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Extreme Rainfall Analyzing In The Departments Of Zou And Collines (Central Part Of Benin Republic)

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ABSTRACT: In West Africa, the sharp decline in rainfall since the 1970s has occurred in conjunction with an increase in flood damage. If an increase in the vulnerability of the populations is undeniable, the question of an 'evolution of the rainfall hazard in particular of the most intense rains remains - especially in a context where the reheating climate should be accompanied by an intensification of the global hydrological cycle. The region of the Zou and Collines Departments (DZC) is located in the center of Benin where more than 65% of the population is engaged in agriculture as its main socio-economic activity. It is a traditional type of agriculture whose annual development follows the rhythm of the climate. In these conditions of total dependence on rain-fed agriculture, yields also follow the rhythm and quality of annual rainfall. Therefore, rainfall variations induced by climate change can only negatively impact agricultural yields. The main objective of this research is to make a comparative study of the evolution of rainfall extremes from two synoptic stations (Bohicon in the south and Savè in the north) of our field of study and this from rainfall data at the daily time step from 1961 to 2018. Thus, eight (08) indices with a sawtooth fluctuation reflecting changes in rainfall evolution were selected. The calculation of seven (07) of these indices was performed using ClimDex software in the R environment. The number of annual rainy days (NjP) is calculated from R-Instat +. It appears from this study that at both stations, five of the seven indices calculated namely, the maximum rainfall of one day (Rx1day), the maximum cumulative rainfall of 5 days (Rx5daiy), the very wet days (R95) the extremely wet days (R99p) and the consecutive dry days (CDD) have increased. While, the annual total rainfall (PRCPTOT) and consecutive wet days (CWD) experienced a decrease. In general, the region of DCZ is experiencing fluctuating rainfall with an ascendancy of dry sequences during the cropping seasons. This situation inevitably affects human activities, in this case agriculture, which remains the main socio- economic activity of the majority of the population.

Key words: Departments of Zou and Collines, trends, rainfall, extremes

1. INTRODUCTION

In developing countries, populations are increasingly exposed to violent climatic phenomena, and as a result, the study of climatic hazards is becoming a major societal issue. Repeated floods, droughts, heat waves, strong winds, etc. are extreme manifestations of the climatic components that influence the extreme manifestations of climatic components that negatively affect human activities, Kouame Y.M. et al. 2013, p11. These climatic changes could lead in their extreme values to harmful consequences such as floods or drought on the environment. However, agriculture, which is mainly rainfed, remains a very important source of income for this region and could therefore probably be compromised by this change and these devastating extreme climate variabilities, Boko M. et al. 2007, p8.

Like other West African countries, Benin and particularly the departments of Zou and Collines are still regularly affected by agricultural droughts, which prompts continued efforts to improve knowledge of this hazard and its impacts on the population. But the constant increase in damage related to torrential rains and floods, Eteka J., 2018, p6 also motivates an improvement in knowledge of the hazard around "wet extremes" in order to propose adequate protection and adaptation measures.

1.1. Presentation of the study area

The departments of Zou and Collines are located in the central part of Benin, and are situated between 7° and 8°5 north latitude and between 1°4 and 2°4 east longitude (Figure 1). Covering an area of 19075 km^2, this zone territorially represents 1/6 of the national territory with 1,514,365 ha of cultivable space, Adam K. S. and Boko M. 1993, p10.

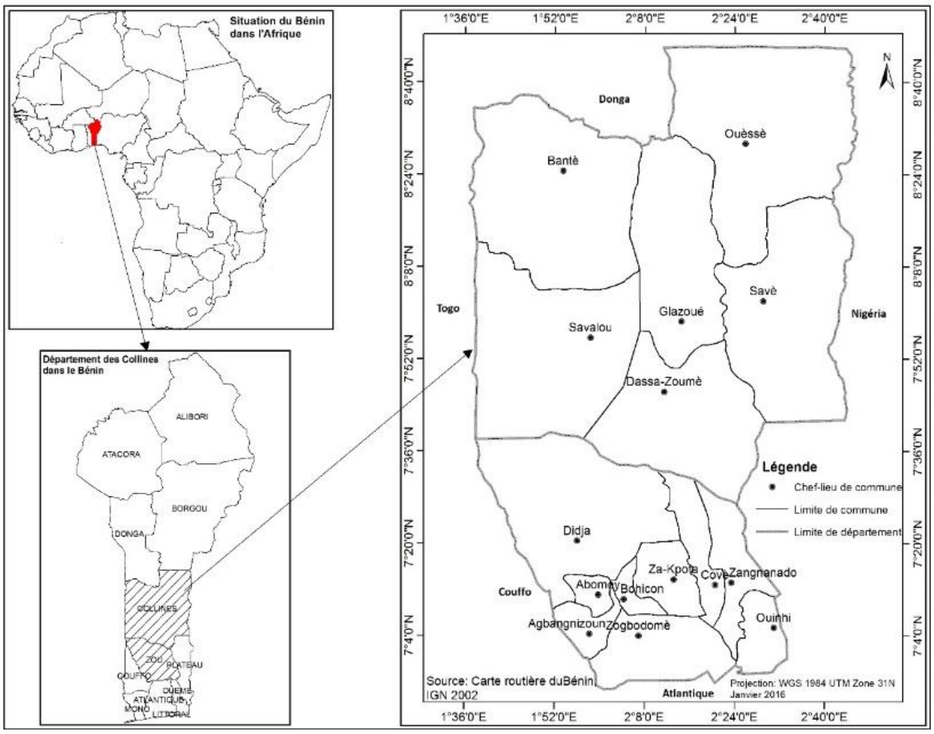
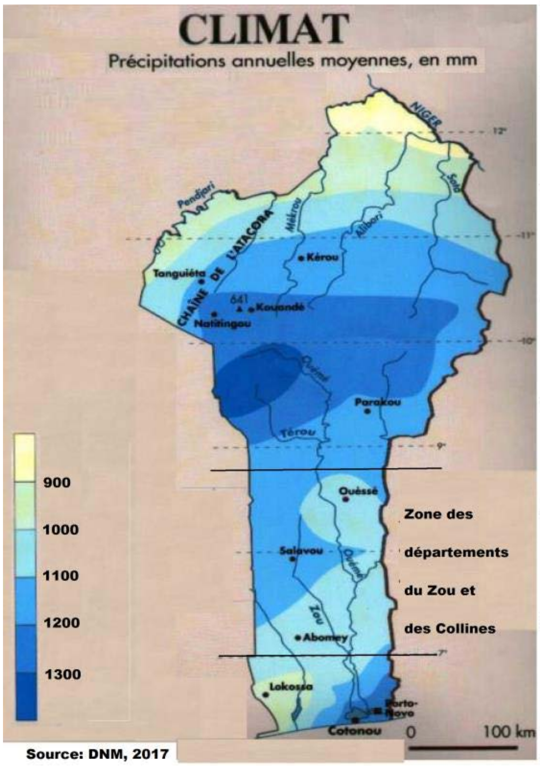


