Aliou SOW, Daouda LOUM, Mody SIDIBÉ,
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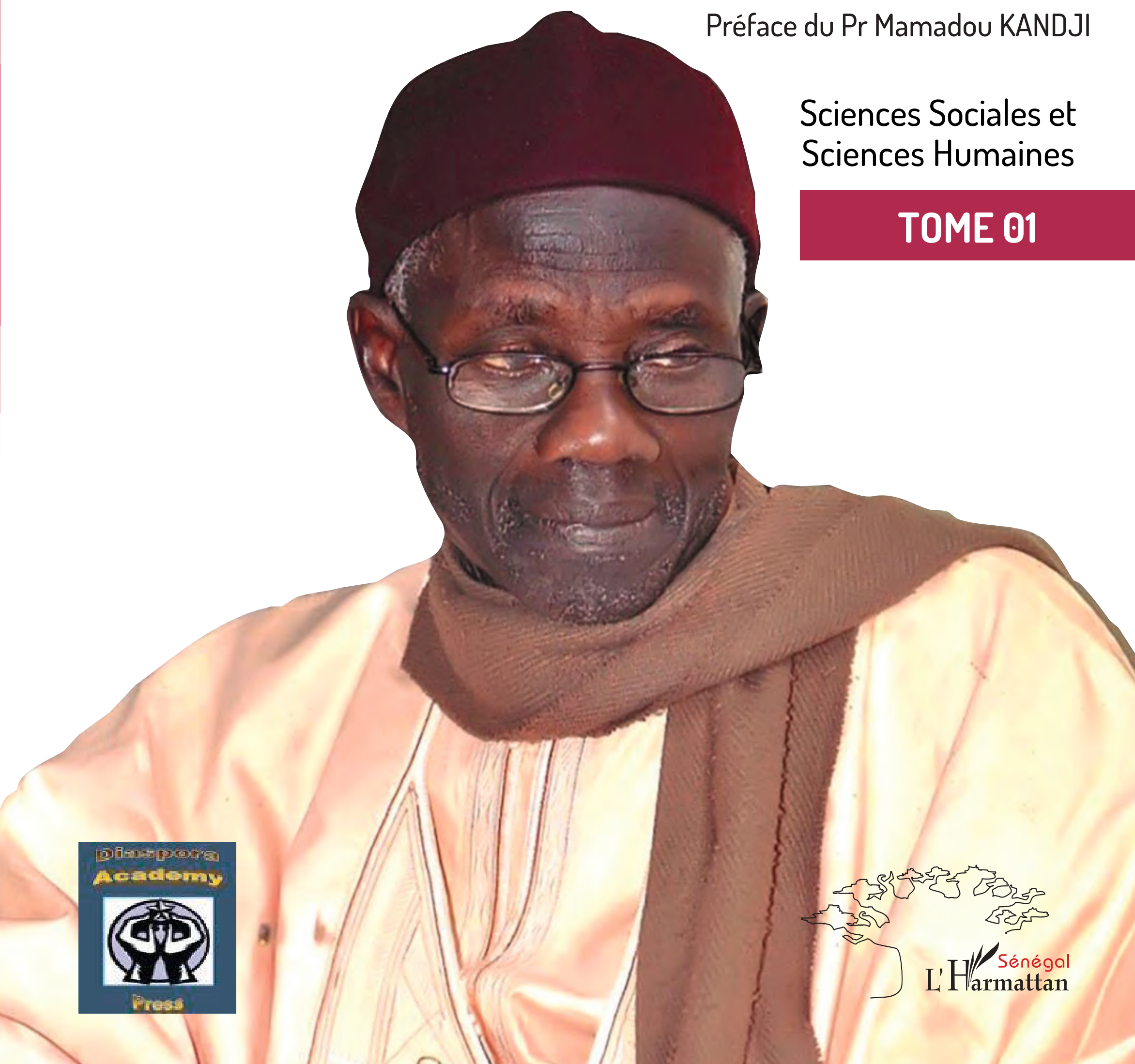
LE TERRITOIRE DE L'ANGLICISTE

Mélanges offerts au Doyen Moctar BÂ

Préface du Pr Mamadou KANDJI

Sciences Sociales et Sciences Humaines

TOME 01



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INDIVIDU ET SOCIÉTÉ

Analysis of the Rainfall Evolution in Casamance (Senegal) and in the Gambia from 1931 to 2018

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Introduction

West Africa is today marked by noticeable changes in climatic parameters. Among these, precipitation remains the determining parameter in an area where human activities, particularly agricultural, are subject to it. This close dependence of agriculture on rainfall, makes this area essentially vulnerable to such variations in rainfall patterns. Rainfall variability is of great concern to rural populations who feel threatened when the rains do not fall at the expected time. Moreover, rainwater is the symbol of life because it remains essential for the fertilization of seeds and the continuity of the natural balance. Also, any delay, in the onset of the rainy season, causes a disorganization of activities. This situation made Sagna *et al.* (2015, 2) say that “the drop in rainfall, through the phenomenon of drought, is a real scourge.”

