Spatio-temporal variability of the onset and end dates of the rainy seasons in the Bounkani region (North-East of Côte d'Ivoire).

Abstract

In Côte d'Ivoire, 80% of rural activities are based on rain-fed agriculture, although the country has been experiencing a disruption of its rainfall regime for several decades. This study was conducted in this context in order to deepen the previous knowledge on the rainfall regime of the Bounkani region through the spatio-temporal distribution of the dates of the beginning and end of the rainy season. The rainfall data used are of the CHIRPS type for the 1981-2020 period. The application of rainfall indices allowed us to observe surplus and deficit years. These variations indicate a downward trend. The average rainfall has decreased from 1050 mm during the decade 1985-1995 to 950 mm in 2011-2020, a loss of 100 mm. This deficit was reflected in the onset and end dates as well as the number of rainy days of the rainy seasons. The study of the number of rainy days of the rainy season reveals that they have a very low downward trend. Indeed, the starting dates of the rainy season are increasingly late. On average, the start of the season, which was between April 6 and 10 in the years 1981-1995, has shifted from May 1 to 5 in the decade 2011-2020 in the North of the region. While, the South records an average date of season start from April 1 to 5 in the years 1981-1995 and from May 6 to 10 in the decade 2011-2020, a shift of more than 30 days. The start of the rainy season is progressive along the South-North gradient. Conversely, the end of the rainy season occurs first in the North and then extends to the South.

Keywords: GIS and remote sensing, early and late season, rainfall variability, CHIRPS, IDW, Côte d'Ivoire.

Introduction

Since the 1970s, West Africa has experienced one of the greatest rainfall variations observed on a global scale. These variations are reflected in rainfall deficits that have affected the countries of the Gulf of Guinea (Brou and Chaléard, 2007 ; Paturel *et al*, 1995 ; Servat *et al.* 1997 ; Balliet *et al.* 2016). Côte d'Ivoire is not immune to this reality, particularly in the north of the country. The new climatic context has deteriorated considerably and the situation is more alarming in the North-East sector (Brou, 2010). This is the most deficient area in terms of cumulative annual rainfall in Côte d'Ivoire (Brou, 2009). The implications of these climatic variations on water resources are particularly high and affect many sectors of activity such as livestock and agriculture (Ardoin-Bardin, 2004). Agriculture, which occupies a predominant place in the national economies, remains one of the activities most affected by these climate variations.

Nearly 80% of Ivorian agricultural production is rain-fed (Noufé, 2012). However, changes in the descriptive elements of the rainy season led to disruptions in crop production. This situation is therefore worrying, especially for rural communities whose agricultural activities represent the bulk of their income. According to Ahoussi et al.(2013)The disruption of existing cropping systems, such as crop calendars, is already known and observed by farmers in several localities in the country. The dating of new calendars is therefore necessary for better crop planning. In addition, the determination of the onset and end dates of the rainy seasons are crucial issues in tropical Africa, where farming practices are closely dependent on the rains, as they also determine the agricultural calendar and, to a large extent, the quality of the crops. There are several definitions in the literature relating to the determination of the onset and end dates of the rainy season. In particular, those found in studies on rainfall variability and the determination of the onset and end dates of the rainy season in West Africa (Sivakumar, 1988, Joseph et al. 1994, Traore et al. 2000, Camberlin et al. 2003, Ndong, 2003, Marteau et al. 2010) and in Côte d'Ivoire (Balme et al. 2005, Kouassi, 2007, Goula et al. 2010, Noufé, 2011, Dekoula et al. 2018, etc.). Indeed, there is no universally accepted criterion for defining the onset and end of rainy seasons. Kouassi (2007) defines according to Ozer and Erpicum (1995)) defines the beginning of the rainy season as the time (from March 1^{er} to October 31) when the probability of having a rainy day during a given pentad is greater than that of having a dry day belonging to a dry episode of more than 7 days. While Dekoula et al. 2018) and Kouamé et al. (2018)) in their studies in the north of Côte d'Ivoire on the variability of the rainfall regime define the beginning of the rainy season in a bimodal regime as the first day from 1^{er} February when at least 20 mm of rainfall is recorded over two successive days for some and over three successive days for others. And this, without however that it does not have a dry episode of more than 7 consecutive days during the 30 days that follow. It is worth noting that most of the methods used in these studies define a single empirical threshold and set a time interval within which the count must be made. However, none of them have studied the spatial and temporal distribution of these dates in the Bounkani region or even at the national level.

Also, the rainfall data used in these studies come from the '*Société d'Exploitation et de Développement Aéroportuaire Aéronautique et Météorologique*'(SODEXAM). Ivorian researchers agree that the SODEXAM station data are not regularly distributed and have gaps over a decade or so due to the socio-political crisis of 2002. In Côte d'Ivoire, the station grid indicates an average density of one station per 3000 km² (Lienou, 2007, Noufé, 2011, Dekoula, et al, 2018etc.).

For an in-depth study of the rainfall regime, daily data are indispensable, although they are difficult to access, particularly in Côte d'Ivoire, where the network of stations is not very dense.

In this study, the method used to determine the onset and end dates of the rainy season is suitable for all regions (universal). It is very accurate. Indeed, this method allows the calculation of a threshold for each locality according to its rainfall. In addition, the rainfall data used in this work are of satellite type. They cover the entire study area, thus allowing a good spatial analysis. This dataset (CHIRPS) is reliable, accurate with high resolution and freely available. They have been proven in several studies (Seregina et al. 2018 ; Didi et al. 2020 ; Sie et al. 2021).

In light of the above, it is essential to know and understand the onset and end dates of the rainy seasons in order to control and define a new agricultural calendar. This study contributes to the knowledge of the rainfall regime in the Bounkani region through the determination and spatial and temporal distribution of the onset and end dates of the rainy season.

Study area

The Bounkani region is located in the northeast of Côte d'Ivoire between 2.60° and 4.30° west longitude, and 8.20° and 9.95° north latitude (Fig. 1). It is located 550 km from Abidjan, the economic capital, with an area of 22,091 km² or 6.9% of the national territory. However, half of its area is occupied by the Comoé National Park, which covers 11,090 km². The region covers the departments of Nassian, Doropo, Tehini, and Bouna. This area is bordered to the north by Burkina Faso, to the east by Ghana, to the west by the Tchologo region and to the south by the Gontougo region with which it forms the Zanzan district. It is the largest region of Côte d'Ivoire with a population of 427037 inhabitants in 2021 (INS, 202121) or 38.8hbts/km². The main activity of the population is mainly agricultural. Its climate is Sudanian with a rainy season and a dry season. The average annual rainfall is between 900 and 1,200 mm (Sie et al, 2021).