Figure 1: Administrative situation of the departments of Zou and Collines

In the north, the landscape is an undulating peneplain with hills averaging 300 m in altitude on Precambrian material consisting of more or less metamorphosed granitic rocks: granite, granito-gneiss, gneiss and oiled gneiss. On other hand, in the south, the relief is made up of plateaus with depressions with geological substrates bearing the soils of the sub-region that territorially represents the department of Zou. These are the terminal continental soils and their variants. Hydromorphic soils and black soils are found in some areas. The hydrographic network region is composed of small valleys with flat bottoms. The vegetation varies from open savanna in the south to wooded savanna and even open forest in the northwest.

Due to its geographical configuration, this area is representative of the major climatic zones that determine Benin (Figure 2).

The rainfall regime is embedded in the rainfall system that governs Benin. This characterizes this territorial portion as a relatively well-watered area. Average annual rainfall varies between 900 mm and 1200 mm with an uneven distribution of rainfall (Figure 2)



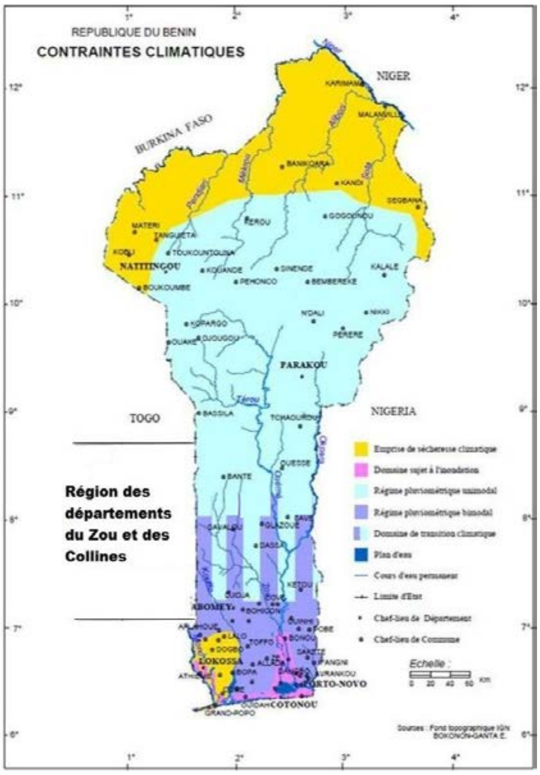


Figure 2: Climate of Benin Figure 3: Map of climatic constraints of the study area

(Sources: IGN topographic base, BOKONON-GANTA E., 1992)

Rainfall patterns vary in time and space. Thus, the parallels 7°45 and 8°30 delimit three domains: a bimodal domain south of 8°N, a unimodal domain north of 8°. Between these two domains, there is a climatic regime domain called transitional climate zone. The inter-annual variations in rainfall occurrences (sometimes uni-modal, sometimes bimodal) confirm the random nature of this so-called transitional climate regime (Figure 3).

Figure 3 shows the different sectors where the rainfall status imposes major constraints, but also the change where the alternating moisture regime (unimodal or bimodal) constitutes to some extent a natural limiting factor for the development of socio-economic activities, in this case agriculture. The average temperature varies between 27 and 31°C on a monthly basis, Ogouwale E, 2006, p47. The average minimum temperature is 20°C. The maximum temperature is close to 37°C in March and drops to 30°C in July. It increases again from October and remains at 35°C the rest of the time. The average monthly thermal amplitude can reach 10°C, with minima in August and maxima in March, Adam and Boko, 1993, p15.

2. MATERIALS AND METHOD

2.1. Materials

1.1.1. Climatic databases

Data collection combined qualitative and quantitative methods. The rainfall data used in this study are on a daily and annual time step and cover the period 1961-2018, i.e. a 58-year chronicle. They were collected from the services of Météo-Bénin. Two (02) synoptic stations are taken into account. These are Bohicon (in the south) in the sub-equatorial climate zone and Savè in the north in the humid tropical climate zone of our study area (Figure 4).

Figure 5 shows from the 8% N parallel, ACMAD, 2015, p12, the geographical distribution of the two major climatic zones in effect in the Zou and Collines departments. The analyses were based on the statistical data from the processing. Thus, frequencies, averages were calculated. The compiled and synthesized results were represented in the form of tables and graphs.

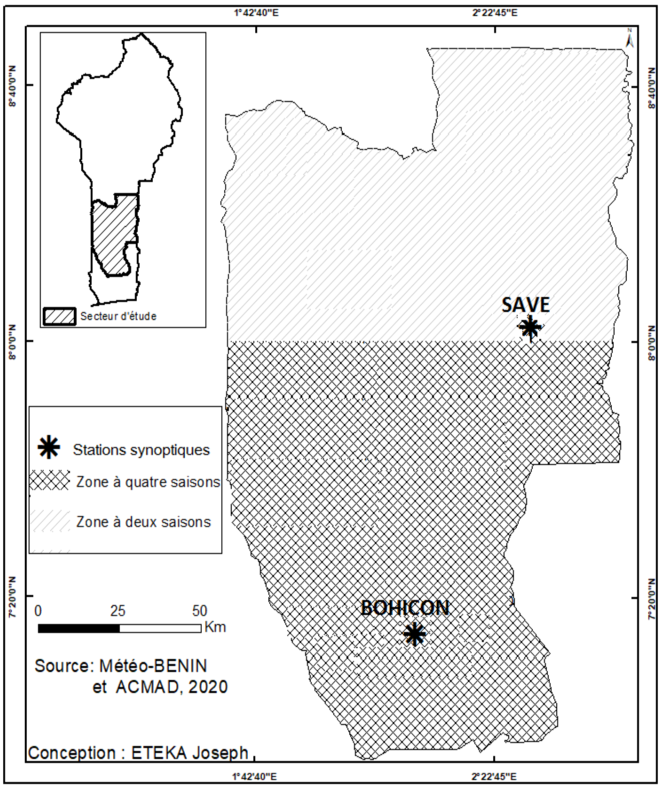


Figure 4: Synoptic station layout

2.1. 2. Treatment of missing data

The study period (1961-2018) presented some gaps. In order to overcome this problem, the method of gap filling by simple linear regression adopted by Yabi, 2006, p16, was used. According to the calculations, only the station of Savè has scattered daily gaps over the period 1999-2010. These gaps represent 3.56% of the series.

