Climatic Variability and Agricultural Season: Analysis of the Evolution of Essential Agroclimatic Parameters in Central East Cote D'ivoire

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Abstract— *The relationships between rainfall indices and the increase in agricultural production in Côte d'Ivoire over the period 1980-2010 do not show significant results of the current climatic trends. The study of the beginnings of the agricultural season of the "old cocoa-loop" highlights the rainfall variations that have persisted since the 1970s, and exposes rainfed agriculture to climatic risks. In addition, both daily and seasonal rainfall data collected from 1961 to 2010 were analyzed to reveal the current rainfall trends. It is worth to note that the simple study of the chronological series of the effective installation of precipitations shows both a delay and sudden fluctuation of the agricultural seasons throughout the region under investigation, at the end of the 1960s and the beginning of the 1970s. Other variables such as "the duration and the end" of the season, allow a more "qualitative" characterization of the investigated phenomenon. They provide additional information regarding both the manifestations of the rainfall variability and the confirmation of the importance of the phenomenon. The risks to which rainfed agriculture is exposed in relation to the current rainfall conditions are: disruption of the agricultural cycle, loss of seeds, and reduction in yield.*

Keywords— climatic variability, agricultural season, Central-East of Côte d'Ivoire.

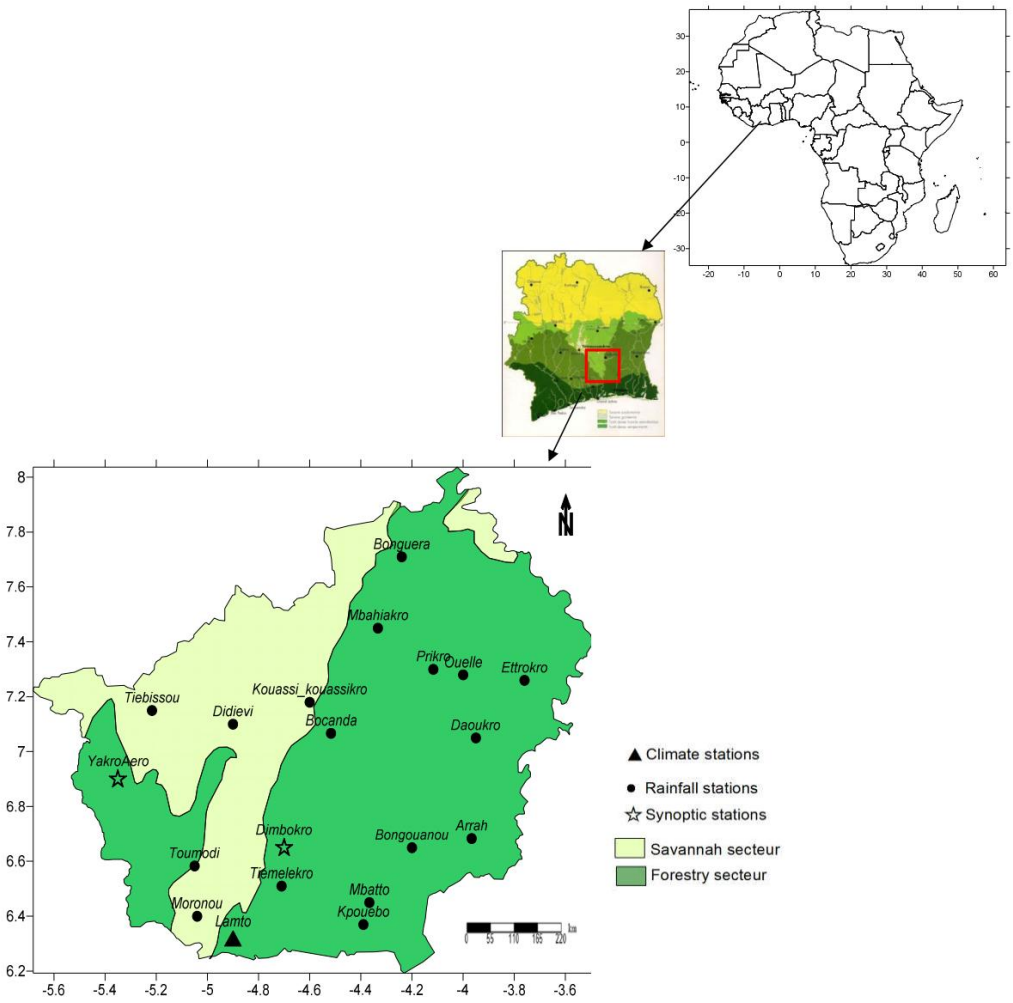
I. INTRODUCTION

Agriculture is no longer the main source of money income in many rural areas of West Africa owing to the low agricultural productivity due to climatic hazards. Even with the gradual return of rainfall, it is probable that this trend will continue. Climatic hazards are a real concern for all West African countries owing to their adverse socio-economic and environmental effects. Interannual fluctuations in rainfall represent the main climatic hazard for West African countries such as Côte d'Ivoire, whose economy is principally based on agriculture [1]. This is of the pluvial type, i.e. dependent on rain, which is the most variable climatic element. The decline in rainfall that began in the Gulf of Guinea countries at the end of the 1970s, became more intense in Côte d'Ivoire during the 1980s and 1990s before experiencing a certain remission during the 2000s [2,10]. Thus, these rainfall recessions induce variability in agricultural calendars through the variation of start and end dates, as well as the duration of the seasons [3,9]. Therefore, the fundamental question that emanates from these observations is the following: what are the variations of the major agroclimatic parameters in the Center-East of Côte d'Ivoire? Thus, this study aims to show the modifications of the major agroclimatic parameters of the agricultural calendars in the Center-East of Côte d'Ivoire between 1971 and 2020. Once prosperous and a major center of rural immigration, the east-central part of Côte d'Ivoire has experienced an inversion of the situation in recent years, which has made it an important center of emigration. The decline in planting activity can be observed both in terms of areas and in terms of