is recorded between August and September. Temperatures vary from a daily minimum of 16 ° C (December) to a maximum of 40 ° C in March and April.

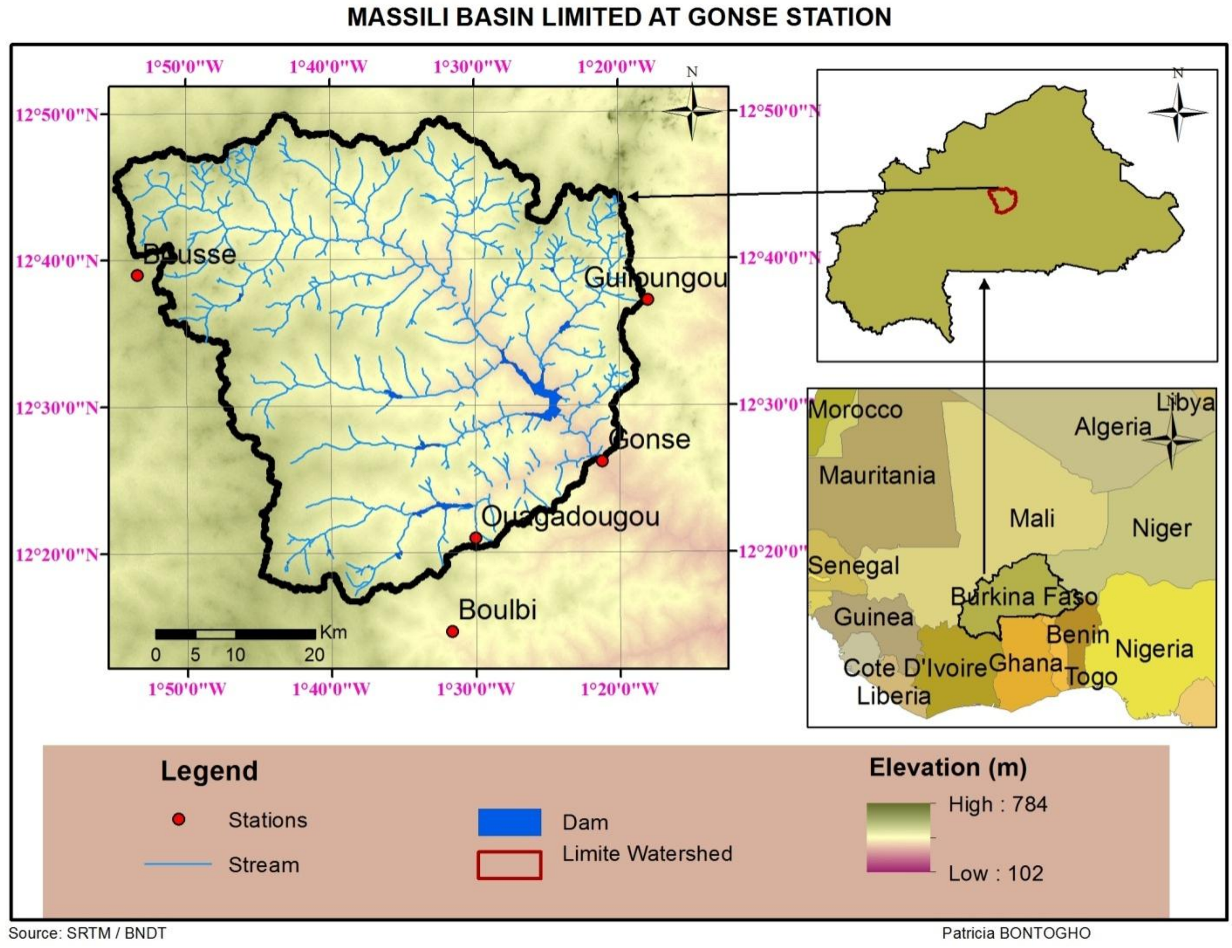


Figure 1: Location of Massili basin limited at Gonse station

2.2 *Data*

The climate data sets used for this study covers a period of 51 years (1961 to 2012). It was obtained from the National Meteorological Agency (DGM) and comprised of daily observed rainfall as well as minimum and maximum temperature. As the basin includes the synoptic station of Ouagadougou where all climate parameters are measured, the temperature data were only available for the station in Ouagadougou. However, rainfall data were available from four stations (figure 1): Ouagadougou, Guiloungou, Bousse and Boulbi. To ensure that trend results are accurate, consistency and homogeneity tests were performed on the entire data sets. The data quality check showed that the data are not homogenous and consistent. Thus the data need to be corrected. The correction of the data was thus done using the method of the nearest stations and linear regression.

