Spatial and temporal variability of rainfall in the south-central Senegalese groundnut basin: Fatick and Kaolack regions

ABSTRACT

One of the manifestations of climate change in the Sahel is a decrease in rainfall, which has led to a sharp decline in water potential in the Senegalese groundnut basin. The objective of this study is to understand the changes in rainfall through time and space, in the south-central groundnut basin, to better plan water management for sustainable development. The rainfall data used ranges from 1961 to 2020 for the sites of Gossas, Foundiougne, Guinguineo and Nioro, and from 1951 to 2020 for the sites of Fatick and Kaolack. Pettitt and Buishand break tests were used to detect changes in ainfall patterns, Hubert segmentation was used to highlight sub-periods within the time series, and Standardized Precipitation Indices (SPI) were used to highlight deficits and surpluses. The results of break tests and Hubert segmentation show a decrease in average rainfall between the 1960s and 1970s, and an increase between the 1990s and 2000s, for some of the sites. The decrease in the 1960s and 1970s was early in sites in the Fatick region (Gossas, Fatick and Foundiougne) and late or absent in the Kaolack region (Guinguineo, Kaolack and Nioro). As for the increase in the 1990s and 2000s, it was first observed in the south and center of the study area in the 1990s (Nioro and Kaolack). In the 2000s, the increase was observed further north (Fatick and Gossas).The Standardized Precipitation Index (SPI) shows reduced rainfall for 1971-2000 compared to the surrounding periods. Coefficient of variation values show that dispersion is lowest in the wetter years 1950 for two sites (Fatickand Kaolack), 1990 and 2000 for four sites (Gossas, Foundiougne, Guinguineo and Nioro). The highest coefficients of variation were detected in the drought years 1960, 1970 and 1980 for these four sites (Gossas, Foundiougne, Guinguineo and Nioro). This is not the case at the Fatick site, where the coefficients of variation for the 1970s, 1980s and 1990s are higher than those for 2000 and 2010. Coefficients of variation increase in the 2010s at five sites (Kaolack, Gossas, Foundiougne, Guinguineo and Nioro). The highest coefficients of variation were recorded in 2010 in Gossas, Guinguineo and Nioro.The decrease in average rainfall from the 1960s to the 1990s, and the increase in the 1990s and 2000s detected in most of the study sites, corroborates results of other studies from West and Central Africa.

Keywords: Climate change, rainfall variability, south-central groundnut basin, Senegal

Introduction

The impacts of climate change are clear in the Sahel, where rainfall has been strongly affected in recent decades. According to Servat *et al.*(1999), the drought observed for more than twenty years in the Sahelian countries is also felt further south, in regions of Africa with more humid climates. In the 1970s-1980s, a drastic decrease in rainfall was observed throughout West Africa,which persisted until the end of the twentieth century (Ali, Lebel, 2009). West Africa is experiencing a succession of dry and rainy climatic episodes punctuated by periods of drought whose intensity and spatial extension have become exceptional since 1970 (Kouassi *et al.*, 2017). At the local level, the work of Ndong (1995) and Sagna

(1995)concludes that the unfavorable rainfall trends noted since the 1970s in the Sahel have not spared the Sudanian part of Senegal. In the same vein, (Diagana, Mankor, 2008), maintain that the climatic context in the groundnut basin is characterized by a decrease in rainfall. Climate studies show that in addition to the decrease in total rainfall, climate change has also had an impact on the number of rainy days, as well as on the timing of the start, end, and duration of rainy seasons. According to Ndong (1995), the decrease in rainfall totals since the 1951-1960 rainy decade has been accompanied, in general, by a decrease in the number of rainy days. In the Thies region, (Diallo, 2021) showed that cumulative rainfall is concentrated in a short rainy season from June to October, with maximum rainfall amounts observed from July to September. Rainy season start dates fluctuate more than end dates, meaning that rainy season durations are most dependent on start dates (Camberlin *et al.*, 2003). Rainfall variability and deterioration are at the root of the decline in water resources in the Sahel. The results of studies by Goula *et al.* (2006), Jung (2006) and Kouassi *et al.* (2010) show that climate variability, in particular the decrease in annual rainfall amounts, has a direct impact on surface water resources and groundwater flow. In West Africa, drought results in a drastic decrease in river flows, or even a cessation of flow in certain sections (Chappell, Agnew, 2004; Nicholson *et al.*, 2000). According to Sambou *et al.* (2018), climate variability is a reality that is asserting itself with notable impacts on water resources at a time when demand for water is growing.

The decrease in rainfall and the resulting reduction in surface water supplies are likely to be a challenge forvarious water-related development projects; hence the interest in conducting studies on this climatic variable. The objective of this study is to understand the changes in rainfall through time and space, in the south-central groundnut basin, to better plan water management for sustainable development.

Study area

The groundnut basin is located between 14° 15' and 17° 15' West and 13° 6' and 16° 15' North, covering central westernSenegal. This study focuses on the south-central part of the groundnut basin, which covers the regions of Kaolack and Fatick. The area is bounded to the north by the Diourbel region, to the northwest by the Thies region, to the south by the Republic of the Gambia, to the east by the Kaffrine region, and to the west by the Atlantic Ocean (Figure 1). It covers an area of 12 042 km².