production [4,9]. In recent decades, the Center-East of Côte d'Ivoire has suffered a drop in rainfall marked by droughts [5,10]. The economic consequences of such climatic and ecological changes are dramatic in this region mainly oriented towards farming [6]. The irregularity of the temporal distributions of precipitations and the heterogeneity of their spatial distribution constitute today the essential characteristics of the pluviometry of this region. The analysis of rainfall over the three sub-periods 1971-2000, 1981-2010 and 1991-2020 shows that agriculture has been going through a rainfall crisis for five decades now. The typical aspects of rainfall variability are its persistence and amplitude [7]. The impact of this phenomenon has been observed through the drying up of the majority of water points, the rotting of seedlings, a reduction in arable land, lower yields and the resurgence

of diseases (human, plant and animal). .Thus, entire regions have become more vulnerable than in the past, thus weakening their agricultural future and accentuating the process of deforestation [8]. In addition, this has imposed on them transformations in their lifestyles, regardless of the economic sector considered [9,7]. These characteristics give the climate a determining role in the development of the agricultural season and in agricultural production. Thus, given their immediate and lasting repercussions on agriculture and on humans. This variability leads to great uncertainty on the date of sowing which, on the same site, can occur over a period of nearly two months depending on the onset of the rains [10]. Our interest as a geographer aims to assess the extent of the evolution of rainfall in the Center-East in order to reveal its influence on the agricultural season. In agriculture, it has been shown that farmers who are convinced of the existence of climate variability have better capacities to manage risk and change. They are likely to anticipate it, learn and organize themselves and they are more willing to modify their systems [8,9]. Hence, an understanding of this climatic phenomenon could at least help to program interventions aimed at stabilizing and increasing yields [11].

II. AREA OF STUDY

The study is located in the ecological zone of the forest-savannah contact or "V Baoulé". It is located between longitudes 3° and 6° West and latitudes 6° and 9° North. It includes the administrative regions of Iffou, N'Zi, Moronou and the northern part of the Bélier region (Figure 1). Agro-economically, this area has been known as the "cocoa loop". With a climate combining the humid tropical (two wet and two dry seasons) and the dry tropical (one wet and one dry season), the studied area records temperatures oscillating between 14 and 33°C, humidity varying between 40 and 70% and an average annual rainfall of 1100 mm. It is a vast ensemble (the altitudes vary little from 80 m to 120 m) whose monotony is interrupted to the east by the hills of Bongouanou whose highest peak culminates at 615 m. The study area is characterized by an environment of both savannah and forest and is part of the mesophilic sector of the Guinean domain in Côte d'Ivoire [12].



Source : SODEXAM, 2019

FIGURE 1: Geographical location of the study region and characteristics of rainfall stations (Central-East of Côte d'Ivoire).

