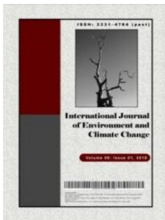

International Journal of Environment and Climate Change

9(9): 503-517, 2019; Article no.IJECC.2019.043
ISSN: 2581-8627
(Past name: British Journal of Environment & Climate Change, Past ISSN: 2231–4784)

Impact of Local Global Warming on Rainfall and Annual Cocoa Water Requirements in the Regions of Lôh-Djiboua and Gôh in West-central Côte d'Ivoire

Jean-Noël Ehounou[1,2*], Brou Kouamé[1], Mathias G. Tahi[1], Emmanuel K. Kassin[1], Charles S. Dékoula[1,2], Guy F. Yao[1], Hypolith K. Kouadio[1,3], Angelo E. B. N'guessan[1] and Nagnin Soro[2]

[1]National Centre for Agronomic Research, Centre National de Recherche Agronomique (CNRA) Abidjan, Côte d'Ivoire.
[2]Félix Houphouët-Boigny University, Université Félix Houphouët-Boigny (UFHB), Abidjan, Côte d'Ivoire.
[3]Jean Lorougnon Guédé University, Université Jean Lorougnon Guédé (UJLOG), Daloa, Côte d'Ivoire.

Authors' contributions

This work was carried out in collaboration among all authors. Authors JNE, BK, EKK and NS designed and wrote the study protocol. Author JNE conducted the documentary research, wrote the 1st draft and the revisions to the manuscript. Authors MGT, CSD and HKK participated in the elaboration of the 1st draft, the statistical analysis and provided a major contribution in the elaboration of the final document. Authors GFY and AEBN took part in the interpretation of the results and contributed to the development of the final document. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJECC/2019/v9i930135
Editor(s):
(1) Dr. Alice Maria Correia Vilela, Assistant Professor, University of Trás-os-Montes and Alto Douro, Portugal.
Reviewers:
(1) Olumide Adesina, Olabisi Onabanjo University, Nigeria.
(2) Janilson Pinheiro de Assis, Federal Rural University of the Semi-Arid (UFERSA), Brazil.
(3) Hen Friman, H.I.T - Holon Institute of Technology, Israel.
Complete Peer review History: http://www.sdiarticle3.com/review-history/50827

Original Research Article

Received 13 June 2019
Accepted 16 August 2019
Published 05 September 2019

ABSTRACT

Aims: To understand the role of the interannual variability of cumulative rainfall and maximum dry sequences in cocoa production in the Centre-Ouest, one of the cocoa basins in Côte d'Ivoire, in order to propose technical routes more adapted to current rainfall conditions.
Study Design: Collection, analysis and processing of daily rainfall data collected by the rain gauges at Divo and Gagnoa stations.

**Corresponding author: E-mail: ehounoujn@gmail.com;*

Location and Duration of Studies: Divo Cocoa Research Station of the National Center for Agricultural Research, between January 2017 and June 2019.
Methodology: The rainfall regime of each locality was determined to assess the impact of rainfall changes on the seasonality of rainfall. The interannual variability of rainfall was studied from the reduced centred rainfall indices. The break years in the time series were detected at both stations from the Khrono Stat software. The interannual cumulative rainfall were analysed for each station and compared to the minimum threshold allowed for cocoa trees. The means of the maximum interannual dry sequences and their probabilities of occurrence were determined using the agrometeorological software called Instat + Version 3.37.
Results: The rainfall regime in the area studied (west-central Côte d'Ivoire) has not been modified by the post-rupture rainfall recession as is the case in other parts of the country; it remains a bimodal system characterized by two rainy seasons and two dries during the year. The Divo and Gagnoa regions have been facing a general recession in rainfall since 1966 in Gagnoa and 1972 in Divo. However, the locality of Gagnoa has experienced an increase in rainfall since 2000. Most of the rupture detection tests identified rainfall rupture dates identical to those indicated by the interannual variability highlighted by the rainfall indices. In Gagnoa and Divo, the interannual cumulative rainfalls after the years of rainfall break are reduced compared to those before these rainfall accidents. This situation has led to an increase in the maximum interannual dry sequences in the departments studied.
Conclusion: Local climate change has created difficult rainfall conditions after years of rainfall break for cocoa trees as their water needs are increasingly reduced, especially in Divo in Lôh-Djiboua where the downward trend in rainfall has been continuous since 1972. In Gagnoa since the beginning of this century, there has been a new wet period that allows rainfall to adequately meet the cocoa tree's water requirements.

Keywords: Local global warming; rainfall; annual cocoa water requirements; west-central Côte d'Ivoire.

1. INTRODUCTION

Since immemorial time, the climate has been constantly changing. But the new development model adopted by humanity with the advent of the industrial era has made man the main architect of current climate change. The recent history of climate characterized by the exceptional warming of the climate system is a perfect illustration of this. The effects of this global warming on the planet, in relation to local climates, are felt in different ways. In West Africa, global warming is mainly reflected in a fairly significant decrease in annual rainfall with rainfall deficits in the order of 20 to 30% and decreases in river flows [1-4]. Due to its geographical location, Côte d'Ivoire is inevitably suffering from this widespread rainfall recession. Indeed, several specialists [5-12] have shown that the decline in annual rainfall levels began in the north of the country before gradually spreading to the central and coastal south. And since the early 1970s, this situation has worsened across the country. This climate variability has affected not only the precipitation regime, but also hydrological and plant resources [13]. The southern forest of Côte d'Ivoire, which, like the rest of the country, depends mainly on rain-fed agriculture both as a direct means of food and as a source of income, is particularly vulnerable to changes in local rainfall. In the Central West, which is one of the main cocoa-producing regions, rainfall instability does not always allow cocoa farmers to achieve the expected yields. This situation poses serious threats to the country's economy, which is mainly dependent on cocoa production. This study was therefore initiated in order to ensure the sustainability of cocoa production in this region, which represents the second cocoa loop in Côte d'Ivoire. It will enable the various actors in the cocoa sector to better understand the evolution of the essential rainfall factors in cocoa production, which despite recent work in the study area [14] remain relatively unknown.

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 km^2 (Fig. 1). These regions belong to the district of Gôh-Djiboua, which is located in the humid tropical zone [15] where rainfall fluctuates between 1200 and 1600 mm per year [16] 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 [17,18]. 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 trees.