The climate in the south-central part of the groundnut basin is Sudan-Sahel. The Sudano-Sahelian zone records rainfall between 500 and 1000 mm (Leroux, 1996), and is characterized by six to eight months of the circulation of *alize* and four to six months of monsoon. *Alize* is a dry trade wind coming from the Azores anticyclone and flowing towards the Meteorological Equator (ME) without crossing the Geographic Equator, whereas the monsoon comes from the Saint-Helene anticyclone, travels across the ocean where it warms and moistens before arriving in West Africa. In Fatick, the climate is marked by a Sahelo-Sudanese variant (dominated by the circulation of *alize*) and a Sudano-Sahelian variant (marked by a longer duration of the monsoon). Fatick is also influenced by the maritime climate on the coastal part of the departments of Foundiougne and Fatick(ANSD/Fatick, 2019). In Kaolack, continentality predominates and the climate is characterized by relatively high temperatures, with maximums fluctuating between 36and 37°C over the period 2000-2019 (ANSD/Kaolack, 2019 ; Sambou *et al.*,2012).

In Fatick, surface water is composed of the perennial rivers of the Sine, Saloum and Gambia, as well as their tributaries located in the department of Foundiougne, namely the Bandiala, Soundougou, Nianing-Bolong and Diomboss. There are also temporary waterways consisting of marigots and ponds. Groundwater is made up of Maastrichtian, Paleocene, Eocene and Terminal Continental aquifers (ANSD/Fatick, 2019). In Kaolack, the hydrographic network is made up of surface waters: the Saloum River and two tributaries of the Gambia River (Baobolong and Miniminiyang Bolong) and groundwater (ANSD/Kaolack, 2019).

The population of the south-central groundnut basin was estimated to be 2.025.792 in 2019, with 1.155.433 in Kaolack and 870.359 in Fatick(ANSD/Fatick, 2019; ANSD/Kaolack, 2019). The area is facing a degradation of natural resources, particularly plant resources, due to rainfall deficits and human activity. In addition, salinization and erosion impoverish cropland (ANSD/Fatick, 2019; ANSD/Kaolack, 2019).

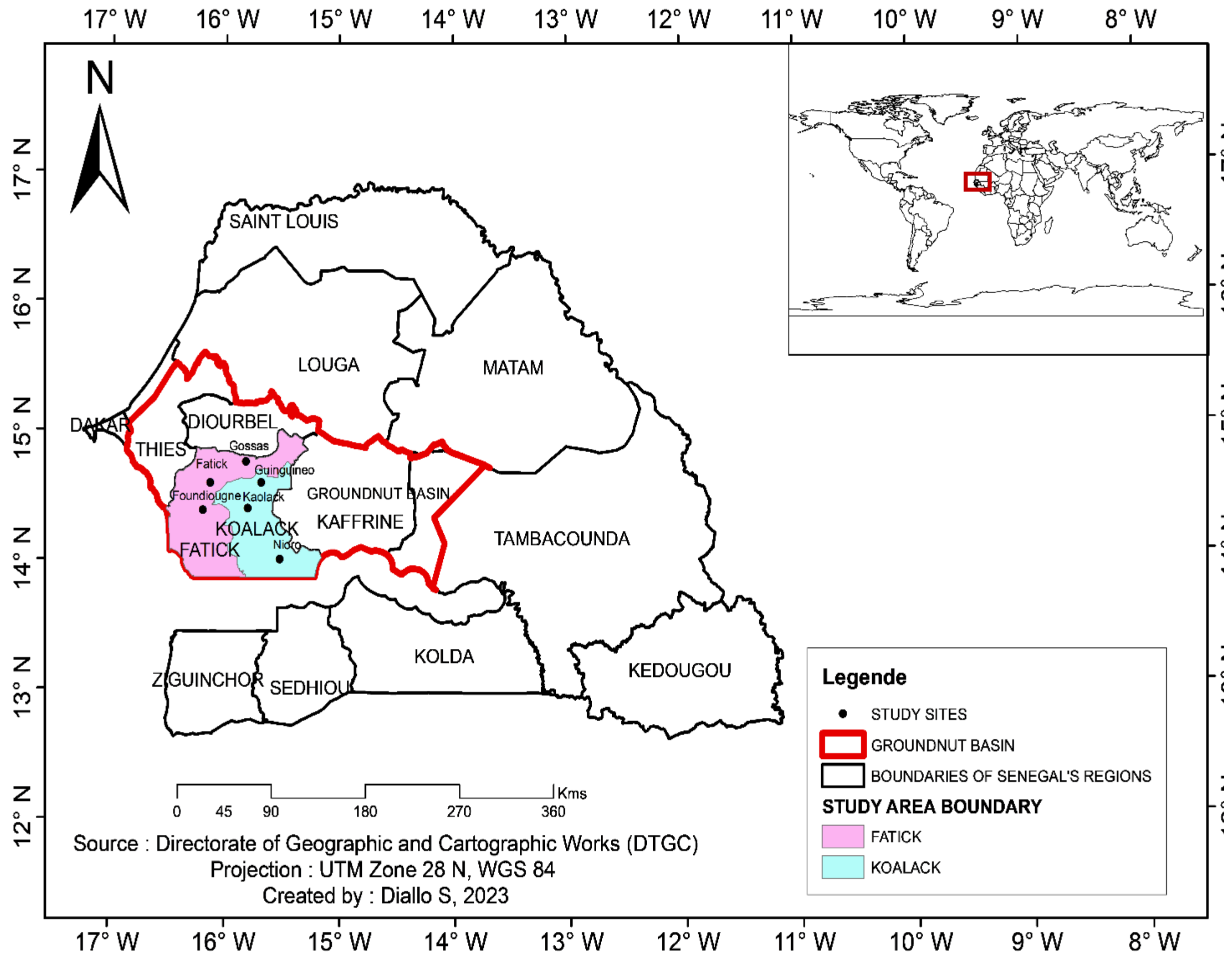

Figure 1: Location and study sites of the south-central Senegalese groundnut basin.