According to Jean Le Borgne (1988, 20), “1968 is, for the region as a whole, a year of large deficits whose rates exceed 50% in the north, 60 and 70% in the north-west”. He added, “After 1969, above-average for most stations, the period of drought began, the longest, the most intense, the most extensive that the region had known since the beginning of measurements and, with it, all boreal Africa south of the

Sahara". Marcel Leroux (1995, 223) agreed and noted that the "great" drought began in the Sahelian zone in 1968. It spread in the Sudanian and Guinean part with several consequences. Those were a decreasing rainfall, lower flows and groundwater levels, drying wells and ponds that makes livestock farming difficult, a salinization of paddies, a considerable degradation of the vegetal cover, a significant change in farming practices, etc. Several other authors (Lamb, 1982 ; Carbonnel and Hubert 1985 ; Nicholson, 1986 ; Hubert and Carbonnel, 1987 ; Hubert *et al.*, 1989 ; Marius, 1995 ; Dione, 1995 ; Lubès-Niel *et al.*, 1998 ; Paturel et al., 1998 ; Nicholson et al., 1999 ; Servat *et al.*, 1999 ; Host *et al.*, 2002 ; Dacosta *et al.*, 2002 ; Sané, 2003 ; Sène, 2007 ; Sambou, 2015 ; Diédhiou, 2018) reported a decrease in precipitation in the area between the late 1960s and the early 1970s which is not synchronized.
Casamance and the Gambia are not spared by this rainfall variability that will be analyzed, throughout this work, over the series from 1931 to 2018. The choice of this time-series is more consistent with a logic of harmonization, since some stations keep records longer than others. Nevertheless, the length of the series will make it possible to detect different periods with their particular rainfall characteristics.

1. Presentation, Data and Methods of the Study

1.1. Presentation of the Study Area

Casamance is located in southern Senegal and covers an area of 30,000 km^2. It is bordered by the Republic of The Gambia to the north, by the Republics of Guinea Bissau and Guinea to the south, by the Tambacounda region to the east and by the Atlantic Ocean to the west. It has three administrative regions: Ziguinchor, Sedhiou and Kolda which are also known as Lower Casamance, Middle Casamance and Upper Casamance respectively.

The Gambia, which covers an area of 11,300 km^2, is an enclave within Senegal that shares with it 749 km of border. It stretches along the last 320 km of the Gambia River, 20 to 50 km from either side of the river. It is bordered by Casamance to the south, by the Tambacounda region to the east, by Kaffrine, Kaolack and Fatick regions to the north and by the Atlantic Ocean to the west (Figure 1).

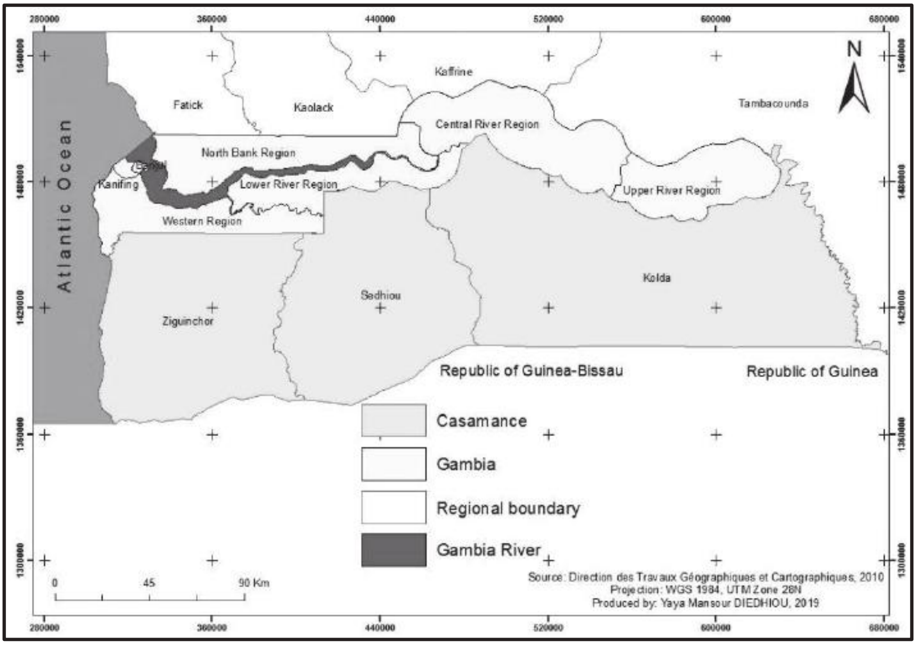


Figure 1: Study area

In view of the mechanisms of climate, but also the rainfall dynamics, the study area is in the north-Sudanian and south-Sudanian climatic zones. More specifically, it straddles four climatic domains: the coastal north-Sudanian domain with Banjul as a station, the coastal south-Sudanian domain with Ziguinchor, the continental north-Sudanian domain with Kerewan and Georgetown and the continental south-Sudanian domain with the stations of Sedhiou and Kolda. This is an area where rainfall conditions are different.

1.2. Data and Method

Annual data from six stations were gathered to perform the rainfall analysis (Table 1). In Senegal, they were collected from the National Agency for Civil Aviation and Meteorology (ANACIM), at the Regional Directorate for Rural Development (DRDR) of Sedhiou and through the operation of the Departments of the Hydrological Service of the Overseas Scientific and Technical Research Office (ORSTOM). For the Gambian stations, the data came from the meteorological section of that country (the Department of Water Resources).

