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Spatio-temporal distribution of climate risks in the District of Borgou in North Benin: what the historical series show

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ABSTRACT
In the current context of climate change, the definition of effective and efficient adaptation strategies requires a good knowledge of climate risks at the national or even local scale. This article proposes a spatio-temporal analysis of climate risks in the district of Borgou in northern Benin. Daily satellite observation data of rain (TAMSAT) and temperature reanalysis (ERA5) corrected for bias (quantile-mapping) over the period from 1981 to 2019, as well as in-situ observation data over the period from 1960 to 2019 were used. These data made it possible to estimate the trends of 03 agro-climatic indices and 03 indices of precipitation and extreme temperatures using the Sen slope, then to statistically evaluate these trends by the Mann-Kendall test or the of Mann-Kendall modified according to whether the series are stationary or not.The results revealed a significant trend towards a late start to the rainy season throughout the district, a significant trend towards the precocity of the end of the rainy season and an increase in the length of the maximum dry spell in the west of the district, with regard to the agro-climatic indices. As for the precipitation and extreme temperatures, it is observed a significant increase in temperatures of 0.8°C to 1.1°C with reference to the period 1981-2010. Hot nights (TN90p) and days (TX90p) have a significant upward trend throughout the district.

Keywords: Climate risks, Spatio-temporal, Borgou, North-Benin.

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I. INTRODUCTION

Africa remains one of the most vulnerable continents to climate variability and change because of the multiple stresses it experiences and its low capacity to respond and adapt (IPCC, 2007). Climate change could worsen existing problems and create new combinations of risks on the continent (Akinnagbe & Irohibe, 2014). For example, sub-Saharan Africa has experienced high rainfall variability at interannual and decadal scales (Nicholson & Palao, 1993; Moron, 1994). The region has also experienced increased drought due to increased temperature and reduced rainfall (Ozor & Nnaji, 2011). Benin, in the general context of sub-Saharan Africa, is faced with the challenge of inter-annual and intra-seasonal rainfall instability and their consequences (Boko et *al*.,2012 ; Afouda et *al*., 2014).

The district of Borgou, one of the twelve in Benin, is subject to the adverse effects of climate change (PANA-BENIN, 2008) whose manifestations are reflected in the variability of climatic parameters and the recurrence of extreme meteorological events (PAS-NAP, 2019). In addition, several studies on farmers' perception and intra-seasonal variability in Benin reveal that agricultural production is subject to many climatic risks such as rising temperatures, the late start of the rainy season, long rainfall breaks, early end of seasons, etc. (Agossou et *al*., 2012 ; Adjakpa et *al*., 2017). However, few studies analyze the spatio-temporal variability of current climate risks to better guide decision-making. The overall objective is to identify current risks in the district of Borgou based on current climate data. Specifically, this will be:

- To study the variability and trend of climatic and agroclimatic parameters
- Assess current climate extremes.

II. METHODOLOGY

Study area

The districtof Borgou, between 8°50' and 10°60' north latitudes; and between 1°54' and 3°60' East longitudes (figure 1) covers an area of 25,856 km² (23% of the national territory) including 13,962 km² of arable land (54% of the total area of the district). The soils are more or less sandy tropical ferruginous types (Azontondé, 1991). The vegetation of Borgou is lush. It is a savannah with a diversified physiognomy where the density of trees decreases towards the North (RGPH3-INSAE, 2004).

The choice of the district of Borgou is justified by the fact that it constitutes one of the agricultural regions of Benin (about 66% of the population practices agriculture) and maize is one of the three most cultivated products by agricultural households in all the municipalities of the district (RGPH4-INSAE, 2016). Also, despite its agricultural potential and its accelerated population growth, few studies have identified climate risks at the level of the district in relation to the perception of farmers intending to formulateadaptation strategies to help decision-making.