2.2 Data used and Analysis Methods

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 Control Program of the National Centre for Agronomic Research (CNRA); but also from the historical database of the Office for Scientific Research of the Overseas Territories (ORSTOM), now the Development Research Institute (IRD).

2.2.2 Analysis methods

2.2.2.1 Period selection, criticism and data filling

The time window chosen for this study (70 years) has the advantage of having fairly homogeneous data with complete annual series, with the exception of a few missing data, particularly on the Divo station, where the incomplete data from 1946 were replaced by those from the Tiassalé station, only 60 km away. This rather long database, covering recent years, provides objective and more representative trends of the current climatic conditions of the departments studied. Moreover, we can only talk about climate change or warming by analyzing the evolution of the climate over very long periods, sometimes going beyond 100 years. This is why the United Nations Framework Convention on Climate Change defined climate change as "changes in climate attributed directly or indirectly to human activities that alter the composition of the atmosphere and complement the natural climate variability observed over very long periods of time" [11]. In other words, the longer the period considered, the more the resulting global warming can be attributed to human action. Of course, 30 years is enough to make a serious study of the climate as recommended by the World Meteorological Organization; but the results of such a study will be attributed to the natural evolution of the climate and not to human activities.

2.2.2.2 Characterization of the rainfall regime in the regions studied

The analytical components used to characterize the rainfall regime mainly concern monthly and annual rainfall totals. These climatic variables make it possible to identify monthly and annual rainfall trends in the study area and to highlight the interannual variability of rainfall.

For the characterization of the rainfall regime, the treatment consisted in calculating the average monthly totals for each station in the area over the reference period (1946-2015).

The annual totals made it possible to study the quantities and rates of rainfall. They are calculated by the simple cumulation method:

$$\sum_{i=1}^{12} ni \quad (1)$$

with $n =$ monthly values.

The arithmetic mean $\bar{X}$ was used to study rainfall patterns over the reference period. It is expressed as follows:

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} xi \quad (2)$$

with: $xi =$ monthly rainfalls by year et $n =$ number of years.

2.2.2.3 Reduced centred Lamb or Nicholson Indices

It is a method that was developed by Lamb [19] and adopted by [20]. The rainfall index is the ratio of the difference between the annual precipitation amount at station i and the average annual precipitation amount over the standard deviation of the period considered. It is a reduced centred variable that is used to study the interannual variability of rainfall. The annual rainfall indices are calculated according to the formula proposed by [20]:

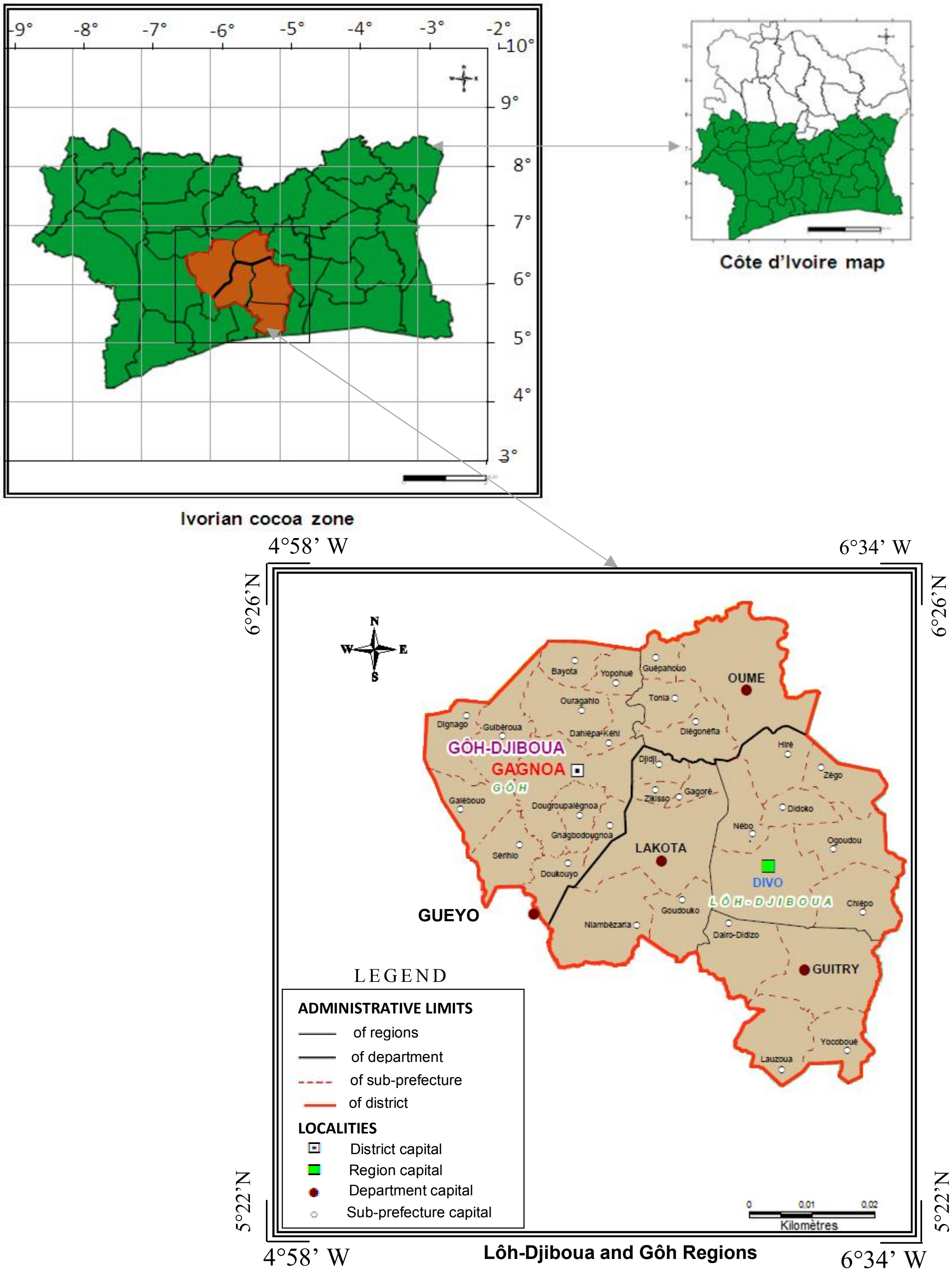

Fig. 1. Study area presentation

$$I_i = \frac{X_i - \bar{X}}{\delta} \quad (3)$$

Where

I_i =Rainfall index of year i
X_i =Annual rainfall of year i
$\bar{X}$ =Mean interannual rainfall over the reference period
δ =Value of the standard deviation of interannual rainfall over the reference period