Data and methods

The data, collected by the National Agency of Civil Aviation and Meteorology, describe the annual and monthly rainfall amounts at the sites of Gossas, Foundiougne, Guinguineo, Nioro, Fatick and Kaolack (Figure 1). The data series in Gossas, Foundiougne and Guinguineo and Nioro extend from 1961 to 2020, and from 1951 to 2020 for Fatick and Kaolack (Table 1).

Table 1: Study sites, with location and duration of rainfall data.

Station	Type of station	Latitude	Longitude	Years
Gossas	Rainfall	14°30 N	16°5 W	1961-1920
Foundiougne	Rainfall	14°7 N	16°28 W	1961-2020
Guinguineo	Rainfall	14°20 N	15°57 W	1961-2020

Nioro	Rainfall	13°44 N	15°47 W	1961-2020
Fatick	Climatological	14°20 N	16°24 W	1951-2020
Kaolack	Synoptic	14°8 N	16°4 W	1951-2020

To analyze the temporal patterns in rainfall described in these time series, we used the Pettitt and Buishand break tests, Hubert's segmentation, and the Standardized Precipitation Index (SPI).

The break tests allow us to test stationarity in time series of annual rainfall amounts, and to determine the timing of any break points at which an abrupt change or jump occurs (Lubes-Niel *et al.*,1998).

Pettitt's test

Pettitt's test(Pettitt, 1979) is a non-parametric test used to identify breaks in time series, and has previously been used to study rainfall data (Diallo *et al.*, 2022; Paturel *et al.*, 1998; Sambou *et al.*,2018). Pettitt's test works by decomposing the main series of *N* elements into two subseries at each time *t* between *1* and *N*-1. The main series has a break at time t if the two subseries have different distributions. The Pettitt variables (*U*) are defined by the following:

$$Ut, N = \sum_{i=1}^{t} \sum_{j=t+1}^{N} Dij$$

Where $Dij = sgn\,(x_i - x_j)$ with $sgn\,(x) = 1$ if $x > 0$; $sgn\,(x) = 0$ if $x = 0$, and $sgn\,(x) = -1$ if $x < 0$.

The test is based on the *KN* statistic, which is defined by the maximum absolute value of *Ut, N* for (*t*) varying from 1 to *N*-1. The absence of a break in the series of size *N* constitutes the null hypothesis H_0. If H_0 is rejected, the test highlights the *t* at which the break occurs.

Ut, N = Test index

N = size of the time series

t = time

sgn = abbreviation for sign

KN= maximum absolute value of Ut, N

Buishand test

The Buishand test gives well for any change in mean occurring in the middle of the series. However, the Buishand test is a parametric test that assumes a normal distribution of the variables in the series, so normalization (Square Root, Logarithm, Box and Cox) may be required prior to its use. Assuming a uniform *a priori* distribution for the position of the break t, Buishand (1982) statistic U is defined as:

$$Eq\ 1: U = \sum_{k=1}^{N-1} (S\square^{x}/\mathrm{D}x)^2/\mathrm{N}(\mathrm{N}+1)$$

where:

$$Eq\ 2: S\square = \sum_{i=1}^{k}(xi - \bar{x})$$

$S\square$ = partial sum

Dx = standard deviation of the series

xi = annual rainfall amounts for year *i*

$\bar{x}$ = annual average rainfall for the given period

The nullhypothesismeansthatthereis no break in the time series. Rejection of the nullhypothesismeans a break in the time series.
The break tests were implemented using XLstat softwarewith an alpha level of 0.05 to determine the statistical significance of our results.

Hubert's segmentation

Hubert's segmentation is appropriate to search for multiple changes in the mean of a time series. It provides one or more break times (or possibly none) that separate contiguous segments whose means are significantly different according to the Scheffé test (Scheffé, 1999). The Scheffé test is a post-hoc test used to determine significant differences between group means in an analysis of variance (Hubert *et al.*, 1989). The significance level of the Scheffé test is 1 %.

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI), created by McKee *et al.* (1993), is used to characterize rainfall variability. It is calculated according to the formula: $SPI = \frac{(Xi - Xm)}{Si}$,where

Xi = annual rainfall amounts for year *i*; *Xm* = annual average rainfall for the given period;

Si = standard deviation of annual rainfall amounts over the same period.

The SPI allows for the rapid detection of drought situations and the evaluation of their severity. The index defines the severity of the drought in different classes. Negative annual values indicate a dry year compared to the chosen reference period, and positive values indicate wet years(Table 2).

Table 2: SPI drought and wetnesslevel classification (McKee et al., 1993).

SPI Value Range	Drought andWetnessLevel
SPI ≤−2.0	Extreme drought
−2.0 < SPI ≤−1.5	Heavy drought
−1.5< SPI ≤−1.0	Drought
−1.0 < SPI < 1.0	Normal
1.5 > SPI ≥ 1.0	Wet
2.0 > SPI ≥ 1.5	Heavy wet
SPI ≥ 2.0	Extreme wet

Coefficients of variation

We calculated the coefficient of variation of annual precipitation as an indicator of the year-to-year variability in total rainfall. We calculated it, for each site, for each decade, and compared it between decades to identify changes in rainfall variability through time. We did not conduct tests of statistical significance for this data.

Results

Rainfall breaks

Pettitt's and Buishand tests both show breaks ($p < 0.01$) in the rainfall times series at Fatick and Kaolack and ($p=0.021$ and $p=0.007$) at Nioro. While no breaks were detected by Pettitt's test in Gossas ($p = 0.297$), Foundiougne ($p = 0.778$) or Guinguineo ($p = 0.299$), breaks were detected by the Buishand test in Gossas ($p = 0.049$), but not in Foundiougne ($p = 0.247$) and Guinguineo ($p = 0.059$).