3 Method

3.1 *Climate data analysis*

The main ways to characterize the frequency, intensity and duration of climate extremes is to calculate climates indices based on daily time series of temperature and rainfall (Karl *et al*., 1999; Peterson *et al*., 2002). For the purpose of this study, eight climate indicators were calculated. The selection of these indices was done to satisfy the needs of decisions makers and rural population and to support efforts in the implementation of adaptation strategies. For instance, the analysis of the consecutives dry days (CDD) aims to detect the period of dry spell occurrence. Knowledge on the exact period of dry spell occurrence is meaningful as it renders farmers ready for the application of complemented irrigation. In addition, onset and offset information analysis may help to avoid early seeding. Awareness on the trend of total precipitation and extreme rainfall occurrence (R1day) may help water resources managers to better cope with flood management, but also with consequences related to the spread of water borne diseases. Information about consecutive warm days (WSDI) reveals the trend of temperature and in case where WSDI is increasing mitigation decisions should be made to reduce greenhouse gas release.

Table 2: List of the climate indices

Indices	Name	Formula
PRCPTOT	Amount of annual rainfall	$PRCPTOT_j = \sum_{i=1}^{I} RR_{ij}$ (03) RR_{ij} :The daily precipitation amount on day i in period j. I represents the number of days in j
RX1day	The maximum 1-day values for period j	$Rx1day_j = \max(RR_{ij})$ (04) RR_{ij} : The daily precipitation amount on day i in period j.
CWD	The largest number of consecutive days where the rainfall is higher than 1mm	$RR_{ij} \geq 1mm$. RR_{ij} the daily precipitation amount on day i in period j
CDD	The largest number of consecutive days during the rainy season where the rainfall is lower than 1mm	$RR_{ij} < 1mm$ RR_{ij} the daily precipitation amount on day i in period j
TXx	Annual maximum of the daily maximum temperatures	$TNx_{kj} = \max(Tn_{kj})$ (05) Tx_{kj} is the daily maximum temperatures in month k in period j.
TNn	The annual minimum of the daily minimum temperature	$TNn_{kj} = \min(Tn_{kj})$ Tn_{kj} : the daily minimum temperatures in month k in period j.

CSDI	Cold spell duration indicator (annual maximum duration)	$Tn_{ij} < Tn_{in}10$ Tn_{ij} the daily minimum temperature at day i in period j and $Tx_{in}10$ the 10th percentile of the annual minimum temperature Annual count of days with 3 consecutive days when TN<10th percentile
WSDI	Warm spell duration indicator(annual maximum duration)	$Tx_{ij} > Tx_{in}90$ Tx_{ij} the daily maximum temperature on day i in period j and $Tx_{in}90$ is the 90th percentile of the annual maximum temperature Annual count of days with 3 consecutive days when TX>90th percentile

Onset and cessation of the rainy season

The onset of the growing period (OGP) at a given location is the date after May 1st when total rainfall over three consecutive days is at least 20 mm, with no dry spell exceeding 7 days during the following 30 days (SivaKumar, 1991). The cessation date of the growing period (CGP) is defined as the date after September 1st when the soil water content down to 60 cm depth is nil with a daily potential evapotranspiration of 5 mm (Maikano, 2006). Recently, Salack *et al*. (2011) proposed a method in order to determine the onset and rainfall cessation in Africa and this method was applied in this study as it involved rainfall times series only. According to this author, the onset is established when 3 days accumulation is equal or more than 20 mm starting from first (1st) May and not follow by 7 consecutive dry days (<1mm). The offset is defined with the appearance of 20 consecutive days after the 1st September without rainfall event higher than 1mm.