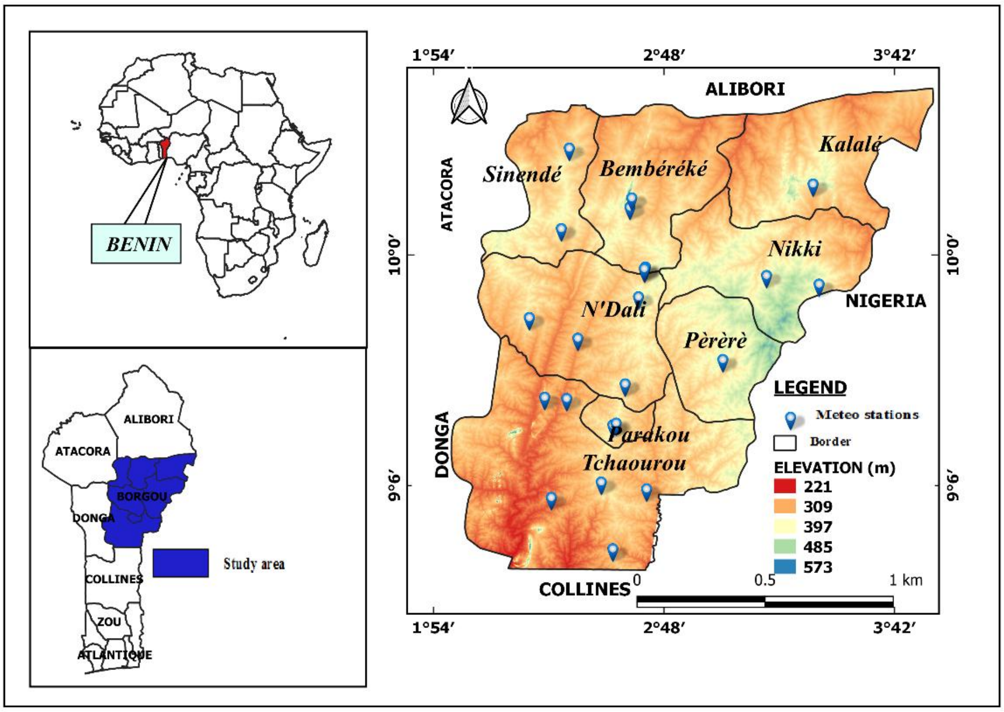


Fig1 : Map of Borgou district.

Data

First of all, daily time series of precipitation and temperature (maximum and minimum) of the synoptic station of Parakou over the period 1960-2019 are extracted from the database of the National Meteorological Agency of Benin (METEO BENIN) and used. Then, for a spatio-temporal characterization of the current climatic risks on the Borgou, the merged data of precipitation and temperature were used. The combination was carried out with ERA5 reanalysis data for temperatures and Africa Rainfall Climatology version 2 (ARC2) for precipitation over the period from 1981 to 2019 over the whole country. Extraction was carried out in the district of Borgou. Twenty-six (26) stations represented contributed to the fusion of this data for this article.

Methods

Current climate risks

Variability of precipitation and temperature series

The rain index and temperature anomalies were determined to characterize the evolution of the climate in the district of Borgou. The synoptic station of Parakou being the most representative of the area, these data were used for this purpose. Thus, the interannual reduced centered anomalies of rainfall are determined by Lamb's formula (1982):

$$I_p = \frac{x_i - \bar{x}}{\sigma(x)} \quad \text{Equation 1}$$

Where : I_p = rain index; xi = rainfall of the year i ; $\bar{x}$ = average height et σ = standard deviation of the rain series over the period 1981-2010. TheI_p index expresses anomalies, particularly in terms of deficit and surplus or dry years and wet years. The standardized precipitation index defined by WMO 2012show that a drought begins when its value is less than or equal to -1 and ends when its value becomes positive. To better appreciate the years, table 1 is used. About the temperatures, the simple anomalies were calculated according to the formula:

$$I_T = x_i - \sigma(x)$$ Equation 2

Table I: Meaning of standardized precipitation index.

