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Climate variability impact on cotton production in North Cote d'Ivoire

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Abstract

In Cote d'Ivoire, cotton ranks third in exports after cocoa and coffee. Moreover, it constitutes a vital economic resource in Cote d'Ivoire savannah region. Due to climate variability, the cotton sowing period, from May 20 to June 20, is less and less respected. In this context, this study objective was to analyze, in conjunction with cotton production, the wet season length, from 1992-1995 to 2015-2018 in Korhogo region. So, stationarity tests were used as well as two climatographic types, rainfall, potential evapotranspiration (PLv-PET) and PET-Relative Humidity (ETP-RH), reinforced by means comparisons. For this purpose, data were collected from airports aeronautical operation and meteorological development company at Korhogo station. Overall, there was a non-significant downward trend in rainfall from 1990 to 2023. Looking deeply, this reduction trend was 58 days decrease (-27%) in wet season length on 2015-2018 period, compared to an average 214±16 days annual length on 1992-1995. In fact, the wet period has shrunk significantly, from 151±24 to 103±6 days (-32%). At the same time, there was no significant difference in active growing season duration, between periods 1992-1995 and 2015-2018, although 22 days decrease was observed. Indeed, despite the relatively short study's period length, there was shortening wet periods, combined with late rainy seasons start. Consequently, farmers sowed later. These conclusions lead to a suggestion of new cotton variety's introduction with adapted cycle, as well as new agricultural practice initiations. These include forecasting sowing dates by area and adapting alternative cultivation techniques, which improve soil's useful water reserve.

Keywords: Climate variability; Cotton; Growing Period; Rainfall

1. Introduction

Global warming causes extreme weather events, such as long-term droughts whose devastated Eastern Africa, rain torrents in Libya, whose killed thousands of people, and destroyed dams[1]. Africa, where only 4% of the world's greenhouse gases are emitted, is affected by climate change consequences[1]. In fact, West Africa has been facing a novel climate variability phenomenon for around 30 years, which had a considerable impact on population lives[2]. Thus, agricultural production is affected by climate change, following the increase in environmental event frequencies and intensities[3]. These consequences have been described by Brou et *al.*[2], as less pronounced in the Sahel regions than in Cote d'Ivoire.

Here, cotton is the third most important crop after cocoa and coffee and constitutes a primary economic resource in the Savannah region[4]. Also, cotton farmers gained around 86 billion CFA francs (FCFA) distributed during 2016-2017 campaign and 108 billion FCFA for 2017-2018[5]. Indeed, unpredictable climate variability has considerably disrupted cropping systems in Cote d'Ivoire[6]. In fact, rainfall is characterized by two rainy seasons in the south compared to a single main one in the north[7]. The rainy season begins randomly, with dry spells of varying duration[7]. Thus, for short-

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cycle crops such as food crops and cotton, this variability results in high risks for production[7]. This is an important income-generating activity, which is threatened with disruption by climate change vagaries.

Indeed, the lack of water at plant growing cycle start leads to late sowing at risk[8]. These inter annual variability at start and end dates of the useful rainy season causes difficulties in respecting the crop calendar[8]. The consequence was a drop in cotton plantings in 2022 compared to 2021, linked to rainfall[9]. Already in 2019, Soviadan et *al.*[10] observed a significant negative impact of climate change at 1% level on cotton production in Togo. In fact, in 2023 erratic rainfall in West Africa, partially led to late planting and failure to achieve sowing targets[11]. Then, compared to 2023 May and June rainfall, 2024 recorded water quantities in Côte d'Ivoire are down with -3 and -20 mm respectively[11]. This situation will have a negative impact on early seeding rate[11]. Regression showed more significant effects on cotton yield variation linked to changes in rainfall quantities than temperature during 1990 to 2020 period[12]. Njanji[12] also mentioned that factors other than climate may have effects on the continuous decline in cotton production. Those effects can come from boll worms[13]. Sowings are staggered over the years and are concentrated between June 11 and July 10[8]. In this context, where the challenge is to increase plots' productivity, to improve producers 'income, the link between cotton trees maximum mass, and environmental factors, namely, average region climatic characteristics was established[14]. Indeed, in Sub-Saharan Africa northern part, the main factor in productivity remains the rainfall level[15]. In fact, these rains are so important for producers and ecosystems in West Africa, that most of the studies concerning climate variability analysis focus on them[16,17]. Thus, these research activities are as important as environments are very unequal to these climatic extremes, in terms of exposure, effects and adaptive response[18]. Answers which depend on the understanding of the phenomena[18]. Finally, all these works made it possible to identify and evaluate the droughts based on their progressive appearances[19]. Thus, since 1854, the beginning of these observations, the main dry periods identified were those from 1911 to 1913, from 1940 to 1943 and 1968 to 1976/1979[6,20]. However, Bodian[21] noted a second break existence located in the middle of 1998, thanks to the Pettitt test, and in 2002 following Lee-Heghinian test, and Hubert method. This resulted in considerable drop observation in the rainy days number accompanying the drought, as well as a reduction in rainfall above 50 mm[21]. Consequently, the sowing dates precision for a rainfed crop such as cotton, covering Côte d'Ivoire northern part is crucial[22]. Its implementation must consider the vegetative growth period length. It is therefore important, to observe such a period, to analyze agroclimatic data over an adequate year length. Indeed, time series analysis, like hydro-meteorological one, is an important tool for identifying climatic variations[5]. In short, the recent rainy season length evolution is particularly important. This involves confirming or not the continuing trend towards a reduction in the rainy season, as noted by Ozer et *al.*[23], in Cote d'Ivoire cotton production area. This analysis was rainfall interpretation, evapotranspiration and relative humidity data through their interactions.