Table 3: p-values from Pettitt's and Buishand tests for rainfall time series at the six meteorological stations. Blue backgrounds indicate statistically significant breaks detected. Blue cells indicate detection of a statistically significant break.

Sites	Pettitt	Years of break	Buishand	Years of break
Gossas	0,297	No break	0,049	2004
Fatick	0,003	1969	0,001	1969
Foundiougne	0,778	No break	0,247	No break
Guinguineo	0,299	No break	0,059	No break
Kaolack	0	1971	< 0,0001	1971
Nioro	0,021	1998	0,007	1998

Nullhypothesisrejected

Similar break years were detected for Fatick (1969), Kaolack (1971) and Nioro (1998) (Figure 2 and Figure 3). In Fatick, Pettitt's test detected a decrease in average rainfall of 233.1 mm, or 29.3 %, between 1951-1969 and 1970-2020. In Kaolack, the decrease was 216.1 mm, or 27.7 %, between 1951-1971 and 1972-2020. In Nioro, Pettitt's test detected an increase in average rainfall of 211.4 mm, or 30.2%, between 1961-1998 and 1999-2020.These three breaks were also detected by the Buishand test.

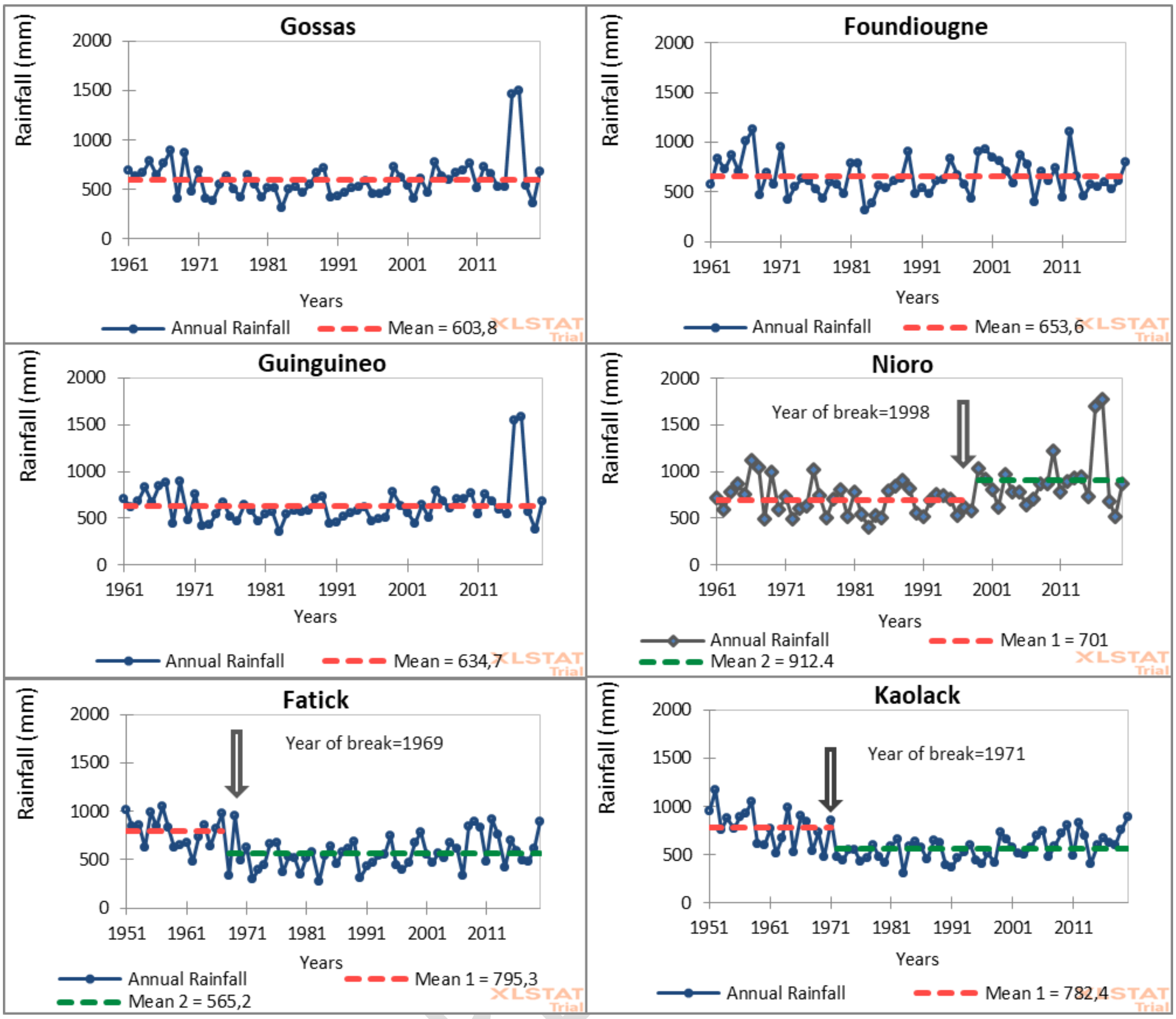

Figure 2: Pettitt's test of rainfall for Gossas, Foundiougne, Guinguineo and Nioro (1961-2020) and Fatick and Kaolack (1951-2020).

The Buishand test also detected later increases in average rainfall in Gossas and Nioro. In Gossas, a break was detected in 2004. Here average rainfall increased by 168.7 mm, or 30.2 %, from 1961-2004 to 2005-2020 (Figure 3).