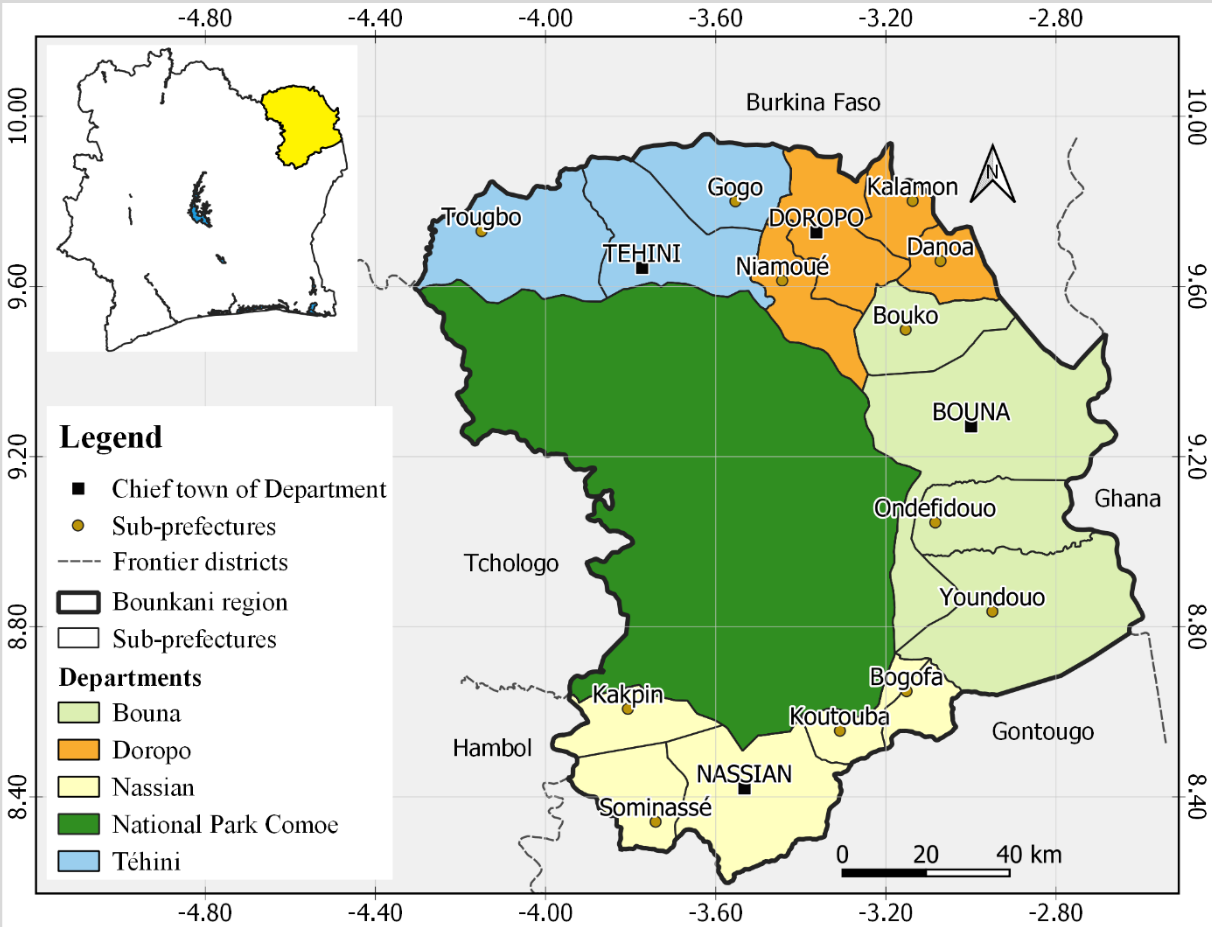

Figure 1: Location of the Bounkani region

Data and methods

Study data

The data used are the Climate Group Hazards InfraRed Precipitation (CHIRPS) satellite products. They are available for over 40 years (1981 to present) with monthly, decadal, pentadal, and daily rainfall (Funk et al., 2015). In this study, annual, monthly, pentadal and daily products from 1981 to 2020 were used for studies of rainfall variability, rainy season onset and end dates.

There are 12 SODEXAM rainfall or hydrometric stations in the region. These stations are irregularly distributed and do not cover the entire area, especially in the park. Also, the data from these stations are incomplete. To overcome these problems, the coordinates of existing and fictitious stations were used to extract rainfall data from the CHIRPS products. This allowed for a homogeneous distribution of stations with reliable and accurate data (5 km resolution) for a better analysis of rainfall variability.

The rainfall data from these 33 stations, homogeneously distributed in the region, were used for the spatial distribution (Figure 2). These data are freely available online [(https://www.chc.ucsb.edu/data/chirps).](https://www.chc.ucsb.edu/data/chirps)

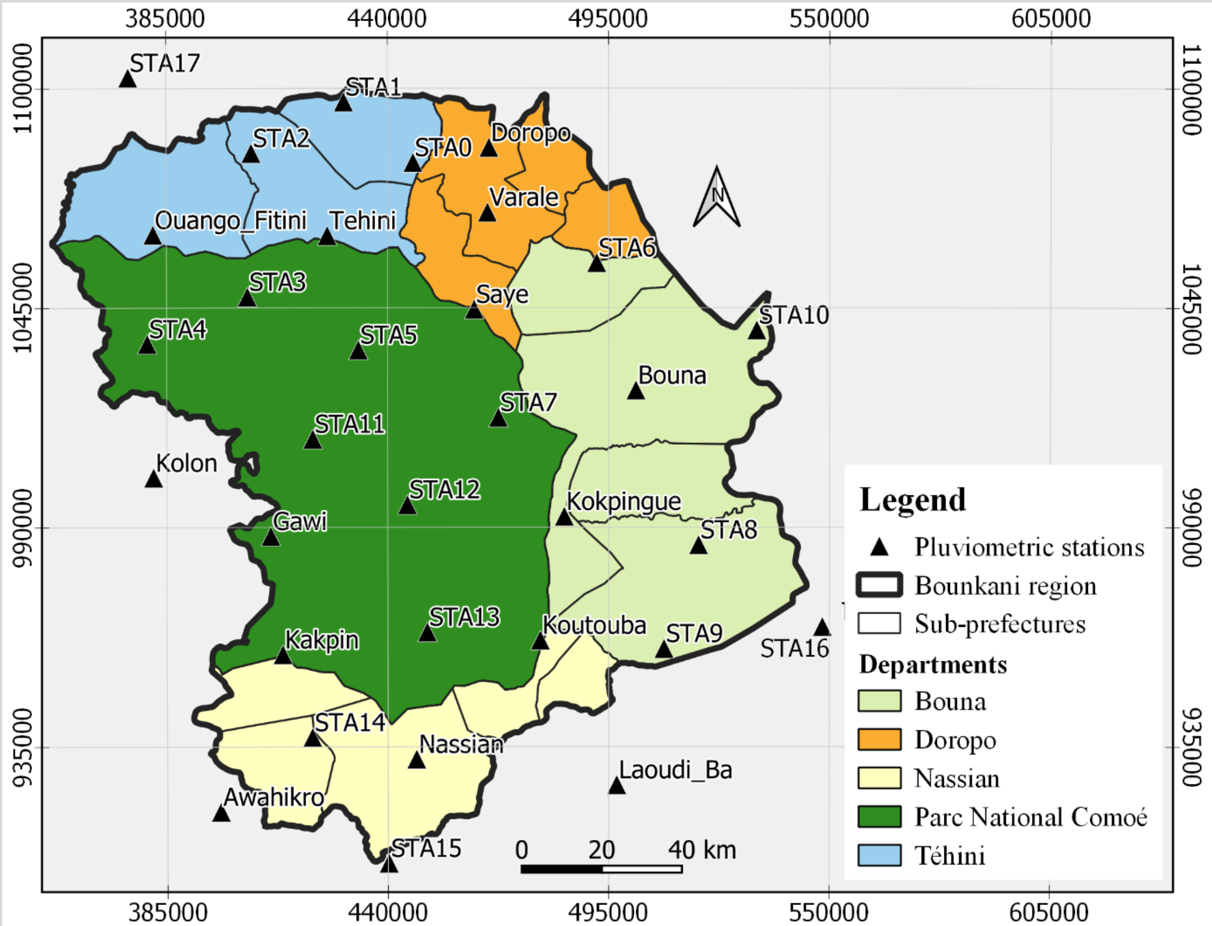

Figure 2: Spatial distribution of rainfall stations

Methods

Interannual and seasonal variation in precipitation

The study of rainfall variability was carried out using the analysis of annual and monthly rainfall data from the CHIRPS products. In order to assess the evolution of rainfall during the different years of the study period, the Nicholson rainfall index and the Hanning low-pass filter of order 2 were applied. These methods have the advantage of highlighting the periods of surplus and deficit in rainfall. The rainfall evolution or rainfall trend was observed using the regression line.

