__Original Research Article__

Seasonal and intra-seasonal changes in major rainfall indicators in the Ivorian cocoa zone in a context of global warming: the case of the Gôh and Lôh-Djiboua regions in west-central Côte d'Ivoire

ABSTRACT

Write abstract as per journal style

Aims: To understand the evolution of seasonal and intra-seasonal rainfall indicators involved in cocoa production in the Centre-West, one of the cocoa basins in Côte d'Ivoire, in order to propose technical routes adapted to the climatic conditions of the region.
Study design: Collection and processing of daily rainfall data collected by rain gauges at Divo and Gagnoa stations from 1946 to 2015.
Place and duration of studies: Divo Cocoa Research Station of the National Center for Agricultural Research, between January 2017 and June 2019.
Methodology: The break years in the time series were detected at both stations from the KhronoStat software. Key seasonal and intra-seasonal rainfall indicators for cocoa were determined and studied using the Intat+ version 3.36 agro-meteorological statistical analysis software. The behaviour of these rainfall descriptors was analysed during each sub-period by comparison. These key indicators are the dates of the beginning of the main useful rainy season (URS), the dates of the end of the URS, the duration of the URS, the cumulative rainfall and the intra-seasonal dry sequences which are the agroclimatic parameters directly influencing the main flowering of the cocoa tree on which 90% of the harvest depends.
Results: Seasonal and intra-seasonal rainfall indicators in Gagnoa and Divo are generally declining after the break-up years detected in 1972 in Divo and 1966 in Gagnoa. After the breaks, the starts of the useful Rainy Season are later and the ends are earlier than before, which results in a shortening of the post-break length of the URS and a reduction in cumulation.
intra-seasonal in both localities. Conversely, the maximum dry sequences of URS show a slight increase after the break-up dates. The station of Gagnoa was less affected by the rainfall recession than that of Divo where the downward trend in seasonal and intra-seasonal rainfall events is more severe.
Conclusion: The scarcity of seasonal and intra-seasonal rainfall events in Divo and Gagnoa is more drastic in Divo than in Gagnoa, but it remains low and does not yet pose a significant threat to cocoa production in the Gôh and Lôh-Djiboua regions.

Keywords: Seasonal and intra-seasonal changes, major rainfall indicators, cocoa farming area, Central West, Côte d'Ivoire

1. INTRODUCTION

One of the greatest scourges facing humanity today and which future generations will inevitably have to face is not of viral or bacterial origin, but of environmental origin. Indeed, global warming appears to be the main concern of humankind in the 21st century. This is why each year a major supranational conference is organized to consider concerted and effective action by all countries of the world against the common enemy, whose sometimes extreme manifestations (storms, cyclones, tsunamis, torrential rains, floods, prolonged droughts, forest fires, bush fires, etc.) are becoming increasingly regular and widespread. In West Africa in general and Côte d'Ivoire in particular, climate change has long been reflected in an unprecedented reduction in rainfall amounts and river flows, as well as in a disruption of seasonality and rainfall patterns [1, 2, 3, 4], before also resulting in increasingly recurrent flooding due to a return to better rainfall conditions from the 2000s onwards [5, 6]. Climate variability has affected not only the rainfall regime but also the hydrological and plant resources [7] on which the country remains closely dependent. However, despite the fundamental importance of agriculture in the Ivorian economy, very few studies have been carried out on the involvement of climate factors in agricultural production; most research is devoted solely to the impact of climate variability and change on hydrological resources on the one hand and on groundwater resources on the other hand [2, 1, 8, 9, 10, 11, 12, 13, 14, 15, 16]. As Ivorian agriculture is predominantly rainfed, climate instability resulting from permanent changes in both monthly and annual rainfall amounts, as well as the sometimes unpredictable behaviour of climatic events within rainy seasons, is likely to disrupt agricultural yields and the incomes of the populations that depend on them.
Cocoa farming, which is the spearhead of the country's economy, is unfortunately not spared by this situation. As a reminder, since 1977, Côte d'Ivoire has been the world's largest producer of cocoa, accounting for more than 40% of world production. Cocoa production accounts for 40% of export earnings at the macroeconomic level and contributes 10% to GDP formation. On the social level, about 600,000 farm managers provide a livelihood for nearly 6 million people [17]. Cocoa is grown mainly by small farmers on an area of more than two million hectares producing 1.2 million tonnes of merchant cocoa annually. Cocoa is therefore the driving force of the Ivorian economy.
Faced with the predominant role of cocoa farming in the national economy, this study aims to analyse the evolution and potential impact of seasonal and climatic events.
intra-seasonal factors determining cocoa production in the Centre-West, which is one of the bastions of cocoa in Côte d'Ivoire. The ultimate objective is to enable the various actors in the cocoa sector to put in place more resilient measures to deal with climatic hazards