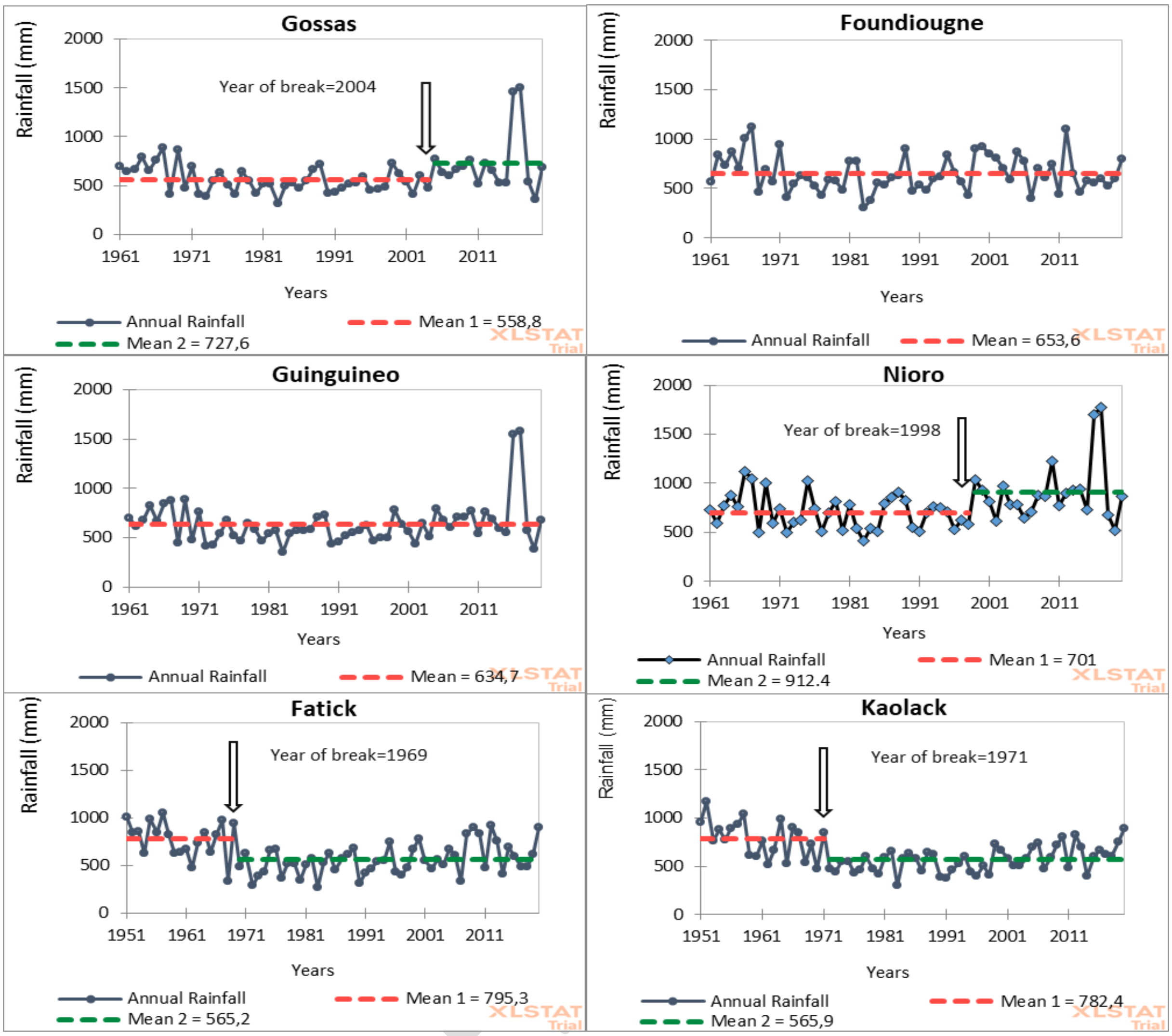

Figure 3: The Buishand test of rainfall for Gossas, Foundiougne, Guinguineo and Nioro (1961-2020) and Fatick and Kaolack (1951-2020).

Hubert's segmentation

Hubert's segmentation detected decreases in rainfall in the late 1960s/early 1970s for four of the six stations: 1967 for Foundiougne and Fatick, 1969 for Gossas, and 1971 for Kaolack. It also detected increases in rainfall from 2015 in Guinguineo and Nioro, related to the high annual rainfall amounts observed across these western sites in 2016 and 2017. Additional breaks are also identified at individual sites, such as in Fatick (2007) and Kaolack (1998) (

Table 4).

Table 4: Hubert segmentation results. Grey cells indicate the end of a segment, prior to the beginning of a new segment, i.e. a break year.

Site	Segment 1				Segment 2				Segment 3				Segment 4			
	Start	End	Mean	Standard deviation	Start	End	Mean	Standard deviation	Start	End	Mean	Standard deviation	Sart	End	Mean	Standard deviation
Gossas	1961	1969	708.3	144.3	1970	2015	550.2	110.2	2016	2017	1483	26.8	2018	2020	527.3	161.4
Fatick	1951	1967	795.3	161.2	1968	2007	525.4	144.3	2008	2020	687.5	184				
Foundiougne	1961	1967	834.2	188.3	1968	2020	629.8	166.5								
Guinguineo	1961	2015	605.9	127.3	2016	2017	1561.4	23.1	2018	2020	543.5	152.3				
Kaolack	1951	1968	925	135	1969	1971	694.7	165.3	1972	1998	503.8	95.6	1999	2020	642.3	124.8
Nioro	1961	2015	748,6	181,1	2016	2017	1734.5	54.5	2018	2020	688.7	172.8				

Years of break

The decrease in average rainfall in the 1960s and 1970s was early in the Fatick region. It was detected in 1967 in Fatick and Foundiougne, and in 1969 in Gossas. On the other hand, in the Kaolack region, the decrease in the 1960s and 1970s was late or non-existent. It was noted in 1971 in Kaolack and absent in Guinguineo and Nioro (

Table 4). So the decrease in the 1960s and 1970s is significant at some sites and insignificant at others. It is also observed in different years at different sites.