Nicholson Rainfall Index (I_p)

It allows the observation of interannual rainfall variations over a long series of observations (Nicholson et al., 1988). The calculation of this index was carried out on the rainfall data of the four departments of the study area for a period of 40 years of observation. The Nicholson index is expressed by equation (1):

$$I_p = \frac{(X_i - \bar{X})}{\sigma} \textbf{ (Eq. 1)}$$

X_i the precipitation of year i,

$\bar{X}$ the average annual precipitation over the observation period and

σ the standard deviation over the same period.

2nd order Hanning low pass filter

According to Soro et al (2011)the elimination of seasonal variations allows a better observation of interannual fluctuations. In this case, the annual rainfall totals are weighted using the following equations recommended by Assani (1999):

$x_{(t)} = 0.06x_{(t-2)} + 0.25x_{(t-1)} + 0.38x_{(t)} + 0.25x_{(t+1)} + 0.06x_{(t+2)}$ for $3 \leq t \leq (n-2)$ **(Eq. 2)**

where $x_{(t)}$, the weighted rainfall total of term *t*, $x_{(t-2)}$ and $x_{(t-1)}$ are the rainfall totals of the two terms immediately preceding term *t*, and $x_{(t+2)}$ and $x_{(t+1)}$ are the rainfall totals of the two terms immediately following term *t*.

The weighted rainfall totals of the first two terms [$x_{(1)}$, $x_{(2)}$] and the last two terms [$x_{(n-1)}$, $x_{(n)}$] of the series are calculated using the following expressions (*n* being the size of the series):

$X_{(1)} = 0.54x_{(1)} + 0.46x_{(2)}$ **(Eq. 3)**

$X_{(2)} = 0.25x_{(1)} + 0.50x_{(2)} + 0.25x_{(3)}$ **(Eq. 4)**

$X_{(n-1)} = 0.25x_{(n-2)} + 0.50x_{(n-1)} + 0.25x_{(n)}$ **(Eq. 5)**

$X_{(n)} = 0.54x_{(n)} + 0.46x_{(n-1)}$ **(Eq. 6)**

To better observe the months of rainfall deficit and surplus in the four departments (Bouna, Doropo, Tehini and Nassian), the moving averages were centered and reduced using the formula **(Eq. 1).** This method appears to be more efficient because it allows for a perceptible division of the wet and dry seasons.

Variability in the onset and end dates of the rainy seasons

To identify the dates of the beginning and end of the rainy season for the different stations in our study area, the determination criteria as used by Marengo *et al* (2001) and Giráldez *et al* (2020) were applied. This method is done in two steps:

- First, there was a question of determining specific precipitation thresholds for each station above or below which the season will start or end. These thresholds were calculated by an analysis of the frequency and intensity of smoothed pentadal precipitation. The precipitation threshold is obtained in two steps: i) the 3rd order moving average was applied to smooth out irregularities in the time series. ii) The 50th percentile of precipitation between January and June was used as the threshold for identifying the start of the rainy season. To identify the end of the rainy season, the threshold was the 50th percentile of rainfall between July and December (Giráldez et al., 2020). The onset and end dates at each station are defined by a particular rainfall threshold (Table 2).

- Second, the rainy season onset date was defined when the first pentad of a set of 6-8 consecutive pentads exceeds the precipitation threshold previously identified in Table 2. Similarly, the end date of the rainy season was determined as the date before the first pentad of a set of 6 to 8 successive pentads that do not exceed the previously identified rainfall threshold (Table 2).

Table 2: Onset and end date thresholds for each station

N°	Stations	Long.	Lat.	Early season threshold (mm)	End of season threshold (mm)
1	**Awahikro**	-3.923	8.310	16.03	17.00
2	**Bouna**	-2.983	9.267	11.09	19.72
3	**Doropo**	-3.317	9.817	9.58	23.10
4	**Gawi**	-3.811	8.935	13.46	21.87
5	**Kafolo**	-4.415	9.583	10.78	24.81
6	**Kakpin**	-3.783	8.667	14.96	19.02
7	**Kokpingue**	-3.146	8.981	13.33	21.04
8	**Kolon**	-4.076	9.067	13.40	22.21
9	**Koutouba**	-3.200	8.700	15.99	18.37
10	**Laoudi_Ba**	-3.027	8.372	18.28	16.66
11	**Nassian**	-3.480	8.430	16.12	17.84
12	**Ouango Fitini**	-4.078	9.617	10.40	24.29
13	**Saye**	-3.350	9.450	10.93	23.29
14	**Tehini**	-3.683	9.617	10.36	22.82
15	**Varale**	-3.320	9.670	10.24	22.88
16	**STA0**	-3.489	9.782	9.62	23.23
17	**STA1**	-3.637	9.894	9.10	23.43
18	**STA2**	-3.856	9.803	9.40	23.02
19	**STA3**	-3.864	9.477	10.87	22.63
20	**STA4**	-4.091	9.370	11.53	23.53
21	**STA5**	-3.613	9.358	11.66	22.82
22	**STA6**	-3.072	9.556	10.43	24.16
23	**STA7**	-3.295	9.205	12.18	23.32
24	**STA8**	-2.841	8.916	13.55	19.16
25	**STA9**	-2.920	8.681	15.55	18.54
26	**STA10**	-2.709	9.403	10.83	23.68
27	**STA11**	-3.716	9.155	12.58	22.63
28	**STA12**	-3.501	9.007	13.35	21.37
29	**STA13**	-3.456	8.718	15.70	17.98
30	**STA14**	-3.716	8.479	15.65	18.37
31	**STA15**	-3.543	8.194	15.93	15.57
32	**STA16**	-2.561	8.731	13.92	18.72

33	**STA17**	-4.201	9.918	9.89	24.46

Analysis of rainy days

The determination of the number of rainy days per year and per season was made on grounds of the daily rainfall data. A day is considered rainy if the amount of precipitation received that day is greater than or equal to 1 mm. The number of rainy days is evaluated on a seasonal basis.

Spatial and temporal variation in the onset and end dates of the rainy season

In this study, we used the Inverse Distance Weighting (IDW) interpolation method for the spatial distribution of data from the thirty-three (33) stations in the area of interest. This method is effective and robust for data (rain, temperature, etc.) that are continuous and evenly distributed over the area as is the case in this work.