2. METHODOLOGY

2.1 DESCRIPTION OF THE STUDY AREA

The study was carried out in the Centre-West of Côte d'Ivoire, in the regions of Lôh-Djiboua and Gôh, whose respective chief towns are Divo and Gagnoa. It is located in the second cocoa loop (1960-1970) between latitudes 5°22' and 6°26' N and longitudes 4°58' and 6°34' W and covers an area of 10792 km2 (Figure 1). These regions belong to the district of Gôh-Djiboua, which is located in the humid tropical zone [18] where rainfall fluctuates between 1200 and 1600 mm per year[19] and is divided into four seasons: a major rainy season from March to June, a small dry season in July and August, a small rainy season from mid-September to mid-November, and a major dry season from December to February. The average humidity of 85% is subject to strong seasonal variations. The average temperature is 27°C and varies annually between 19° and 33°C. The duration of annual exposure is about 1800 to 2000 hours. The predominant climax is the semi-deciduous dense rainforest. The soils are moderately to highly desaturated ferrallitic [20, 21]. The humus horizon is thin, but rich in organic matter, weakly acidic and well structured under primary forest. These soils are suitable for perennial crops such as coffee and cocoa.

2.2. Data used and methods of analysis

2.2.1. Data used

To carry out this study we used daily rainfall data from Divo and Gagnoa over the period 1946-2015. The rainfall database used comes from the meteorological service of the Sustainable Soil Management and Water Management Programme of the Centre National de Recherche Agronomique (CNRA); but also from the historical database of the Office pour la Recherche Scientifique des Territoires d'Outre-Mer (ORSTOM), now the Institut de Recherche pour le Développement (IRD).

2.2.2. Methods of analysis

2.2.2.1. Period selection, criticism and data filling

The temporal window chosen for this study (70 years) has the advantage of having fairly homogeneous data with complete annual series, with the exception of certain years when some data are missing, particularly on the Divo station, where the incomplete data of 1946 were replaced by those of the Tiassalé station, only 60 km away. This recent and fairly long database provides objective and more representative trends of the current climatic conditions of the departments studied.

2.2.2.2. Methods for determining breaks within inter-annual rainfall series

The "KhronoStat" software, designed by HydroSciences Montpellier and freely accessible on the SIEREM website (http://www.hydrosciences.org/spip.php) [22] was used to detect possible breaks in time series. A break can be generally defined by a change in the probability law of the time series at a given time, most often unknown [11]. This program includes many specific tests of a change in the behaviour of the variable in the time series. The detection of breaks within time series required the application of a set of methods, including the Pettitt test [23], the Buishand "U" method [24], the Bayesian procedure of Lee and Heghinian [25] and the Hubert segmentation procedure [26]. It is at the end of the application of these various tests that a failure date detected by the majority of the tests was chosen.