2.2. Methodology

2.2.2. Methods for studying rainfall variability,

They concern the parameters of central tendency, dispersion and analysis of indicators of extreme rainfall events. Precipitation was summarily analyzed from the statistics. Indeed, graphical representations of the polynomial moving average or smoothing were made for a step of 04 years.

2.2.3. Central tendency parameter

The arithmetic mean is the most widely used statistical tool in climatology studies, Houdénou C., 1999, p23; Vissin E., 2007,p58. In this study, it was calculated over a 58-year series, and remains representative of the climate over a long period, Brücher E., 2009, p37. It is obtained by summing the distinct values that have been observed, each of which is assigned a weight equal to its frequency, Vissin E., 2007, p67. It is expressed as follows:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

(*n* is the number of observations)

The average $\bar{x}$ permitted to identify the different rainfall patterns, the average fields and to characterize the evolution of the different rainfall indexes.

♦ Dispersion parameter

The dispersion parameters are calculated from the fundamental central tendency parameter that is the mean. But in the context of this study the choice is made the coefficient of variation.

♦ Coefficient of variation

It is the most used means to test and quantify the variability of a reality or a statistical phenomenon. It is the ratio of the standard deviation to the mean, expressed as a percentage. It is written as follows: $C_v = \sigma(x)/\bar{x}$ when $\bar{x}$ is the mean and σ(x) the standard deviation

The coefficient of variation is a parameter that makes it possible to compare the degree of variability of rainfall in space. However, it cannot be applied to all regions, especially in desert environments, because it sometimes exaggerates and amplifies variability.

♦ Coefficient of variation

This is a statistical index that expresses the intensity and positive or negative direction of the linear relationship between two quantitative variables, Amoussou, 2010, p43. It is a measure of linear relationship, that is, the ability to predict one variable x by another y using a linear model. In this study, it is used to measure the degree of linkage or dependence that exists between rainfall and years of occurrence for the two stations located at different latitudes in the departments of Zou and Collines. It is noted r and defined by the formula:

$$r = \frac{\frac{1}{n}\sum(x_i - \bar{x})(y_i - \bar{y})}{\sigma(x)(y)}$$

Where: n is the total number of individuals; x_i and y_i are the values of the series; and $\bar{y}$ are the means of the variables; σ(x) and σ(y) represent their respective standard deviations. This coefficient varies between -1 and +1 and that the intensity of the linear relationship is stronger the closer the coefficient value is to +1 or -1 and weaker the closer it is to zero (0). On the other hand, when r = 0, there is no linear relationship between the variables.

♦ Coefficient of determination

The coefficient of determination is the square of the r (linear regression coefficient) and determines how well the regression equation fits to describe the point distribution. It has been used in many fields, including meteorological characterization to better appreciate the relationships between parameters, Totin H. 2010, p7; Kodja J. et al., 2011, p6; Faye et al., 2015; Koumassi, 2014, p8. It is obtained by the formula: R^2.

- if $R^2 = 0$: this means that the equation of the regression line determines 0% of the distribution of points and justifies that the mathematical model used does not explain the distribution of points at all;

- if $R^2 = 1$: this means that the equation of the regression line is able to determine the distribution of the points. It justifies that the mathematical model used and the parameters “a” and “b” of the regression line calculated are those that determine the distribution of the points.

Graphically, the closer the coefficient of determination is to 0, the more diffuse the scatterplots are around the regression line, and the closer the R^2 tends to 1, the closer the scatterplots are to the regression line. When the points are exactly aligned with the regression line, $R^2 = 1$.

Linear trend analysis (expressed as % per year) was performed from 1961 to 2018 by linear regression between the different rainfall indices and time (in years). The slopes thus estimated were grouped into two classes indicating significant (Ha) and non-significant (H0) trends. The boundary of the two classes considered is defined from the Mann-Kendall t-trend statistical tests used to test the assumption of a slope equal to 0.

Thus, when applying these assumptions to the trends in rainfall totals at the two smooth stations, the trend is said to be significant when the probability p of the t-test applied to the regression slope is less than 0.05, while it is not significant when it exceeds the 0.05 threshold.

The use of the indices is of paramount importance as these values allow easy comparisons of trends between the two sub-regions belonging to different climate zones. Indices of climate extremes are easily understood and manageable for socio-economic climate impact studies, Christensen et al., 2002, p32.

♦ Smoothing

The smoothing in this study is a polynomial regression of degree 4. It is a statistical analysis that describes the variation in rainfall that is considered as the random variable explained from a four-year sliding polynomial function of the explanatory random variable that is time expressed in years. This is a special case of multiple linear regression, where the observations are constructed from the powers of a single variable. The graphical representations of the smoothing (the moving or sliding average) allow the removal of inter annual transient fluctuations and to identify long-term trends. This reduces the noise of the time series variation.

2.2.4. Method of analysis of indicators of extreme rainfall events

Events constitute important factors of vulnerability of populations, Hountondji Y.C. et al., 2001, p9, particularly extreme rainfall events. To better understand these phenomena, the development of indices is suggested as a relatively simple way to better understand these phenomena, the development of indices has been suggested as a relatively simple means of analyzing changes in precipitation events that potentially have an effect on the natural and human environment.

Many indices are based on percentiles with thresholds set to assess moderate extremes that typically occur a few times per year rather than the high-impact events observed once per decade. For precipitation, percentile thresholds are calculated from the sample of all rainy days (regardless of precipitation amount) in the study period. These indices provide a direct assessment of trends in the frequency or intensity of both moderate and extreme rainfall events.