Hanning low-pass filter of order 2:

A better observation of interannual fluctuations is achieved by eliminating seasonal variations. In this case, the annual rainfall totals are weighted using the following equations recommended by [21]:

$$X_{(t)} = 0.06x_{(t-2)} + 0.25x_{(t-1)} + 0.38x_{(t)} + 0.25x_{(t+1)} + 0.06x_{(t+2)}\ Pour\ 3 \le t \le (n-2) \quad (4)$$

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

$$X_{(1)} = 0.54x_{(1)} + 0.46x_{(2)} \quad (5)$$

$$X_{(2)} = 0.25x_{(1)} + 0.50x_{(2)} + 0.25x_{(3)} \quad (6)$$

$$X_{(n-1)} = 0.25x_{(n-2)} + 0.50x_{(n-1)} + 0.25x_{(n)} \quad (7)$$

$$X_{(n)} = 0.54x_{(n)} + 0.46x_{(n-1)} \quad (8)$$

The main trends are also highlighted by an affine regression line: $y = ax + b$. (9)

it is obtained by calculating the slope (a), which is a guiding coefficient. If a > 0, we have an upward trend and if a < 0, we have a downward trend.

2.2.2.4 Methods for determining breaks within interannual rainfall series

The "Khrono Stat" software, designed by Hydro Sciences 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 [6]. 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.

It should be noted that the statistical methods applied to rainy time series in this work are commonly used in this type of study because of their robustness and performance. This is the case in particular for the rainfall indices, the Hanning order 2 low-pass filter and the various rupture detection tests. Several recent studies such as [14,12,27,28,11] and [29] have also used these methods.

2.2.2.5 Major rainfall factors 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 favorable climatic conditions, obeying several criteria, the most important of which are as follows: (1) the annual rainfall amounts are between 1200 and 1500 mm [30] but a minimum annual threshold of 1200 mm is sufficient to consider its establishment in a region [31]; (2) the annual duration of the dry season is less than 3 months [30].

In this work, the interannual cumulative rainfall were calculated and compared to the minimum threshold required for cocoa production from Excel version 2016 onwards. Then the maximum interannual dry sequences were determined using Instat+ software version 3.37, as well as the means and percentiles from the descriptive statistical analysis. It should be recalled that 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 [32]. 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 Typology of Rainfall Regimes

The monthly average rainfall totals for Divo and Gagnoa show that the two localities studied have a bimodal rainfall regime, characterized by two rainy seasons and two dry seasons (Fig. 2) and (Fig. 3). In Divo the main rainy season starts on average in March and ends in July, while the minor rainy season begins in September and ends in November. June is the wettest month of the main season with an average maximum value of 238 mm of rain and September is the wettest month of the main season with average totals of 160 mm. A small dry season (July to August) occurs between the two rainy seasons and a large dry season occurs from November to February (Fig. 2).

