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Climate Changes and New Trends in Rainfall in the Catchment Areas of Boutoute and Guidel in Ziguinchor Region, Senegal

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Abstract The rainfall in Senegal in general and particularly in the Lower Casamance has long been discussed in terms of drought and its impact on the lives of men.vIndeed, in the 1970s, precipitation is marked by deficits in the order of 25% compared to the average for the period 1950-2015. In the second half of the 1990s, the situation is gradually reversed.

The objective of this paper is to study this recent evolution of precipitation in the area. The rainfall data used in this study come from the database of the National Agency of Civil Aviation and Meteorology (ANACIM) and from the reconstruction carried out by DACOSTA [1] in 1986 for the stations of Bignona and Niaguisse on the period 1950-1975.To evaluate changes and trends in rainfall variability, we applied the Pettitt break test [2]. The analysis of rainfall trends with simple parameters (means, extreme values, normal, duration in terms of number of days, precipitated volumes) reveals an increase in precipitation in volume and duration in the Boutoute and Guidel catchment.

Keywords rainfall, trend, Rainfall variability, climate change, break test, Senegal

1. Introduction

The fifth Intergovernmental Panel Assessment Report of the Panel on Climate Change (IPCC) states that "climate change will amplify the existing pressure on water availability for society and the natural environment in Africa and on agricultural systems, particularly in semi-arid environments [3].

Climate change will affect especially agriculture through three main factors: (i) changes in temperature; (ii) changes of the concentration of the greenhouse gases in the atmosphere; and (iii) changes in the regime of the rainy season in terms of length, total volume of precipitation and distribution.The natural region of Casamance has not escaped this trend. In the tropical area, two elements mark the climate: rainfall and temperature. In general, precipitation is exclusive water supply in some parts of Africa in General and the Casamance in particular [4]. Water is central of the functioning of the ecosystems of these regions; it is a serious threat if she were to miss [5-6]. Thus, the objective of this work is to make a fine analysis of precipitation in Casamance including Boutoute and Guidel watershed level in order to detect new trends and have the region's response to the effects of the changes climate. The rainfall data used in this study come from the stations of Bignona and Niaguisse on the period 1950-1975. To evaluate changes and trends in rainfall variability, we applied the Pettitt break test [1]. Rainfall analysis will be discussed on an annual and monthly basis.

2. Materials and methods

2.1. Study Area

Since the 1970s, natural environments have evolved in Senegal. The natural region of Casamance has not escaped this trend. The hydrology of our choice territory consists of two contiguous watersheds: Boutoute and guidel. From the geographical point of view, this territory is circumscribed between the latitudes 12 ° 36'N and 12 ° 25 'n and longitudes 16 ° 18'W and 16 ° 06'W.Administratively, it is located in old rural communities of Niaguis (160 km²) and Boutoupa Camaracounda (360 km²) that is a part of the current district of Niaguis. These administrative districts are limited to the North by the Casamance River, to the South by Guinea Bissau, to the West and to the East by the territories of the former rural communities Nyassia and Adéane. These circonconscriptions are home to 35 villages including whose 18 within the scope of the two watersheds as well as the city of Ziguinchor, which unfolds on the eastern flank of the basin watershed Boutoute. The two watersheds span 178.4 km² in total. The Guidel basin overflows slightly to 10.2 km² in territory Bissau Guinean, which makes it a cross-border basin (Figure 1).

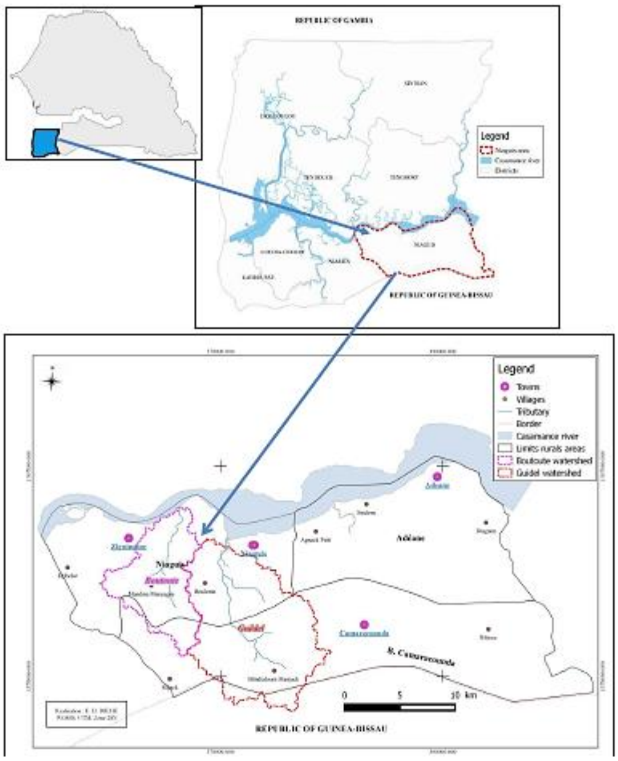

Figure1 : Location of the study area

2.2. Measuring device and data

The rainfall network is relatively dense in Lower Casamance. However, it is struck by several shortcomings, the bad distribution of the rainfall stations recorded in space (Figure 2), the short duration of observations for some rainfall stations and gaps especially in recent periods are not rare phenomena. Taking into account all these elements, we chose the rainfall stations recorded reflected in Table 1.