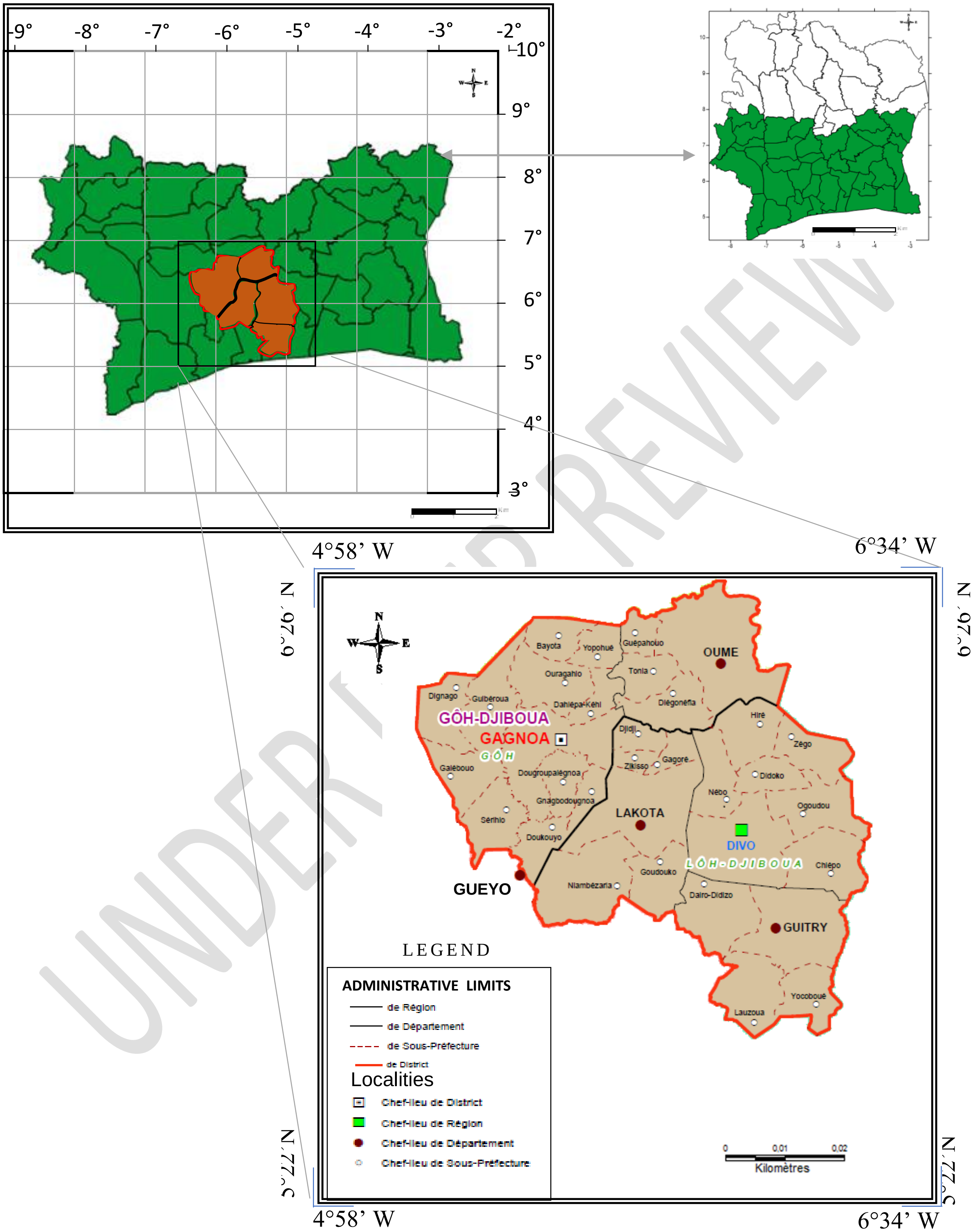

Figure 1: Presentation of the study area

2.2.2.3. Determination of key seasonal and intra-seasonal rainfall indicators in cocoa production

The productivity of a cultivated cocoa tree necessarily requires regular growth, abundant flowering and fruiting as well as well-distributed foliar outbreaks throughout the year. To do this, it must be in favourable climatic conditions, obeying the following criteria: (1) the annual rainfall amounts are between 1200 and 1500 mm[27] but a minimum annual threshold of 1200 mm is sufficient to consider its establishment in a region[28]; (2) the annual cumulative rainfall during the high rainy season is greater than 700 mm[29]. It is this rain that triggers the first flowering of the cocoa tree for the main harvest from September to January; (3) the duration of the dry season is less than 3 months[27] otherwise the cumulative rainfall during this period must be greater than 70 mm[30], (4) because of the weak rooting of its lateral roots, 20 days without rain are sufficient to lose the crop[31]. As part of this work, we analyzed the seasonal and intra-seasonal rainfall descriptors that are critical to the success of cocoa farming, using the Instat+v.3.37 software. These are the start and end dates of the major rainy season or Useful Rainy Season (URS), the length of this season, as well as the cumulative rainfall and maximum dry sequences during the major rainy season.

2.2.2.3.1. Definition of the parameters studied

2.2.2.3.1.1. Start and end dates of the great rainy season in Guinea area

The start and end dates of the URS (Useful Rainy Season) are automatically determined by the Instat+ v3.37 software. The determination of these dates takes into account rainfall, the value of potential evaporation (FTE) and the useful soil reserve.

The approach used for this study is based on both the work of [32] and that of 33] and [34] who adapted Sivakumar's method ([35],[36],[36],[37]) to Ivorian climatic realities. The following criteria for determining the length of rainy seasons in the Guinean zone under bimodal conditions have been established:

- the date of the beginning of the main useful rainy season is after [1] February, when the amount of rain collected in 2 consecutive days is at least equal to 20 mm without a dry sequence of more than 7 days in the following 20 days;