Onset $= \sum_{T=1}^{3} \text{Ri} \geq 20\text{mm} +$ at least 7 days with rainfall more than 1 mm(01)

Cessation $= \sum_{i=1}^{7} \text{Ri} < 1mm\ after\ 1st\ september$ (02)

Rainfall and temperature indices

The other climate characteristics and indices of rainfall and temperature were calculated from the application of Rclimdex tool. RClimdex allows computing all the basic indices of climate extremes recommended by the Expert team from the CCl/CLIVAR for Climate Change Detection Monitoring and Indices (ETCCDMI) (Easterling *et al*., 2003). The (ETCCDMI) undertook a set of regional analyses for understanding climate extremes and trends (Peterson *et al*., 2002; Easterling *et al*., 2003; Vincent *et al*., 2005; New *et al*., 2006). Among the 27 core indices recommended by ETCCDMI, eight indices considered almost relevant for this study area were selected and summarized in Table 2.

4. Results

4.1 Main characteristics of the rainy season

The analysis of onset and cessation of the rain seasons as defined by Salack *et al*. (2011) indicates an upward trend of onset and a downward trend of offset. This indicates that there is a shift in onset and cessation in the past 50 years (figure 2). In 1996 the onset has started earlier at the 144th day of the year, while in 1986 the onset has started later at the 222th day. In addition in 1961 the offset has start earlier (271th day) than the rest of the years (271th day) while in 1976 the offset has occurred in 305th day.

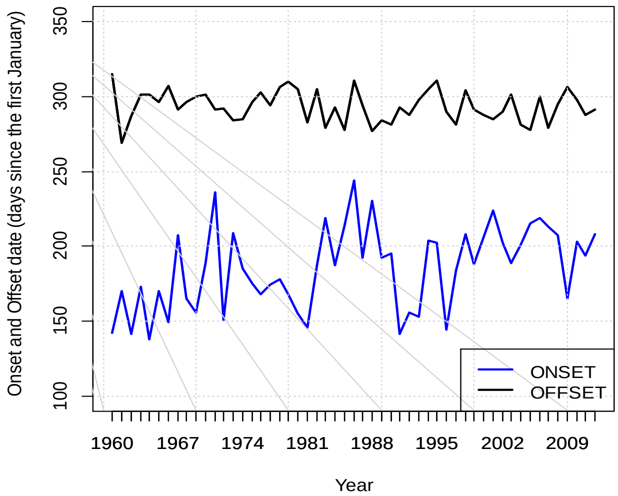


Figure 2: Evolution of the rainy season onset and offset (cessation) date.

4.2 Evolution of the climate indices

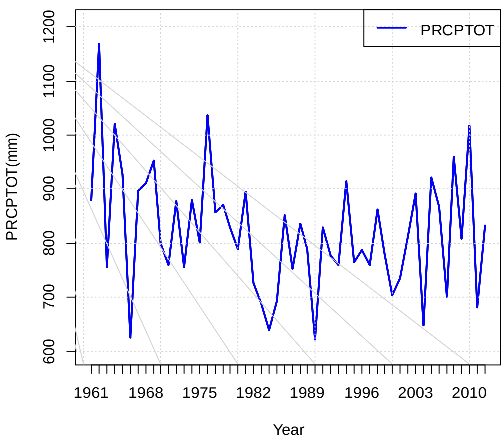
4.2.1 *Evolution of rainfall indices*

The total annual precipitation amount was computed by using the PRCPTOT indices which wet day criteria is a day where RR>=1mm. In general, the results show a slightly decrease of rainfall (figure 3a). This result is in agreement with previous findings showing the decrease in precipitation over the entire Burkina Faso (Hess *et al.*, 1995; Le Barbé and Lebel, 1997; Lebel *et al.*, 2003; Ibrahim *et al.*, 2014) . Moreover, the projections reflect a decrease in precipitation from a rate of 3.4% by 2025 to a rate of 7.3% by 2050 in comparison to the past rainfall NAPA (2007). However the 5 years moving average shows an increase of the rainfall quantity during the previous seven years (2005 to 2011).

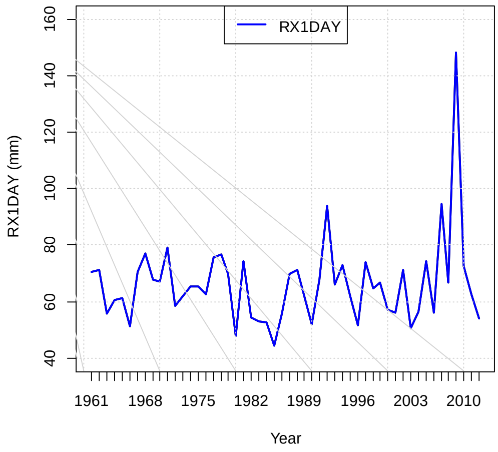
For the period analysed, the recorded maximum one-day precipitation has slightly increased (figure 3b). With 263.1mm, the highest rainfall amount recorded in the basin was measured on the 1st September 2009 (day 245) at Ouagadougou station. An amount of 221.8 mm was also recorded the same day in Boulbi station. In general, extreme events usually occurred between the 141 and the 254 day (21stMay to 11thSeptember) of each year.