Table 1: Characteristics of climatological stations

Rainfall station	Position	Altitude(m)	Duration(year)	Category
Bignona	12°40 N 16°16 W	9	64	Rain gauge
Nyassia	12°22 N 16°22 W	10	64	Rain gauge
Ziguinchor	12°33 N 16°16W	26	65	Synoptic
Niaguisse	12°34 N 16°20 W	26	65	Rain gauge

The choice of these rainfall stations is explained by the fact that they are close to the study area, such as the Ziguinchor (Boutoute watershed) and Niaguisse (Guidel watershed), that they are located at close latitudes and that it is good to study them to understand the general trends (Nyassia and Bignona). They also have the advantage of having at least 30 years of rainfall records.

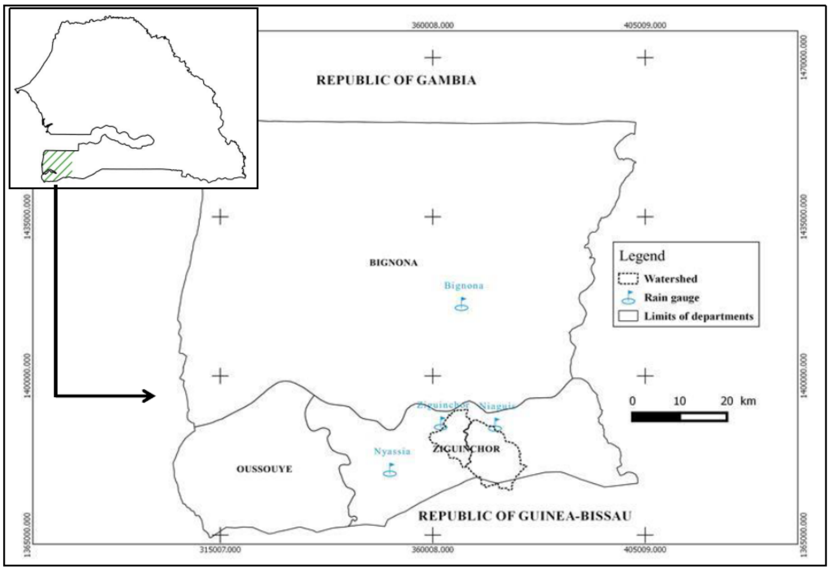

Figure 2 : Location of rainfall stations

Rainfall values were aggregated and analyzed on an annual and monthly scale. All tests and graphs were performed with Microsoft Excel software. The parameters used for the calculations were: significance level of 5%; alternative hypothesis different from zero (0); the p-value was calculated using 10,000 Monte Carlo simulations with a maximum duration of 180sec.; the 99% confidence interval around the p-value:]0.000;0.002[.

3. Results and Discussion

3.1. Detection of breakdowns and interannual variability

We have a long series of rainfall data. It spans some sixty years between 1950 and 2015. The rainfall data used in this study come from the National Civil Aviation and Meteorological Agency (ANACIM) database and from the reconstruction carried out by DACOSTA H. [1] for the stations of Bignona and Niaguisse over the period 1950-1975. To assess changes and trends in rainfall variability, we applied the Pettitt break test [2]. This test makes it possible to detect breaks in a time series of data [7]. It is expressed by the following expression:

$$U(t) = \sum_{i=1}^{t} \sum_{j=t+1}^{n} sign(x_i - x_j) \qquad (1)$$

$$T = max\{|U(t)|, t = 1 \dots n\}. \qquad (2)$$

The sign function is defined as follows: $sign: R \to R$,

$\forall\, x \in R, x \to sign(x)$

$$such\ that \begin{cases} \forall x > 0, sign(x) = 1 \\ x = 0, sign(x) = 0 \\ \forall x < 0, sign(x) = -1 \end{cases}$$

A variant of the statistic is given by:

$$K = max\left\{\left|\frac{U(t)}{\sqrt{nt - t^2}}\right|, t = 1 \dots n\right\}. \qquad (3)$$

The calculation of the probability p, probability of exceeding the k value taken by the statistic T of the test on the observed series is given by:

$$p = P(T \geq k) = 2exp\left(\frac{-6k^2}{T^3 + T^2}\right) \qquad (4)$$

if $p < \alpha$then the null hypothesis is rejected.

For the K statistic, "p" can be calculated using the bootstrap method.

The results obtained following the application of the test for the different rainfall stations are presented in Figure 3.