2. Material and methods

The study area is Korhogo region, located in north Cote d'Ivoire (Figure 1). Data were from the airport's aeronautical operation and meteorological development company (SODEXAM) station in Korhogo. Geographic coordinates are latitude 9°25' N, longitude -5°37' W, and altitude 381 m.

2.1. Equipment

Climatic data were collected between 1990 and 2023 from SODEXAM et Korhogo airport. Climatic variations analysis and its effect on vegetative growth periods involved three variables. Namely, they were the rainfall (PLv) in millimeter (mm), the evapotranspiration potential (ETP) in mm, and relative air humidity (RH) in%. Particularly, periods from 1992 to 1995 and 2015 to 2018 were considered.

Data quality control consisted in looking for outlying data by using XLSTAT 2024.3 software. Aberrant data were noted for rainfall (PLv) during 2002 and 2012 years, corresponding respectively to political crisis beginning and its end in Cote d'Ivoire. Thus, weather data from 2003 to 2011 were not available for Korhogo during this crisis period.

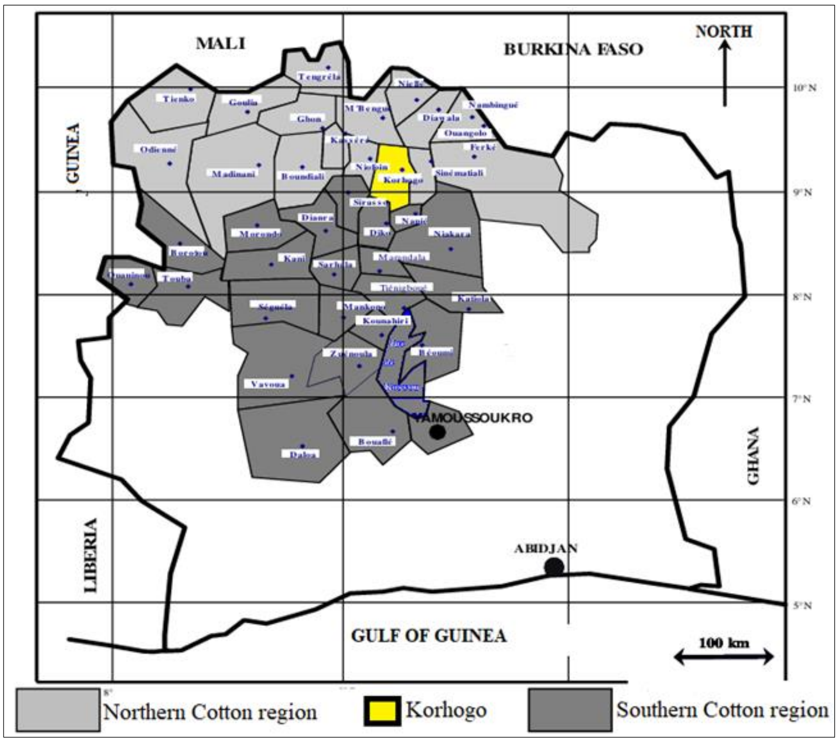


Figure 1 Cotton production zones in Ivory Coast (OCHOU et *al.*[13], 2012)

2.2. Methods

According toBodian[21], filling in missing data can be ensured by the regional vector method (MRV). This MVR is a simple model which makes it possible to represent station rainfall information by an annual indices sequence, region rainfall representative, and by each observation post characteristic coefficient. Two means are commonly used to apply MRV. First, one is based on mode, and the second one uses the average by eliminating values that are too particular, to avoid contaminating estimates with obviously erroneous data[24]. Likewise, climatic data interpolation use is done with meteorological information reconstituting aim, from existing network, at sampled sites level. This concerns neural network method application, which is characterized by non-linearity great flexibility, as well as by its capacity to reconstruct information from partial and poorly defined indices, case of meteorological network data. To proceed with climate data reconstruction, explanatory variables, longitude, latitude and altitude are used; variables to be explained being rainfall and temperatures[25]. For the present study, missing data replacement was carried out considering that mean value is the best estimator[24]. Thus, for PLv, ETP and RH, 2.9% of data were estimated.