Table 1: Stations chosen in the two zones of the study area

Areas	**Stations**	**Latitudes**	**Longitudes**	**Altitudes (m)**	**Types of station**
Casamance	Ziguinchor	12° 33’ N	16° 16’ W	19	synoptic
	Sedhiou	12° 42’ N	15° 33’ W	15	rain-gauge
	Kolda	12° 53’ N	14° 58’ W	8	synoptic
The Gambia	Banjul	13° 27’ N	16° 34’ W	2,7	synoptic
	Kerewan	13° 30’ N	16° 05’ W	15	synoptic
	Georgetown	13° 32’ N	14° 46’ W	1	synoptic

To analyze the rainfall data of the various Casamance and Gambian stations, the Nicholson’s rainfall index method is used (Nicholson et al., 1988). It distinguishes above-average years from below-average ones. The following formula was used to calculate the annual index Ii:

$Ii = (\mu i - Ø) / \Omega$

μi: rainfall of the given year i;

Ø: annual average of the variable over the reference period;

Ω: value of the standard deviation of the variable over the same reference period.

The segmentation method of Hubert *et al.* (1998), **Pettitt’s** (1979) and **Lee and Heghinian’s** (1977) tests are also used. They are applied to identify splits within the rainfall frequency data over the time series. The choice of these methods is based on the robustness of their basis and on the conclusions of a study of simulation of artificially disturbed random series (Bonneaud 1994, quoted by Paturel *et al.*, 1995). The **Khronostat** software allowed us to determine the break years.

Hubert’s segmentation method uses discontinuities but also breaks with central tendency. This procedure identifies one or more discontinuities in a time series. This model can be considered as a test of constancy according to the same author. To carry it out, it is necessary to “divide” or “cut” the series into n segments, so that the average calculated for a segment is significantly different from the average of the neighboring segment (s) (Hubert *et al.*, 1989, p. 355). This condition remains necessary but is not sufficient, because it does not make it possible to determine the optimal segmentation. It must be added that the constraint of the averages of the two adjacent or contiguous segments is significantly different. The constraint then becomes satisfactory under the application of the Scheffe’s test (Dagnelie, 1970). “This procedure seeks the best segmentation (division) of the series subjected to the analysis in contiguous subseries, and this for increasing orders (number of segments or subseries)" (Hubert *et al.*, 1998, 268). If the procedure does not produce an acceptable segmentation ≥ 2, then the null hypothesis of constancy is accepted. This method is beneficial in that it has the ability to search for multiple mutations of the mean in a time series (Kingumbi *et al.*, 2000).

The **Pettitt's test** is non-parametric "because it makes no assumptions about the underlying distribution of the data" and derives from the Mann-Whitney test. This procedure is applied here to certify the results obtained with the classical method. Because of this, the absence of a break in the series (xi) of N size constitutes the null hypothesis (no break within the series). The execution of the test assumes that for any time t between 1 and N, the time series (xi) i = 1 to t and t + 1 to N belong to the same population. The variable to be tested is the maximum in absolute value of the variable Ut, N defined by:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=t+1}^{T} D_{ij}$$

Where
D_{ij} = sgn(Xi-Xj) with sgn(X) = 1 if d > 0; 0 if d = 0 and -1 if d < 0.
With, (d = Xi - Xj).

The rejection of the null hypothesis assumes an estimate of the break year given by the instant t defining the maximum in absolute value of the variable Ut, N.

2. Results of the Analysis

The use of different statistical methods made it possible to highlight the rainfall evolution of the 1931-2018 time series in Casamance as well as in the Gambia.

2.1. Rainfall Trend in Casamance

The analysis of the Ziguinchor series, through the standardized differences, reveals a rainfall break in 1967. It shows two long periods. The period 1931-1967 is wet with an average of 1559.1 mm and the period 1968-2018 is dry with an average of 1246.9 mm. The difference between these two periods is 312.2 mm, a decrease of 20%. Forty seven years of the series are above-average, including 30 years between the beginning of the series and 1967, and 41 are below-average years, 34 of which occurred after the rainfall break (Figure 2). The break, revealed in Ziguinchor by Nicholson's index, is confirmed by Pettitt's test and Lee and Heghinian's method (Figures 3 and 4) and by Hubert's segmentation method (Table 2). The difference between the wettest year, which is 1936 with 2031.3 mm, and the driest, which occurred in 2007 with 669.2 mm, is 1362.1 mm. It is equally important between the break year (1967 with 2006.5 mm, the second rainiest year) and the second driest year (1980 with 745.6 mm), rising to 1260.9 mm.

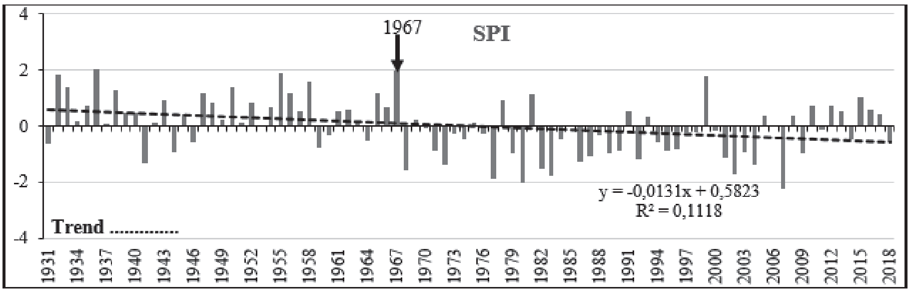
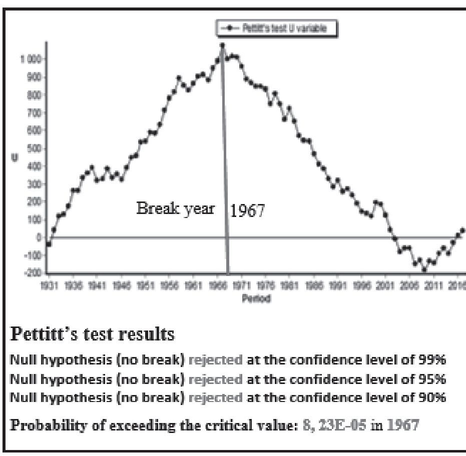