2.5. Choice of indices

The primary objective of this study is to analyze rainfall extremes. In order to achieve this objective, the indices were calculated with the RclimDex, ZHANG X. and YANG F., 2004, 20p, software, using a series of indices and specifically twenty-seven climatic indices (27). For the circumstance, seven of these indices have been retained. These are indices that best express and translate the variability of extreme rainfall values, New M. et al., 2006, p15; Aguilar A. et al., 2009, p23; Hountondji Y.C. et al., 2011, p6. The identities, names, and calculation methods of these indices are presented in Table 1.

Table 1: Selected indices of daily precipitation extremes

Rainfall				
N°	**Indexe**	**Descriptive name**	**Définition**	**Unit of measurement**
1	PRCPTOT	Annual Précipitation	Annual total precipitation in wet days	mm
2	Rx1day	Daily precipitation	Monthly maximum 1-day precipitation	mm
3	Rx5day	Maximum 5-day rainfall accumulation	Monthly maximum consecutive 5-day precipitation;	mm
4	R95p	Very wet days	Annual total precipitation when daily precipitation amount >95th percentile	mm
5		Extremely wet days	Annual total precipitation when daily	

	R99p		precipitation amount >99th percentile	mm
6	CDD	Consecutive dry days	Maximum number of consecutive days with daily precipitation amount <1mm	Day
7	CWD	Consecutive rainy days	Maximum number of consecutive days with daily precipitation amount >=1mm	Day
8	NrD	Number of rainy days	Number of days with cumulative daily rainfall greater than ≥1 mm	Day

NB: For the figures showing the evolution of the indices (RclimDex results), the broken lines indicate the variation of the said indices. The thick lines and the dotted lines represent the trend curve and the smoothing curves, respectively.

The study of rainfall in a geographical area requires the manipulation of a series of data whose processing is facilitated by certain specific software. Thus, in this study, several software packages were used. These are Khronostat, RClimDex, R-Instat plus, Excel.

3. RESULTS

3.1. Analysis and interpretation of rainfall indices

3.1.1. Maximum Rainfall Day Index (R1day)

The R1day index indicates the maximum total precipitation of a rainy day. Figure 6 shows that this index is increasing at the Zou and Collines department station.

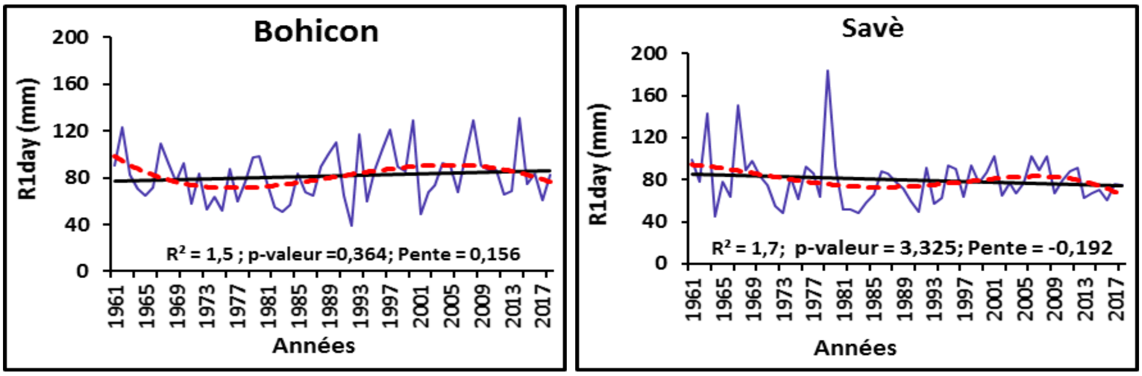


Figure 5: Annual variation and linear trend (solid line) of the RX1day index values at the Bohicon and Savè stations

NB: For all figures, note Pente is Slope estilate and p-valeur is p-value

The trend of the regression line is 1.5 mm/year at Bohicon and 1.7 mm/year at Savè. Thus, in one decade, an antagonistic situation is recorded insofar as this index increases by 15 mm in Bohicon and decreases by 17 mm in Savè. This increase/decrease is corroborated by the slope, which is positive in Bohicon (0.156) and negative in Savè (-0,192). On average, it can be said that in the departments of Zou and Collines, this index increases by 1.6mm/decade, although there is a clear demarcation on either side of the parallel 8°N.

The smoothing curve shows three phases for the evolution of the index at the Bohicon station. The first phase shows a decrease from 1961 to 1977. The second phase is the growth phase from 1978 to 2005 and from 2006 to 2018, there is a decrease in the index. In Savè, the smoothing curve follows practically the same pattern as in Bohicon, but because of the overall decline in the trend (slope = -0.192) varies depending on whether one is in Bohicon or Savè.

3.1.2. Indices of maximum cumulative rainfall over 5 days (RX5day)

Figure 7 shows the evolution of the 5-day maximum cumulative rainfall (RX5day). This is an index that corresponds to the total maximum precipitation over 5 consecutive rainy days during the year. The trend of this index varies depending on whether one is to the south or north of our study area. Thus, while this index is increasing in Bohicon (20 mm/year), it is decreasing in the Savè area (6 mm/year). We note that the increase is less than the decrease. Thus, it can be said that overall this index is changing in the Zou and Collines Departments from 1961 to 2018 (Figure 7). The shape of the slope confirms the overall trend of a decrease in the volume of precipitation in the South-North gradient.

The observation of the smoothing curve shows three phases in Bohicon: two phases of decrease 1961-1978 and 2005-2018). On the other hand, the growth phase covers the period 1979 à 2004. In Savè, the smoothing curve seems to adopt a single decrease trend over the study period.