Inverse Distance Weighting (IDW) is based on the assumption that features that are close together are more similar than those that are farther apart. To predict the value of an unmeasured sample point, IDW will use the values of the known samples surrounding that prediction point. The known values of the samples closest to the prediction point will have more influence on the predicted value than those further away. The advantage of the IDW method is that it is intuitive and efficient. This interpolation method works best with uniformly distributed points that have no outliers (Azpurua and Dos Ramos, 2010).

Thus, it weights nearby points more than those that are farther away, hence the name inverse distance weighting. The value of the prediction point is given by the following general equation:

$$\hat{Z}(s_o) = \sum_{i=0}^{n} \lambda_i Z(s_i) \qquad \textbf{(Eq. 17)}$$

where $\hat{Z}(s_o)$ is the value, we are trying to predict for the location s_o ;

n is the number of measured sample points surrounding the prediction location that will be used in the prediction;

λ_i is the weight assigned to each measured point we will use and these weights will decrease with distance;

$Z(s_i)$ is the value observed at the location s_i.

The weights at the location s_i can be determined by:

$$\lambda_i = d_{i0}^{-p} / \sum_{i=1}^{N} d_{i0}^{-p} \sum \lambda_i = 1 \qquad \textbf{(Eq. 18)}$$

As the distance increases, the weight is reduced by a factor p. d_{i0} the distance between the prediction point s_o and each of the measured sample points s_i. The power parameter p influences the weighting of the measured point value on the prediction point value; that is, as the distance between the measured sample points and the prediction point increases, the weight (or influence) that the measured point will have on the prediction will decrease exponentially. The weights of the measured point that will be used for the prediction are scaled so that their sum is equal to 1 (Hodam *et al.*, 2017)**.**

Results and discussion

Results

Interannual variability of rainfall

Figure 3 illustrates perfectly that the amount of rainfall is decreasing in the Bounkani region. The observed reduced centered indices (Fig. 3a) show a decrease in rainfall over the entire chronicle with a small non-significant slope (a= - 0.007) and Figure 3b also presents the average cumulative rainfall amounts per quinquennium. This figure shows that the 1986-1990 five-year period received a large amount of rain (about 1090 mm) in the region, unlike the three following five-year periods (1991-1995, 1996-2000 and 2001-2005), which recorded a gradual decline in rainfall to 985 mm, or a loss of 100 mm. A recovery of rainfall from 2006 to 2010 with an average rainfall of 1057 mm, is followed by a considerable decline from 2011 to 2020 corresponding to a drop of about 80 mm of rainfall.

For more details on the evolution of rainfall in the region, we have determined the deficit and surplus months of the different quinquennia. For the study of these months, we used monthly data.

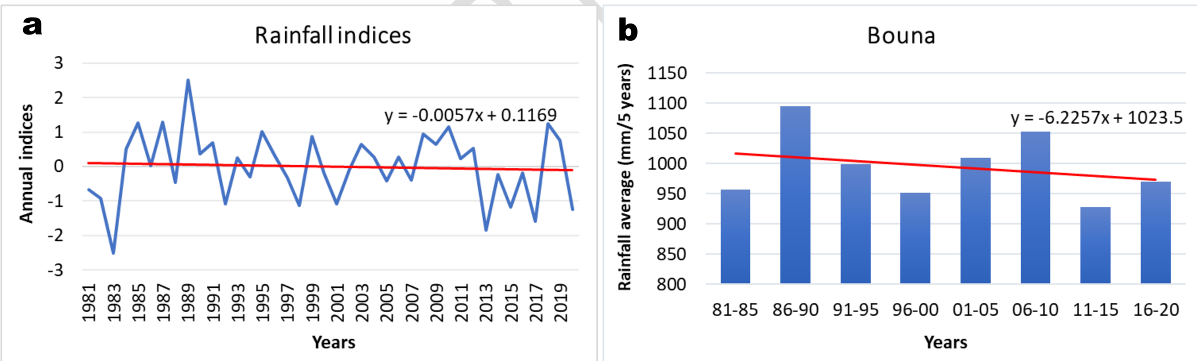

Figure 3: Interannual variability of rainfall from 1981 to 2020

Seasonal variation in rainfall

The second-order Hanning low-pass filter and the reduced centered index applied to the five-year average of the rainfall series makes it possible to observe the surplus and deficit months in the study area (Figure 4). It can be seen that in the Bounkani region the rainy season comprises six (06) months that generally begin in May and end in October, except in the Nassian department, where the rainy season lasts seven months (Fig. 4d). It extends from April to October with a wet transition generally observed in August. This period precedes the main dry season, which lasts 5 months (November-March). There is a clear variation in the rainy season in Bouna department (Fig. 4a). From 1981 to 1985 and from 1991 to 1995, the rainy season began in April, but from 1986 to 1990 and from 1996 to 2020, it began in May. For a better precision of the seasonal variation, the dates of onset and end of the rainy season of the different departments and the 33 stations of the study area were determined.