The Nicholson[3] rainfall index, is a reduced centered variable which reflects a year "i" rainfall deviation from considered period average rainfall in relation to standard deviation[26]. This difference reflects either surpluses or deficits in climate series annual rainfall. Thus, surplus and deficit periods' successions highlight series climatic changes. Nicholson index mathematical expression is defined by equation (Eq) 1:

$$I_P = \frac{(P_i - P)}{\sigma} \ldots\ldots\ldots (Eq\ 1)$$

Ip: Nicholson index or rainfall index
Pi: year i annual rainfall
P: considered period average rainfall
σ: series standard deviation.

Available climatic data quantity explained this method choice. Indeed, the chosen period length is not enough for breaks in rainfall series detection methods such as HUBERT segmentation[27]. Indeed, a break is defined as a change in random variables probability law, whose successive realizations define time series studied[16]. Thus, the sample size used for this study shows that looking for a break is not in question. Indeed, interest is focused on observing PLv-ETP and ETP-HR climatographic trends in identified series. However, it looks important to analyze collected data stationarity by using Pettit's'[28] homogeneity tests. In fact, Assemian[26] identified the year 1968 as a rainfall break between 1920 and 2005.

Likewise, Dekoula *et al.*[6] considers 1971-2000, as a dry break period between 1951 and 2000, in Cote d'Ivoire. In addition, Bambara[29] detects 1995 to 2015 as the 3rd break period between 1956 and 2015 in Burkina Faso. It appears that 1992-1995 and 2015-2018 periods could coincide respectively with a rainfall break period end, and another one beginning, hence homogeneity test importance.

Wet season was analyzed using climate diagram which consists in producing on a same figure monthly rainfall curves, potential evapotranspiration and half-potential evapotranspiration as a function of year months (PLv, ETP and ETP/2)[29]. This diagram, named Franquin curve[30], materializes the wet season, which represents water intake and losses balance. Three periods characterized the wet seasons:

- Pre-humid period (preh), period before wet period, rainfall is between ETP and half-ETP.
- Wet period or humid period (H), period when rainfall is higher than the ETP.
- Post-humid period (psth), located after humid period where rainfall is between ETP and half-ETP.

According to standardized gradations, monthly variations in potential evapotranspiration, ETP in mm, and the relative air humidity (RH in %) lead to ETP-RH chart. That chart defines the active vegetation period. ETP-HR climate diagram presents an ETP gradation scale corresponding to two RH gradations scale. Thus, on abscissa, years' months are reported, RH (%) is indicated on chart right and ETP (mm) is indicated on left. From this curve, the period when water conditions were optimal for plant growth, when RH was higher than ETP was obtained. This period is called "active vegetation period[31]. According to Morel[7], satisfying ETP half allows the plant to develop, it is a period favorable to growth, but which does not allow flowering or fruiting. This procedure aims to adopt the same time periods for considered variables. Thus, for diagram linking ETP to air RH, ETP was considered as first variable while rainfall is first variable, for the one linking the rainfall and ETP.

Then, from above, three hypotheses group were put forward. The first one concerns data series stationarity or homogeneity, with Box-Pierce, Ljung-Box, McLeod-Li[32] and Pettitt tests. Second and third, are linked respectively to wet season and active vegetation period, they involve t-tests for means value comparing in justification process.

Looking at the rainfall regularity, the hypotheses were:

- H01, Rainfall data at Korhogo station were homogeneous from 1990 to 2023,
- Ha1, there was a difference between data mean values from 1990 to 2023.