- the end date of this season corresponds to the first day after [1] July when soil capable of containing 70 mm of available water is completely exhausted by a daily loss of evapotranspiration of 4 mm; i.e. when the water balance is zero.

2.2.2.3.1.2. Duration of great rainy season

The duration of each rainy season is obtained by differentiating between the start and end dates of the seasons.

2.2.2.3.1.3. Cumulative rainfall

Seasonal rainfall totals are the sum of the rainfall amounts recorded during a rainy season. It represents the amount of rain collected during the agricultural season.

2.2.2.3.1.4. Maximum dry sequences

A dry sequence is defined as the number of consecutive rain-free days with a height greater than the minimum value (1 mm) of the smallest of the classes of daily precipitation amounts proposed by the international standards defined by the World Meteorological Organization [38]. The different classes are defined according to the number of rainy days with a height between: 1 and 10 mm (P1); 10 and 30 mm (P2); 30 and 50 mm (P3); >50 mm (P4).

3. RESULTS

3.1. DETECTION OF YEARS OF BREAKS IN THE RAINFALL SERIES

Most of the tests identified rainfall breaks in 1972 at Divo station and in 1966 at Gagnoa station (Table 1). These results indicate a specific change in the average in the rainfall series of the departments studied.

Table 1: Breaks in the rainfall series established by the various tests

Stations	**Failure tests**								
	Pettitt		**Lee and Heghinian**		**Buishand**		**Hubert**		**Date indicated by the majority of tests**
	Year	**Proba.**	**Year**	**Proba.**	**Year**	**Proba.**	**Year**	**Proba.**	
Divo	1972	0,001	1955	0,65	1972	0,99	1953 ; 1956	0,1	**1972**
Gagnoaa	1966	0,00678	1966	0,1968	1966	0,99	1954 ; 1965	0,1	**1966**

Proba : Probability

3.2. SEASONAL AND INTRA-SEASONAL MUTATIONS OF THE MAIN CLIMATIC VARIABLES OF THE COCOA CROP YEAR

3.2.1. Start of the Useful Rainy Season (URS)

Before the break-up years, the season began on average on 7 March in Divo and 8 March in Gagnoa. On the other hand, after the breakdowns, URS begins on average on 17 March in Divo and on 7 March in Gagnoa. The onset of URS is therefore on average 10 days later in Divo (current period) than before 1972, unlike in Gagnoa, where the season is currently one day earlier than in the period before 1966 (Table 2).