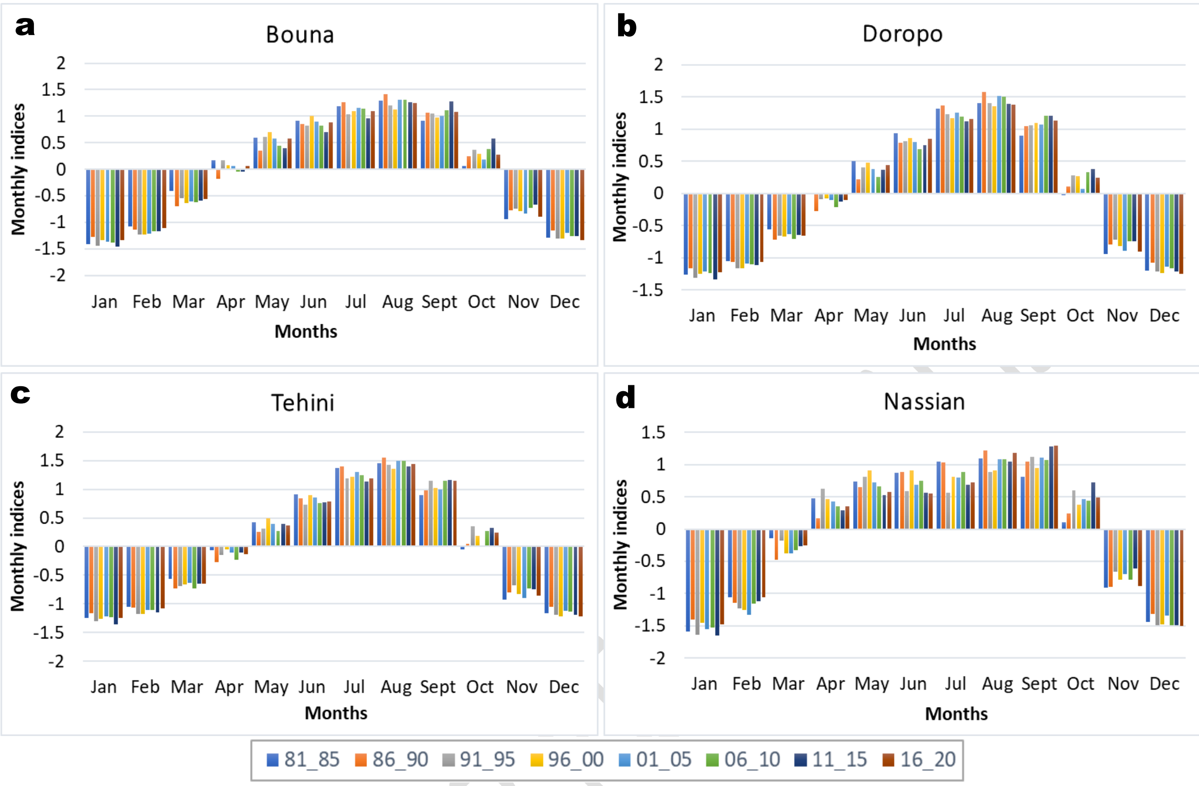

Figure 4: Seasonal variability of rainfall from 1981 to 2020

Variations in the onset and end of rainy seasons

The variation in the dates of the onset and end of the season is illustrated in Figures 5 and 6 respectively. Three (3) departments in the region, namely Bouna, Doropo and Tehini have an increasing trend (Fig. 5). This reveals that the rainy season is starting later and later in these areas over time. The start date varies between pentad 14 (6-10 March) and pentad 30 (26-31 May) in Bouna department. Doropo is located between the 18$^{\text{ème}}$ (26-31 March) and 26$^{\text{ème}}$ (6-10 May) pentad with two (02) years (1998 and 2003) of late onset (29$^{\text{ème}}$ pentad), i.e., more than two weeks later. Like Doropo, in Tehini department, the start date oscillates between the 18$^{\text{ème}}$ (26-31 March) and the 26$^{\text{ème}}$ (6-10 May) pentad with the year 2013 having an early start (6-10 March) of rain and the year 2003 having a late start (21-25 May).

Unlike the first three departments, Nassian has a declining trend in season onset date. This declining trend shows that in the southern part of the region, the rainy season tends to start a little earlier over time. The start of the season evolves between the 13$^{\text{ème}}$ (March 1-5) and 30$^{\text{ème}}$ (May 26-31) pentad.

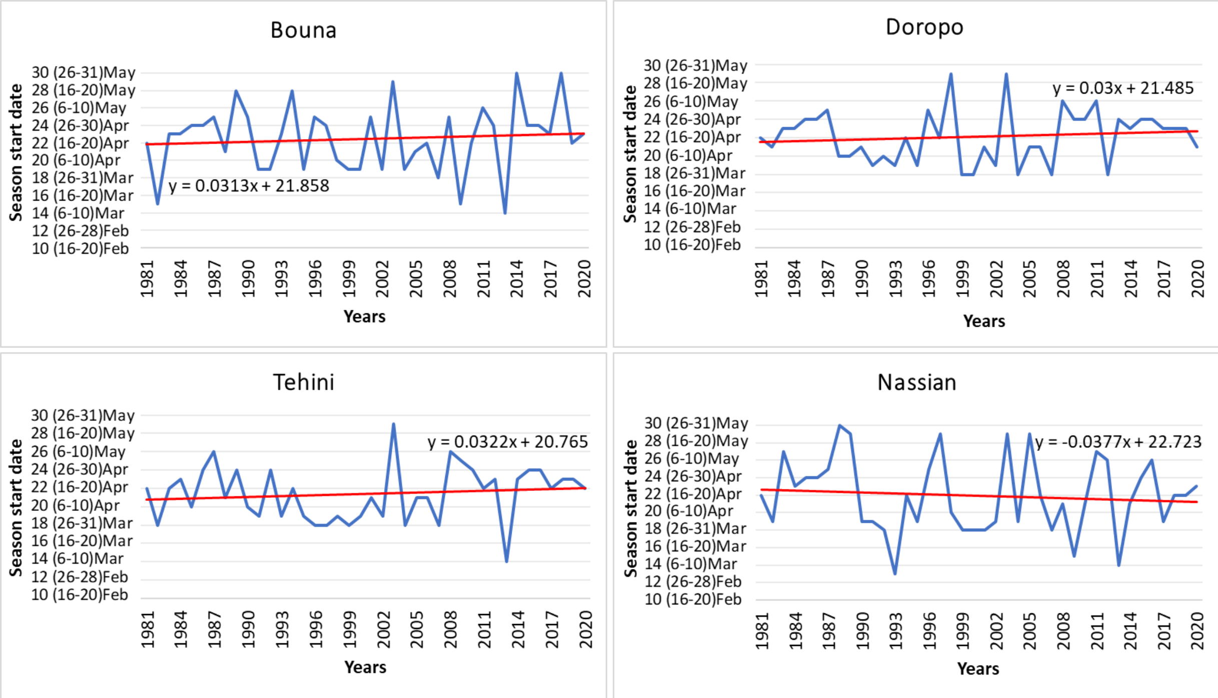

Figure 5: Variability of rainy season onset dates from 1981 to 2020

As for the end dates of the rainy season in the four departments that make up the Bounkani region, represented by Figure 6, it is apparent that the region as a whole is showing an upward trend with low slopes averaging 0.03. This reflects the fact that the end dates of the rainy seasons tend to occur later in the study area. However, the end dates vary differently across the departments. In Bouna and Tehini departments, the end of the rainy season varies between the 51ème (Sept. 11-15) and 61ème pentad (Nov. 1-5), while in Doropo and Nassian departments, the end of the rainy season fluctuates between the 49 (Sept. 1-5) and 61 (Nov. 1-5) pentads. In addition, early season ends (21-25 Aug.) were recorded in Doropo and Tehini departments in 1981.