III. MATERIALS AND METHODS

3.1 Data collection

In order to characterize the essential agroclimatic parameters, daily rainfall records from 11 observation posts in the center-east of Côte d'Ivoire over the period 1971-2020 were used (SODEXAM, 2020). These positions were chosen because of the regularity of the observations. Potential Evapotranspiration (ETP) and soil water retention capacities or Useful Reserve (RU) as defined by Perraud (1971) were used. The RU values should be considered as indicative orders of magnitude for a study across Côte d'Ivoire. In addition, the average ETP of 4 mm per day was considered. Missing values were filled in using the average of neighboring stations in order to have complete, homogeneous and long series.

3.2 Analysis method

The start and end dates of the agricultural season were determined by taking into account the amount of rain, the value of potential evaporation (ETP) and the useful reserve of the soil. The various parameters (start dates, end dates and duration) of the growing season were calculated over the period from 1971 to 2020 with the reference period 1971-2000. On this basis, to characterize the climatic variability in the Center-East of Côte d'Ivoire, the rainfall normals for the periods 1981-2000 and 1991-2020 are analyzed and compared with the reference period. These time scales are retained in order to understand the evolution of the agricultural calendar of the study period (1971-2020). The duration of the agricultural season is calculated by deduction between the start date and the end of the season. The date of the beginning of the agricultural campaign is determined as soon as an accumulation of rainfall of 20 mm is recorded in one or two successive days and provided that no sequence of 10 days without rain is observed in the 30 days which follow this accumulation. The choice of the 30-day period makes it possible to prevent false starts to the agricultural campaign which are a constraint to the installation and development of crops [13,7]. The average start date of the 1971-2000 reference period in our study area is the 83rd day of the year, i.e. March 23. Due to the food characteristic of the Center-East, the last useful rain in our study region should above all allow the harvest of the yam in good conditions and, possibly, the plowing at the end of the cycle. Hence, the average end of the agricultural season is located from the 320th day of the year, i.e. November 15, when the soil water reserve reaches 0.05 mm [13]. The determination of dry and wet rainfall sequences makes it possible to assess the quality of the agricultural season, in terms of good spatial and temporal distribution of rainfall and sufficient quantity to positively impact the progress of agricultural activities. A start is considered early when it occurs two weeks before the average date. It is also considered late when it occurs two weeks after the average date. Similarly, an end is considered early when it occurs two weeks before the average date and is considered late when it occurs two weeks after the average date [14]. The cumulative rainfall heights recorded during the season made it possible to obtain the seasonal rainfall height by calculating the cumulative frequency using the equation (1) [15]:

$$F(x) = \frac{i-0,5}{N} \quad (1)$$

With, i = rank of the observation and n = number of observations (number of years retained). This formula made it possible to better determine the level of instability at the start and end of the agricultural season in the area under investigation.

IV. RESULTS

4.1 Differences in agroclimatic parameters and statistical significance of Averages

4.1.1 Rainy season start dates

The analyzes of the start dates of the big season evolve irregularly without any apparent periodicity. Thus, the beginnings of the late and early seasons alternate at unequal and unpredictable intervals (Table 1).

TABLE 1
AVERAGE DISTRIBUTION OF START DATES AND DIFFERENCE IN AGRICULTURAL SEASON (1971-2000; 1981-2010; 1991-2020) BY LOCALITY YAKRO AERO=YAMOUSSOUKRO

Start of the *season*	1971-2000	1981-2010	gap (days)	1981-2010	1991-2020	gap (days)	1971-2000	1991-2020	Gap (days)
Arrah	18 mars	21 mars	3	21 mars	29 mars	8	18 mars	29 mars	11
Bocanda	25 mars	30 mars	5	30 mars	4 avril	5	25 mars	4 avril	10
Bongouanou	20 mars	26 mars	6	26 mars	6 avril	11	20 mars	6 avril	17*
Didiévi	27 mars	30 mars	3	30 mars	6 avril	7	27 mars	6 avril	10
Dimbokro	23 mars	26 mars	3	26 mars	2 avril	7	23 mars	2 avril	11
Mbahiakro	25 mars	1er avril	7	1 avril	4 avril	3	25 mars	4 avril	10
Mbatto	24 mars	29 mars	5	29 mars	5 avril	7	24 mars	5 avril	12
Prikro	25 mars	27 mars	2	27 mars	1er avril	5	25 mars	1er avril	7
Tiébissou	22 mars	4 avril	13	4 avril	7 avril	3	22 mars	7 avril	16*
Toumodi	24 mars	28 mars	4	28 mars	6 avril	9	24 mars	6 avril	13
YakroAero	23 mars	27 mars	4	27 mars	5 avril	9	23 mars	5 avril	13