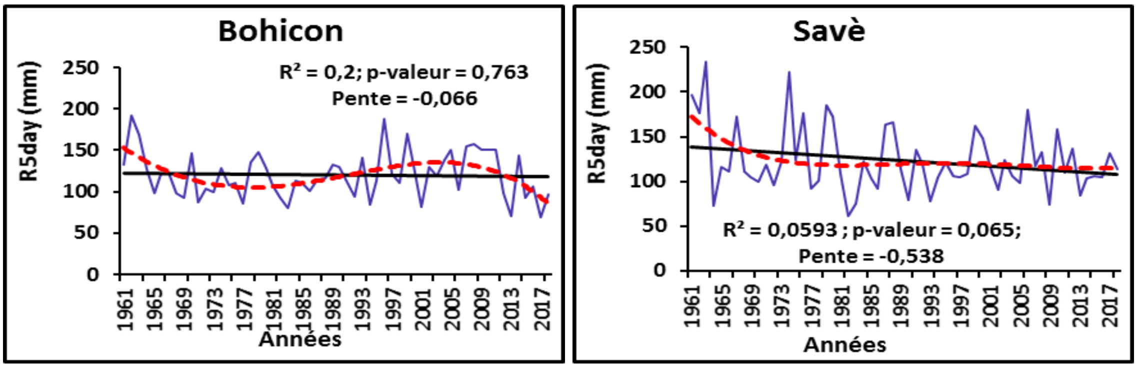


Figure 6: Annual variation and linear trend (solid line) of RX5days index values at Bohicon and Savè

In sum, we can say that the index of wet sequences of maximum total precipitation over 5 consecutive rainy days during the year is increasing in Bohicon, while it is decreasing in the Savè region further north in our study area.

3.1.3. Very wet day index (R95p)

Total rainfall is divided into percentiles and the R95p index represents the 95th percentile of cumulative rainfall above the 95th percentile. These are the very wet rainy days. In the context of our study, we have materialized this index in Figure 8. The curve of this index shows the evolution during the selected period, i.e. 1961-2018 at the Bohicon station with a trend value of 2.6 mm/year. This means that in 59 years (1961-2018), this index has increased by 150.8 mm. On the other hand, at Savè, this index has decreased by 6.8 mm per year, i.e., an overall decrease of 4,39%.

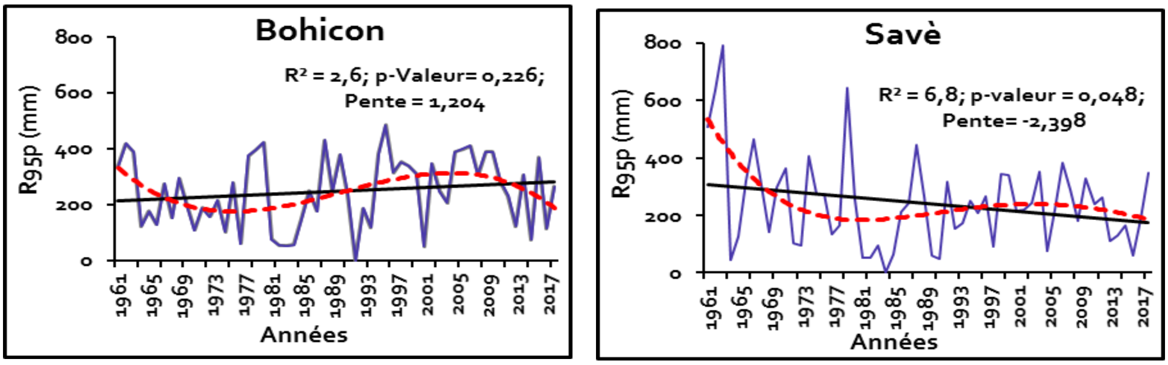


Figure 7: Annual variation and linear trend (solid line) of the R95p index values at the Bohicon and Savè

An analysis of the smoothing curve shows that the evolution of this index has undergone:

-In Bohicon three phases distributed as follows: two phases of decrease (1961-1974 and 2004-2018). As for the period of increase from 1975 to 2003.

-In Savè, this index has experienced three phases in its evolution. These are two phases of (1961-1980 and 2008-2018) and one phase of growth (1981-2007).

3.1.4. Extremely wet day index (R99p)

From the observation of Figure 9, it can be seen that extremely wet days (R99p) are increasing by 9 mm/year in Bohicon and 4.1 mm/year in Savè, i.e. an increase of 1.4 mm/year in Zou and Collines departments. This means that in 58, the days increased by 522 mm in Bohicon while it decreased by 237.8 mm in Savè. When we look at the interpretation of the smoothing curve, we see that the curve is almost identical for the two stations. Indeed, we note that the index of extremely wet days (R99p) has undergone three major phases of evolution reflected by the shape of the smoothing curve: a growth phase and two phases of decline that frame the growth phase. However, the decrease is more pronounced in Savè, where the cumulative rainfall drops from 200 mm, whereas it is 153 mm in Bohicon (y-axis value).

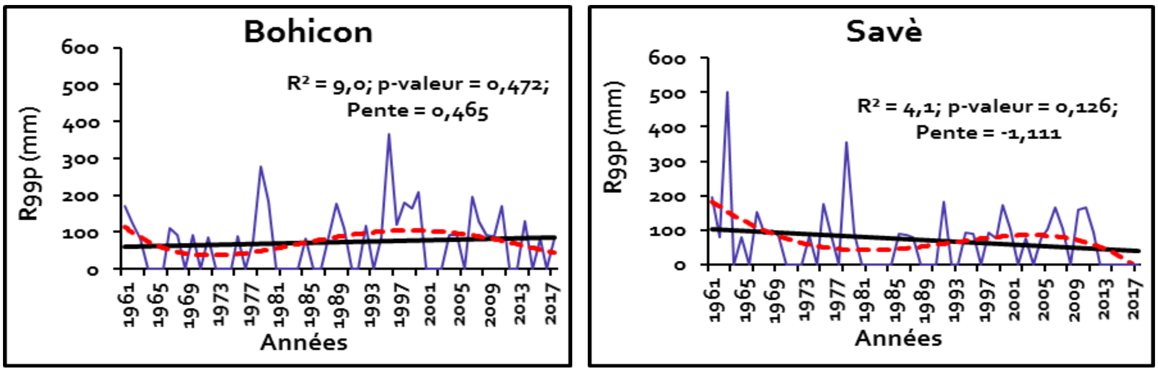


Figure 8: Annual variation and linear trend (solid line) of the values of the R99p at Bohicon and Savè

The very wet days (R95p) and the extremely wet days (R99p) constitute the most important daily water inputs in relation to their thresholds (at the 95th percentile and 99th percentile).

Due to the amount of water brought in, they can contribute to natural geohazard phenomena such as flooding, landslides, soil erosion, etc. Indeed, the Heavy Rains are not without disadvantages for plants: waterlogging, flooding, etc.. These are extreme values at risk but at the antipode of drought which are however two situations that negatively impact agricultural yields in the departments of Zou and Collines.