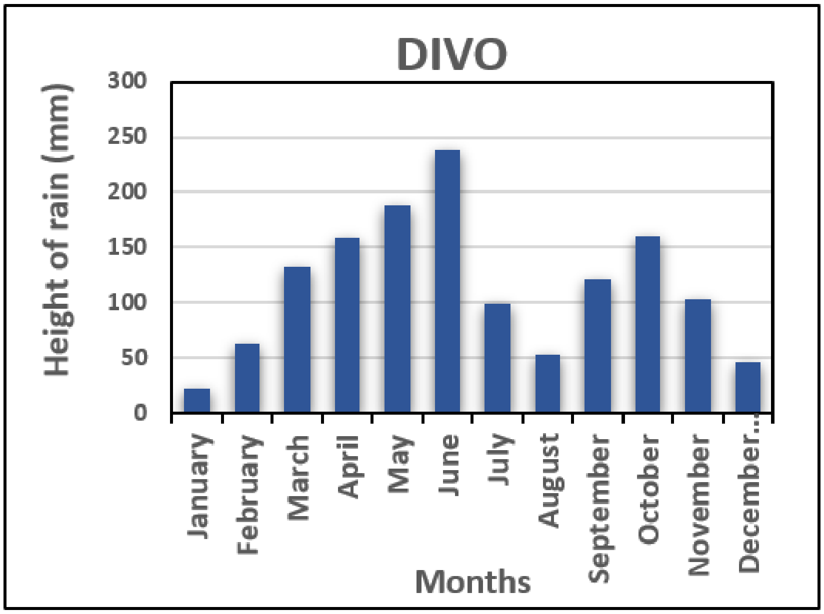

Fig. 2. Rainfall regime of the Divo station

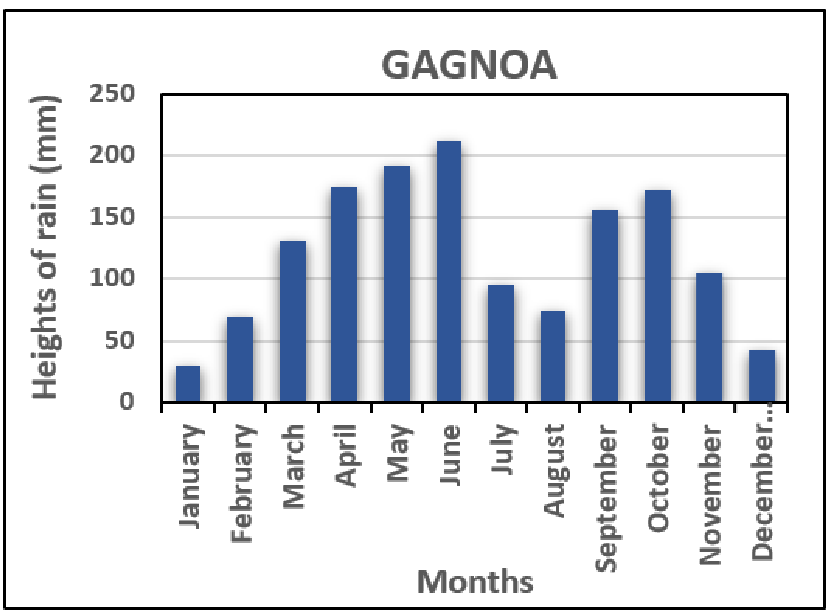

Fig. 3. Rainfall regime of the Gagnoa station

In Gagnoa, the main rainy season begins on average in March and ends in July. It is followed by a short dry season from July to August. The short rainy season extends from September to November and leads to a long dry season from December to February. June and October are the wettest months of the large and small rainy seasons respectively with a maximum average value of 211 mm in June and 172 mm in October. (Fig. 3). In general, rains are more abundant in Gagnoa than in Divo. Indeed, with the exception of March, June and July, all other average monthly totals recorded during the year at Gagnoa station are higher than those at Divo station (Fig. 2 and Fig. 3). It is also noted that the months of March, April, May, June, September and October are the wettest months of the year in both regions (Fig. 2 and Fig. 3).

3.2 Interannual Variability and Precipitation Trend

Precipitation evolves according to two main trends in both localities. The first period, 1946-1971 in Divo and 1946-1965 in Gagnoa, reflects an upward trend in precipitation (excess period) (Fig. 4). The second period, which starts from 1972 to 2015 in Divo and 1966 to 2000 in Gagnoa show a downward trend in rainfall (excess period). The station of Gagnoa has a second (excess) wet period from 2000 to 2015 (Fig. 5).

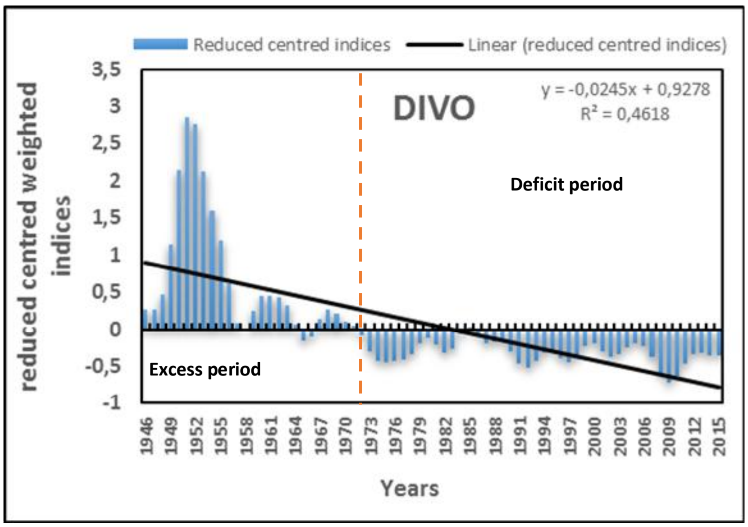

Fig. 4. Interannual rainfall evolution at Divo over the period 1946-2015

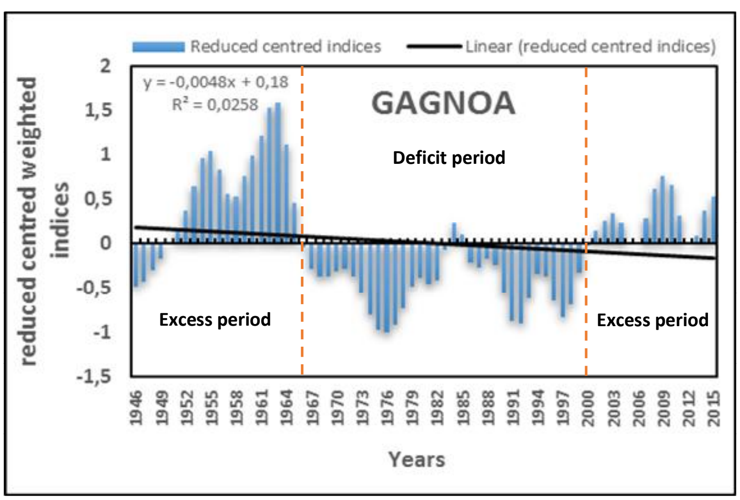

Fig. 5. Interannual rainfall evolution at Gagnoa over the period 1946-2015

3.3 Detection of Years of Rainfall Break

The tests used identified ruptures in 1972 at Divo station and in 1966 at Gagnoa station (Table 1). The methods of Pettitt, Lee and Heghinian, Buishand and Hubert reached the same conclusion for the Gagnoa rainfall series. On the other hand, the test results are more random for Divo's time series, which is more heterogeneous. However, these rupture dates are obtained by the majority of the tests (2/4 for Divo and 3/4 for Gagnoa). In addition, they confirm the apparent years of disruption highlighted by the evolutionary trends of the interannual rainfall indices at each station (Table 1).

3.4 Analysis of Interannual Cumulative Rainfall

3.4.1 Interannual cumulative rainfall of Divo

The evolution of interannual cumulative rainfall in Divo before the break-up (1946-1971 period) shows that for 23 years out of 26, the annual totals reach or exceed the minimum annual threshold required for cocoa trees in Côte d'Ivoire, which is 1200 mm (Table 2). Eighty-eight percent of the overall water needs of cocoa trees are therefore met. In 12% of cases, accumulations of less than 1200 mm are not sufficient to meet the water needs of cocoa plants (Table 2). Over the period 1946-1971, the average cumulative rainfall was 1701 mm.

During this period, the annual rainfall in Divo is therefore largely favorable to cocoa farming. Over the post-breakup period (1972-2015), however, only 43% of the years meet the cocoa tree's water requirements, and in 57% of cases rainfall is insufficient. On average, 1218 mm of rain falls in this locality (Fig. 6).

3.4.2 Interannual cumulative rainfall for Gagnoa

Gagnoa's interannual cumulative rainfall show a much more pronounced variability than those of Divo (Fig. 7). Over the period before the break-up (1946-1965), the city of Gagnoa received an average of 1520 mm of rain. 96% of years have rainfall greater than or equal to the threshold required for cocoa production, while only 4% of years receive less than 1200 mm of rain. In contrast, in the post-rupture period (1966-2015), it rains on average 1395 mm. In addition, only 84% of the years reach or exceed 1200 mm when 12% of the years are in deficit (Table 3).