standardized Precipitation index	Definitions
2,0 and more	Extremely wet
from 1,5 to 1,99	Very wet
from 1,0 to 1,49	Moderatelywet
from -0,99 to 0,99	Next to normal
from-1,0 to -1,49	Moderatelydry
from -1,5 to -1,99	Very dry
-2and less	Extremely dry

Source : WMO, 2012

Trends of agroclimatic parameters

The criterion of Sivakumar, (1988) adapted to the countries of the Gulf of Guinea and used by the AGRHYMET Regional Center (CRA) during the seasonal forecasts of the agro-hydro-meteorological characteristics was retained to determine the agroclimatic parameters. Thus, in the north of the country the season starts from March 15th, when at least 20 mm of rain is recorded in 01 to 03 consecutive days and this without dry episodes of more than 10 days in the 30 days which follow and takes end when from October 1st, a soil capable to contain 70 mm of available water is completely exhausted by a daily loss of evapotranspiration of 4 mm. The maximum dry spell represent the maximum number of consecutive days without rain (P <= 0.85 mm) between the start and end dates of the season.

The Mann-Kendall test was applied to assess trends. Sen's slope estimator was used to assess the magnitude of these trends.

Trends in climate extremes

Three indices of the 27 proposed by ETCCDMI were chosen (PRCPTOT: Total annual precipitation, Tx90p: number of days when maximum temperatures (Tx) are above the 90th percentile of maximum temperatures, Tn90p: number of days when minimum temperatures (Tx) are above the 90th percentile of minimum temperatures. The reference period chosen in the determination of these indices is 1981-2010. These indices will make it possible to highlight the extent of variability and climate change.

III. RESULTS

Current climate risks

Variability of precipitation series and temperature evolution

From 1960 to 2019, the annual rainfall amounts varied between 620 mm and 1558 mm. The highest accumulations were observed in 1960, 1963, and 1988 and the years 1970 and 1983 recorded the lowest accumulations (Figure 2). Overall, a non-significant downward trend (Mann-Kendall test) in annual rainfall totals is noted. The Pettitt test applied at 5% significancelevel to the series of annual rainfall accumulations detected a non-significant break.

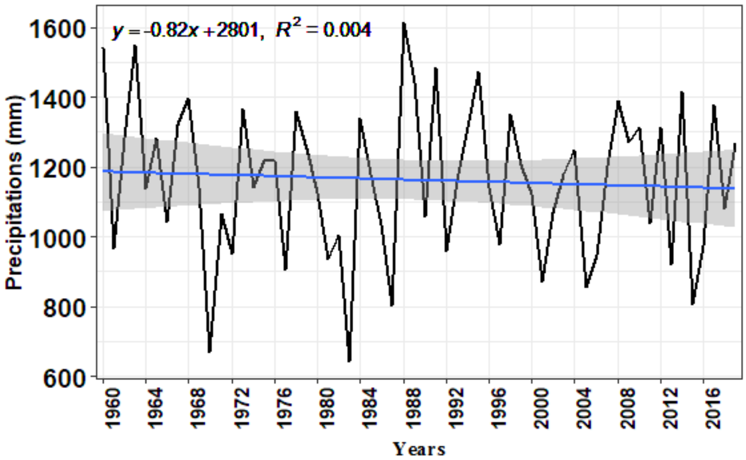


Fig2: Interannual evolution of rainfall amounts in Parakou from 1960 to 2019.

The evolution of rainfall accumulations is characterized by a strong inter-annual variation. However, there are 3 wet periods (1960-1968, 1988-1999, 2007-2010), 3 dry periods (1969-1972, 1980-1987, 1999-2006), and 2 periods of alternating wet and dry years (1973-1979, 2010-2019). Extremely dry years are 1970 and 1983 and very wet years are 1960, 1963, and 1988 (Figure 3).