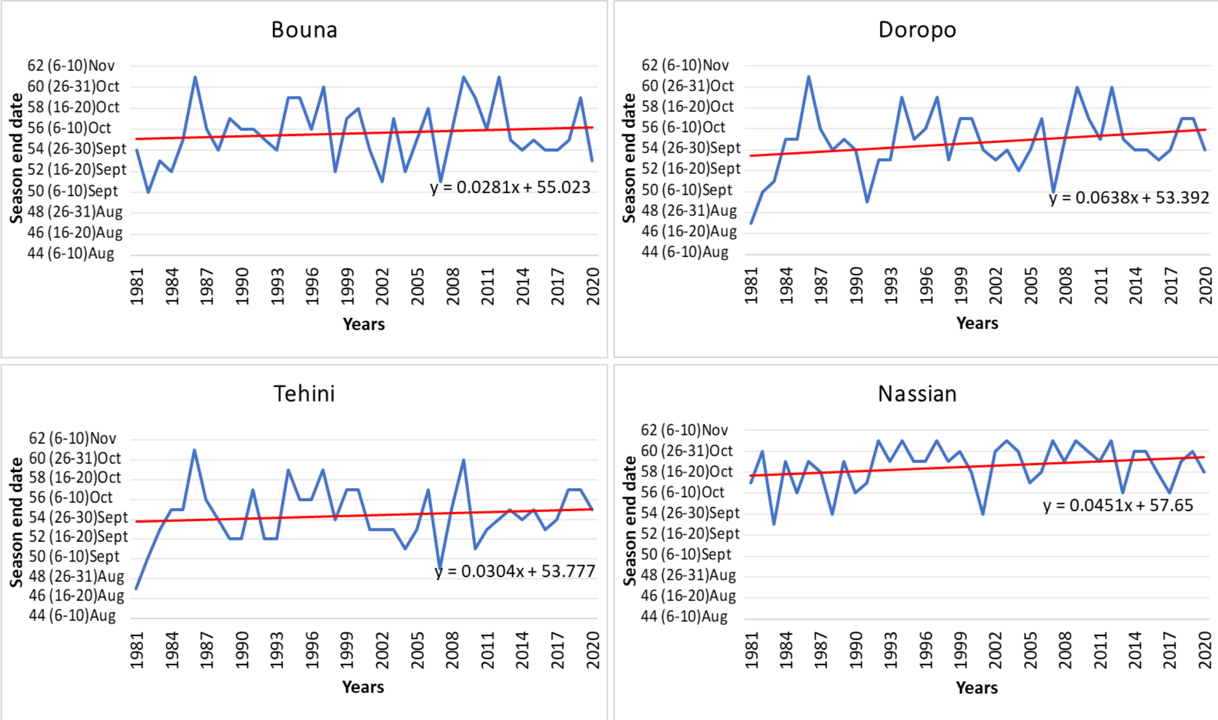

Figure 6: Variability of rainy season end dates from 1981 to 2020

After determining the onset and end dates of the seasons, the analysis of rainfall amounts during the rainy season is presented in Figure 7. There is a decrease in rainfall amounts from 1981 to 2020 in the departments of the Bounkani region, with the exception of Doropo, which shows an increasing rainfall trend. The departments concerned by the decrease in rainfall are Bouna, Tehini, and Nassian with rainfall varying between 500 mm and 1100 mm during the rainy season. Rainfall in Doropo department varies between 600 mm and 1250 mm during the rainy season.

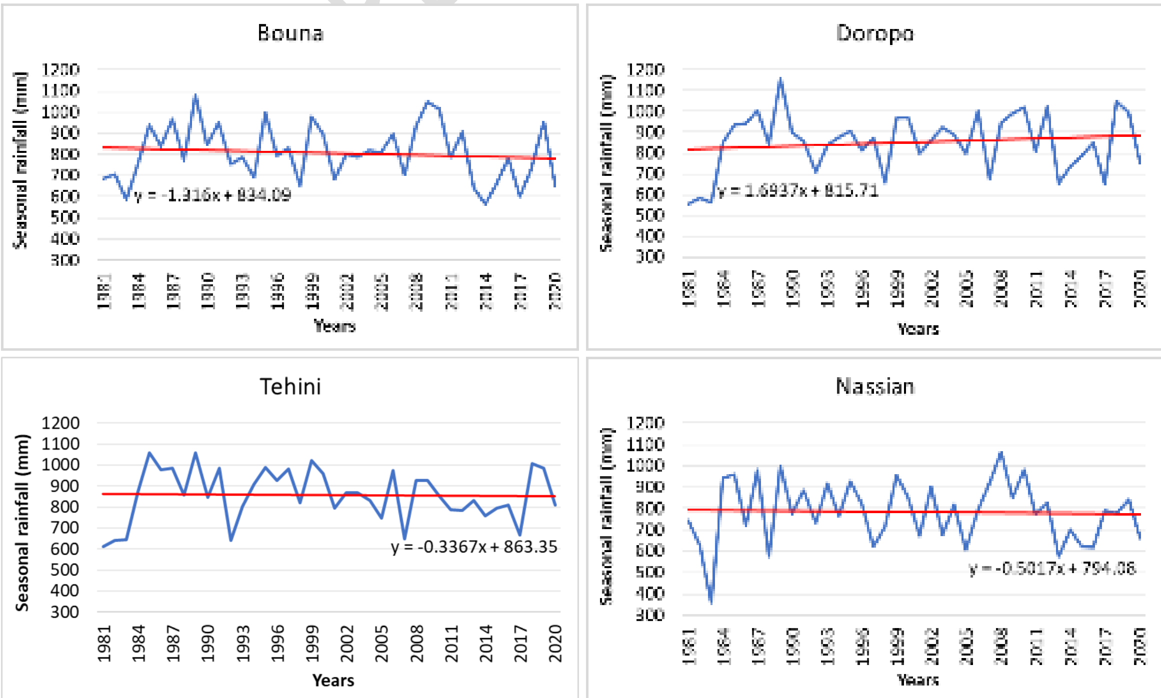

Figure 7: Variation in rainfall amountsin the rainy season from 1980 to 2020

Spatial variation in season onset and end dates

Onset date of the rainy season

The spatial distribution of rainy season onset dates (Figure 8) shows a uniformity in the start of the season in the Bounkani region during the 1981-1985 five-year period. In this period, the start of the season was between April 11 and 15. However, the extreme south had an earlier start to the season than the north, which started a month later. The 1986-1990 five-year period shows that the start of the season varies between pentads 21 and 25 (11 Apr-5 May). This variation is observed in the east in Youndouo Sub-Prefecture and in the west in Comoé Park. In this first decade (1981-1990), a variation in season onset dates is observed. Initially, the region that had a season onset date (11-15 Apr) has now shifted to a date between 01 and 05 May, a shift of about 20 days.

The next three quinquennia 1991-1995, 1996-2000 and 2001-2005 show an earlier start of the season than the previous decade (1981-1990). The dates are located between pentads 17 and 19 (21 Mar-5 Apr). Furthermore, the 1991-1995 five-year period shows that the rainy season tends to start earlier in the South, which generally begins in pentad 17 (21-25 Mar), and then progresses towards the North. From 2001 to 2005, the rainy season began more or less during pentad 19 (1-5 Apr) throughout the region, except for a few sub-prefectures in the departments of Bouna (Bonna, Ondefidouo) and Nassian (Sominassé), which experienced a delay of about one week.

The last three quinquennia (2006-2020) of the study period shows a shift in rainy season onset dates that varies between pentads 21 and 29 (11 Apr-25 May). The 2011-2015 quinquennium shows a strong shift in season onset dates in the time series (1981-2020). This shift is more pronounced in the southern part of the region, particularly Nassian and the southern part of Bouna department. These areas have a late start to the season (21-25 May) in the 2011-2015 five-year period compared to the 1991-2000 decade, during which the season started between 21 and 25 March. This corresponds to a delay in the start of the season of about 2 months or 60 days.