3.5 Maximum Interannual Dry Sequences

3.5.1 Maximum interannual dry sequences at Divo

The cocoa tree cannot tolerate the occurrence of a dry season of more than 3 months in the year. This approach makes it possible to verify that this variable dangerous for plant development and growth is not exacerbated by local climate change. Examination of the maximum interannual dry sequences at Divo shows that generally over the two periods no year has a dry sequence greater than 90 days. The average maximum dry sequence before rupture is 11 days while the maximum dry sequence after rupture is 15 days. This represents an average extension of 4 days (Table 4).

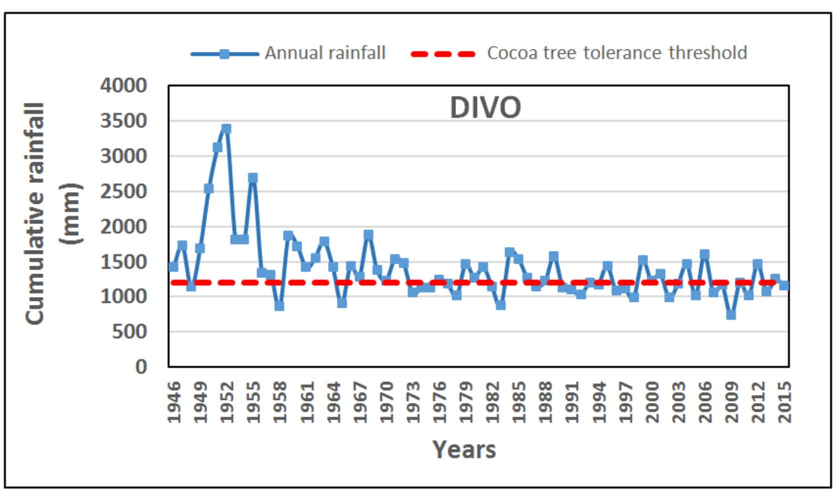

Fig. 6. Variability of interannual cumulative rainfall at Divo over the period 1946-2015

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

Stations	Tests de rupture								
	Pettitt		Lee et heghinian		Buishand		Hubert		Date indiquée par la majorité des tests
	Year	Proba.	Year	Proba.	Year	Proba.	Year	Proba.	
Divo	1972	0,001	1955	0,65	1972	0,99	1953; 1956	0,1	1972
Gagnoa	1966	0,00678	1966	0,1968	1966	0,99	1954; 1965	0,1	1966

Proba: Probability

3.5.2 Maximum interannual dry sequences at Gagnoa

In Gagnoa, there is only one year that has a dry sequence that is more than 3 months long after the rupture (93 days). The average of the maximum dry sequences increased by one day compared to the period before 1966. It has gone from 11 to 12 days. However, despite this slight extension of the maximum dry sequences, they remain less important than in Divo (Table 4).

Table 2. Descriptive statistics of interannual cumulative rainfall in Divo

Station	Divo	
Periods	**1946-1971**	**1972-2015**
Years of observations	26	44
Maximum	3384	1634
Minimum	861	738
Average	1701	1218
Standard deviation	614	203
Coefficient de variation (%)	36	17
Cumulative ≥ 1200 (%)	88	43
Cumulative < 1200 (%)	12	57

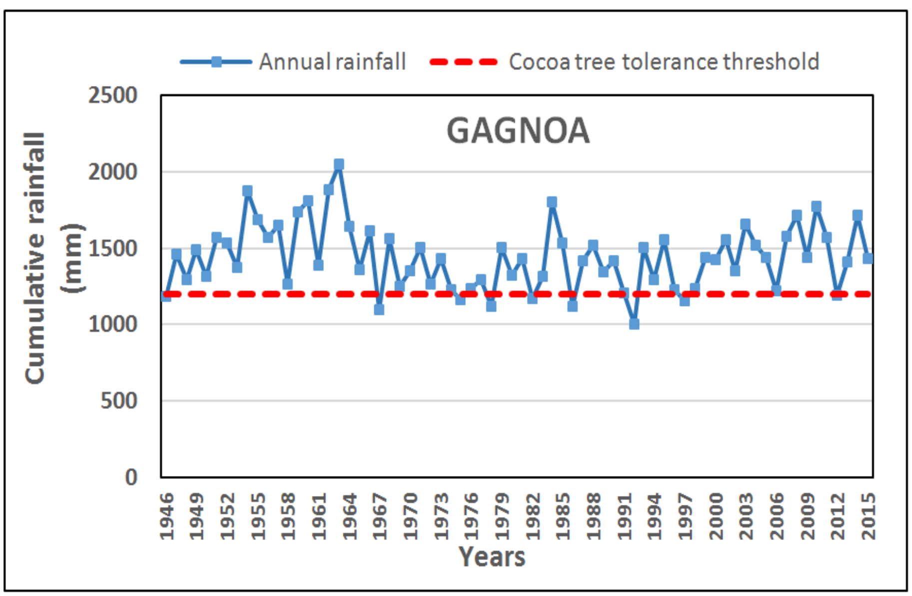

Fig. 7. Variability of interannual cumulative rainfall at Gagnoa over the period 1946-2015

Table 3. Descriptive statistics of interannual cumulative rainfall in Gagnoa

Station	Gagnoa	
Periods	**1946-1965**	**1966-2015**
Years of observations	25	45
Maximum	2048	1801
Minimum	1099	1002
Average	1520	1395
Standard deviation	239	187
Coefficient de variation (%)	16	13
Cumulative ≥ 1200 (%)	96	84
Cumulative < 1200 (%)	4	16

Table 4. Descriptive statistics of the maximum interannual dry sequences at Divo and Gagnoa

Station	Divo		Gagnoa	
Periods	**1946-1971**	**1972-2015**	**1946-1965**	**1966-2015**
Maximum	57	89	61	93
Minimum	2	2	1	2
Average	11	15	11	12
Standard deviation	9	13	9	12
Coefficient de variation (%)	79	83	88	99
DS ≤ 90 jours (%)	100	100	100	99