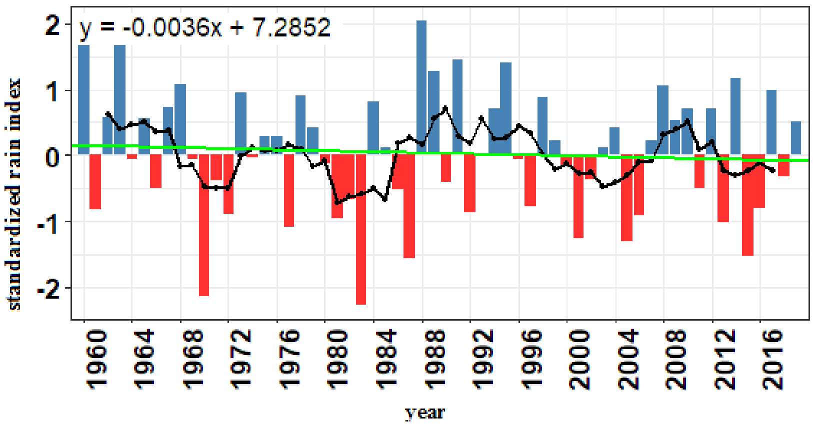
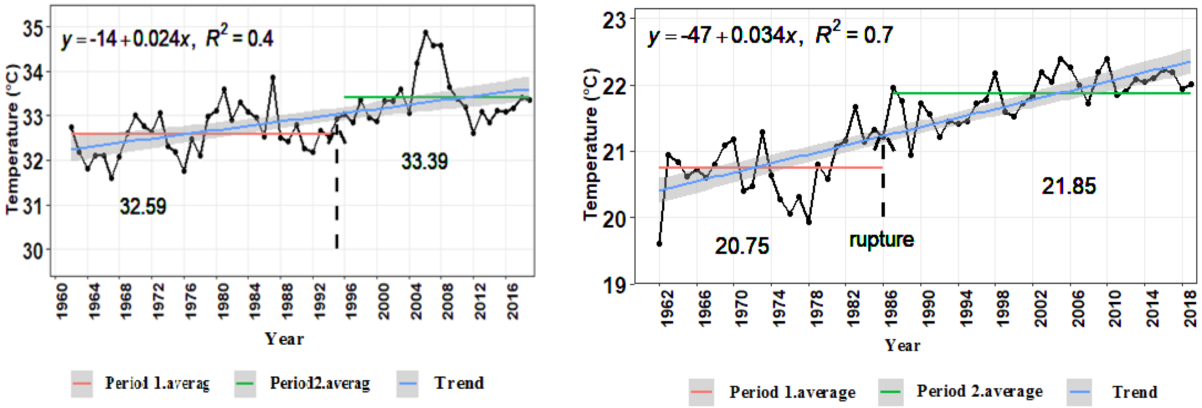