Source : SODEXAM, 2019; *Écarts statistiquement significatifs

The installation of the date of the average start of the rainy season varies according to the time periods of analysis. Based on the thirty-year periods, the average starts of the rainy season (March 23 between 1971 and 2000) experiences a shift in space and time in the study region. . This shift reflects a clear and generalized decrease in annual rainfall and the late start of agricultural activities in the region (April 1 to April 7 between 1991 and 2020). The month of March was the most affected in all the stations in the region? The onset of the rainy season went from March 23 (1971-2000) to April 4 (1981-2010) and April 7 (1991-2020) respectively on average. On average, the start date of the rainy season between 1971 and 2020 is 15 days late. The analysis of the dates of the beginning of the rainy season over a long series shows strong temporal and spatial variability in the Center-East of Côte d'Ivoire. This phenomenon is more marked in the savanna region (Mbahiakro, Tiébissou, Toumodi and Yamoussoukro). Such a development renders the cropping calendars determined on the basis of empirical knowledge ineffective. There is, in fact, a persistence of the water deficit around 1990 in the two cases of analysis, which is confirmed in the analysis of the evolution of the third sequence (1991-2020). The first two normals are marked by a west-east direction shift in the study area. This means the increasingly late start of the normal season (1971-2000) and a renewal of the rainfall for the decade (2000-2010); this could be accompanied by a good condition for plant productivity. The month of March (beginning of the long rainy season) seems to be very affected by the rainfall recession (Table 1). June remains the wettest month. The wettest months remain March, April, May and June, which saw a regression in the amount of precipitation. Such characteristics jeopardize the smooth running of the agricultural campaign, the calendar of which is set according to average values. This instability and decline in the trend indicate a late start to the agricultural season. In 90% of cases, that is to say one year out of 10, the start date is prior to or equal to March 15 for all stations in the region. In other words, four out of five years, the start date of the season is after March 15.

4.1.2 Rainy season end dates

Like the beginning of the seasons, the analysis of the dates of the end of the rainy season show a change and a precocity during the period considered from 1971 to 2020 (Table 2):

TABLE 2
AVERAGE DISTRIBUTION OF END DATES AND DIFFERENCE IN AGRICULTURAL SEASON (1971-2000; 1981-2010; 1991-2020) BY LOCALITY YAKROAERO=YAMOUSSOUKRO

End of the season	1971-2000	1981-2010	gap (day)	1981-2010	1991-2020	gap (day)	1971 -2000	1991-2020	gap (day)
Arrah	20 nov	10 nov	- 10	10 nov	5 nov	-5	20 nov	5 nov	- 15*
Bocanda	30 oct	14 nov	+15	14 nov	2 nov	-12	30 oct	2 nov	+3
Bongouanou	20 nov	13nov	-7	13 nov	29 oct	-15	20 nov	29 oct	-22*
Didiévi	16 nov	5 nov	-11	5 nov	14 nov	-11	16 nov	14 nov	-22*
Dimbokro	19 nov	8 nov	-11	8 nov	9 nov	1	19 nov	9 nov	-10
Mbahiakro	14 nov	9 nov	-5	9 nov	22 oct	-18	14 nov	22 oct	-23*
Mbatto	13 nov	4 nov	-9	4 nov	15 nov	+11	13 nov	15 nov	+2
Prikro	22 nov	8 nov	-14	8 nov	7 nov	- 1	22 nov	7 nov	-15*
Tiébissou	16 nov	1 nov	-15	1 nov	18 oct	-14	16 nov	18 oct	-29*
Toumodi	20 nov	18 nov	-2	18 nov	17 nov	- 1	20 nov	17 nov	-3
YakroAero	20 nov	6 nov	-14	6 nov	16 nov	+10	20 nov	16 nov	-4

Source : SODEXAM, 2019.oct.= octobre ; nov. =novembre; Note : * Écarts statistiquement significatifs