DS: Dry sequences

4. DISCUSSION

It is now certain that global warming is having an impact on all regions of the world. But these demonstrations and targets are diverse. In Côte d'Ivoire, this phenomenon is mainly reflected in a disruption of rainfall patterns and an unprecedented reduction in interannual rainfall amounts, observed in most regions of the country around 1970. The study of rainfall patterns in the two localities analysed informs us that their typology has not yet been affected by the overall decline in rainfall that occurred in Côte d'Ivoire in the late 1960s and early 1970s. The rainfall patterns in Divo and Gagnoa remained bimodal as [15]'s work on the general climate in Côte d'Ivoire had already demonstrated. Indeed, [15] had shown that the regions of Gôh and Lôh-Djiboua belong to the humid tropical zone in which the distribution of rains obeys a seasonality typical of the bimodal regime which is characterized by four seasons including two rainy seasons and two dry seasons: a major rainy season from March to June and a minor dry season in July and August; a minor rainy season from mid-September to mid-November and a major dry season from December to February. The seasonal distribution highlighted in this study in the localities of Divo and Gagnoa is generally in line with that of Eldin, with the exception of the apparent end of the high season, which occurs more and more during July, and the dry season, which is likely to be shortened in Gagnoa. This situation could be explained by the fact that Eldin's study period was fairly homogeneous (excess rainfall and less fluctuating) while the period 1946-2015 covers two periods with opposite climatic behaviours. Divo's analysis of average monthly rainfall totals also indicated that June and September, with average totals of 238 mm and 160 mm respectively, are the wettest months of the large and small rainy seasons. A study of the water balance in central Côte d'Ivoire, particularly in the departments of Bocanda, M'bahiakro and Dimbokro, which also have a bimodal system, [9] led to the same conclusions. Previous work by Diomandé [33] and [34] in the same region had also indicated that June is the wettest month of the major rainy season and September the best watered month of the minor rainy season. Our results showed that June (211 mm) is like Divo, the wettest month of the main season in Gagnoa but that the best watered month of the main season in Gagnoa is October (172 mm). Recent work by [14] in the same area confirms these monthly rainfall characteristics in Gagnoa. Like us, these authors have proven that the months of March, April, May, May, June, September and October receive the highest amounts of rainfall in the year in Gagnoa and Divo.

Moreover, the analysis of the interannual rainfall totals for the two regions investigated reveals that, thanks to post-rupture rainfall averages of 1218 mm in Divo and 1395 mm in Gagnoa, which exceed the minimum annual threshold of 1200 mm required by the cocoa tree, these two localities are still suitable for cocoa production. This result is consistent with that obtained by [35] who, in a study called rainfall variability and perspective for cocoa replanting in west-central Côte d'Ivoire over the period 1978-2007, noted that the interannual rainfall average recorded over this period (1249 mm in Divo and 1395 mm in Gagnoa) was above 1200 mm, making these two departments still favorable for cocoa production [35]. But this flattering general observation only masks the water deficit to which cocoa trees are increasingly exposed in the study area. This is the case in particular over the period 1971-2015 in Divo where only 43% of the years have accumulations above 1200 mm, the remaining 57% are in deficit for cocoa plants. This situation is similar to the one described by [14] in Divo over the period 1986-2015. These researchers found rainfall deficits in 60 to 80% of the years studied. The period 1971-2015, which includes the 1986-2015 sub-period, is therefore subject to water stress that is worrying for the future of cocoa production in the Divo Region. In the rest of their study [14] showed that the interannual rainfall totals observed in these localities reveal a deficiency in cocoa production in 50 to 80% of the years in Divo and in 20 to 30% in Gagnoa. Our study also fits into this framework by presenting more favorable rainfall conditions in Gagnoa, where it is noted that after the break only 12% of the years are below the minimum allowed.

In addition, the various statistical tests, in particular those of Pettitt, Lee and Heghinian and Buishand, detected major rainfall accidents in the rainfall series of the two localities studied. These climate anomalies, which correspond to sudden changes in stationarity in the evolution of daily time series, have been widely studied in several studies on climate variability in West Africa. As a reminder, many studies have identified changes in stationarity observed in African hydroclimatic series during the 20th century, especially those corresponding to a sudden drop in precipitation in the late 1960s in the Sudano-Sahelian zone [36-41] and in the Guinean and Sudano-Guinean zone [42-45]. 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 rupture dates were detected by the majority of tests in 1972 in Divo and in 1966 in Gagnoa. These dates are perfectly consistent with the break-up years indicated by [43] 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 [15]. Indeed, by studying the evolution of the time series of 33 rainfall stations in West Africa in the Sahel, Sudano-Guinean and Guinean zones, [38] have revealed significant breaks, most of which occurred 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 [44]. 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. The interannual variability of precipitation in the Gôh and Lôh-Djiboua regions shows different evolutionary trends on either side of the break-up years. Thus, there are upward trends marking periods of excess rainfall between 1946 and 1971 in Divo and between 1946 and 1965 in Gagnoa. However, after the break-up years, rainfall trends declined significantly. These post- and pre-break climatic provisions are corroborated by the work of [49] and by many experts such as [50] 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 of the Daoukro departments, Bocanda, Agnibilékro, M'bahiakro and Abengourou all break down into two periods of wet and dry or deficit and excess respectively before and after the ruptures. However, the station of Gagnoa has another surplus period after 1966, which extends from 2000 to 2015. This is due to a return to better rainfall conditions in many parts of the country, sometimes causing flooding as evidenced by the work of [44] and [10].

As for the maximum interannual dry sequences, they are almost all less than 3 months [51] and even if it is true that they increase after rainfall accidents as is the case in various studies [52,53,13,54, 55], they remain marginal and do not significantly impact cocoa production in the regions studied.

5. CONCLUSION

This study, undertaken in the regions of Gôh and Lôh-Djiboua in west-central Côte d'Ivoire, made it possible to characterize the recent rainfall pattern in the study area and determine the current evolutionary trend in rainfall in the localities of Divo and Gagnoa. In general, it is noted that despite local climate changes, the bimodal rainfall regime, typical of the humid tropical climate, has remained unchanged in both Divo and Gagnoa. On the other hand, sudden changes in the average evolution of rainfall patterns occurred around 1970 (1972 in Divo and 1966 in Gagnoa). From these break-up dates, there is a general rainfall recession in the two departments studied, which manifests itself in a reduction in interannual rainfall totals and an elongation of the maximum dry sequences after the breaks. However, this downward trend is less marked in Gagnoa where the rate of satisfaction of the cocoa tree's water needs is higher. The Gôh region therefore remains more favorable to cocoa production than the Lôh-Djiboua region in this context of global warming.