Fig 3 : Standardized precipitation index in Parakou from 1960 to 2019

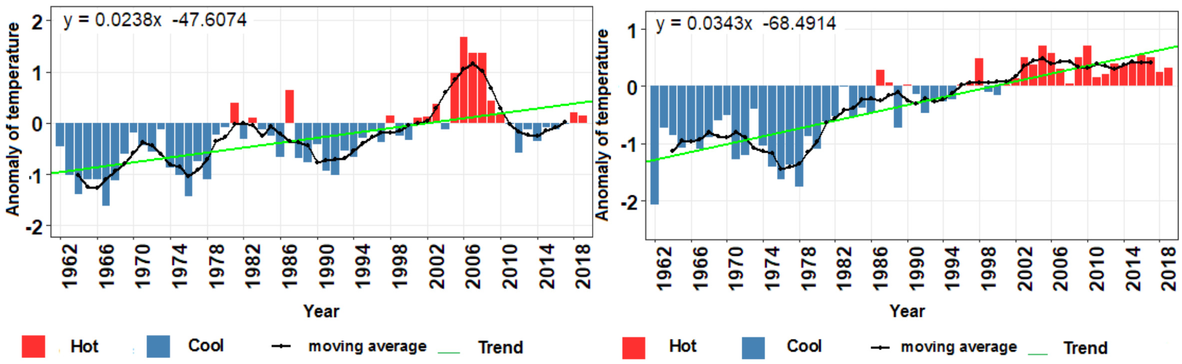
Trend and variability of temperatures

The evolution of maximum and minimum temperatures over the period from 1960 to 2019 reveals a significant upward trend with the Mann Kendall test and at 5% significancelevel. In the Pettitt test, a rupture was detected in 1995 for the maximum temperature and 1986 for the minimum temperature (Figure 4a and 4b). By comparing the means of the sub-series before and after rupture, there is an increase of 0.8°C for the maximum temperature and 1.1°C for the minimum temperature. The maximum and minimum temperatures anomaly release two thermal periods, a cold period and a warm period. The last thirty years remain the warmest for the minimum temperature over the entire period (Figure 5 b).



a) Maximum temperatures b) Minimum temperatures

Fig 4: Evolution and trend of maximum (a) and minimum (b) temperatures from 1960-2019 in Parakou.

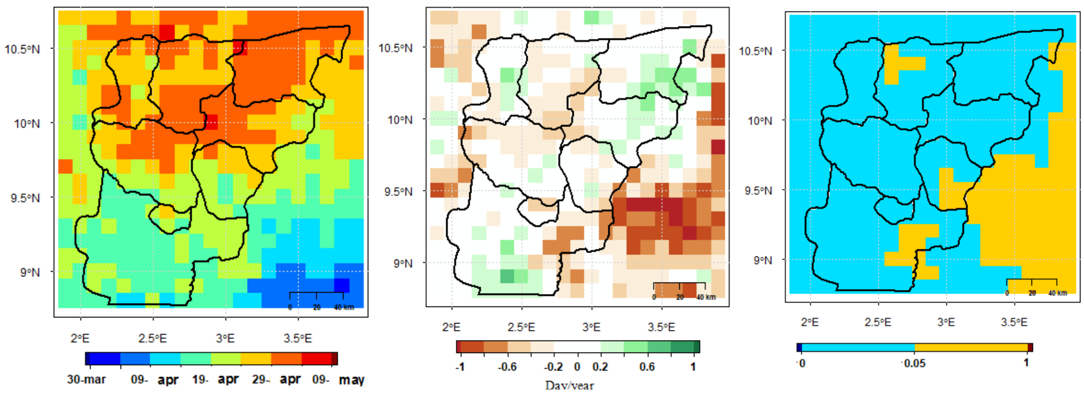


a) Maximum temperatures b) Minimum temperatures

Fig 52 : Anomaly of maximum (a) and minimum (b) temperatures in Parakou from 1960 to 2019.

Trends of the onset dates of the rainy season

The rainy season starts on average around the 2nd ten days of April in the southern part of Borgou and the 1st ten days of May in the north (figure 6a), and, overall, has a significant normal to late trend (p-value <0.05).

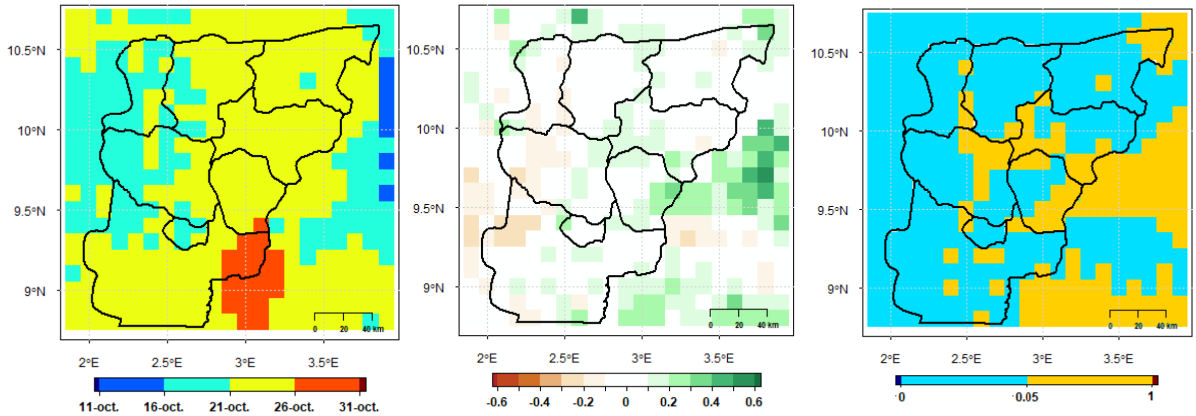


a) Average start dates *b) trend* *c) p-value*

Fig 63 : Average start of season dates (a) in the district of Borgou, their trends (b) and the p-value of the Mann-Kendall test (c)