Figure 2: Evolution of the Standardized Precipitation Index at Ziguinchor from 1931 to 2018



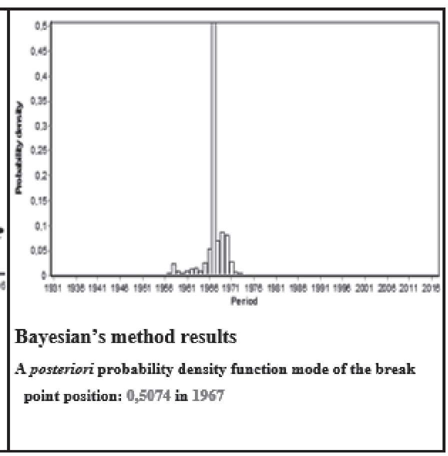


Figure 3: Break year with Pettitt's test at Ziguinchor from 1931 to 2018

Figure 4: Break year with Lee and Heghinian's test at Ziguinchor from 1931 to 2018

Table 2: Segmentation of the series 1931-2018 at Ziguinchor with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1967	1559,1	266,4
1968	2018	1246,9	286,7

The examination of the rainfall series of Sedhiou using Nicholson's index shows that a break occurred in 1969 (Figure 5), which then shows two periods. The wet period (1931-1969) has an average of 1382.6 mm and the dry one (1970-2018) an average of 1086.6 mm. The difference between these two periods is 296 mm, a decrease of 21.4%. The series has 36 above-average years, of which 26, or 72.2%, are found between the beginning of the series and 1969 and 52 below-average years, of which 39, or 75%, appear after the rainfall break. Pettitt's and Lee and Heghinian's tests detected the break in 1969 too (Figures 6 and 7) as well as Hubert's test (Table 3). It is at the same time the rainiest year with 1955.8 mm. Comparing it to the less rainy year, which is 2002 with 737.1 mm, the difference is 1218.7 mm. Between 1955 with 1812.4 mm (the second rainiest year) and 1983 with 741.1 mm (the second driest year), the difference reached 1071.3 mm.

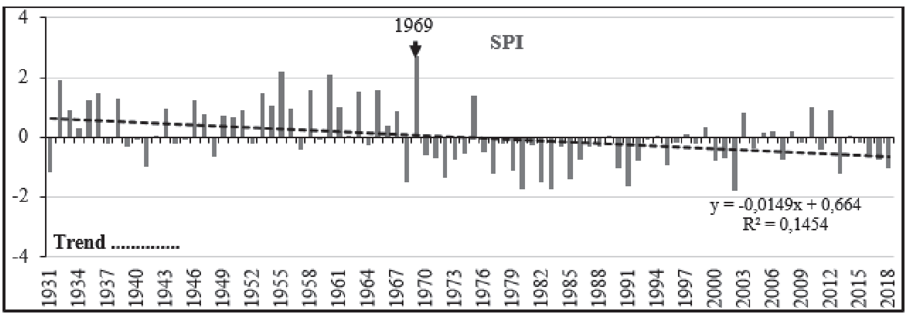
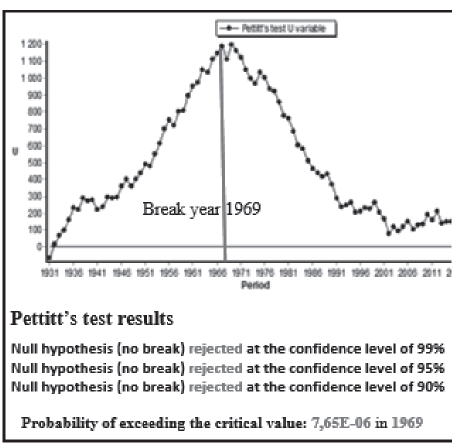


Figure 5: Evolution of the Standardized Precipitation Index at Sedhiou from 1931 to 2018



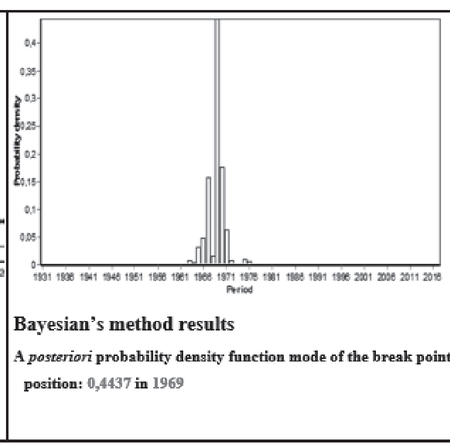


Figure 6 : Break year with Pettitt's test at Sedhiou from 1931 to 2018

Figure 7: Break year with Lee and Heghinian's test at Sedhiou from 1931 to 2018

Table 3: Segmentation of the series 1931-2018 at Sedhiou with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1969	1382,6	236,1
1970	2018	1086,6	194,8