Similarly, looking at the wet season, the hypothesis 2 was that:

- H02, wet season durations were similar for periods 1992-1995, and 2015-2018,
- Ha2, wet season durations differed for years 1992-1995, and 2015-2018,

Following, taking care of the active vegetation periods, the hypothesis 3 was:

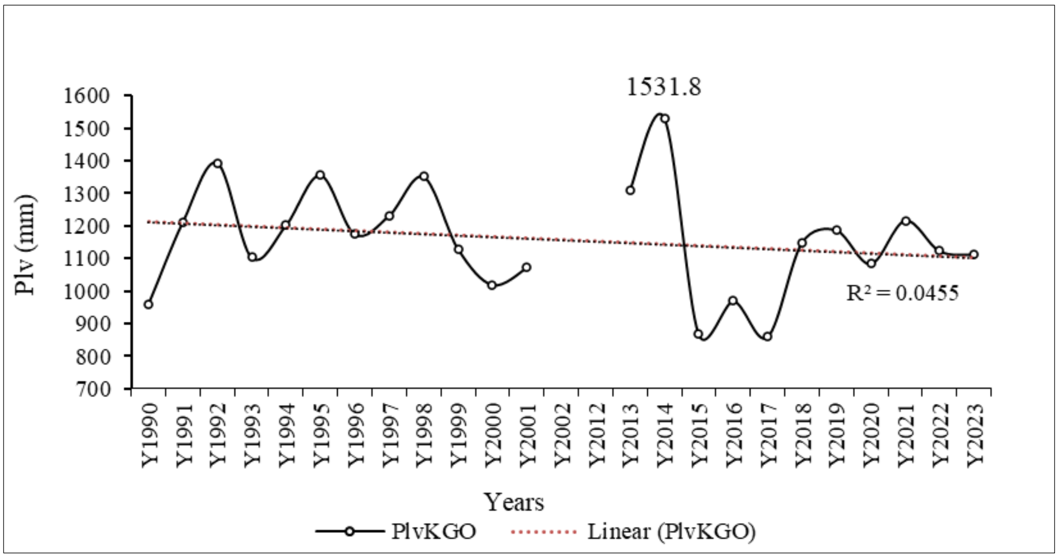
- H03, active vegetation period durations were similar for years 1992-1995, and 2015-2018.
- Ha3, active vegetation period durations differed for the years 1992-1995, and 2015-2018.

3. Results and discussion

The results cover the rainfalls, rainfalls' indices, and the wet seasons' lengths.

3.1. Rainfall

The rainfall data covered intervals from 1990-2001 and 2013-2023 (Figure 2). They showed a downward trend at Korhogo station between 1990 and 2023. This is evidenced by the rainfall indices (IdPlvKGO) observed for rainfall from 1990 to 2023 (Figure 3). Indeed, there were more IdPlvKGO positive values in 1990-2001 for 8 values, than 2013-2023 with 6 values.



Source: SODEXAM (2024)

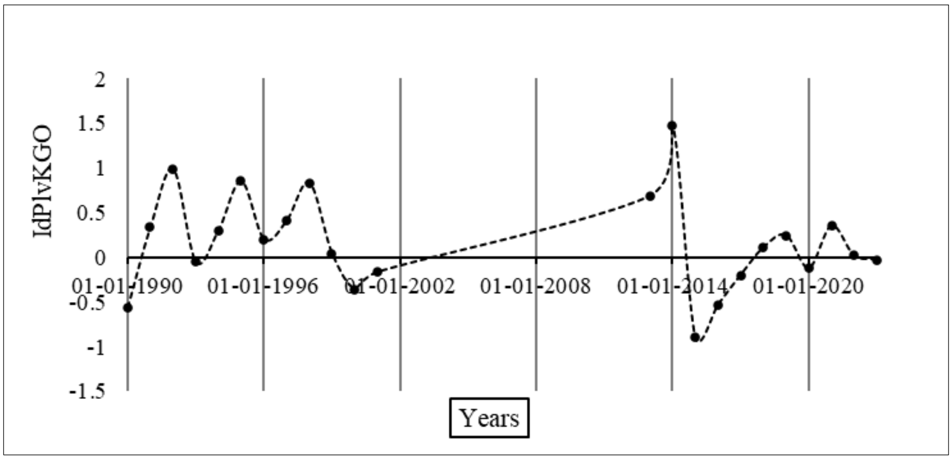
Figure 2 Rainfall in 1990-2001 and 2013-2023 periods for Korhogo station

On the other hand, statistical analysis on white noise was not significant at 5% threshold (Table 1). Indeed, calculated p-value probabilities for Box-Pierce, Ljung-Box and McLeod-Li tests were all above 0.05 significance level. White noise is an example of a stationary temporary series.