There is a fluctuation of the end of season date throughout the study region. Considering the evolution of the date of November 15, it turns out that there is a variation in the end of the season date and that it would also be earlier and earlier. The analysis of the average values (1971-2020) shows an inequality in the spatial distribution of rainfall in Central Côte d'Ivoire. Indeed, at equal latitude, the savannah sectors (Tiébissou, Prikro, Didiévi, Ouéllé and Kouassi-Kouassikro) experience a sudden end-of-season shutdown (310th day of the year, i.e. October 30). In the two major ecological regions, forest and savannah, the end of the season is more spread out (i.e. between October 22 and November 16). For Anhuf (1993), the northern limit of the dense humid forest is reached at an annual rainfall level of about 1000 mm. Similarly, the distribution of the most important daily rainfall events follows this same north-west/south-east gradient. In the Center-East region, the rainfall regimes have undergone significant changes that result in decreases in precipitous annual heights that can reach 20 to 25%. This drop in rainfall affects each month whether it is dry or wet. There is also a trend in many savannah areas to move from a more humid climatic regime called "Guinean" to a drier regime [17,18]. The end of the agricultural season is generally less spread out over time (1st decade of October).

4.1.3 Rainy season durations

Analysis of the duration of the rainy season shows that it varies from one time scale to another (Table 3):

TABLE 3
AVERAGE DISTRIBUTION OF DURATION DATES AND DIFFERENCE IN AVERAGE DAYS OF DURATION OF THE AGRICULTURAL SEASON (1971-2000; 1981-2010; 1991-2020) BY LOCALITY YAKROAERO=YAMOUSSOUKRO

duration of the season	1971-2000	1981-2010	gap (day)	1981-2010	1991-2020	gap (day)	1971-2000	1991-2020	gap (day)
Arrah	171	170	-1	170	171	+1	171	171	0
Bocanda	142	160	-18	160	161	+1	142	161	-17*
Didiévi	159	164	-5	164	161	-3	159	161	-8
Bongouanou	169	168	-1	168	149	-19	169	149	-20*
Dimbokro	165	156	-9	156	153	-3	165	153	-11
Mbatto	160	165	+5	165	165	0	160	165	+5
Tiébissou	159	141	-18	141	147	+6	159	147	-12
Prikro	154	148	-6	148	141	-7	154	141	-13
YakroAero	165	145	-20	145	141	-4	165	141	-24*
Toumodi	165	163	-2	163	162	-1	165	162	-3
Mbahiakro	163	146	-17	146	141	-5	163	141	- 22*

Source : SODEXAM, 2019 ; Note : * Écarts statistiquement significatifs

The examination of the interannual variability according to the 3 sub-periods 1971-2000, 1981-2010 and 1991-2020 helps to better appreciate the trend of the average duration in the Center-East of Côte d'Ivoire. The average length of the rainy season is 164 days, or 16 and a half decades in 1971-2000 throughout the study region. However, this average hides disparities in each ecological zone.

The ends of season dates are early for 98% of positions after the break years, i.e. the entire study region. The longest gaps (greater than 20 days) were observed in M'bahiakro, Bongouanou and Yamoussoukro. These results agree with those of Dekoula et al. (2018) who studied the variability of intra-seasonal rainfall descriptors with agricultural impact in the cotton basin of Côte d'Ivoire. However, these authors used time series from 1950 to 2000. Goula Bi et al. (2010) also obtained at similar discrepancies for the start dates, end dates and lengths of agricultural seasons in Côte d'Ivoire between the periods 1951-1980 and 1971-2000. Thus, this study is an update of the variability of agricultural calendars in the Center-East of Côte d'Ivoire. These updated results also show the persistence of the reduction in season lengths until 2020. During the period (1971-2000), in the savannah sector (Mbahiakro, Prikro, Didiévi, Tiébissou), the rainy season lasted an average of 160 days in decades. Sometimes, it covers only 147 days on average between 1991 and 2020. In the two ecological zones (forest and savannah), the average duration of the rainy season between 1971 and 2000 which is 158 and 152 days increases respectively to between 1991 and 2020 at 167 and 162 days of rain. Indeed, the impact of this early end seems unremarkable in the localities of Arrah, Didiévi and Toumodi, in the other localities. It negatively impacts the length of the rainy season with an average reduction of 20 days in Bongouanou, 22 days in Mbahiakro, 24 days in Yamoussoukro, 17 days in Bocanda and 13 days in Prikro. A season length of less than 150 days appears in the forest region and extends to the vicinity of Bongouanou and Mbatto. On the other hand, the relative improvement in annual rainfall totals observed since the 1990s has not yet led to an improvement in the length of the agricultural season, which has still remained low. This new trend reflects the manifestation of migration from the subequatorial bimodal regime to a Sudanese monomodal regime.