At Kolda, the break occurred in 1971 (Figures 8, 9 and 10). The two major periods of this series are 1931-1971 (a wet period with an average of 1232.3 mm) and 1972-2018 (a dry period with an average of 1008.8 mm). The difference between these two periods is 223.5 mm, a decrease of 18.1%. Forty two years are above-average, of which 26 have appeared between the beginning of the series and the rainfall break and 46 are below-average years, including 31 after the same break year. This represents on the one hand 61.9% and on the other hand 67.4% of each of the two periods. Hubert's segmentation method detected a first break in 1956 with a 1204.3 mm average and a second break in 1958 with an 1890.7 mm average (Table 4). The highest-average year remains 1958 with 2152.2 mm. It is followed, in second position by 1957 with 1629.2 mm. These two years, despite a rainfall difference of 523 mm, are the rainiest episode of the series. Comparing them to the two driest years at Kolda, which are 2016 with 409.6 mm and 1980 with 565.9 mm, the deviations are respectively 1742.6 mm and 1063.3 mm.

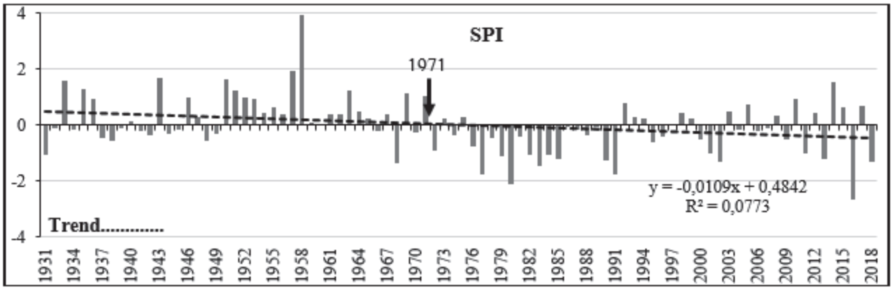


Figure 8: Evolution of the Standardized Precipitation Index at Kolda from 1931 to 2018

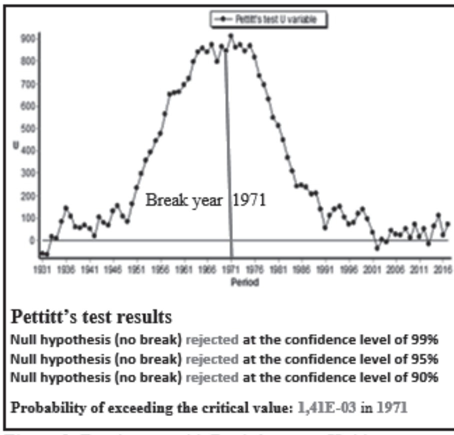


Figure 9: Break year with Pettitt's test at Kolda from 1931 to 2018

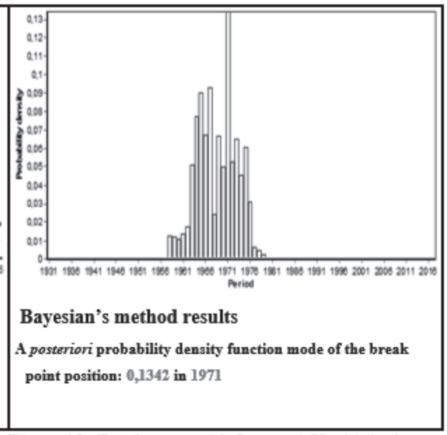


Figure 10: Break year with Lee and Heghinian's test at Kolda from 1931 to 2018

Table 4: Segmentation of the series 1931-2018 at Kolda with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1956	1204,3	204,6
1957	1958	1890,7	369,8
1959	2018	1047,4	230,8

2.2. Rainfall trend in the Gambia

At Banjul, the break occurred in 1967 according to Nicholson's index (Figure 11). The period 1931-1967 is considered wet with an average of 1187.6 mm and that of 1968-2018 as dry with an average of 816.2 mm, a difference of 371.4 mm and a decrease of 31, 3%. Pettitt's, Lee and Heghinian's tests (Figures 12 and 13) as well as Hubert's segmentation method confirm the existence of a break in 1967 (Table 5). This series includes 42 above-average years, of which 71.4% were recorded before the break, and 46 below-average years, of which 84.8% appeared after the break. The most important rainfall difference, between 1936 (the rainiest year with 1669.1 mm) and 1983 (the driest year with 357.8 mm), is 1311.3 mm. Similarly, the following two years in terms of rainfall and drought, 1958 and 2013, have a significant rainfall difference of 1226.9 mm.