Table 2: Average start dates for URS in Divo and Gagnoa

Station	**DIVO**		**GAGNOA**	
Period of time	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Average	March 7	March 17	March 8	March 7
Standard deviation	21	27	18	19
Coefficient of variation (%)	31	35	26	28

3.2.2. End of the Useful Rainy Season (URS)

Before the breaks, the season ends on average on 27 August in Divo and on 8 August in Gagnoa. After the breaks, the end of the season occurs on average on July 27 in Divo, i.e. one month earlier than the period before the break. It is also, on average, one day earlier (August 7) than the pre-break period in

Gagnoa. The end of the season that occurred, on average, much earlier in Gagnoa (19 days earlier than in Divo) now takes place much later (11 days later than in Divo) (Table 3).

Table 3: Average end dates of URS in Divo and Gagnoa

Station	**DIVO**		**GAGNOA**	
Period of time	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Average	August 27th	July 27th	August 8	August 7
Standard deviation	55	14	29	40
Coefficient of variation (%)	23	7	13	18

3.2.3. Lengths of the URS

On average, during the period 1946-1971 in Divo, the main rainy season lasted 173 days (≈ 5 months 23 days) while during the post-rupture period (1972-2015), it did not exceed 132 days (≈ 4 months 12 days); a 41-day shortening (≈ 1 month 11 days). On the other hand, in Gagnoa, URS has an average lengthening of 4 days compared to the period before rupture (1946-1965). It went from 154 days (≈ 5 months 4 days) to 158 days (5 months 8 days). Before the breaks, the useful rainy season was on average longer in Divo, but this shortening by more than one month reversed the trend (Table 4).

Table 4: Average length of URS in Divo and Gagnoa

Station	**DIVO**		**GAGNOA**	
Period of time	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Average	173 days	132 days	154 days	158 days
Standard deviation	63	31	29	44
Coefficient of variation (%)	37	24	19	29

3.2.4. Intra-seasonal rainfall totals for URS

During the two sub-series before the breaks observed at the two stations, the average Divo accumulation is 1168 mm while the Gagnoa accumulation is 886 mm. However, during the two post-rupture periods, the average intra-seasonal rainfall totals are 701 mm in Divo and 826 mm in Gagnoa respectively. The average of the cumulative heights, which was higher at Divo, experienced a clear post-breakdown regression to reach almost the required threshold. Gagnoa experienced a smaller reduction (Table 5). Regardless of the station and the observation period, the cumulative threshold (700 mm) required to meet the cocoa tree's water requirements during URS is exceeded (Table 5).

Table 5: Average cumulative rainfall (mm) of URS in Divo and Gagnoa

Station	DIVO		GAGNOA	
Period of time	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Average	1168	701	886	826
Standard deviation	670	211	216	257
Coefficient of variation (%)	57	30	24	31

3.2.5. Maximum dry sequences

3.2.5.1. Maximum intra-seasonal dry sequences of URS

Before ruptures, dry sequences within the Useful Rain Season last on average 8 days in Divo and 7 days in Gagnoa during URS. On the other hand, the maximum post-rupture dry sequences of URS are up by 1 day in Divo and Gagnoa, where they are worth 9 days and 8 days respectively. It can be seen that in Divo, dry sequences greater than 20 days and 30 days are almost non-existent before rupture (respectively 1% and 0%) while during the post-rupture period, 5% of years contain dry sequences of more than 20 days and 3% have dry episodes of more than 30 days. In Gagnoa, on the other hand, the importance of non-rainfall episodes of more than 20 days in URS remains unchanged after the break (2% of years) (Table 6).