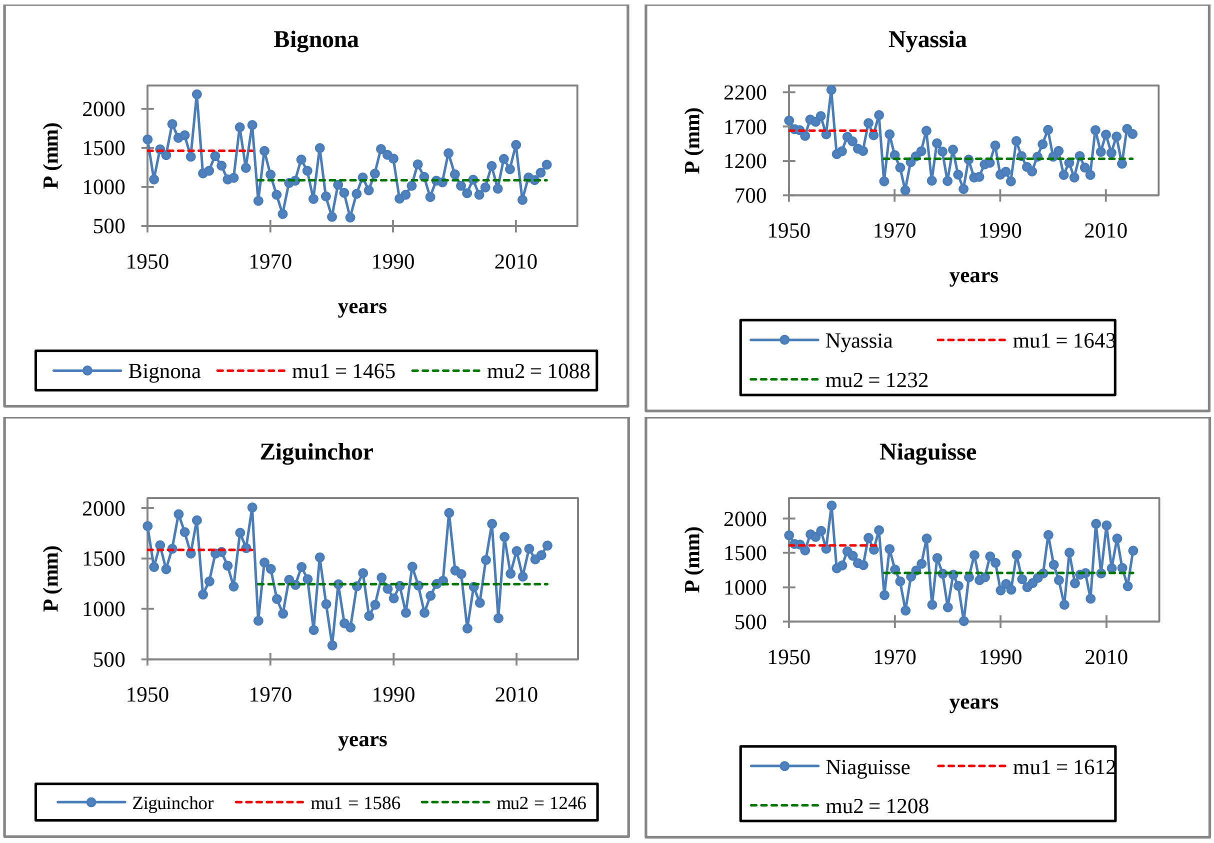

Figure 3: NiaguisPettitt test results from Bignona, Nyassia, Ziguinchor and Niaguisse rainfall station

The results of the Pettitt test parameters applied to the four rainfall stations studied are presented in Table 2.

Table 1: Pettitt test parameters result at the four stations studied

Rainfall Station	**K**	**T (break date)**	**p-value (bilateral) or probability of obtaining a zero value**
Bignona	593	1967	0.001
Nyassia	671	1967	0.000
Ziguinchor	550	1967	0.003
Niaguisse	628	1967	0.000

Thus, for all stations, the year of rupture occurs in 1967. In addition, another test was carried out over a shorter period (1970-2015) and revealed another rupture on the Ziguinchor station series from 1995 onwards. This allows us to divide the series into three periods: 1950-1967, 1968-1995 and 1996 to 2015 (Table 3).

Table 3: Mean annual rainfall

	Nyassia	**Ziguinchor**	**Niaguis**	**Bignona**
Mean. 1950-1968	1604	1549	1573	1431
Mean. 1969-1995	1177	1150	1151	1072
Mean. 1996-2015	1324	1394	1300	1129
		Variation (%)		
Moy. 1969-1995	-26.6	-25.7	-26.8	-25.0
Moy. 1996-2015	12.4	21.2	12.9	5.3

Thus, for these three periods (Table 3):

- The first period is 1950 to 1968. The averages of all stations are high and above 1400 mm. Thus, Nyassia records 1604 mm, Ziguinchor 1549 mm, Niaguisse 1573 and Bignona 1431mm. These means are above the mean of their respective series (Table 3). This period is qualified as wet because it receives mean values above the 1950 to 2015 series mean.
- the second period is between 1969 and 1995. It corresponds to a decrease in means of rainfall. The means for the period (1969-1995) fall below 1200 mm. Deficits relative to the mean of the first period (1950-1968) are very pronounced and exceed 25% (Table 3).
- the last period extends from 1996 to 2015. It is characterised by a mixed evolution of the stations but with a firm tendency to improve the mean rainfall of most of them. These go back to the 1300 mm bar except in Bignona which records 1129 mm. The deficits were reduced by 12.4% in Nyassia and Niaguisse, by 21.2% and 5.0% respectively in Ziguinchor and Bignona compared with the mean for the period 1969-1995.