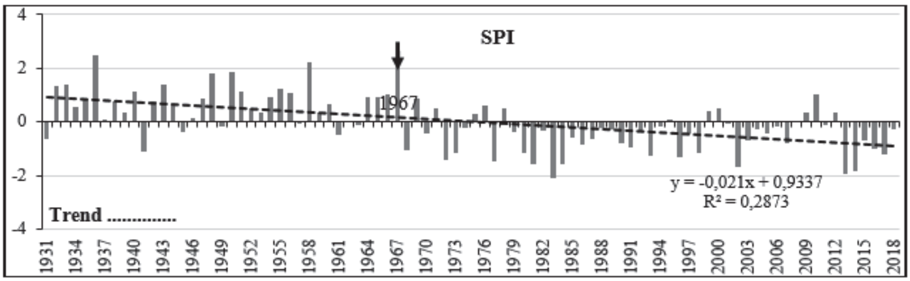


Figure 11: Evolution of the Standardized Precipitation Index at Banjul from 1931 to 2018

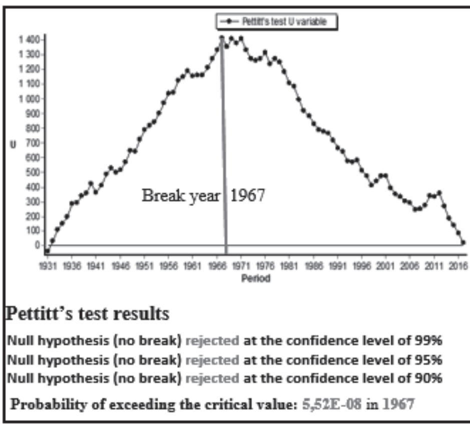


Figure 12: Break year with Pettitt's test at Banjul from 1931 to 2018

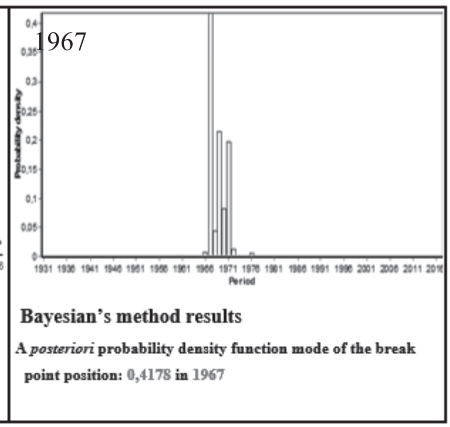


Figure 13: Break year with Lee and Heghinian's test at Banjul from 1931 to 2018

Table 5: Segmentation of the series 1931-2018 at Banjul with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1967	1187,6	237,7
1968	2018	816,2	223,5

The analysis of Kerewan's series, using Nicholson's index, reveals the existence of a break in 1967 (Figure 14). There are two main periods: 1931-1967 which is a wet period with an average of 1103.2 mm and 1968-2018 which is a dry period with an average of 834.5 mm. The difference between these two periods is 268.7 mm, a decrease of 24.4%. Pettitt's and Lee and Heghinian's tests show a break in 1967 (Figures 15 and 16) too, which is confirmed by Hubert's segmentation method (Table 6). This series of Kerewan has 43 above-average years, of which 69.8% appeared before the break and 45 below-average years of which

84.4% were noted after the 1967 rainfall break. The two extreme rainfall values were noted in 1950 with 1720, 4 mm and in 1990 with 432.0 mm, a difference of 1288.4 mm. The other two years that follow, in terms of the importance and the rainfall, 1943 with 1587.0 mm and 1977 with 444.9 mm, are found with a difference of 1142.1 mm.

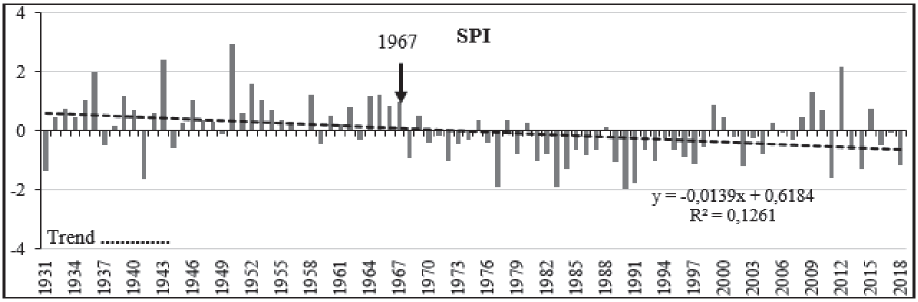
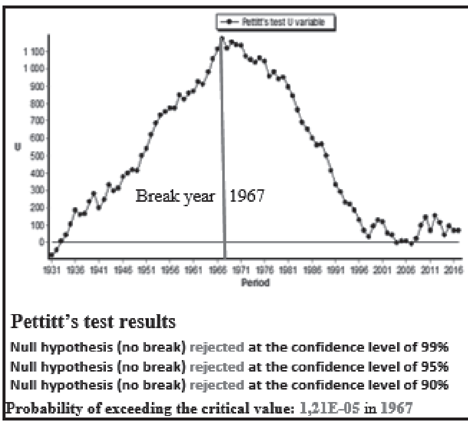


Figure 14: Evolution of the Standardized Precipitation Index at Kerewan from 1931 to 2018



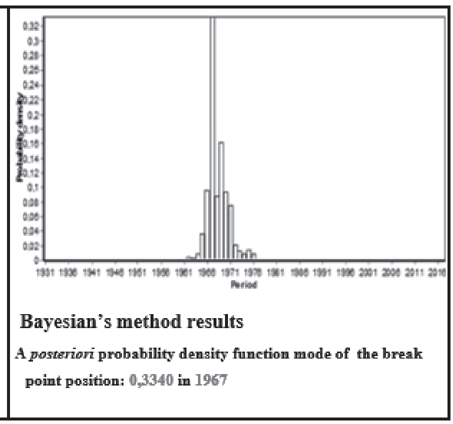


Figure 15: Break year with Pettitt's test at Kerewan from 1931 to 2018

Figure 16: Break year with Lee and Heghinian's test at Kerewan from 1931 to 2018

Table 6: Segmentation of the series 1931-2018 at Kerewan with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1967	1103,2	234,8
1968	2018	834,5	220,2