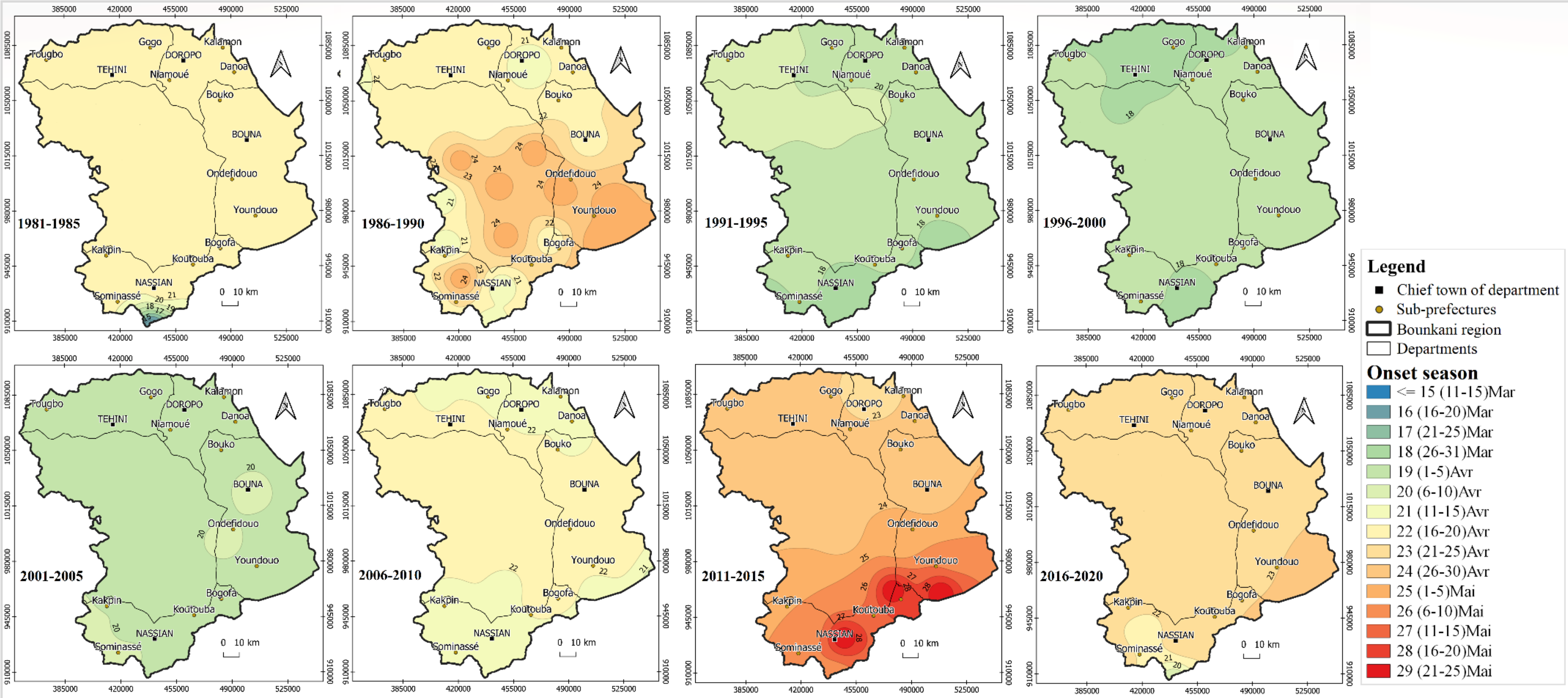

Figure 8: Map of the spatial and temporal distribution of the onset dates of the rainy season from 1981 to 2020

End of rainy season date

Figure 9 presents a spatial distribution of rainy season end dates in the Bounkani region. There is an increasing gradient from north to south in the date of the end of the season. In general, the end of the season occurs first in the north of the region and then gradually moves southward. We note that during the 1981-1985 five-year period, the region experienced shifts in the end of the season, particularly in Tehini Department and the sub-prefectures of Danoa and Bouko. In these localities, the rainy season ended between September 1 and 15. While the South of Nassian recorded the end of the season between October 6 and 20, one month after the rains stopped in the North.

The 2001-2005 and 2006-2010 five-year periods show a change in end dates along the South-North gradient. The northern half of the region experienced a season end in pentad 53 (Sept. 21-25) during the 2001-2005 quinquennium. While in the second part of the decade (2006-2010), the region observed a delay in the end of the rainy season. It thus shifted from pentad 53 to pentad 60 (26-31 Oct.) respectively in the south and east of the study area. With the exception of Tehini department, which maintained its end-of-season period.

The last decade 2011-2020, on the other hand, shows a decrease in the ending date trend. The southern part of the region that had recorded the end of the season during pentad 60 has regressed by 2 pentads corresponding to 10 days of lag.

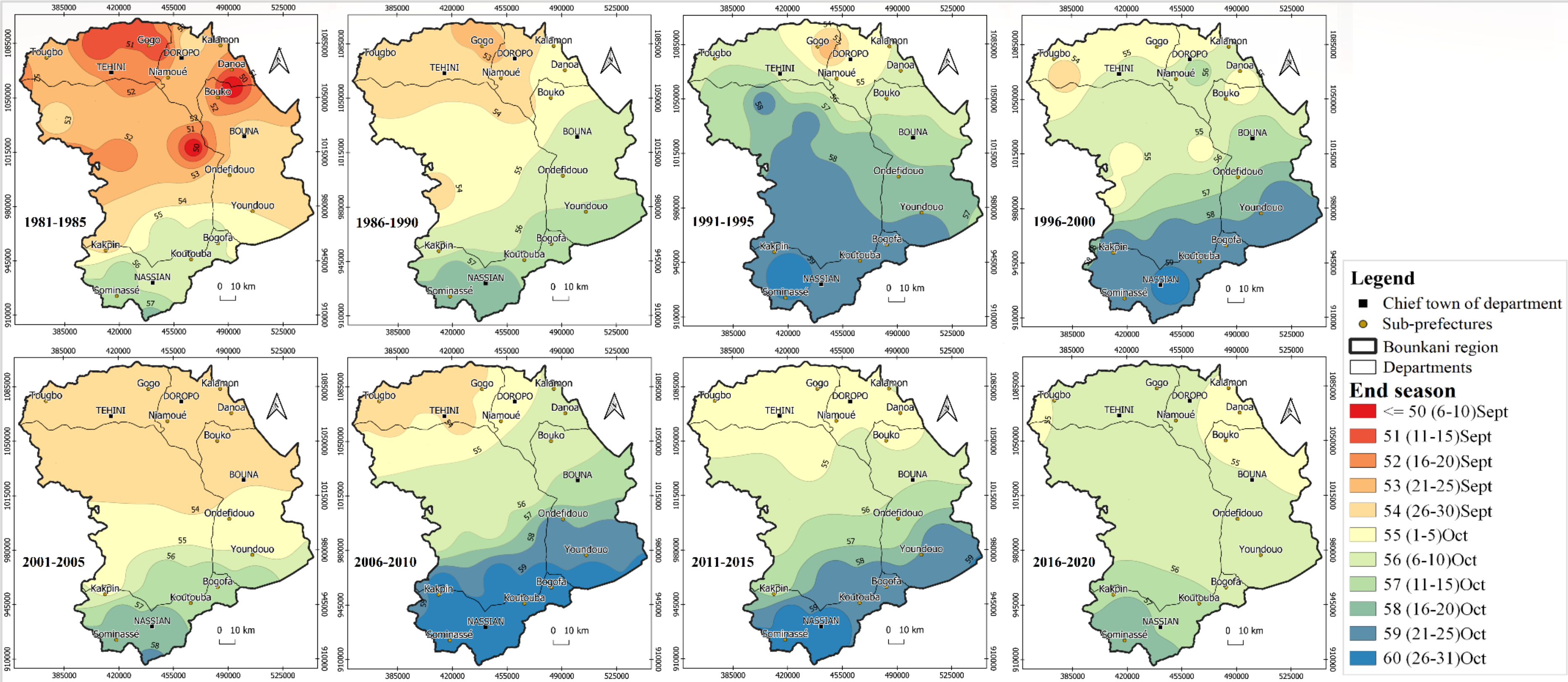

Figure 9: Map of the spatial and temporal distribution of the end of the rainy season from 1981 to 2020

Statistical analysis of rainy days

Obtaining the onset and end dates of the rainy season allowed for a statistical analysis of rainy days during the rainy season. Figure 10 shows the variations in the number of rainy days during the rainy season. There is a slight downward trend in the number of rainy days in Bouna and Tehini with slopes a=-0.05 and a=0.025 respectively. In contrast to the previous departments, Doropo and Nassian experienced an increase in the number of rainy days with a steeper slope for Nassian (Figure 10).