As a result of this analysis, we detect that the evolution of rainfall is not linear. It varies over time and the rainfall means of the last period (1996-2015) show an improvement trend in terms of annual rainfall volume (Figure 3).

While the Pettitt test made it possible to distinguish breaks in rainfall series, the calculation of the deviation from the mean makes it possible to follow the evolution of deficit and surplus years [8]. The deviation from the mean is obtained by the following expression:

$$\boldsymbol{E_i}(\%) = {}^{(\boldsymbol{P_i} - \boldsymbol{P_m})}/_{\boldsymbol{P_m}} \times \mathbf{100} \qquad (5)$$

With E_i representing the mean deviation, P_m is the average rainfall module and P_i is the total of the year considered.

This calculation reveals the alternation of the deficit and surplus years with respect to the mean of the series (Figure 4 and 5).

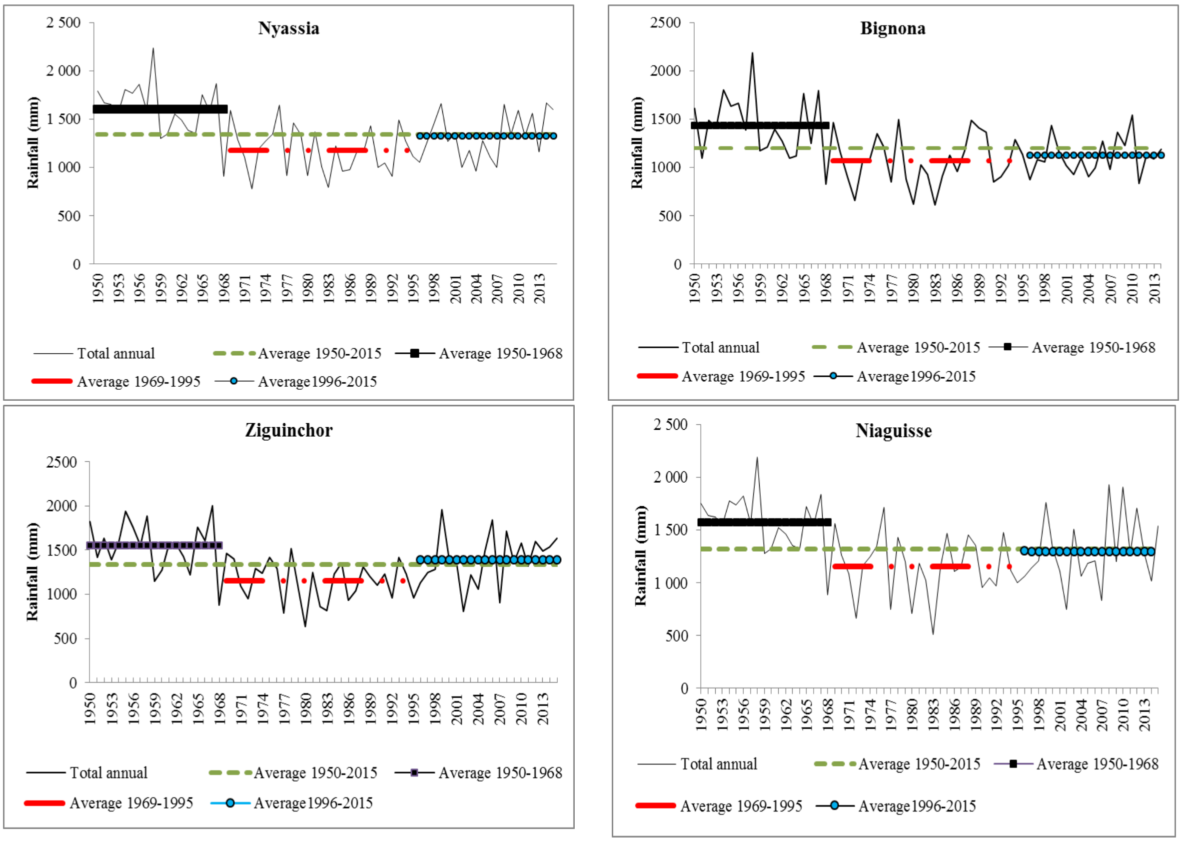

Figure 4: Interannual variability of rainfall at the Nyassia, Bignona, Ziguinchor and Niaguis stations