Trend of the end dates of the rainy season

The end of the rainy season is observed during the second half of October throughout the district (Figure 7a) and shows a normal to late trend, except for the west of the district (Tchaourou, Sinendé and N'dali) where a tendency towards precocity observed is significant.

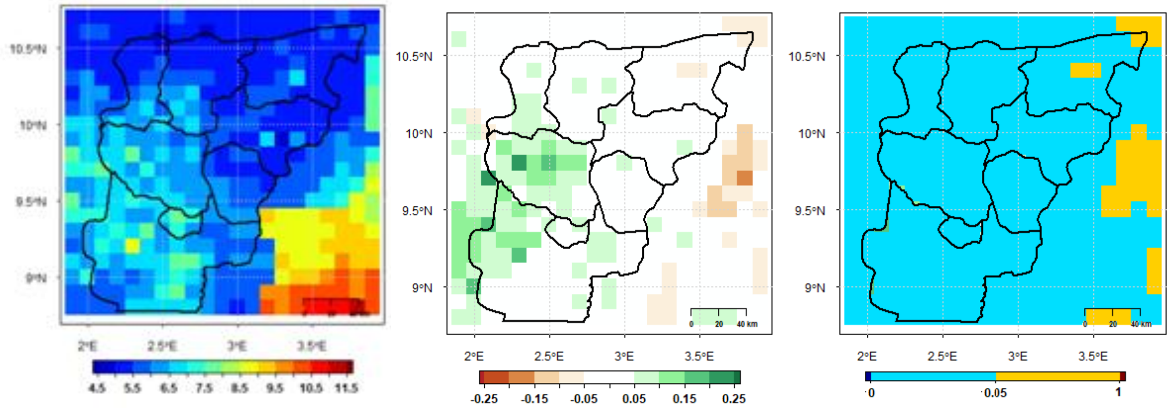


a) Average end dates b) trend c) p-value

Fig7 : Average end-of-season dates (a) in the Borgou district, their trends (b) and the p-value of the Mann-Kendall test (c).

Trend of maximum dry spells

The average of the longest dry spells observed throughout the district during the period from 1981 to 2019 is less than 10 days. The longest are observed in the region of Tchaourou, N'dali, Sinendé and Parakou with a significant upward trend, particularly in N'dali, Tchaourou and Sinendé to the west of the district of Borgou (Figure 8).



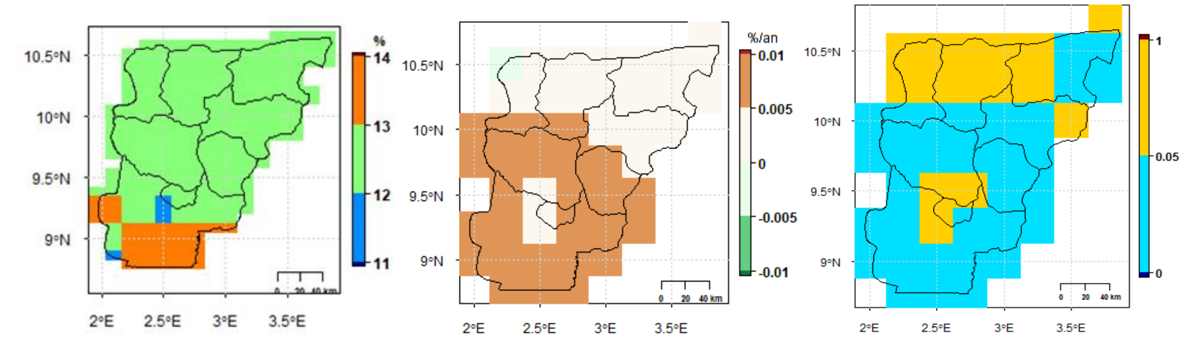
a) Dry spell average b) trend c) p-value

Fig 8: Average of the longest dry sequences (a) in the district of Borgou, their trends (b) and the p-value of the Mann-Kendall test (c).