Table 1 Rainfall series stationarity test results

Variable	Average in days	Standard deviation	Tests
Korhogo Rainfalls' Indexes	0,172	0,55	Box-Pierce NS*
Rainfall (mm)	97,16	93,22	Pettitt NS

*NS: Not significant

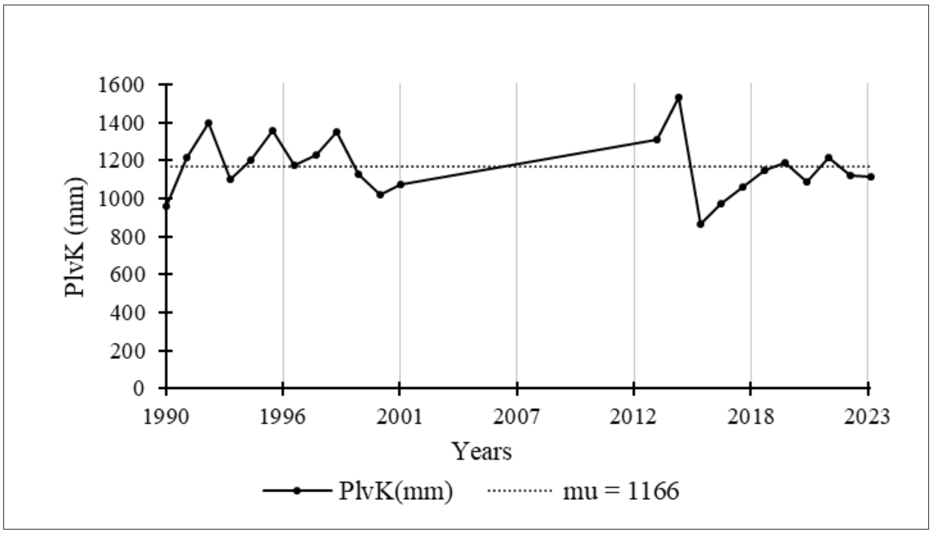


Source: XLSTAT descriptive analysis of rainfall index data

Figure 3 Rainfall indices from 1990 to 2023 at the Korhogo station IdPlvKGO: Korhogo station Rainfalls′ indexes

A time series is said to be stationary if its statistical properties remain stable over time, looking at the variance, expectation, and autocorrelation[33]. This shows that there is stationarity over this period. This observation was confirmed by the Pettitt test, which showed homogeneity over the period from 1990 to 2023 (Figure 4). In short, the rainfalls were similar (p=0.06). In terms of rainfall data stationarity, although interannual rainfall was homogeneous in

Korhogo, it induced climatic dynamics which could influence wet season duration. The reduction in wet season duration was also noted by Bambara[29] and this in wet period starting detriment. From 142 days duration before 1961-1980 period rupture, wet season decreased to 106 days after 1981-2015 rupture, resulting in 36-day shortening (-25%)[29]. Considering observed homogeneity over the period, it's possible that this situation resulted from rainfall intra-annual variability[7].



Source: Pettitt test, SODEXAM 2024 rainfall data

Figure 4 Rainfalls' homogeneity test, Korhogo station for1990-2001, and 2013-2023 periods

It should be noted that 1992-1995 period marked second rainfall break end, while 2015-2018 is 3rd rainfall break started, identified by Bambara[29]. Indeed, a multi-model approach to improve climate change projections' robustness revealed that western Sahel may experience substantial drying, mainly due to reduced rainfall[34]. In fact, Cote d'Ivoire is experiencing a rainfall deficit, which began in 1969 and was characterized by around 19% reduction in annual rainfall[26]. Thus, Korhogo zone, in the north, was marked by a downward trend in precipitation between 1998 and 2013[6,35]. Indeed, the need for water was so crucial that its scarcity over crop growing period constituted a threat for it[36]. In fact, between 500 mm[6] and 700 mm rainfall were needed annually[37] for cotton cultivation in Cote d'Ivoire. At this level, a sharp drop appearance in rainfall from 2011 to 2016, in cotton zone could have negatively influenced cotton productivity[6].

In recent years, research has been focused on rural areas. So, given that climate perceptions are more sensitive there, because these areas inhabitants' daily activities partly depend on climate conditions[18]. However, extreme rainfall consequences can have major impacts on urban populations' living conditions[18]. In short, for rainfall, climatic dynamics in West Africa are accompanied by rainy season duration shortening[29].