The application of Nicholson's index method to the Georgetown rainfall series shows the existence of a break in 1967 (Figure 17) with two major periods. The first period, considered wet, goes from 1931 to 1967 with an average of 1018.3 mm and the second period, rather dry, goes from 1968 to 2018 with an average of 786.6 mm. The difference between these two periods is 231.7 mm, a deficit of 22.8%. Pettitt's and

Lee and Heghinian's tests detected the break in 1967 too (Figures 18 and 19). Hubert's segmentation method confirmed the break year (Table 7) as well. The above-average years in this series are 40 of them, of which 67.5% were recorded before the break and 48 years are below-average, of which 79.2% were observed after the break. The two rainiest years - 1936 and 2005 - are found on either side of the break year. Their deviations from the two driest years - 1983 and 2014 - are 1019.7 mm and 886.5 mm. The predominance of below-average years after the rainfall break shows the persistence, even today, of the sequels of the drought despite the exceptional rainfall of 2005.

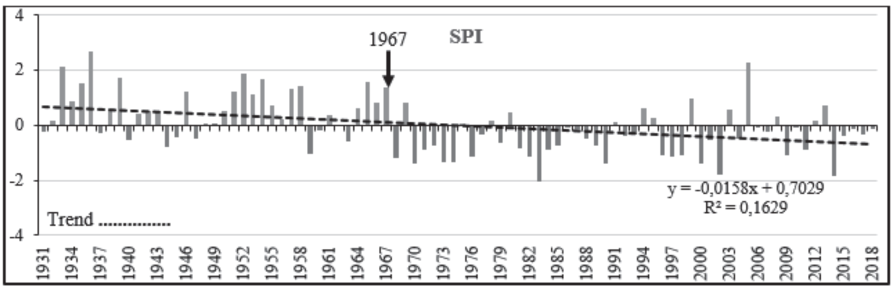
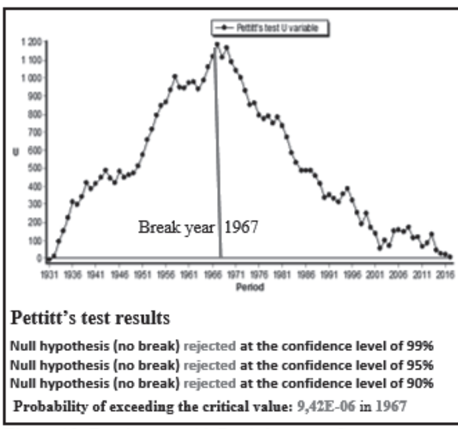


Figure 17: Evolution of the Standardized Precipitation Index at Georgetown from 1931 to 2018



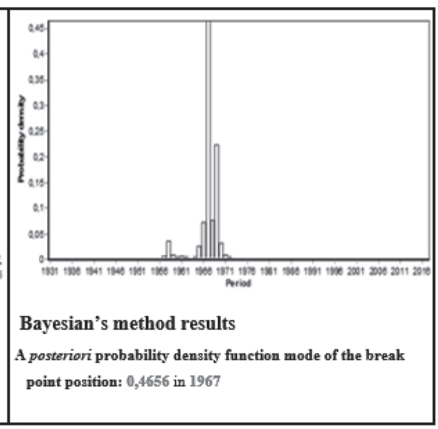


Figure 18: Break year with Pettitt's test at Georgetown from 1931 to 2018

Figure 19: Break year with Lee and Heghinian's test at Georgetown from 1931 to 2018

Table 7: Segmentation of the series 1931-2018 at Georgetown with Hubert's procedure

Scheffe's test level of significance: 1%			
Beginning	End	Mean	Standard deviation
1931	1967	1018,300	192,799
1968	2018	786,553	175,808

2.3. Summary of the results according to climate domains

The different methods used in the data processing made it possible to highlight, on the one hand, the rainiest and driest years and, on the other hand, the rainfall breaks that occurred in different years in Casamance but in the same year in the Gambia. The acquired findings, reported about the different climatic domains, reveal that the rainiest years occurred before 1967, except in the continental north-Sudanian domain where the year 2005 at Georgetown with 1375.9 mm and the year 2012 at Kerewan with 1515.2 mm are some of the rainiest. The years 1932, 1936, 1943, 1950, 1955, 1958 and 1967 were relatively rainy in the different climatic domains (Table 8). They have been the four rainiest years at Ziguinchor (in the coastal south-Sudanian area) and at Banjul (in the coastal north-Sudanian area). They appeared three times at Kolda (in the continental south-Sudanian domain) and at Kerewan (in the continental north-Sudanian domain).

All the driest years occurred after 1967 and the most frequent are: 1977, 1980, 1983, 1991, 2002 and 2014. There are at least three of them at each station (Table 8). The years 2000, 2002, 2007, 2013, 2014 and 2016, which are among the driest, reflect the persistent nature of the drought, despite some rainfall improvements noted at some stations since 1999.