Trends in climate extremes

Proportion of hot days (TX90P)

On average 14% or 40 to more than 50 hot days, are observed annually throughout the district (figure 9). Hot days are on the rise in the southern half of the district (Tchaourou, Parakou, N'dali, Pèrèrè…) with a significanttrend.

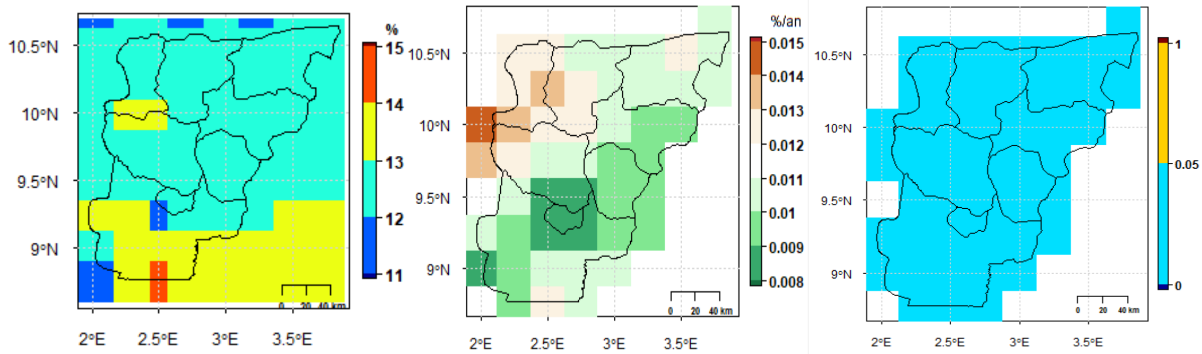


a) Annual average (Tx90p) b) trend c) p-value

Fig 9 : Annual mean of hot days (a), their trends (b) and Mann-Kendall test p-value (c).

Proportion of hot nights (TN90P)

On average 16% or 40 to 60 hot nights per year were recorded in the district (Figure 10). The trend in the number of hot nights is on the rise in the municipalities of Sinendé and Bembèrèkè and on the decline in the municipalities of Parakou and Tchaourou over the period 1981 to 2019. In general, the whole of the district is experiencing a significant trend (p-value < 0.05) to the increase in the number of hot nights.



a) Annual average (TN90p) b) trend c) p-value

Fig10 : Annual mean of hot nights (a), their trends (b) and Mann-Kendall test p-value (c).

Discussion

Current climate risks

The evolution of rainfall totals at the Parakou station is marked by a strong inter-annual variation. These annual rainfall accumulations from 1960 to 2019 have an overall insignificant downward trend. The Pettitt test applied at the 5% significance level to the series of annual rainfall accumulations detected a non-significant break.

This trend is similar to that obtained by Gnanglè et*al*., (2011) in the Sudanian zone of Benin where a perceptible decrease in rainfall of -5.5 mm/year on average was observed over the time series from 1960 to 2008 . (Boko et *al*., 2012) for their part, by analyzing climatic data from meteorological stations in Benin over the period 1951-2010, clearly perceived that the northern part of Benin, closer to the Sahelian climate, experienced an annual rainfall decrease between 11% and 28%.

Concerningtemperature over the period from 1960 to 2019, a significant upward trend is observed. A break was detected in 1995 for the maximum temperature separating the series into two sub-series with a cold period from 1962 to 1995 and a warm period from 1996 to 2019. For the minimum temperature, the break was detected in 1986 where a period cold from 1962 to 1986 and a warm period from 1987 to 2019 emerge. By comparing the means of the sub-series before and after rupture, an increase of 0.8°C for the maximum temperature and 1.1°C for the minimum temperature emerges.