3.2. Wet seasons

Table 2 T-test result for comparing number of days means per period

Variable	Average in days	Standard deviation
WS 1992-1995	214[a]	16
WS 2015-2018	156[b]	16
PreH 1992-1995	48[c]	22
PreH 2015-2018	32[c]	15
H 1992-1995	151[d]	24
H 2015-2018	103[e]	6
PstH 1992-1995	15[f]	6
PstH 2015-2018	21[f]	10

WS: wet season, PreH: Pre-humid, PstH: Post humid

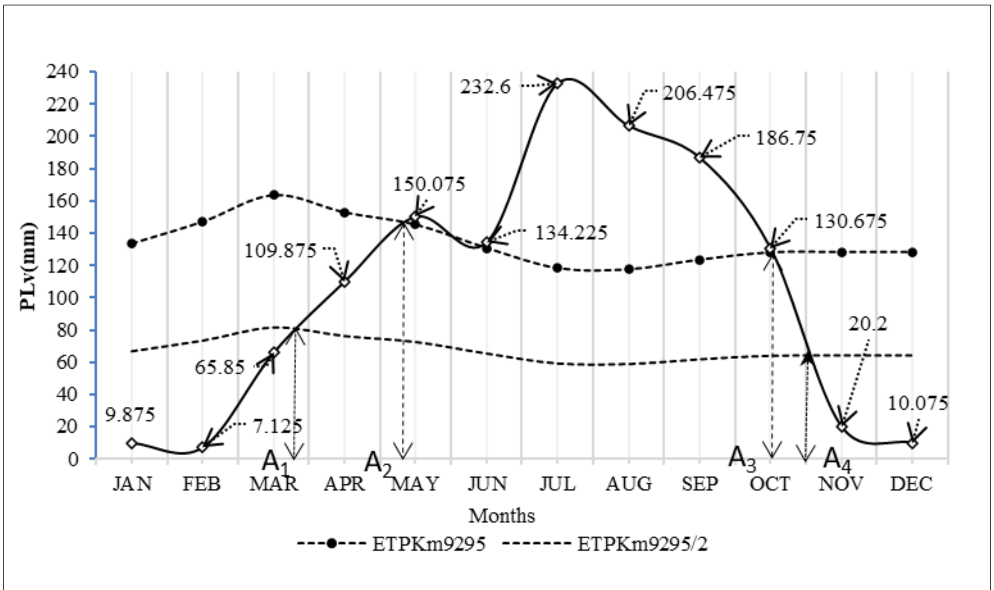
The wet season has three periods of determination. Namely, they are pre-wet period, wet period and post-wet period. They were made by using a graph which involved rainfall and potential evapotranspiration. This determination was related to two selected periods, 1992-1995 and 2015-2018 (Table 2).

It appeared that there was a significant difference between wet seasons for periods 1992-1995, and 2015-2018 (p=0.002). From 1992 to 1995, years included in 1990-2001 block, pre-wet period was represented by the interval A1-A2 (Figure 5). That figure was obtained by the monthly rainfall moving average, to illustrate the general trend. The period started on March 3rd decade and ended on May 1st decade. It lasted 48±22 days on average. While, from 2015 to 2018, the pre-wet period was represented by the interval B1-B2 (Figure 6). The pre-humid section started from April end to June 3rd decade. It represented 32±15 days on average. However, at 5% error threshold, there was no significant difference between 1992-1995 and 2015-2018.

From 1992 to 1995, humid periods corresponded to A2-A3 (Figure 5). The wet beach started from May 2nd decade to mid-October. This period extended over 151±24 days on average. Then, from 2015 to 2018, this period corresponded to B2-B3 (Figure 6). The wet period started from June 3rd decade to October beginning and was estimated at 103±6 days. It was characterized by a significant difference between1992-1995 and 2015-2018 intervals (p=0.026).

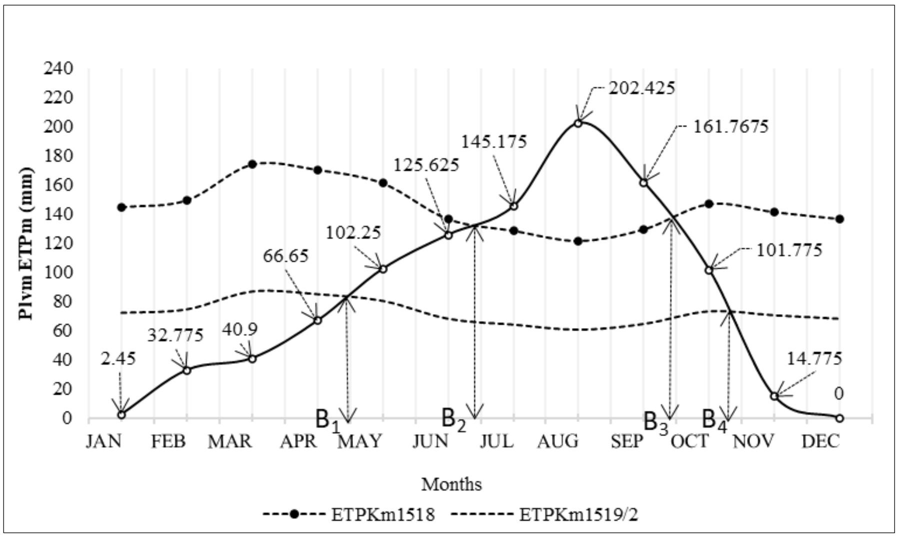
From 1992 to 1995, the post-humid period was represented by A3-A4 (Figure 5). Post-wet range started from mid-October to early November, and lasted 15±6 days on average. Then, from 2015 to 2018, the post-humid period concerned B3-B4 spots (Figure 6). It started from October to November 1st decade, and lasted 21±10 days on average. However, at 5% threshold, there was no significant difference between 1992-1995 and 2015-2018 intervals.