The results also show that sites in the south-central part of the Senegalese groundnut basin saw an early increase in average rainfall in the 1990s. The Nioro and Kaolack sites each showed an increase in 1998 (Figure 3 and

Table 4). While sites located at higher latitudes saw an increase in average rainfall in the 2000s. The Fatick and Gossas sites showed an increase in 2007 and 2004 respectively (Figure 3 and

Table 4).

Standardized Precipitation Index (SPI)

The standardized precipitation index (Figure 4) highlights the variability and rainfall deterioration of the study sites. It shows the decrease in annual rainfall amounts in the 1960s and 1970s and the increase in the 1990s and 2000s as revealed by the break tests and Hubert segmentation.

Years with negative indices dominate the period 1971-2000 with more pronounced indices in the decade 1971-1980 for most sites. Positive indices characterize the decades 1951-1960 and 1961-1970 the pre-break and the decades 2001-2010 and 2011-2020 the post-break. Over the period 2001-2020, with the exception of the Foundiougne site, the indices are higher in the decade 2011-2020 (Figure 4).

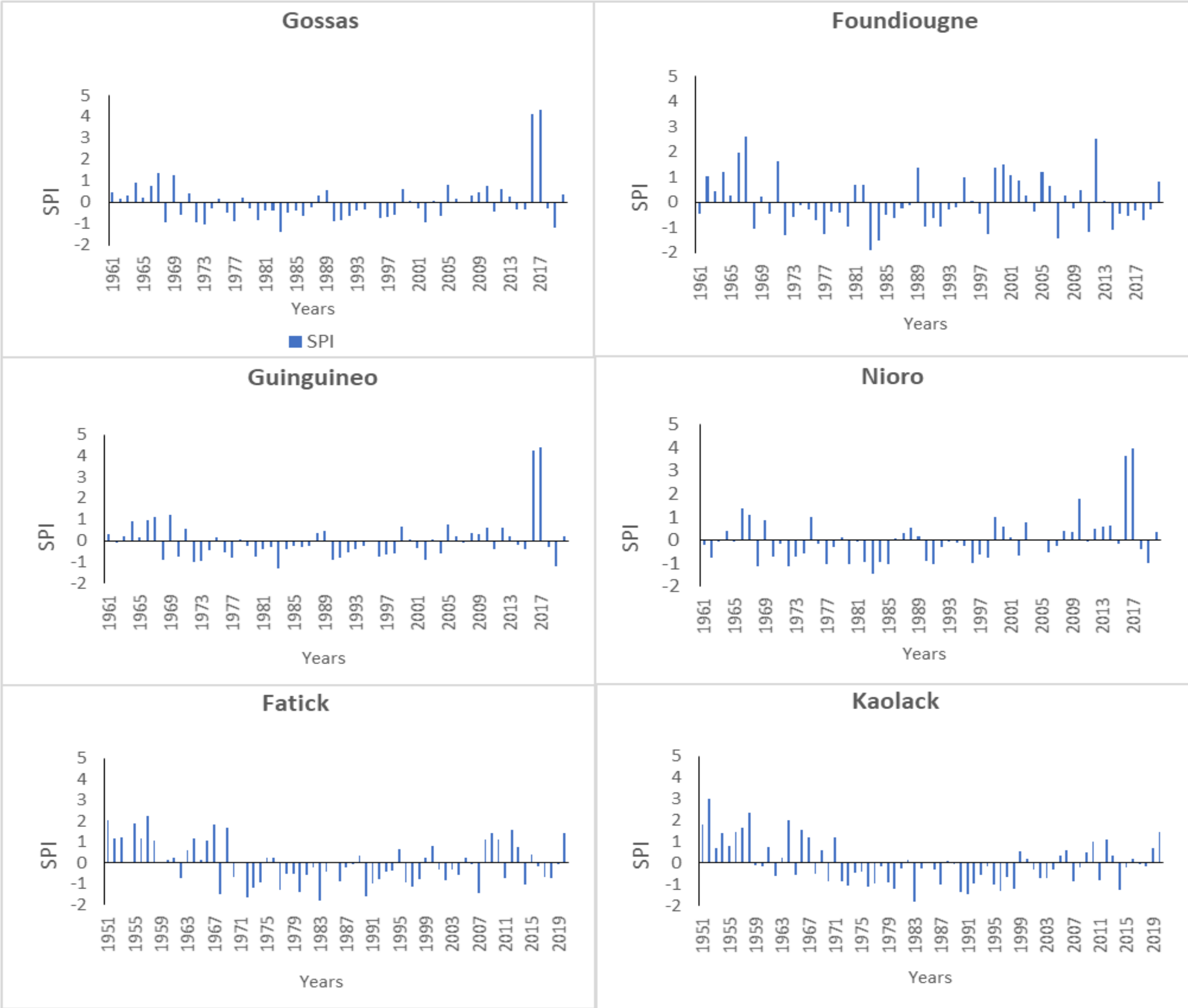

Figure 4: StandardizedPrecipitation index for Gossas, Foundiougne, Guinguineo and Nioro (1961-2020) and Fatick and Kaolack (1951-2020).