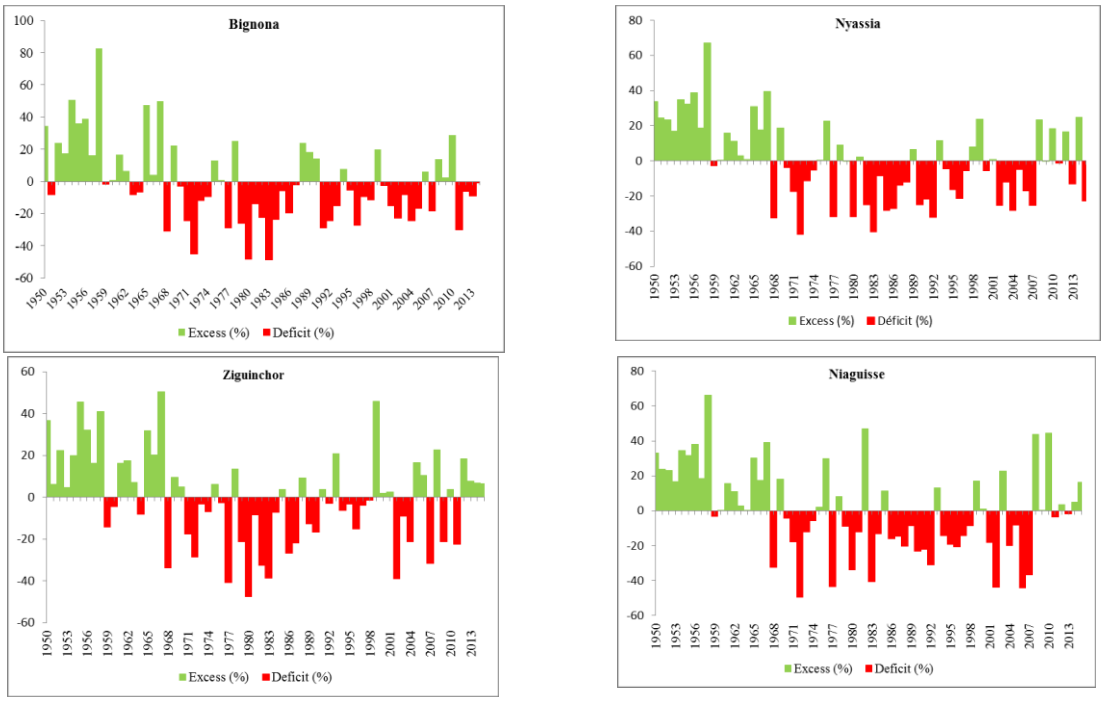

Figure 5: Deviations from the annual mean of the individual stations

During the 1950-1968 period, there were fewer deficit years (Table 4). Considering the 19 years of the first period, the deficit years represent between 15% and 26% of the series. So the period is overall surplus and stable with a low coefficient of variation ≤ 0.18. In the second period (1969-1995) the number of dry years varies between 70% in Bignona and 81% in Niaguisse. The series is globally in deficit and has a high variability of between 0.20 and 0.25.Over the last period (1969-2015), the number of deficit years decreased and the variability fluctuated between 0.18 and 0.22 depending on the stations. It is globally less than 60% except in Bignona with 67%. The deviation from the mean also indicates a trend towards a reduction in the number of deficit years (Table 4).

Table 4: Deficit evolution between 1950 and 2015 (D: deficit, E: Excess)

1950-1968			1969-1995				1996-2015		
D	E	Deficit years (%)	D	E	Deficit years (%)	Station	D	E	Deficit years (%)
2	17	10	21	6	78	Nyassia	12	8	60
4	15	21	20	7	74	Ziguinchor	9	11	45
2	17	10	22	5	81	Niaguis	11	9	55
5	14	26	19	8	70	Bignona	10	5	67

3.2. The raising of extreme values

The study of the extreme values of the different series can help to detect a new trend in precipitation trends on an annual scale. Indeed, the increase of the extreme values of a series can constitute an index of an improvement of the rainfall in the region.

Figure 6 reveals an unequivocal finding. All stations in the area record an increase in the minimums in the last period. Indeed, the period 1969-1995 is marked by a subsidence of the minimums. The lowest minimum is recorded in Niaguis in the eastern part of the watersheds with 508 mm in 1983. The last period (1996-2015) records an increase in the minimums rising above the 800 mm mark except in Niaguis where it is 746 mm.

Maximums also follow the same trend. During the first period (1950-1968) the maximums exceeded the 2000 mm cap, and their subsidence during the second period (1968-1995) was followed by a significant increase in their value. They crossed the 1500 mm mark again in Nyassia to the west and Bignona to the north of the study area. In the study area, the Ziguinchor and Niaguis stations exceeded 1900 mm during the third period.

The analysis of minima and maxima gives an idea of the quantities recorded during a period. The increase in these statistical parameters is an indication of the positive trend in precipitation.