ACKNOWLEDGEMENTS

We express our infinite gratitude to all the energies that contributed to this study. To the managers of the meteorological service of the Sustainable Soil Management and Water Control Program of the National Agricultural Research Centre for the climate data made available to us. To the researchers of the CNRA Cocoa Program for their wise advice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Servat E, Paturel JE, Lubès H, Kouamé B, Ouédraogo M, Masson JM. Climatic variability in humid Africa along the Gulf of Guinea. Part I: Detailed analysis of the phenomenon in Côte d’Ivoire. Hydrol. Sci. J. 1997;191:1-15.
2. Paturel JE, Servat E, Kouamé B, Lubès H, Ouédraogo M, Masson JM. Climatic variability in humid Africa along the Gulf of Guinea. Part II: an integrated regional approach. Hydrol. Sci. J. 1997; 191:16-36.
3. Brou YT, Servat E, Paturel JE. Human activities and climate variability: Case of the Ivorian southern forest, IAHS Publ. 1998;252:365-373.
4. Bigot S, Brou YT, Diédhiou A, Houndenou C. Factors of rainfall variability in Côte d'Ivoire and relations with certain environmental changes. Drought. 2005; 16(1):14-21.
5. Ardoin-Bardin S, Lubès-Niel H, Servat E, Dezetter A, Boyer JF. Analysis of the persistence of drought in West Africa: characterization of the situation in the 1990s. IAHS Publication. 2003;278:223-228.
6. Ardoin-Bardin S. Hydroclimatic variability and impacts on water resources in large river basins in the Sudano-Sahelian zone. Doctoral thesis. University of Montpellier II. 2004; 437.
7. Kouassi AM, Kouamé KF, Goula BTA, Lasm T, Paturel JE, Biémi J. Influence of climate variability and land use change on the rain-flow relationship based on a global modelling of the N'zi (Bandama) catchment area in Côte d'Ivoire. Revue Ivoirienne des Sciences et Technologie. 2008;11:207-229.
8. Kouassi KF, Diomandé BI, Koffi KN. Type of responses provided by farmers to rainfall constraints in central Côte d'Ivoire: Case of Daoukro department. 18th Colloquium of the International Climate Association. Liège; 2015.
9. Fossou RMN, Lasm T, Soro N, Soro T, Soro G, De Lasme OZ, Baka D, Onetie OZ, Orou R. Climate variability and its impact on groundwater resources: The case of the Bocanda and Dimbokro stations in central eastern Côte d'Ivoire (West Africa). Larhyss Journal. 2015;21: 97-120.
10. Noufé D, Lidon B, Mahé G, Servat E, Brou YT, Koli Bi Z, Chaléard JL. Climate variability and rainfed maize production in eastern Côte d'Ivoire. Hydrol, Sci. J. 2015 ; 56(1):152-167.
11. Kanga KHM. Drought and socio-spatial vulnerability in the northeast quarter of Côte d'Ivoire. Single doctoral thesis, Alassane Ouattara University, Bouaké. 2017;347.

12. Dékoula CS, Kouamé B, N'goran EK, Yao FG, Ehounou JN, Soro N. Impact of rainfall variability on the growing season in the cotton production area of Côte d'Ivoire. European Scientific Journal, ESJ. 2018; 14(12):143-156.
13. Aguilar LAAA. Impact of recent climate variability on Senegal's niayas ecosystems between 1950 and 2004. Thesis; Université du Québec à Montréal, Québec. 2009; 185.
14. Kassin KE, Kouamé B, Coulibaly K, Tahi GM, N'Guessan WP, Aka AR, Assi ME, Guiraud BH, Koné B, Yao GF. Prospects for sustainable cocoa farming from the rainfall balance in the last thirty years at Lôh-Djiboua and Gôh post-pioneers regions, Côte d'Ivoire. 2018;9(11): 188-198.
15. Eldin M. Le climat In le milieu naturel de la Côte d'Ivoire. 1971;73-108.
16. Kouamé B, Koné D, Yoro G. Rainfall in 2005 and 2006 in the southern half of Côte d'Ivoire: In. The CNRA. 2006;12-13.
17. Perraud A. Soils. In: The natural environment of Côte d'Ivoire. ORSTOM thesis no 50; 1971.
18. Oswald M. Reconstruction of a society through several crises: The rural Bété society. Thesis of 3rd cycle. Institut Nationale Agronomique Paris-Grignon, Paris. 1997;1:146-180.
19. Lamb PJ. Persistence of Subsaharan drought. Nature. 1982;299(8):46-48.
20. Nicholson SE, Kim J, Hoopingarner J. Atlas of African rainfall and its interannual variability. Department of Meteorology, Florida State University Tallahassee, Floride. 1988;237.
21. Assani AAA. Analysis of the temporal variability of precipitation (1916-1996) in Lumbashi (Congo-Kinshasa) in relation to certain indicators of atmospheric (southern oscillation) and oceanic (El Niňo/La Niňa) circulation, Sécheresse. 1999;10(4):245-252.
22. Boyer JF, Dieulin C, Rouche N, Cres A, Servat E, Paturel JE, Mahé G. SIEREM an environmental information system for water resources. IAHS Publication. 2006;308:19.
23. Pettitt AN. A non-parametric approach to the change-point problem. Applied statistics. 1979;28:126-135.
DOI: 10.2307/2346729
24. Buishand TA. Tests for detecting a shift in the mean of hydrological time series. Journal of Hydrology. 1984;58:51-69.
25. Lee AFS, Heghinian SMA. Shift of the mean level in a sequence of independent normal random variables: A Bayesian approach. Technometrics. 1977;19(4): 503-506
26. Hubert P, Carbonel JP, Chaouche A. Segmentation of hydrometeorological series. Application to rainfall and flow series in West Africa. Journal of Hydrology. 1989;110:349-367.
27. Dékoula SC, Kouamé B, N'Goran KE, Ehounou JN, Yao GF, Kassin KE, Kouakou BJ, N'Guessan BEA, Nagnin S. Variability of rainfall descriptors with agricultural impact in the cotton basin of Côte d'Ivoire. Journal of Applied Biosciences. 2018;130:13199-13212.
28. Faye M, Fall A, Faye G, Etienne VH. Rainfall variability and its impact on agricultural yields in the Terres Neuves region of eastern Senegal, Belgeo. 2018;1.
(Accessed on 30 April 2019)
Available:http://journals.openedition.org/belgeo/22083; DOI : 10.4000/belgeo.22083
29. Bouba L, Sauvagnargues S, Gonne B, Ayral PA, Ombolo A. Rainfall trends and flood hazard in Extreme North Cameroon. Geo-Eco-Trop. 2017;41(3):20.
30. Brou YT, N'Goran JAK, Bicot S, Servat E. Climate risk and agricultural production in Côte d'Ivoire: Effect of rainfall variations on cocoa production. In: Proceedings of the 14th International Conference on Cocoa Research (Accra, Ghana. 2003;259-267.
31. Mossu G. The cocoa tree. The tropical agriculture technician. Maisonneuve and Larousse. ACCT. 1990;159.
32. O.M.M. Guide des pratiques climatologiques, (100). Geneva, Switzerland. 1990;515.
33. Diomandé M. Impact of the change in rainfall on agricultural production systems in the forest-savannah contact zone of Côte d'Ivoire, Doctoral thesis, Félix Houphouët Boigny University, Abidjan. 2013;228.
34. Brou YT, Akindes F, Bigot S. Climate variability in Côte d'Ivoire: Between social perceptions and agricultural responses. Cahiers Agricultures. 2005;14(6):533-540.