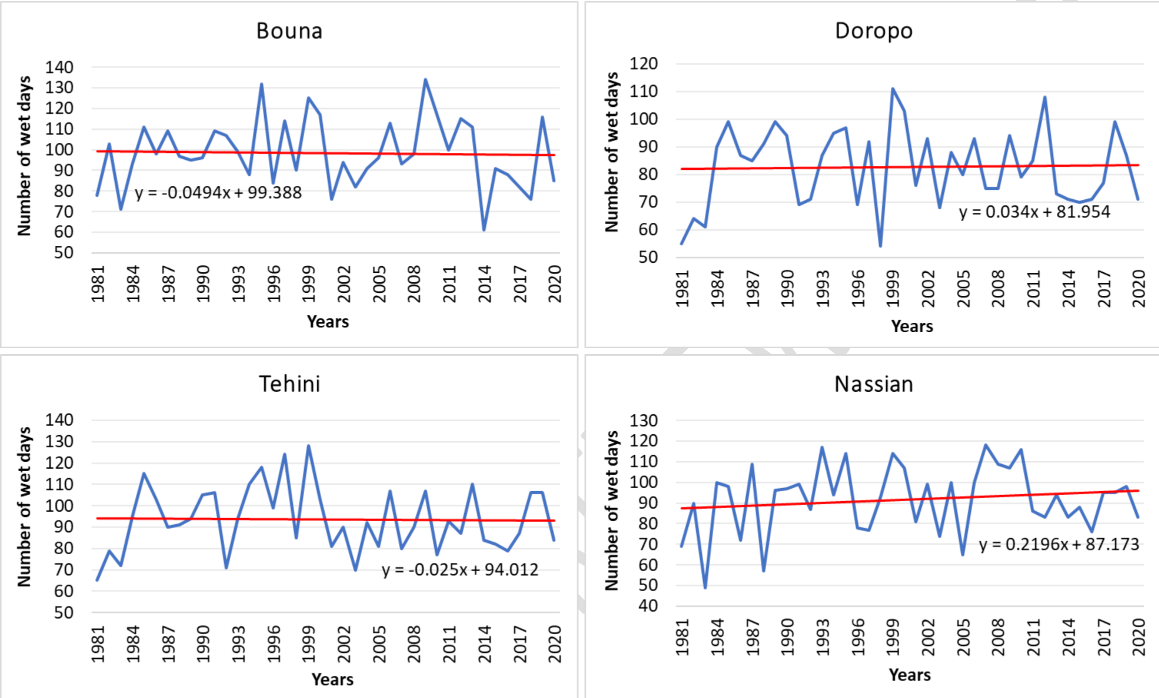

Figure 10: Change in number of rainy days from 1981 to 2020

Discussion

In recent years, the rainy season has been confronted with anomalies arising from rainfall descriptors that are an important factor in rainfed agriculture. Indeed, the results obtained from statistical methods (Nicholson index, regression line) reveal that the Bounkani region has recorded a decrease in rainfall from 1981 to 2020. The chronicle shows deficit periods (the five-year periods 1981-1985 and 2011-2015 with rainfall of 930 mm and 950 mm respectively). According to Brou (2009), this is the most deficient area in terms of cumulative annual rainfall in Côte d'Ivoire. The year 1983 recorded a severe drought in the West African region, which was followed by a resumption of rainfall until 2013, which also recorded very little rainfall. This alternation of wet and dry periods has been illustrated by several previous studies (Noufé et al., 2015, Dekoula et al., 2018, etc.). These studies show the decline in rainfall at the end of the 1960s in the north of Côte d'Ivoire, which gradually spread southwards (Brou, 1997 ; Bigot *et al.* 2005 and Noufé *et al.* 2011). This disfunctioning of rainfall observed over the last few decades has had repercussions on the distribution of seasons.

Pentadal data were used for an accurate determination of the onset and end dates of the rainy season to guard against the risks of false starts and early ends during the rainy seasons in the study area. The results show a shift in the onset and end dates of the rainy season. This shift is observed by a slight shift in the onset and end dates of the rainy season in the departments of Bouna, Doropo and Tehini. This means that the duration of the rainy season in these departments is almost stationary. While Nassian shows a decrease in the trend in the onset dates of the wet season, the trend in the end dates varies little. These trends indicate a delay in the start of the rainy season in this department and little variation in the end of the season. This shows that there is a shortening of the length of the rainy season in this department. This difference between the northern and southern localities can be explained by their belonging to different climatic regimes. Indeed, the Bounkani region is located in the Sudanese climate regime (monomodal), except for the department of Nassian, which is located in the south in the transition zone between the Sudanese climate and the equatorial climate with an attenuated transition and bimodal regime. This department straddles the gap between the monomodal and bimodal regimes. This corroborates the work of Noufé (2011) which reveals that the separation of these two climatic domains in the northeast quarter of Côte d'Ivoire follows the Nassian-Farako line south of Comoé National Park. In addition, there was a decrease in the amount of rainfall during the rainy season throughout the region except for Doropo, which recorded a slight increase. Brou (2010) and Kanga and Assi Kaudjhis (2016) also noted a decrease in rainfall in the Bounkani area in their study on rainfall variation from 1951 to 2010 in the northeast of Côte d'Ivoire.

The maps of spatio-temporal distribution of the dates of the beginning and end of the seasons show a progressive onset and end of the season in the Bounkani region. The progressive start according to the South-North gradient is caused by the movement of the monsoon from the Atlantic and conversely the end that occurs according to the North-South gradient is generated by the migration of the harmattan from the continent. These phenomena are the basis for determining the number and duration of the rainy season (Eldin, 1971). These results confirm those of Noufé et al.(2015) who presented a latitudinal evolution of the start of the rainy season in eastern Côte d'Ivoire.

Conclusion

This study has highlighted the high variability of rainfall from 1981 to 2020 in the Bounkani region of northeastern Côte d'Ivoire. This variation is characterized by an alternation of surplus and deficit years. The in-depth analysis indicates a seasonal variation, and the wet months are thus determined in order to assess the rainfall amounts during these periods for crops. A decrease in rainfall was observed in the region during the rainy season. In fact, the 1986-1995 decade received an average rainfall of about 1050 mm, whereas the 2011-2020 decade received 950 mm, or a loss of 100 mm. This rainfall recession is more pronounced in Bouna, which recorded an average rainfall of 730 mm during the 2011-2020 decade.

In order to better understand seasonal variations for efficient rainfed crop planning, the onset and end dates as well as the number of rainy days (rainfall ≥ 1mm) of the rainy season were determined. This increased trend reflects a shift in the season. The rainy season tends to start later and later in the Bounkani region. Nassian remains the most affected area with more than one month delay in the decade 2011-2020 compared to that of 1986-1995. In contrast, the trend in the variation of end dates in our study area is quasi-stationary over the study period. End dates vary on average between 1er to 5 October in the North and 16 to 20 October in the South. Furthermore, South-North and North-South gradients are observed for the onset and end dates of the rainy season in the Bounkani region, respectively.

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