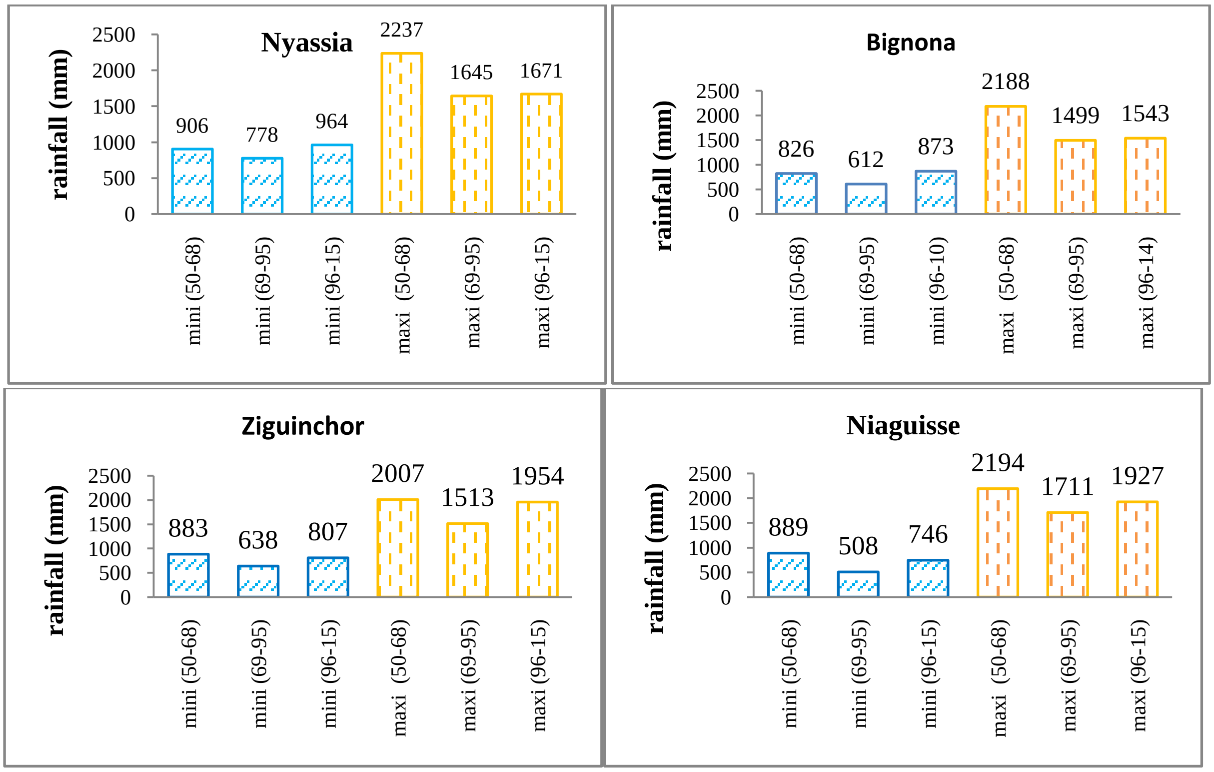

Figure 6: evolution of annual extreme values

3.3. Evolution of normal rainfall

Climate normal is an average of a climatic parameter calculated over a period of thirty years. It is used as a reference to track precipitation fluctuations from one period to another. We calculated the following normals: 1931-1960,1941-1970,1951-1980,1961-1990,1971-2000 and 1981-2010 for 4 stations. The results were used to produce Figure 7.

The latter shows a progressive decrease of the normals of the different stations. It also shows the proximity of the Nyassia, Niaguis and Ziguinchor stations, 15 km apart from each other. The analysis of evolution of the normal of the different rainfall stations also shows a downward trend in precipitation.

However, on the last normal the situation appears to be improving for all stations with an increase in the normals value. It promises an improvement in the situation.

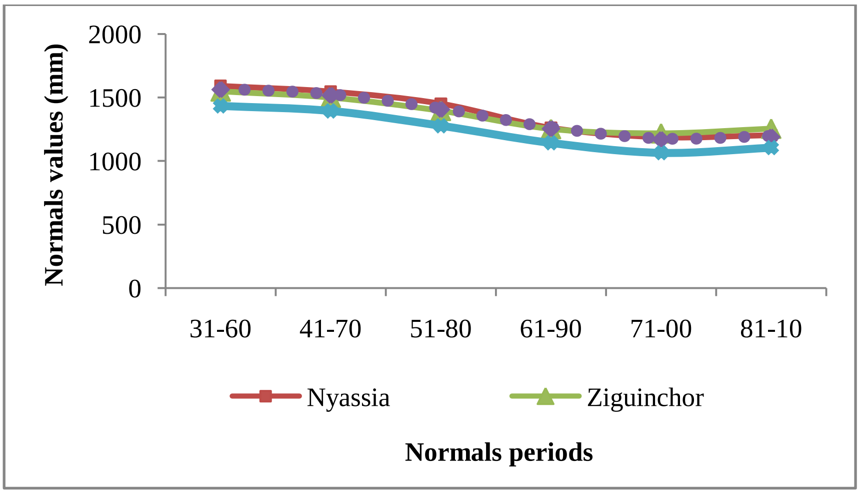

Figure 7: Variation in normal rainfall value 31-60 to 81-10

3.4. Monthly rainfall analysis

The improvement in annual volumes is directly related to monthly precipitation. Thus, this section is devoted to the analysis of precipitation on a monthly scale. Two parameters used to study this trend: the duration of the rainy season and the decadal precipitated volumes at the two stations directly concerned with the zone.

3.4.1. Monthly distribution of precipitation

The rainy season generally lasts 5 to 6 months. Figure 8 shows that at the two stations (Ziguinchor and Niaguis), August is the wettest month of August. It receives on average 416 mm at Ziguinchor and 316 mm at Niaguis, i. e. 31% and 33% of the annual volume calculated over the 1980-2015 period, respectively.