35. Kassin KE, Koné D, Kouamé B, Yoro GR, Assa A. Rainfall variability and prospects for cocoa replanting in West Central Côte d'Ivoire. Journal of Applied biosciences. 2008;12:633-641.
36. Sircoulon J. Variation in river flows and lake levels in West Africa since the beginning of the 20th century. In: The Influence of Climate Change and Climatic Variability on the Hydrologic Regime and Water Resources (Proc Vancouver Symposium). IAHS Publication. 1987;168: 13-25.
37. Hubert P, Carbonnel JP. Statistical approach to aridification in West Africa. Journal of Hydrology. 1987;95:165-187.
38. Hubert P, Carbonel JP, Chaouche A. Segmentation of hydrometeorological series. Application to rainfall and flow series in West Africa. Journal of Hydrology. 1989;110:349-367.
39. Demarée GR, Nicolis C. Onset of Sahelian drought viewed as a fluctuation-induced transition. Quaterly Journal of the Royal Meteorological Society. 1990;116:221-238.
40. Moron V. Precipitation variability in tropical Africa north of the equator (1933-1990) and relationship with ocean surface temperatures and atmospheric dynamics. Doctoral thesis, University of Burgundy, Climate Research Centres, Dijon. 1993;219.
41. Nicholson SE. An overview of African rainfall fluctuations in the last decade. Journal of climate. 1993;6:1463-1466.
42. Adewi E, Badameli K, Dubreuil V. Evolution of potentially useful rainy seasons in Togo from 1950 to 2000. Climatology. 2010;7:89-107.
43. Soro TD, Soro N, Oga YMS, Lasm T, Soro G, Ahoussi KE, Biémi J. Climate variability and its impact on water resources in the square degree of Grand-Lahou; 2011.
44. Noufé D. Changement hydroclimatique et transformation de l'agriculture: Exemple des paysanneries de l'Est de la Côte d'Ivoire, Thèse de doctorat de géographie, hydrosciences Montpellier, Université Paris 1 Panthéon-Sorbonne, Paris. 2011;375.
45. Afouda F, Salako APM, Yabi I. Intra-seasonal instability of rains during the main agricultural season in the commune of Kétou in Benin, Revue de Géographie du Laboratoire Leïdi; 2014.
[ISSN 0851-2515– No 12, December 2014]
46. Klassou SD. Recent climato-hydrological trends and their consequences on the environment: The example of the Mono River basin (Togo-Benin). Doctoral thesis, University of Bordeaux III. 1996; 472.
47. Brou YT. Climate, socio-economic changes and landscapes in Côte d'Ivoire. Mémoire de synthèse des activités scientifiques présenté en vue de l'obtention de l'Habilitation à Diriger des Recherches, Université des Sciences et Techniques de Lille, France. 2005;212.
48. Niasse M, Afouda NA, Amani A. Reducing West Africa's vulnerability to climate impacts on water resources, wetlands and desertification. Elements of a regional strategy for preparation and adaptation. 2004;71.
49. N'Go AY, Kouassi KH, Soro GE, Mélèdje H, Goula BTA, Savané I. Dynamics and impact of climate on water and agricultural resources in the Southwest. International Journal of Innovation and Applied Studies. 2017; 19(2):304-314.
50. Kanohin F, Bachir MS, Aké GE, Savané I. Climate variability and coffee and cocoa production in humid tropical areas: The case of the Daoukro region (Central-Eastern Côte d'Ivoire). International Journal of Innovation and Applied Studies. 2012;2(1):194-215.
51. Dibi Kangah PA, Mian KA. Agroclimatic analysis of the cocoa zone in Côte d'Ivoire. Journal of Geography of the University of OuagaI Prof Joseph KI-ZERBO. 2016;2(5): 45-68.
52. Balliet R, Saley BM, Eba ELA, Sorokoby VM, N'Guessan BHV, N'dri OA, Djè KB, Biémi J. Evolution of extreme rainfall extremes in the Gôh Region (Central West Côte d'Ivoire), European Scientific Journal. 2016;12(23): 74-87.
53. New M, Hewiston B, David B, Tsiga SA, Kruger A, Manhinsue A, Gomez B, Coelho CAS, Masisi DN, Kalulanga E, Bulane E, Fortunata L, Mdoka ML, Lajoie R. Evidence of trends in daily climate extremes over southern and West Africa.

Journal of Geophysical Research. 2006;111:D14102.
DOI: 10.1029/2005JD006289

54. Sahani M, Moeyersons J, Vandecasteele I, Trefois P, Ozer P. Evolution of rainfall characteristics in the urban area of Butembo (DRC) from 1957 to 2010. Geo-Eco-Trop. 2012;36:121-136.
55. Mélèdje NH, Kouassi KL, N'Go YA, Savané I. Characterization of drought occurrences in the transboundary Bia river basin between Côte d'Ivoire and Ghana: contribution of Markov chains. Cah Agric. 2015;24:186-97.
DOI: 10.1684/agr. 2015.0755

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle3.com/review-history/50827