Coefficients of variation

Coefficients of variation increase in Fatick and Kaolack from the 1950s to the 2010s. Coefficients are lower in the wettest years (1950s). At four sites (Gossas, Foundiougne, Guinguineo and Nioro), coefficients of variation are higher in the 1960s, 1970s and 1980s and lowest in the 1990s and 2000s. Coefficients increase in the 2010s at these five sites (Kaolack, Gossas, Foundiougne, Guinguineo and Nioro). In Fatick, coefficients in the 1970s, 1980s and 1990s remain lower than in the 2000 and 2010. Gossas, Guinguineo and Nioro show the highest coefficients in the 2010s (Figure 5).

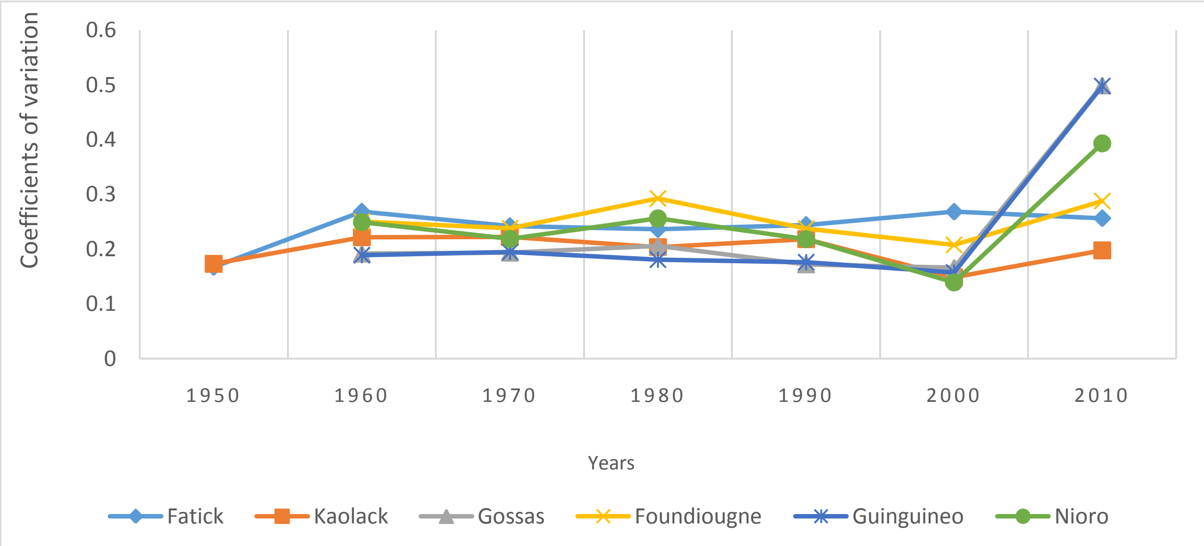

Figure 5: Coefficients of variation for Gossas, Foundiougne, Guinguineo and Nioro (1961-2020) and Fatick and Kaolack (1951-2020).

Discussion

The results of our analyses show a climatic break in the late 1960s/early 1970s in the south-central part of the Senegalese groundnut basin. Pettitt's and Buishand tests detect significant decreases in annual rainfall amountsin Fatick (1969) and Kaolack (1971). This decrease in annual rainfall amountsis also revealed by Hubert's segmentation method, which detected a decrease in average rainfall in Fatick (1967) and Kaolack (1971), as well as in Gossas (1969) and Foundiougne (1967). While a decrease in rainfall is visually noticeable for Guinguineo and Nioro around the same time (Figure 2 and Figure 3), no statistically significant decrease was detected. Break detection methods and Hubert segmentation show that the decrease of the 1960s and 1970s was first observed at sites in the Fatick region. In the Kaolack region, the decrease is late or insignificant. The longitudinal position of the two regions may explain the early decrease in annual rainfall amounts in the Fatick region compared with the Kaolack region. A profound decrease in rainfall amounts around this time has also been found in other studies conducted in Senegal by Dacosta *et al.* (2002), Sarr (2009), and Bodian (2012, 2014). These breaks or periods of decrease in average rainfall are also generally in line with the fluctuation of the rainfall regime observed between the late 1960s and early 1970s elsewhere in West and Central Africa (Barbé, Lebel, 1997; Mahé, Olivry, 1995; Nicholson, 2001; Paturel *et al.*, 1998; Servat *et al.*, 1998, 1999). In general, drought has been affecting our planet's tropical zone since the 1970s (Olivry, Sircoulon, 2005).

The decreases in recorded rainfall range from 22.3 % in Gossas to 33.9 % in Fatick, between periods before and after the detected breaks. These decreases are in the same range as was found by Bodian (2012), who found that drought in the Senegal River basin has been accompanied by a reduction in heavy rainfall (over 50 mm). These deficits are also in the same range as those reported by Nicholson (1983), who noted a deficit of 50 % in the Sahel between 1976 and 1980. Rainfall deficits are also of the same order as those obtained by Servat *et al.* (1999) which can exceed 25 % on the Atlantic coast and in North Africa during the decades from 1950 to 1980.