September is the second wettest month with an average of 326 mm in Ziguinchor and 356 mm in Niaguisse, i. e. 26% and 28% of the rainfall respectively. This month is wetter in Niaguisse than in Ziguinchor. In the works of MONTOROI J. P [9], in August was the wettest in 70% of the cases between 1922 and 1990. Currently, the situation has changed for both stations. In fact, August remains the wettest month with 54% of the cases, i. e. a clear decrease in frequencies. The month of September also rose to 20% to 24% of cases between 1922 and 1990. This shows the increased participation of September in the precipitated annual volume. Moreover, if these two months are deficit, so is the season.

The months of June and October each record around 100 mm. The month of May contributes slightly with a total of less than 10 mm or ±1% of the precipitation.

The preponderance of August and September is related to the prolonged presence of the meteorological equator during this period. The entire area is swept by the damp monsoon in the direction of the Atlantic Ocean. Much of this humidity is left in maritime Casamance between Ziguinchor and Cap Skriring.

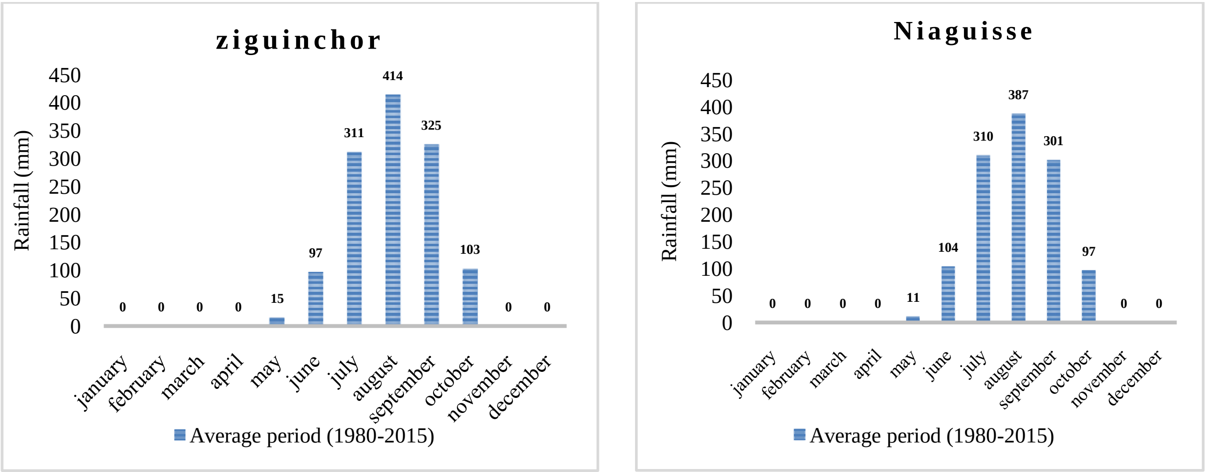

Figure 8: Monthly rainfall distribution in Ziguinchor and Niaguisse

3.4.2. Evolution of the duration of the rainy season

The length of the season corresponds to the number of rainy or not rainy days between the beginning and end of the season. This number varies from year to year and follows a north-south gradient from 80 days in Louga to 140 days in Kolda over the 1950-2000 period [10]. At the Ziguinchor and Niaguis stations, the average duration is 130 and 133 days respectively over the 1980-2015 period. The length of the longest season is 149 days in Ziguinchor and 169 days in Niaguis. The shortest seasons last 91 days and 104 days respectively in Ziguinchor and Niaguis. These values were calculated over the 1980-2015 period and recorded in Table 5.

Table 5: Beginning and end of the rainy season at Ziguinchor station

	ZIGUINCHOR (1980-1995)				
	beginning			**end**	
	precocious	Normal	late	precocious	Normal
	may	june	july	september	october
amount (%)	20	75	5	10	90
	ZIGUINCHOR (1996-2015)				
amount (%)	5	95	0	0	100

A more detailed analysis reveals that late starts and early endings disappeared during the period 1996-2015 (Table 5). Thus, the number of early starters increases from 20% to 5%, the number of late starters disappears and the normal increases from 75% to 95%. As for the ends, they take place exclusively in October, especially in the fourth week. This influences a new trend in the duration of the rainy season [11].

Between 1980 and 1995, the length of the season is lower than the 1980-2015 series average with 123 days in Ziguinchor and 131 days in Niaguis (Table 6 and Figure 9).

Table 6: Evolution of the duration of the rainy season

	Ziguinchor	**Niaguis**
Mean 1980 -2015	130	133
Mean 1980 - 1995	123	131
Mean 1996-2015	136	134
Maxi	149	163
Min	91	104

The seasons were relatively short. They started late in June and end prematurely in late September or early October. But from 1996 onwards, the season lengthens by 13 days in Ziguinchor and 3 days in Niaguis, taking into account the difference between the averages for the two periods. In the years to come, farmers will complain of a long season that hinders crop maturation, not a shorter season that prevents crops from reaching this stage.

On this optimistic note, we think it is interesting to see the precipitated monthly volumes.