Table 8: Rainiest and driest years in the different climatic domains of Casamance and the Gambia

Climatic domains	Stations	4 rainiest years and their rainfall in mm				4 driest years and their rainfall in mm			
Coastal south-Sudanian Domain	Ziguinchor	**1936**	**1967**	**1955**	**1932**	**1983**	**1977**	**1980**	**2007**
		2031.3 mm	2006.5 mm	1980.8 mm	1965.7 mm	817.9 mm	790.3 mm	745.6 mm	669.2 mm
Continental south-Sudanian Domain	Sedhiou	**1969**	**1955**	**1960**	**1932**	**1991**	**1980**	**1983**	**2002**
		1955.8 mm	1812.4 mm	1780.6 mm	1729.5 mm	772.4 mm	752.2 mm	741.1 mm	737.1 mm
	Kolda	**1958**	**1957**	**1943**	**1950**	**1991**	**1977**	**1980**	**2016**
		2152.2 mm	1629.2 mm	1558.3 mm	1543.6 mm	655.8 mm	648.4 mm	565.9 mm	409.6 mm
Coastal north-	Banjul	**1936**	**1958**	**1967**	**1950**	**2002**	**2014**	**2013**	**1983**

Sudanian Domain		1669.1 mm	1628.8 mm	1601.4 mm	1512.2 mm	474.8 mm	437.0 mm	401.9 mm	357.8 mm
Continental north-Sudanian Domain	Kerewan	**1950**	**1943**	**2012**	**1936**	**1991**	**1983**	**1977**	**1990**
		1720.4 mm	1587.0 mm	1515.2 mm	1468.0 mm	485.2 mm	452.8 mm	444.9 mm	432.0 mm
	Georgetown	**1936**	**2005**	**1933**	**1952**	**2000**	**2002**	**2014**	**1983**
		1468.0 mm	1375.9 mm	1349.2 mm	1292.3 mm	587.7 mm	496.0 mm	489.4 mm	448.3 mm

The analysis of the percentages of above-average years and below-average ones shows the predominance of the latter. Indeed, except in the coastal south-Sudanian area where the above-average years are more numerous with 53.4%, in the other climatic areas the below-average years remain more frequent with a maximum percentage of 59.1% at Sedhiou in the continental south-Sudanian domain. This percentage is 54.5% at Georgetown in the continental north-Sudanian domain (Table 9). The manifestation of the drought since the various breaks observed remains palpable.

Table 9: Percentage of above-average and below-average years in the different climate domains

Climatic domains	Stations	Percentage of above-average years	Percentage of below-average years
Coastal south-Sudanian Domain	Ziguinchor	**53.4**	**46.6**
Continental south-Sudanian Domain	Sedhiou	**40.9**	**59.1**
	Kolda	**47.7**	**52.3**
Coastal north-Sudanian Domain	Banjul	**47.7**	**52.3**
Continental north-Sudanian Domain	Kerewan	**48.9**	**51.1**
	Georgetown	**45.5**	**54.5**

Conclusion

The analysis of the rainfall records of Casamance and the Gambia from 1931 to 2018 highlighted the rainfall dynamics over the period considered. This study then raises the issue of rainfall variability across two major periods. A wet period observed globally between 1931 and 1967 and a dry one between 1968 and 2018.

In Casamance, the study revealed that the break occurred in different years. At Ziguinchor, it intervened in 1967 causing a gap of 312.2 mm between the first and the second period and a decrease of 20.02%. At Sedhiou, the break was observed in 1969 and the difference between the wet period and the dry one is 296 mm. The decrease rate in rainfall at that station is 21.4%. At Kolda, the break was noted in 1971 using Pettitt's and Lee and Heghinian's tests with a gap of 223.5 mm, a decrease of 18.1%. However, Hubert's segmentation method detected a first break in 1956 and a second one in 1958.

In the Gambia, this work showed that the break occurred in 1967 at all the stations concerned. At Banjul, the gap between the two periods noted above is 371.4 mm with a decrease of 31.3%. This gap between the two periods is 268.7 mm at kerewan with a reduction of 24.4%. At Georgetown, the gap between the periods 1931-1967 and 1968-2018 is 231.7 mm with a 22.8% deficit.

Given the distribution of the above-average and below-average years and their importance in the rainfall series, we noted the persistence of the drought in the study area, which is confirmed by the various trends. Its manifestation in 2013, 2014 and 2016 at some stations remains worrying. It remains one of the signs of climate change which has become a climatic, ecological, economic and development challenge.

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LE TERRITOIRE DE L'ANGLICISTE
TOME 01

Le professeur Moctar Bâ est l'enseignant que la postérité peut désigner comme le Père fondateur des études anglaises au Sénégal… C'est à cet homme-là, enseignant émérite, à ce « vivant pilier », figure de proue des études anglaises au Sénégal, que ses collègues, ceux-là qu'il a formés, et ceux-là même à qui ses disciples ont passé le témoin, consacrent, dans le même élan de ferveur, ces *Mélanges* : deux tomes réunissant une soixantaine de contributions touchant à des domaines aussi riches que la littérature, la didactique, la grammaire, les sciences sociales et les sciences humaines.

En proposant « *Le Territoire de l'angliciste* » comme titre de ces *Mélanges*, le comité scientifique a voulu mettre l'accent sur le sens pratique qui caractérisait Moctar Bâ.

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