Table 6: Descriptive statistics of the maximum dry sequences of URS in Divo and Gagnoa

Station	DIVO		GAGNOA	
Periods of time	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Maximum	25	56	22	29
Minimum	2	2	2	2
Average	8	9	7	8
Standard deviation	4	8	4	4
Coefficient of variation (%)	59	80	63	58
SS ≤ 20 days (%)	99	95	98	98
SS ≤ 30 days (%)	100	97	100	100
SS ≤ 60 days (%)	100	100	100	100
SS ≤ 90 days (%)	100	100	100	100

SS: dry sequences

4. DISCUSSION

The various statistical tests detected major rainfall accidents in the rainfall series of the two localities studied. As a reminder, many studies have identified changes in stationarity in African hydroclimatic series during the 20th century, especially those corresponding to a sudden decrease in precipitation in the late 1960s in the Sudano-Sahelian zone ([39], [40], [41], [42], [43]) and in the Guinean and Sudano-Guinean zone ([32], [44], [5], [14], [45]). This is why, [46] stated that "the sudden inflection point was observed in 1970 making it the pivotal year between two periods of distinct rainfall patterns". In our case, these break-up dates were identified in 1972 in Divo and in 1966 in Gagnoa. These dates are perfectly consistent with the break-up years indicated by [44] and [47] for the same locations. These ruptures are generally part of the period designated for the majority of West African countries by [2] and [8]. Indeed, by studying the evolution of the time series of 33 rainfall stations in West Africa in the Sahel zone, Sudano-Guinean and Guinean,[40] have highlighted significant ruptures mostly between 1968 and 1972[48]. This is the same observation in our study because although the majority of authors agree that the rupture occurred in Côte d'Ivoire around 1970, this year is only given as an indication [5]. Indeed, it has been designated as a pivotal year in the evolution of time series in West Africa because it corresponds to the break-up date of most stations in the West African region. However, there are several stations that experience a break at dates other than 1970, but which are close to it. After the years of disruption, a general rainfall recession set in in the regions of Gôh and Lôh-Djiboua. These post-breakdown climatic provisions are corroborated by the work of [49] who, in a study on the impact of climate variability on coffee and cocoa production in central-eastern Côte d'Ivoire, which was the first cocoa loop, showed that the rainfall series in the departments of Daoukro, Bocanda, Agnibilékro, M'bahiakro and Abengourou show a dry or deficit period after the breaks.

The study of the evolution of the high rainy season in cocoa production, commonly referred to as the "Useful Rainy Season or URS" in this work and the distribution of its main descriptors throughout the season was essential insofar as several authors ([29], [50], [51], [52]) have shown that it is the rains received during this period of the year that trigger the first flowering of the cocoa tree on which 90% of the harvest generally occurs between September and January depends. A better knowledge of the behaviour of these climatic variables makes it possible to better understand their impact on cocoa production in the study sector. The evaluation of the onset of URS during the wet and dry sub-periods on either side of the break-up years reveals that the post-break-up start of the season in Divo is 10 days later than the pre-break period (17 March compared to 7 March). The same trend is observed in Gagnoa with a one-day post-rupture delay (7 March instead of 8 March). This late post-rupture start is the same as that observed by [32] in southern Togo, a cocoa-producing country with similar climatic conditions to the Ivorian forest south that hosts our study area. During their study, these authors demonstrated that the arrival of the potentially useful high rainy season is later in the 1970-2000 period (post-rupture) than in the pre-break period (1950-1969). Indeed, they observed that early coastal rains that began, on average, from 15 to 28 March in the period preceding the rupture (1950-1969) are now observed only from 29 March. According to [53], a delay of at least 25 days in the beginning of the rainy seasons was observed in the Sudano-Sahelian zone of Nigeria during the 1983 drought, which was a year of extreme drought in West Africa. This delay even reaches 40 to 50 days in some parts of Nigeria during the same year. The work of[54] in relation to the impact of rainfall variability on the water balance of pineapple-grown soils in southern Benin has also shown that the seasons start with a delay of 5 to 25 days. Unlike the start of the useful rainy season, which is late after breaks, the end of URS in Divo and Gagnoa have an early start of one month and one day respectively. These results are consistent with those of ([55], [5], [34]).