3.1.5. Number of consecutively wet days (CWD)

Figure 10 presents the evolution of consecutively wet days at the Bohicon and Savè stations. Analysis of the curve shows a decrease in the index in the region. In both Bohicon and Savè, the slope of the trend line is negative but more pronounced in Bohicon (R^2 = -0.025) than in Savè (R^2 = -0.022). Statistically, this index is significant because the P-value is 0.02 in Bohicon while it is 0.101 in Savè. In conclusion, we can say that the number of consecutively wet days is constantly decreasing in the Zou and Collines departments, but this decrease is more pronounced in the Bohicon region than in Savè. This decrease is in the order of 9.2 mm in Bohicon, i.e., 533.6 mm over the study period, whereas in Savè, it is 4.7 mm per year, i.e., 272.6 mm in 58 years. Contrary the overall pattern of rainfall decrease, which has a south-north gradient, the index of consecutively consecutive wet day decreases from north to south.

The index that characterizes the number of consecutively rainy days determines the length of the rainy seasons and, in turn, determines the agricultural cropping period, especially in the inter tropical zone where irrigation is almost non-existent. The duration of crop cycles is a very important factor in agricultural production. It serves as a compass for farmers in choosing the varieties to be grown, who prefer to opt for shorter cycles depending on the yield capacity of these varieties.

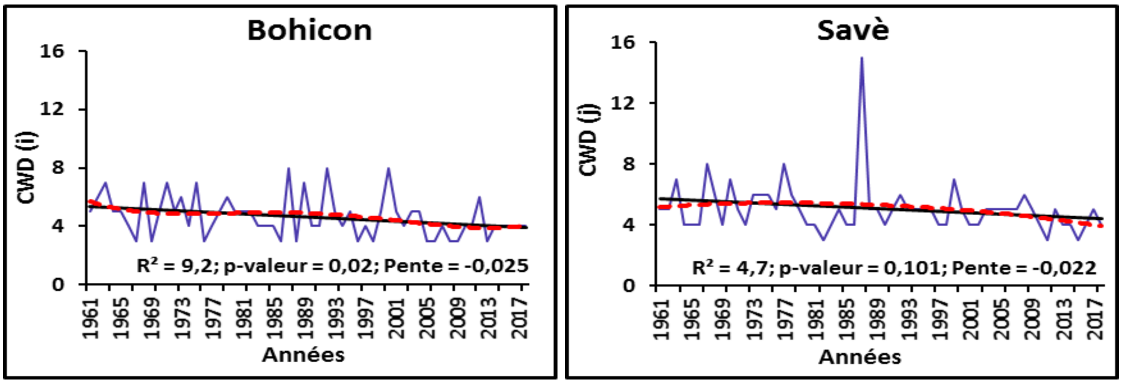


Figure 9: Annual variation and linear trend (solid line) of CWD index values at Bohicon and Savè

A crop variety whose cycle length is significantly longer than the length of the rainy season is automatically tested, so yields deteriorate.

3.1.6. Consecutive Dry Day Index (CDD)

The values of this index vary from 24 to 134 in Bohicon and from 72 to 138 in Savè. The average days are 72 and 88 respectively in Bohicon and Savè. The highest number of consecutive dry days was observed in Bohicon in 1992 with 134 days, while in Savè, this index was 138 days in 1978 with 138 consecutive dry days. The lowest numbers of days (24 days) are observed in 2014 in Bohicon and Savè 1976 with 72 days. The smoothing curve in Figure 11 shows three phases of evolution in Savè. This evolution is characterized by an increase from 1961 to 1973. From 1974, this curve begins a gradual and continuous decline until 2000. The resumption of the increase begins in 2001 and continues until 2018. On the other hand, in Bohicon, we observe an almost convex curve whose beginning corresponds to an increase from 1961 to 2009. From 2010, this curve falls and thus the consecutive dry days begin to decrease until 2018.

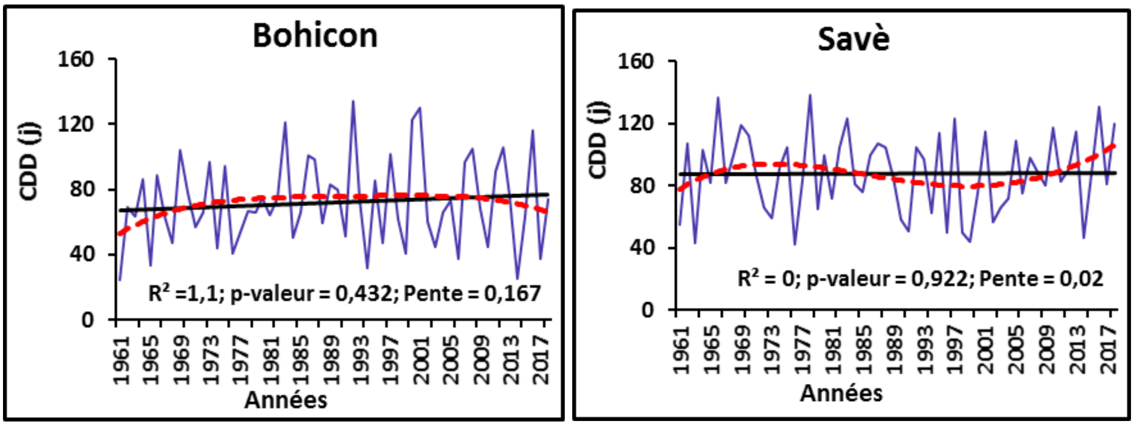


Figure 10: Annual variation and linear trend (solid line) of CDD index values at Bohicon and Savè

From the results obtained from both CWD and CDD, we can say that the Zou and Collines departments are experiencing a relative decrease in the number of wet days, while the dry sequences are increasing. However, it must be said that this trend is stronger in Savè than in Bohicon. In any case, these results confirm the conclusions that nowadays there is an increase in the length of dry occurrences that correspond to dry seasons and a shortening of the rainy seasons in our study area. Consequently, given that the majority of the population in the departments of Zou and Collines engage in almost rainfed agriculture, the occurrence of a sequence of consecutive dry days (CDD) within the rainy season is undoubtedly detrimental to agricultural production, which will be affected by this shortening of useful precipitation insofar as the dry sequences create pockets of drought and therefore situations of water scarcity, which accentuates the water stress of plants and, in turn, agricultural crops. When these sequences occur at the beginning or in the middle of the growth period, they can cause a false start to the season or even mortgage an entire agricultural season, Balliet R., 2016, p33.