Gnanglè et *al*., (2011), also obtained over the period 1960-2008 a trend of a significant increase in the average temperature of more than 1°C in the Sudanian zone of Benin. (Boko et *al*., 2012) perceived in the northern part of Benin, a temperature increase of 1°C over the period 1951-2010.As for Hounzinmè et *al*.,(2017), a gradual increase in temperatures from 1963 to 2012 was detected with enhancement in 1998.

On average, the rainy season starts around the 2nd ten days of April in southern Borgou (municipality of Tchaourou) and the 1st ten days of

May in the northern part. Overall, the start of the rains in the district has a normal to significant late trend. These results are in line with a study carried out by the AGRHYMET Regional Center in Benin (CRA/CILSS, 2015), which showed that the Nikki station presents an alarming situation with a trend towards highly significant late start dates in the period 1991-2010 compared to the period 1961-1991. In addition, this study underlined that the start date of the rainy season in the north ranges on average between the 1st and 2nd decade of May. Also, these results corroborate those of Issa et *al*.,(2017); Yolou et *al*., (2017) in northern Benin which demonstrated that intra-seasonal instability is manifested by late starts of the rains (20 and 35% of the years).

The end of the rainy season is observed during the second half of October throughout the district. It presents a significant normal to late trend over the whole of the district except for certain localities in the west of the district, for example Tchaourou and N'dali, where a tendency to earliness is observed. The study carried out by the AGRHYMET Regional Center in Benin (CRA/CILSS, 2015) reveals that the rainy season ends during the first ten days of October in the north of the country.However, the work of Issa et *al*.,(2017) ; Yolou et *al*., (2017) shows that the intra-seasonal variability of rainfall is manifested, among other things, by an early end to the rains (10% of years over the period 1961 and 2010).

Extremes climate trends

On average, 40 to more than 50 hot days are observed annually throughout the district. Hot days have a significant upward trend in the southern half of the district (Tchaourou, Parakou, N'dali, Pèrèrè…). These results are consistent with the study carried out by the AGRHYMET Regional Center in Benin showing an upward trend in the average number of hot days over the period 1991-2010 (CRA/CILSS, 2015).

With regard to hot nights, their annual average value varies between 40 to 60 in the district with a spatial disparity over the period 1981 to 2019. Thus, a significant upward trend is observed in the Municipalities of Sinendé and Bembèrèkè while whereas in the municipalities of Parakou and Tchaourou, the trend is rather downward. This observation partially confirms the results of CRA/CILSS (2015) which indicate a general decrease in the frequency of cold nights over the period 1991-2010 in Benin. Sounouké et *al*., (2022), also found after investigation in Borgou area that more than 55% of maize farmers of the district of Borgou perceived extremely hot days and nights.

IV. CONCLUSION

The objective of this study was to identify the current climatic risks in the district of Borgou based on observed climatic data. Overall, a non-significant downward trend in annual rainfall totals is noted. The start of the rains in the district has a normal to late trend with increasingly long dry spells in the municipalities of Sinendé, N'dali and Parakou to the west of the district of Borgou. The evolution of maximum and minimum temperatures over the period from 1960 to 2019 reveals a significant upward trend. Regarding the minimum temperature, the last thirty years remain the warmest over the entire period.

As far as climatic extremes are concerned, the trend of annual cumulative amounts of rain on very wet days is on the rise in the west of the district and is significant. Warm days are on the rise in the southern half of the district. Overall, the entire district is experiencing a significant trend towards an increase in the number of hot nights.

Ultimately, the results of this research reveal a strong occurrence of intra-seasonal and seasonal climatic risks associated with global warming in the district of Borgou in Benin. These results challenge the scientific community and decision-makers. They suggest that adaptation measures must be developed and/or disseminated in the farming environment to ensure the resilience of producers in a changing climate context.

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