V. DISCUSSION

The analysis of the evolution of climatic parameters in the Center-East of Côte d'Ivoire are in agreement with the conclusions of the work carried out in West Africa in general [17,18,19] and in Côte d'Ivoire. Ivory in particular [20,21]. The disturbances of the agricultural season determined during this study are generally after 1970 and confirm previous studies [10,15,22]. In forestry, the month of July generally marks the end of the growing season. However, in the savannah region the rains seem to stop late during the period 1970-2010. This apparently late end is in fact due to the transfer of the rains from the short rainy season to the months of July and August and reflects global changes in the distribution of precipitation in this region. We are thus witnessing a real change in the rainfall regime characterized by the progression of the tropical climate to this zone classified as a Subequatorial climate. As such, we share the opinion of Brou taken up by Noufé who specifies that: the precipitation deficit is accompanied by a modification of the distribution in the direction of a transition to a tropical climate [28,6]. To measure the extent of the temporal disturbances of the parameters of the agricultural season, a farmer says: "The yam harvest, which used to be done all year round, now only takes place between October and January due to poor production. The early cessation of the small rainy season rains reduces the possibility of maize bearing cobs, and if it does, those cobs are grainless." It also results from these balances that the agricultural campaign is badly affected insofar as the average length of the season is less than the duration of the vegetative cycle of the crop species (yam).

In Benin, the work of certain authors has also shown that the quality of the agricultural seasons has seriously deteriorated over the past few decades [23,25]. The length of agricultural seasons is getting shorter and shorter. Similarly, false starts and rain interruptions at the heart of the season are increasing. The analysis of the length of the season confirms a very high variability from one normal (30 years) to another and a reduction in the agricultural season throughout the study area. The significant reduction in precipitation appears in the form of episodes of strong deficits in 1972-1973, 1982-1984 and 1997 also seen elsewhere in the Sudano-Sahelian zones [24,26,30]. Regarding the end of the season, the results of this study coincide with those of Sivakumar and Paturel, the great intra-annual irregularity of rainfall along the Gulf of Guinea [24,26]. Thus, there is a disturbance in the end and the period of the seasons which reveals a shortening of the rainy season in favor of the dry season which is lengthening [7,20], in phase with the drop in precipitation which has intensified. in Côte d'Ivoire as in the other countries of the Gulf of Guinea during the 1980s and 1990s [28]. This observation was also made in a similar study carried out by Ourega and Biemi in the N'zi-Comoé region [29]. For these authors, since the 1970s, because of the droughts that marked the sub-region, the rainy season presents an accentuated variability which compromises the implementation of agricultural activities whose calendars are modeled on the average rainfall conditions. This finding confirms the fact that in northern Benin, agriculture and livestock are the two human systems most exposed to climate risks [15,24,25]. The probabilities of the end of season date also show a late end of the season in the Sahel [32]. Similarly, the analysis of the

evolution of the number of rainy days in August reveals a disappearance for all stations during the same period. This drop in rainfall, accompanied in West Africa by one of the worst droughts during the 1970s-1990s, is a sign of climate variability, the frequency and intensity of which have increased over the past 30 years [30,26]. Although these stations are few and scattered, the results reflect the regional behavior of the agricultural season in the area studied, from one locality to another, thus confirming the poor annual production recorded for three decades [31,33].

VI. CONCLUSION

The study of the evolution of the rainfall regime in the former Cacao loop in Côte d'Ivoire shows that seasonal variations are associated with a modification of agroclimatic parameters such as the beginning, the end and the duration of the agricultural season. There is a decrease in the length of the season, which has gone from 4 months to 3 months, a delay in the effective onset of the rains and a virtual disappearance of the short rainy season. End of season dates vary little in space and time. While it was believed for a long time to be confined to the savannah region, this analysis showed that the rainfall deficit also affected the forest regions and, more generally, the so-called "wet" region. This fall in rainfall has, of course, consequences on the regimes of watercourses and therefore on the availability of water resources, key to the success of many development projects.

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