It emerged from annual diagrams data statistical analysis that total wet season duration was for 1992-1995, and 2015-2018, 214±16 and 156±16 days, respectively. This represented a significant 58 (-27%) days shortening in average. Likewise, between 1992-1995 and 2015-2018 periods, there was a significant 48 days (-32%) reduction in wet period duration. Overall, it appeared to be a significant reduction in wet season duration. In this context, it was important to analyze active vegetation period evolution. According to PR-PICA[11], intermittent rains with long interruptions limit cotton seedlings establishment. In addition, West African region experienced rain cessation in September or October, depending on counties[38]. Consequently, due to this poor rainfall, at agronomic level, sowing was not carried out on accurate date[8]. Thus, cropping starts are concentrated between June 2nd decade and July 1st[8]. In fact, FAO[31] highlights the wet period importance for varieties successfully cultivated outside their origin area. The observed wet season shortening influences also active vegetation period.



Source: SODEXAM data (2024)

Figure 5 Average wet period duration in Korhogo from 1992 to 1995



Source: Obtained by Moving Average from SODEXAM data (2024)

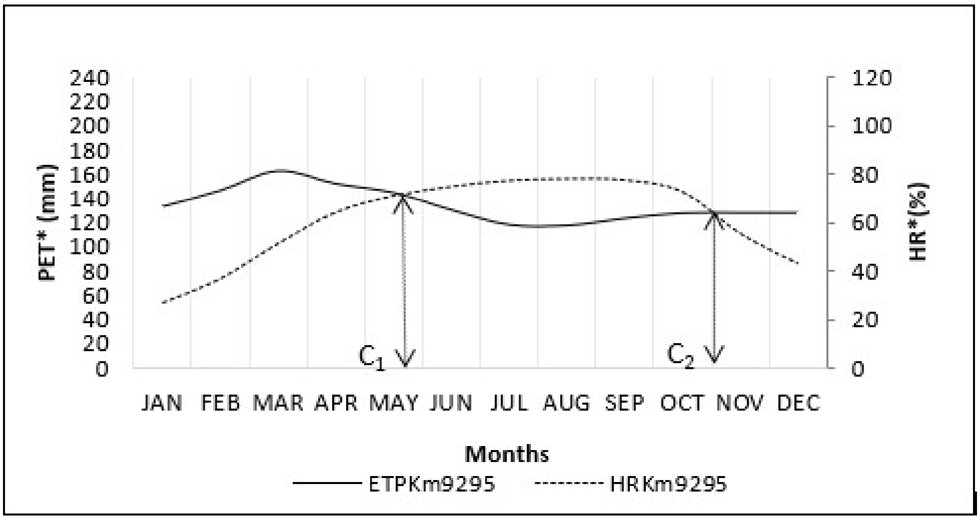
Figure 6 Average wet period duration in Korhogo from 2015 to 2018

3.3. Active vegetation period

The ETP-HR climatographic which defines active vegetation period (AVP) was established for each year in the 2-year groups (Table 3).

Table 3 Active vegetation period (AVP) days

Variable	Average in days	Standard deviation
AVP 1992-1995	153^{g}	17
AVP 2015-2018	131^{g}	27