Concerning the length of the useful rainy season, it can be seen that the later start and earlier end of the main rainy season observed after the rainfall accidents (1966 and 1972) in the two stations analysed necessarily leads to a post-rupture shortening of this season. This is why the duration of URS has been reduced from 173 to 132 days in Divo (shortened by more than a month). This post-rupture regression is corroborated by the work of [32] during which the statistical analysis revealed a narrowing of the duration of potentially useful rainy seasons, due to a delay in their installation and/or early termination. This result is also in agreement with a study by [56] in relation to the identification of rainy season start and end dates in Senegal and East Africa. In this study, these experts demonstrated that in Senegal, significant trends in start and end dates indicate a shortening of the rainy season between 1950 and 1992. Other authors such as [14] have reached the same conclusion in the N'zi catchment area, a tributary of the Bandama River in Côte d'Ivoire. Unlike Divo, we observe that in Gagnoa, on the other hand, URS increased by an average of 4 days. Two main reasons could explain this phenomenon, the first one which is more plausible is the one highlighted by [6] which showed that since the early 2000s, a new period of high rainfall has appeared in many localities in humid tropical climates. The second reason is that put forward by Chaouche [57] who demonstrated during his work in Sudano-Sahelian Africa that the rainy season does not always follow a trend of reduction parallel to that of the annual height.

In terms of rainfall totals recorded within the URS, we have shown that the average intra-seasonal totals collected at Divo and Gagnoa stations (respectively 874 mm and 843 mm) are well above the threshold totals required by the cocoa tree during the useful rainy season. Nevertheless, we note a worrying trend towards a reduction in these accumulations after breaks (701 mm after compared to 1168 mm before in Divo and 826 mm after compared to 886 mm before in Gagnoa). This ability to regress is confirmed by [50] who, by analyzing the sub-period 1978-2007 noted that rainfall averages tended to become insufficient (less than 700mm) to meet the cocoa tree's water needs. Indeed, the latter discovered very low average rainfall totals (only 164.7 mm in Divo and 652.1 mm in Gagnoa).
For the maximum dry sequences of URS, the respective averages after breaks are only 9 and 8 days in Divo and Gagnoa. In addition, during the post-rupture period there are only 5% of years in Divo and 2% of years in Gagnoa that have maximum dry sequences exceeding 20 days without rain that could be harmful to cocoa tree productivity. Similarly, the increase in post-rupture intra-seasonal dry-season sequences [58] of only one day during the useful rainy season is not likely to disturb the flowering of cocoa trees.

5. CONCLUSION (CONCLUSIONS)

This study, initiated in the Centre-West of Côte d'Ivoire, which is one of the main cocoa production areas in the country, updated the distribution of the main seasonal and intra-seasonal rainfall indicators influencing cocoa production in the Gôh and Lôh-Djiboua regions. The various analyses show that Divo and Gagnoa have a clear downward trend after the rainfall breaks identified in 1966 and 1972. This trend towards rainfall depreciation had a direct impact on key seasonal and intra-seasonal indicators during the periods 1972-2015 in Divo and 1966-2015 in Gagnoa. Thus, the start of the Useful Rainy Season is now later and the endings are earlier. This leads to a shortening of URS overall in these departments, which is accompanied by an intra-seasonal decrease in cumulations and an increase in maximum dry sequences during URS. This seasonal and intra-seasonal degradation of agro-climatic variables remains insignificant and is therefore not yet a limiting factor for the sustainability of cocoa production in this historical cocoa bastion. However, if the degeneration of these descriptors continues, these areas could become marginal, which is why improved varieties that are more resistant to climatic hazards, particularly drought, should be developed and disseminated in these regions.

Add policy implication if any

COMPETING INTERESTS

"The authors stated that there are no competing interests."

CONSENT (IF APPLICABLE)

Not concerned

ETHICAL APPROVAL (IF APPLICABLE)

Not concerned

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