This result corroborate with the results of Trenberth *et al.* (2007) showing a clear evidence of changes in the extremes of precipitation. Heavy precipitation events over many areas have become more frequent and brought more severe consequences such as sudden floods, crop yield decreases, occurrence and increase of diseases (mainly waterborne diseases), food insecurity, livestock and human death. With a confidence level of 1% (P value= 0.009937), the consecutives dry days (CDD) are increasing (figure 3c) while the Consecutives Wet Day is decreasing figure 3d).

Previous sub-regional studies on rainfall patterns suggest a decreasing trend in annual total rainfall indices (DIOUF *et al.*, 2001; L'hote *et al.*, 2002). According to Sarr *et al.* (2012) extreme rainfall events became more frequent in the West African Sahel during the last decade, compared to the 1961– 1990 period. This result corroborates the observed upward trend in Massli basin of extremely wet days represented by the RX1Day (figure 3b).



(a)



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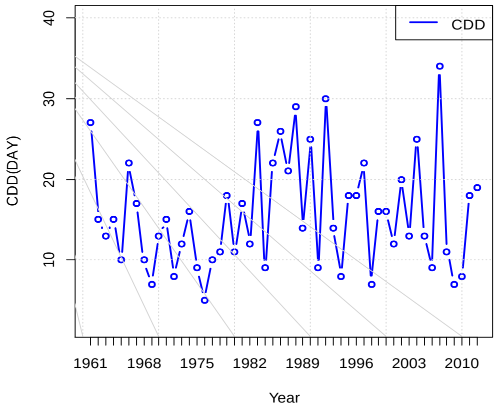
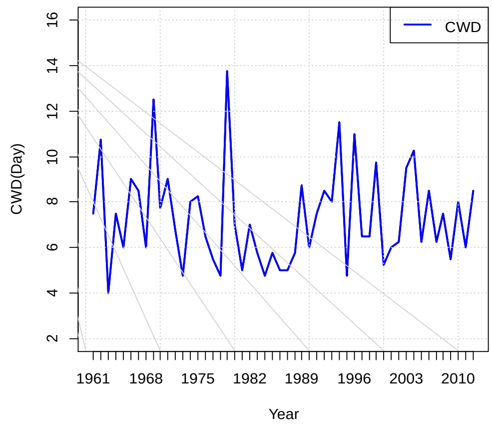


(c)



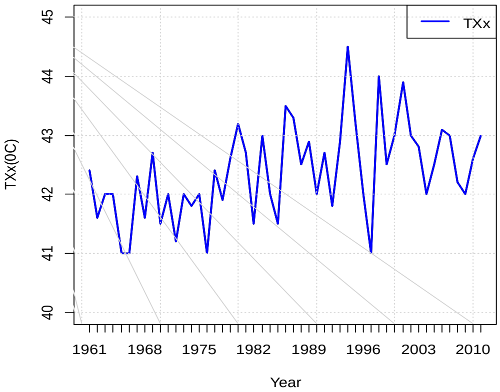
(d)

Figure 3: Inter-annual trends of the rainfall indices from 1961 to 2012: a) Total annual precipitation; b) Maximum 1 day precipitation; c) Consecutive Dry Days; d) Consecutives Wet Days

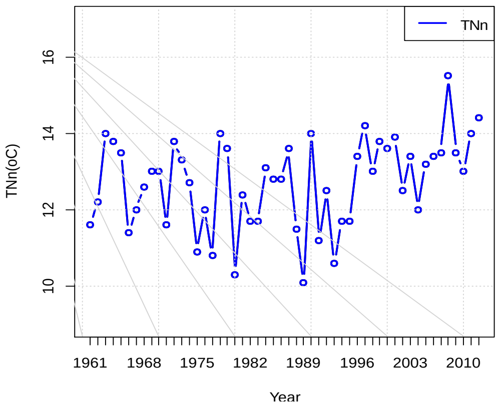
4.2.2 *Evolution of temperature indices*

The annual maximum of the daily maximum temperatures (TXx) shows an increasing trend in the Massili basin (Figure 4a). The trend is statistically significant with a p-value of 1%. The highest maximum daily temperature was measured in 1994 (44.5°C) while the lowest maximum daily temperatures were measured in 1965, 1966, 1976 and 1997(41°C). As shown by various studies, this trend of increasing maximum temperatures is supposed to continue in the future projections (IPCC, 2007).