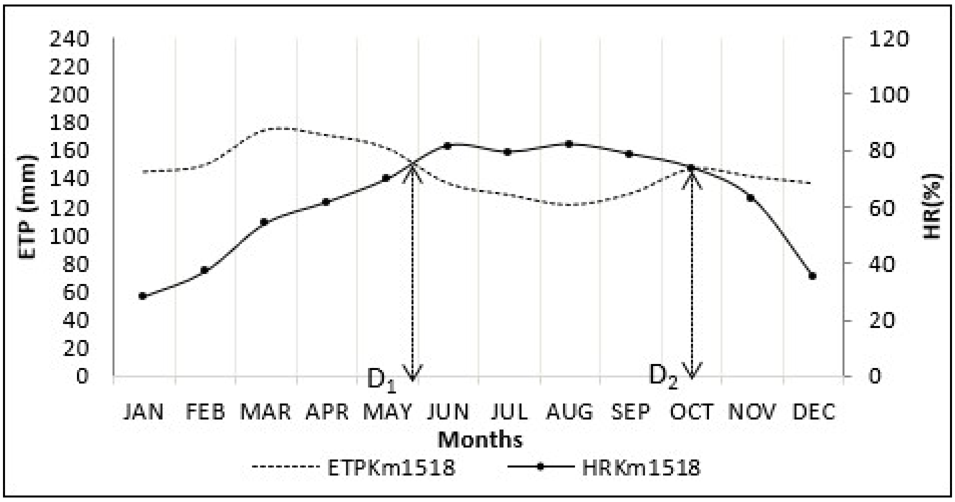
Source: SODEXAM data (2024); PET: Potential evapotranspiration; RH: Relative humidity

Figure 7 Active vegetation period in Korhogo from 1992 to 1995

The drop in AVP observed between 1992-1995 and 2015-2018 intervals was not significant. For 1992-1995 (p=0.228). The active vegetation period is represented by the C1-C2 segment (Figure 7). It starts from May 3rd decade to October end and corresponds to 153±17 days duration. Similarly, for 2015-2018, AVP was represented by D1-D2 segment (Figure 8), and it lasted from May end to mid-October. Its average duration was estimated at 131±27 days. Thus, for

AVP, from 1992-1995 to 2015-2018, there was 22 days (-14%) decrease, which was not significant. The results over the two years studied showed statistically similar active vegetation period durations for 153±17 and 131±27 days in Korhogo. According to Fourier[14], theoretical vegetation period, which evaluates from climatic parameters year time when plant growth is theoretically possible, varies from almost 300 days in the south to less than 150 days in the north.

Continuing, Bambara[29] indicated that active vegetation period duration overall dynamics is decreasing. In short, according to Forestier[39], fruiting phase completion as well as various factors effect can be estimated by seed abortion rate. Indeed, for Kanohin[40], drought effects following rainfall drop, has led to a decrease in coffee, and cocoa productions. In addition, water availability has always been a key factor in driving cotton production[41]. Particularly, its insufficiency can negatively affect physiological, and biochemical processes in the plant, leading to fiber yield loss[41].



Source: SODEXAM data (2024)

Figure 8 Average vegetation period in Korhogo from 2015 to 2018

Thus, the factors that affected rainfall, relative air humidity and potential evapotranspiration had an impact on favorable period duration for rainfed crops development from 1956 to 2015[29]. Also, in these conditions, it's difficult to know when to start short-cycle crops, whether in the first or second rainy season[7]. Farmers are forced to practice successive sowing without success certainty[7]. In this context, farmers' knowledge combination with scientific data can lead to obtaining sustainable adaptation methods to climate change[42]. Thus, these new strategies will appear to populations as innovations in their implementation. According to Pastori[43], it becomes possible to predict that more intensive agricultural practices adoption can enable to effectively increase capacity to adapt to climate change impacts. In short, these sustainable methods involve, among others, the use of hydrophilic organic materials[44], irrigation[45] and/or cultivars with an adapted cycle.

4. Conclusion

It appears from collected data analysis in Korhogo area that, from 1995 to 2018, rainfall experienced a downward trend, which was not statistically significant. In addition, the wet season, over this period, was significantly reduced by around a month and half. This situation affected the wet period which was closely linked to crops establishment. For cotton cultivation, this situation resulted in sowing dates delay, therefore done from June 2nd decade to July 1st decade. This led to late cultivated plots increase, whose final yields were below those produced by planting on wet season beginning. Finally, cotton cultivation was affected by climate change. Also, available land exploitation requires new farming techniques that make it possible to adapt to climatic hazards. By observing climate change over the last three decades and using models that help to predict future climate with a high probability, opportunities have emerged to contribute to populations' resilience. These attitudes include, among others, sowing dates precision for a rain-fed crop such as cotton, with its economic importance. Thus, its implementation must consider not only the wet season duration but also, and above all, the active vegetation period. In this sense, monitoring the useful water reserve in the soil during June and July months in Korhogo is essential. Among available resources as short-term measures, are irrigation and moisturizing organic materials. These absorbent granules seem to offer, under trials confirmation, more application flexibility than irrigation devices. While continuing these studies, it may be considered to recommend cotton varieties with a sufficiently short cycle to be adapted to new wet and active vegetation periods' durations. Finally, research is mainly oriented towards the rural world, given its sensitivity to climatic hazards. However, it is also important to consider urban populations. Indeed, cities are increasingly impacted by extreme climatic phenomena.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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