3.1.7. Annual Rainfall Totals

Figure 13 represents the evolution of the values of annual cumulative rainfall in Bohicon and Savè. Variable over time, the shape of the curves highlights the regression of annual rainfall amounts by the linear trend line. The trend (solid straight line in bold) of the index is the regression of the climatic parameter considered. From the results obtained, it follows that:

- In Bohicon, the R^2 value is 3.2 mm per year. This regression is statistically insignificant ($R^2 > 0.005$) with a p-value of 0.223. As a result, rainfall is increasing by 32 mm per decade. Thus, in 48 years, they have increased by 154 mm. Of course, this linear increase is only the result of annual decreases and increases. Rainfall has fluctuated on an annual scale. Thus, the 154 mm is the overall value of these positive fluctuations observed especially from the 1990s onwards, which are considered to be a period of rainfall resumption of trends towards normal or even surpluses in the Bohicon region. Thus, the highest cumulative rainfall was observed in 1963 with 1861.5 mm and the lowest in 1977 with 537 mm). When we consider the smoothing curve in Figure 13, we see three phases in the evolution of annual accumulations in both Bohicon and Savè: two phases of decrease framing the phase of increase that appears to be the longest. In fact, the decrease from 1961 to around 1,500 mm is more abrupt until 1980. From 1981 onwards, there is a recovery of the smoothed accumulation until 2007, after which the curve begins to decrease once again until 2018.

In Savè, $R^2 = 3.2$ with p-value = -2.528. This value of the regression is well above 0.005 confirming the non-significant character of the correlation between the precipitated blade and the years. But with a negative slope, the trend is in the negative direction meaning that there is a decrease in the volume of rainfall in Savè and its surroundings in the order of 32 mm in 10 years, or 185.6 mm in 58 years. The 4-year smoothing curve for annual rainfall totals has a similar pattern to that of Bohicon. The highest annual accumulations were recorded in 1963 (1927.8 mm) and 1962 (1691.9 mm). These are heights that are no longer reached in the series. This confirms the rainfall break in the 1961-2018 series. The lowest cumulative rainfall was observed in 1983 (633.9 mm).

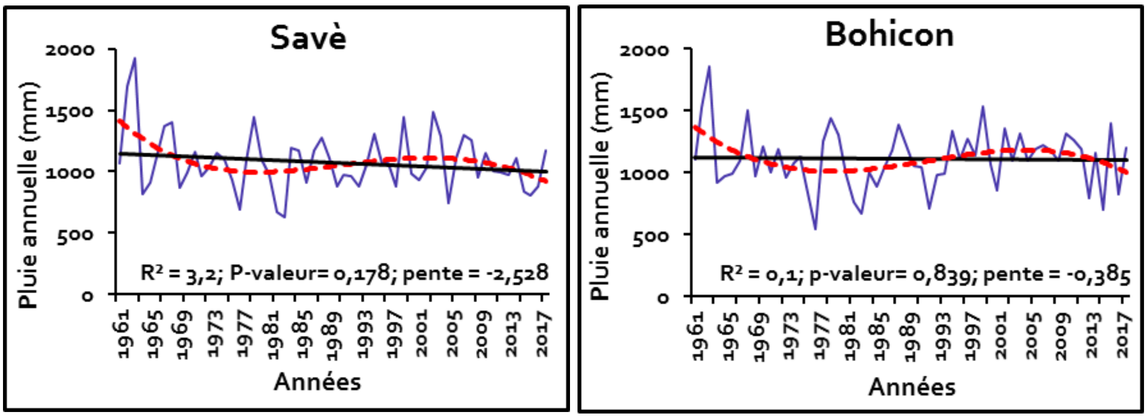


Figure 11: Annual variation and linear trend (solid line) in annual rainfall totals at the Bohicon and Savè

The rainfall totals recorded during a season largely influence agricultural yields. The departments of Zou and Collines recorded an average of 1,094.5 mm of rain over the 1961-2018 study period. This volume is largely sufficient for good crop management, but there is a problem with the geographical distribution of these rainfall amounts: hence the pockets of drought that hinder the harmonious development of agricultural production in the two departments under study.

3.1.8. Indices of average number of rainy days (NdR)

The number of rainy days per year represents the sum of daily rainfall occurrences of more than 1mm. Over the 1961-2018 period, the trend curve (Figure 12) is decreasing in both Bohicon and Savè, confirmed by the sign of the different slopes adopted by the linear curve (-0.1637 in Bohicon and -0.1726 in Savè). From the values of the correlation coefficient (R2) which are 0.0567 in Bohicon and 0.0682 in Savè, we conclude that in the Bohicon region the number of rainy days decreases by 6 days per year, i.e. an average of 348 days in 58 years, the length of the study period. In Savè, R2 = 0.0682, which means that there is a decrease of almost 7 days of rain per year, or 406 days in 58 years.

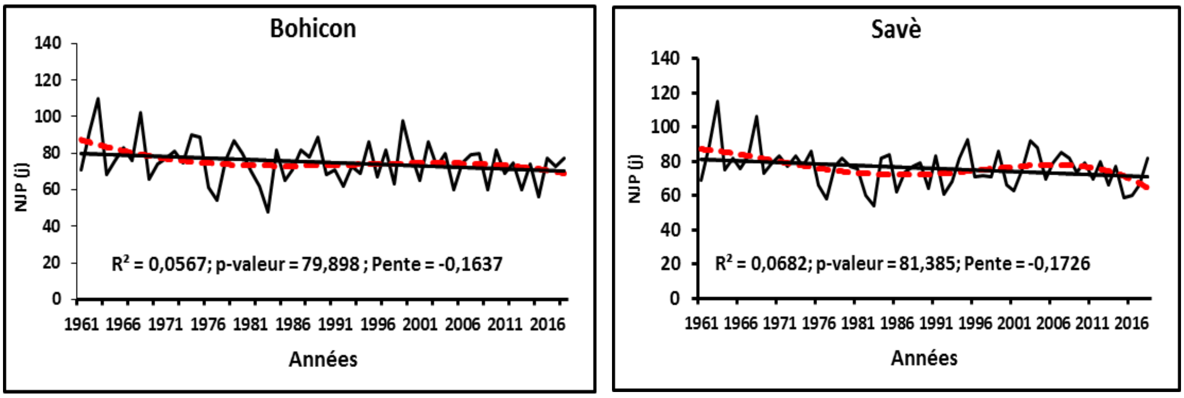


Figure 12: Annual variation and linear trend (solid line) of the NdR index values at the stations of Bohicon and Savè

The decrease in the number of rainy days (marked by the negative value of the slope) constitutes a threat to human activities, especially agriculture. If the poor spatial distribution of rainfall is added to the decrease, then agricultural yields are likely to be negatively impacted.