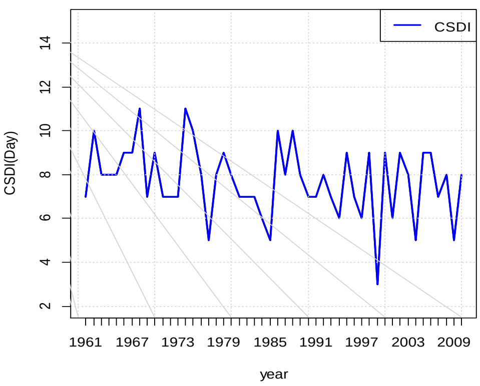
TNn depicting the evolution of annual minimum of daily minimum temperature is also increasing study period (figure 4b). Cold spell duration indicator (CSDI) which is the annual longest duration of three consecutive days with minimum temperature lower than the 10th percentile of minimum temperature has a decreasing trend (Figure 4c). The increasing trends were statistically significant for 5% (0.054231). Those results corroborate with the results of (IPCC, 2007) which state that the phenomenon and direction of trends in weather and climate events has become increasingly deviant from normal, with more warmer and fewer cold days and nights, also warmer and more frequent hot days and nights over most land areas.



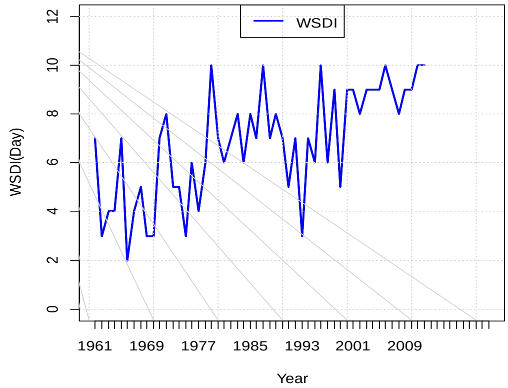
(a)



(b)



(c)



(d)

Figure 4: Evolution of the temperature indices over the Massili basin a) Annual maximum of daily maximum temperature TXx for the period 1961 to 2012; b) Annual maximum daily of minimum temperature (TNx); c) Anomalies of annual CSDI relative to daily minimum temperature (for the 1961–2012 analysis period) d) Anomalies of annual WSDI relative to daily maximum temperature (for the 1960 2011analysis period)

Warm spell duration indices (WSDI) which reflects the annual number of periods with at least 3 consecutive days when the days temperature (TX>90th percentile) is on the rise (Figure 4d). The increasing trends were statistically significant for 1% (0.000478).

5. Discussion

Onset marks the beginning of three major activities - planting, weeding and harvesting (Mortimore and Adams, 1999) which determines the socio-economic life and survival of the farming household. Figure (02) shows a shift from early to late onset. This observation is in concordance with the results of Lodoun *et al.* (2013) for Burkina Faso who found a precocious start of the rainy season, between 1947 and 1955 and a late start from 1955 to 2000 and ends earlier. Since Burkina Faso is a rain-fed and developing country, where about 90% of the working population is engaged in agriculture and livestock (Belemviré *et al.*, 2008), the shortening of the rainy season may exacerbate rural population vulnerability as confirm by (UDAID, 2007): the consequences of climate variability and change affect more the poor populations in developing countries than those living in more prosperous nations The knowledge of the rainy season onset is very important in this sense that these parameters allow respectively farmers to avoid early seeding and eventually the waste of seeds.