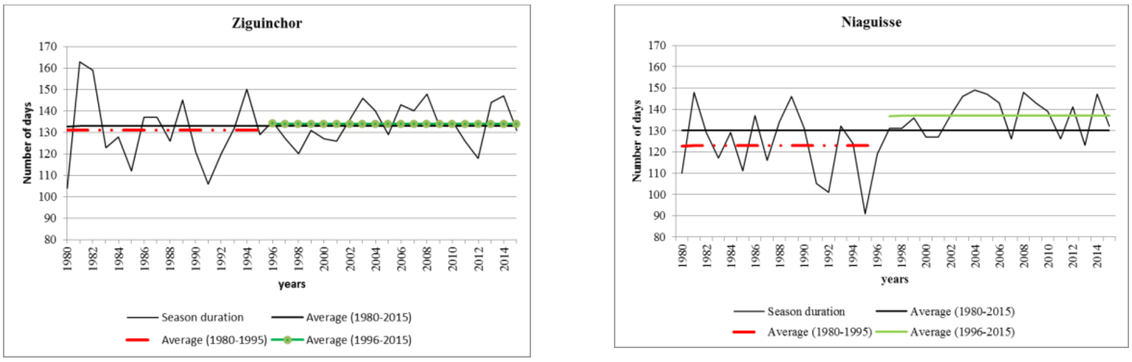

Figure 9: Durée de la saison en nombre de jours à Ziguinchor et à Niaguis

3.4.3. Decadal evolution of precipitated volumes

In many publications, the effect of drought on precipitated volumes has been demonstrated. But, after two decades of drought (1970-1979; 1980-1989), the effects seem to fade gradually for the decades 1990-1999 and 2000-2009 [12]. Indeed, considering the ten-year means of monthly precipitation, we note that monthly volumes increased significantly (Figure 7) during the decade 2000-2009. This increase is in the order of 23.0% in July, 38.8% August and 7.2% in September at the Ziguinchor station. In Niaguisse, it is 16.9% and 31.5% respectively in July and August. This shows an improvement in precipitation in the stations of the Boutoute and Guidel basins.

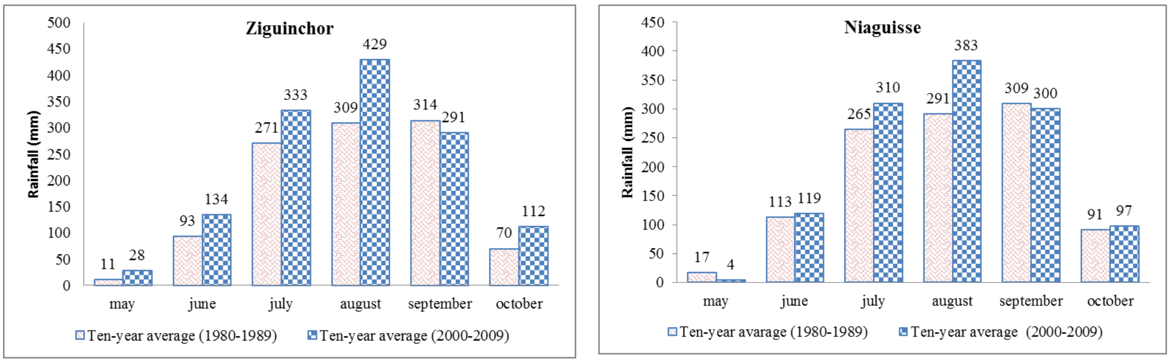

Figure 10: Ten-year means 1980-1989 and 2000-2009

Water availability is essential for community development and vitality. A deficit could eventually jeopardize their project. Thus, the drought of the 1970s seriously compromised the balance of ecosystems and human activities. Today, the debate is not yet decided on the end or not of the drought cycle, especially in this context of climate change.

Analysis of the data on an annual and monthly scale does not allow decreeing the end of drought in the Boutoute and Guidel catchment areas. However, a cluster of indices confirms the trend towards improving precipitated volumes.Indeed, the IPCC in its 2013 report, carried out a simulation on rainfall by 2050. This model shows that with the current climate change, precipitation will increase significantly in the West Africa zone. Recent publications also point in this direction. DESCROIX [13] in 2015, showed an improvement in rainfall in the Senegambia and the middle Niger basin. They note an increase in rainfall in terms of the number of rainy days and precipitation volume. This leads us to say that this increase is not isolated and concerns a large area.

In addition to statistical studies, realities on the field make it possible to confirm the idea of a return of precipitation. The resumption of the long cycle "sanio" millet [14], the resurgence of floods are manifestations of the collateral effects linked to the beginning of this new climatic phase [13].

4. Conclusion

The territories of the Boutoute and Guidel basins went through a period of drought between 1968 and 1995. With the study of annual and monthly rainfall, we have highlighted the improvement of the following contributions in recent years. Annual volumes are increasingly close to the 1950-2015 mean, showing positive trends. We were also able to see that the annual rainfall values have been improving more and more since 1995. Statistical parameters show an increase in annual cumulation. The rainy season lasts longer in terms of the number of rainy days. Volumes also increased significantly during the decade 2000-2009. This augurs well for agricultural activities and water availability in this climate change context.

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