4. DISCUSSION

The study of the evolution of extreme rainfall values in the departments of Zou and Collines (central Benin) confirms the regression of rainfall levels as one moves away from the coast towards the mainland. Otherwise, a decrease in rainfall with a south-north gradient was observed. With regard to rainfall totals (PRCPTOT), there was an overall decrease but a rainfall recovery in the 1990s. This index experienced an overall increase of 1.6 mm/year from 1961 to 2018 in the departments of Zou and Collines. The CWD index decreased by 7.75 days/year in the region. On the other hand, the study showed that the number of days of dry sequences (CDD) increased by 0.4 days/year in Bohicon and 2.4 days/year in Savè, i.e., an average decrease of 1.8 days/year in the Zou and Collines Departments. The NPPs are decreasing at the regional level. These different results confirm that the region is affected by a rainfall recession with a slight rainfall recovery. These results are similar to those of New et al, 2006, p23; Aguilar et al, 2009, p41, Sahani, 2012, p12; Donat et al., 2013, p9; Balliet, 2016, p6.

Houndénou, 1999, p16, uses a comparison of rainfall for the periods 1931-1960 and 1961-1990 to show that Benin has been experiencing a climatic downturn for the last two decades. Following an analysis of the extreme climatic phenomena observed in Niger (floods, droughts, sand and/or dust storms, extreme temperatures, and violent winds), it appears that the general trend of the phenomena is towards an increase. This deterioration is manifested by a reduction in the length of the agricultural season, a decrease in rainfall potential accompanied by a reduction in the number of rainy days and an increase in temperatures. Indeed, in their study on the evolution of extreme daily weather conditions covering southern and western Africa, New M., et al., 2006, p23, showed that, overall, the regions experienced a decrease in total annual rainfall (PRCPTOT) and the number of rainy days. Aguilar A., et al., 2009, p33, in their analysis of rainfall in Central Africa between 1955 and 2006, came to the same conclusions. In addition to cumulates, Donat et al. 2013, p14, in their study for updating the analyses of extreme temperature and precipitation indices since the beginning of the 20th century showed trends in the CDD index towards drier conditions in East Asia, Australia, South Africa, and parts of South America. Similarly Sahani M., 2012, p9, demonstrated the decline of most rainfall indices in the city of Butembo (North Kivu/DRC).

These similarities in rainfall behavior would be of global scale, Assemian et al.,2013, p21, as it is also verified over certain areas of the Pacific, IPCC, 2007, p46; Merle, 1995, p10. Moreover, this change in rainfall could also be accentuated by an increase in air temperature in the Zou and Collines departments and associated with the impacts of greenhouse gases, Ogouwalé E. 2006, p8; Yabi I. 2008,p165 etc.). These changes, in line with a trend in the increase in temperatures of the regions between the two hemispheres of the order of 0.08°C in 10 years, will lead to a deregulation of the migration mechanism of the inter tropical front (ITF). The ITF determines the climate in West Africa, Péné B.C., 2003, p25; IPCC, 2007, 19; Assemian E.et al., 2013, p12. These decreases in rainfall in Benin and particularly in the region of the departments of Zou and Collines, would also be caused by anthropogenic activities such as production techniques that are still at the traditional stage, bush fires, Eteka ,J. 2010, p27, deforestation for the needs of cultivation spaces and for the manufacture of charcoal and firewood, Oloukoï J., 2010, p64, all things that degrade agricultural land facilitated by water erosion. In fact, extensive deforestation in the departments of Zou and Collines, especially in the northern part corresponding to the Collines department, accelerates the degradation of the lands. This degradation of the vegetation has led to changes and disturbances in the hydrological cycles. The forest is one of the primary factors that creates rain. It is in these alarming conditions that climate change is announced with its negative impacts on human activities, especially agriculture, which remains the most exposed. This situation of climate change by decreasing rainfall in the departments of Zou and Collines can have a negative impact on agricultural production, because most of the speculations are linked to rainfall, especially its frequency and spatial distribution, and also the length of the season, especially since rain-fed agriculture is the most widespread in the study area. All extreme rainfall events constitute irrefutable risks whose major consequences are food insecurity and the disorganization of societies in the departments of Zou and Collines.

5. CONCLUSION

In Benin (West Africa), and more particularly in the departments of Zou and Collines, the

Collines, the agricultural drought conditions that have prevailed since the fin 1960s have been accompanied by a 1960s have been accompanied by a significative increase in flood damage that disrupts people's activities. While vulnerability factors related to high population growth and the lack of operational management of natural resources have undeniably increased the risk related to exceptional floods and pockets of drought, one must also question the role played by a possible increase in extreme precipitation. Generally speaking, this question of possible changes in extreme precipitation has been little studied to date in our study area. However, this study does not claim to have addressed all aspects related to extreme precipitation in the departments of Zou and Collines, but it is unique for several reasons. Thus, from a methodological standpoint, the approach is original on two points: - the rainfall data used in the study were analyzed and homogenized from 1961 to 2018 from daily data allowing for relatively homogeneous and representative coverage in the study area; - we used a classical statistical framework, that of the extreme value theory, which was enriched by the use of statistical tests afin to take into account spatial and temporal non-stationarity.

Regarding the results obtained in the field of climate two main contributions are to be retained we will say that the study of the evolution of extreme events through the rainfall indices from 1961 to 2018 that is to say during 58 years of observations has highlighted the fluctuation of the said indices. Indeed, the PRCTOT and CWD indices show significant decreases in the Zou and Collines departments. On the other hand, the CDD index, like the other indices considered in this study, increased over the same period. The combined effect of the variation of these indices are signs that predispose the departments of Zou and Collines to climate disruption.

From the results obtained, the need to improve our knowledge in the area of the link between climate dynamics and human activities becomes an essential and imperative issue in terms of the impacts of extreme precipitation on the populations of the departments of Zou and Collines, whose main socio-economic activity is riverine agriculture, which is entirely dependent on the rainfall regime.

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