Moreover, occurrence of dry spells during the rainy season illustrated by CDD indices is increasing while CWD is decreasing. Consequently, change in climate variability is exacerbating farmers' vulnerability to food security as they are facing lower yields. To cope with this situation, efforts have been undertaken in the context of seeds adaptability. In fact, research has led to the availability of short duration seeds which are adapted to the current rainy season period. Unfortunately most of the seeds must be bought each year and sometimes those seeds are available on the market only many days after the onset. Thus, there is a need to allow for a permanent disposition of early seeds to the peasants before the annual rain season starts. In addition, changes in rainfall quantity and frequency would alter the pattern of stream flows and demands for water (particularly agricultural), spatial and temporal distribution of runoff, soil moisture, and ground water resources (Jain *et al*., 2013) . This may exacerbates consequently the challenge of water management issue in the study area.

The annual rainfall amount shows a slight increasing trend during the last seven years. These results confirms the findings of several authors (Sene and Ozer, 2002; Herrmann *et al*., 2005; Schulz *et al*., 2009) which indicated that the Sahel is growing green again. The slight increase in occurrence of extreme rainfall (RX1Day) illustrated in figure 3b is depicting a watershed which may experience floods. Thus, some precocious adaptation measures must be undertaken. Heavy precipitation events over many areas have become more frequent and brought more severe consequences such as abrupt floods, crops yield decrease, occurrence and increase of disease (mainly water borne diseases), food insecurity, livestock and human deaths. For instance, the watershed has experienced an extreme rainfall on 1st of September 2009, with an amount of 261mm of rainfall recorded in one day (Karambiri *et al*., 2011). During this event; more than 25000 victims were recorded, 11 people died and infrastructure was heavily destroyed. The damage caused by this event showed how the occurrence and the severity of extreme events may impact natural and societal systems In addition daily minimum and maximum temperature are both increasing. Consequently, this finding is in concordance with the note of IPCC (2007) which reveals a global average temperature increase by 0.6 ± 0.2 °C over the last century and a projected increase of 1.4 to 5.8 °C. Moreover, the projections for temperature trends in Burkina Faso based on A2 and B2 scenarios of SRES reflect a most likely increase of mean temperatures that ranges from 2.4°C to 3.9°C in 2050 and from 5.7°C to 9.7°C in 2100 for the A2 scenario, whereas the B2 scenario indicates increases of between 2.4°C and 3.8°C in 2050 and between 4°C and 7.1°C in 2100 (Strzepek and McCluskey, 2006).

Given future projections, it can be argued that the impact of climate change has already started. The increasing trend may have severe impact on human being and nature. Indeed, increased heat is expected to reduce crop yields and increase levels of food insecurity even in the moist tropics, it is predicted that during the next decade, millions of people, particularly in developing countries, will face major changes in rainfall patterns and temperature variability regimes thereby increasing risks in the agricultural sector IPCC (2007). In general, temperature increase and rainfall decrease may lead to high disturbance on agricultural systems (Dyson, 2009).

The decrease of cold spell duration and the increase of warm spell duration combined to the increase of consecutive dry days and the decrease of consecutive wet days, refer to a study realized by (Dai, 2011) showing that warming accelerates land-surface drying by an increase of evaporation, and this increases the potential incidence and severity of droughts, which were observed in many places worldwide. Therefore, there is a risk for Massili basin to experience severe droughts in the future if the trend in WSDI is ongoing.

Conclusion and outlook

Since climate change is unavoidable, it is important to understand the past trend of its patterns at local scale which will serve as precursor for accurate adaptations strategies and options for better land management. The purpose of this paper is thus to present the climate variability in Massili basin This work is realized using daily data of rainfall, minimal temperature and maximal temperature from a 51 years record (1961- 2012). This study provides a comprehensive analysis with regards to the temporal patterns of changes in precipitation and temperature. The general finding that emerges from this study is that high variability of rainfall and temperature has prevailed in the basin. Intensity and frequency of extreme precipitation and temperature events are increasing. Although the annual rainfall remains almost stable, the rainfall season is becoming shorter with more intense events. In addition, the occurrence of dry spell is obvious. Climate change in Massili basin is univocal and the effectiveness of adaptation strategies will depend on the availability of relevant knowledge on the area and the climate pattern. Climate variability analysis will constitute the base for the development of adaptation strategies through the implementation of early warning system. For instance, the increase in the dry spell length found in this study need to be considered in adaptation plans as it may impose challenges for agricultural systems (SivaKumar, 1991; Laux *et al*., 2008). Some adaptations strategies such as complementary irrigation need to be taken into consideration and if considered well implemented. Projections analysis of climate variability over the whole Burkina Faso will allow a best knowledge and awareness of climate variability in order to suggest appropriate adaptation strategies.

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