Annual rainfall amountsincrease again in the 1990s and 2000s for some sites, with the Buishand test revealing breaks at Gossas (2004) and Pettitt and Buishand tests detecting breaks at Nioro (1998). Such increases are also detected by Hubert's segmentation in

Fatick(2007) and Kaolack(1998). It was in the 1990s that the increase in annual rainfall amounts was first recorded in the south and center of the Senegalese groundnut basin. In the north, however, the increase was mostly observed in the 2000s. The decrease in rainfall amounts from the south to the north of Senegal explains this disparity. Indeed, sites located further south in the south-central part of the Senegalese groundnut basin record higher rainfall than those at higher latitudes, due to the presence of the southerly monsoon. These results are in line with those of Mahé et Paturel (2009), who found that in the West African zone, rainfall decreased in the 1970s and then increased in the 2000s, particularly in the Sahelian zone. In the same vein, (Faye *et al.*, 2015) maintain that the period 1995-2004 shows some increase in the upper Senegal River Basin. It is true that rainfall for the five-year period 2000-2004 is close to the average for the period 1950-2004, but this means that it is far removed from that of the period 1950-1969 (Faye *et al.*,2015). Rainfall trends are regional and do not only concern Senegal or the groundnut basin. The area affected by drought in Burkina Faso has also been reduced since 1994 (Diello, 2007). The increase in rainfall observed around the 1990s in the West African Sahel is due mainly to an increase in daily rainfall events of high intensity (Bamba *et al.*, 2015; Panthou *et al.*, 2014). The increase in the 1990s and 2000s did not seem to affect the sites in Foundiougne and Guinguineo. The increase in rainfall amounts in the 2000s at certain sites in the south-central groundnut basin and in the Sahel in general can be explained by an increase in the length of rainy seasons, the number of rainy days, the intensity of the rains, an early start and late end to the rainy seasons.

The standardized precipitation indices also show a predominance of negative indices for the period 1971-2000. The positive indices mark the years before the breaks in the 1950s and 1960s, and after the breaks in the 2000s and 2010s. In the same vein, coefficients of variation are lower in the rainy years 1950, 1990 and 2000. On the other hand, they are higher in the dry years 1960, 1970 and 1980, except in Fatick. Coefficients of variation increase in the 2010s and remain higher for some sites.These standardized indices are consistent with the results of Paturel *et al.* (1996), Lubès-Niel *et al.* (2001), Ardoin-Bardin *et al.*(2003), Ali, Lebel (2009). The contrast between the wetter years of 1950-1969 and the drier years of 1970-2004 is also highlighted by Faye *et al.*(2015). For Senegal as a whole, the period from 1940 to 1969 was characterized by an overall high amount of rainfall, the period from 1970 to 1998 corresponds to the great drought (Ozer *et al.*,2009), and the period from 1999 to 2013 records a return to wetter conditions. According to Diallo *et al.*(2022), in the Thies region, during the 1960s and 2000s, rainfall surpluses predominated, whereas the 1970s, 1980s and 1990s were marked by large deficits. According to Sambou *et al.*(2018), the decades 1938-1947, 1948-1957 and 1958-1967 were wet, while the decades 1968-1977 and 1978-1987 were very dry. Similarly, the periods 1900-1950 and 1995-2015 can be considered as periods of average rainfall, with the periods 1951-1967 and 1968-1995 being wet and dry periods respectively (Descroix *et al.*, 2015).

Conclusion

Annual rainfall data for six sites in the southwestern groundnut basin of Senegal were tested for climatic breaks using Pettitt's and Buishand break tests, then analyzed with Hubert's segmentation method and using the Standardized Precipitation Index (SPI).

The data show decreases in annual rainfall amounts of 20-30 % in the late 1960s and early 1970s in Gossas, Foundiougne (1961-2020) and Fatick and Kaolack (1951-2020). Statistically non-significant decreases in annual rainfall amounts were also observed in the late 1960s and early 1970s at Nioro and Guinguineo. The decrease in annual rainfall amounts was observed in the 1960s for sites in the Fatick region. In the Kaolack region, on the other hand, the decrease is either insignificant or detected in the 1970s.

An increase in annual rainfall amounts of 20-30 % was also noted in the 1990s and 2000s in Gossas, Fatick, Kaolack and Nioro. In the south and south-central parts of the study area, the increase in annual rainfall amounts was observed in the 1990s (Nioro and Kaolack). However, further north, the increase was recorded in the 2000s (Fatick and Gossas).

Thus, the period 1971-2000 is characterized by years with rainfall deficits, most pronounced in the decade 1971-1980. More abundant rainfall amounts predominate at the beginning and end of the time series.

Coefficients of variation increase in Fatick and Kaolack from the 1950s to the 2010s. Coefficients of variation are highest in the dry years 1960, 1970 and 1980 at four sites (Gossas, Foundiougne, Guinguineo and Nioro). On the other hand, they are lower for the wet years 1950 (Fatick and Kaolack), 1990 and 2000 (Gossas, Foundiougne, Guinguineo and Nioro). In Fatick, coefficients of variation are lower in the dry years 1970, 1980 and 1990 than in the wet years 2000 and 2010. Coefficients of variation increase in the 2010s at five sites (Kaolack, Gossas, Foundiougne, Guinguineo and Nioro). Gossas, Guinguineo and Nioro show the highest coefficients of variation in the 2010s.

REFERENCES

Ali, Abdou, and Thierry Lebel. 2009. "The Sahelian Standardized Rainfall Index Revisited." International Journal of Climatology 29(12):1705-14. doi: 10.1002/joc.1832.

ANSD/Fatick. 2019. "Economic and social situation of the Fatick region". Senegal/MEFP/ANSD/SRSDF, Activity report, PDF document 165 p.

ANSD/Kaolack. 2019. "Economic and social situation of the Kaolack region". Senegal/MEFP/ANSD/SRSDK, Activity report, PDF document 161 p.

Ardoin-Bardin, Sandra, Helene Lubes-Niel, Eric Servat, Alain Dezetter, Boyer Jean-François, Gil Mahe, and Jean-Emmanuel Paturel. 2003. "Analysis of the persistence of drought in West Africa: characterization of the situation of the 1990s." Hydrology of the Mediterranean and Semiarid Regions (Proceedings of an international symposium held at Montpellier, April 2003), IAHS Publ . no (278):223‐ 28.

Bamba, Adama, Bastien Dieppois, Abdourahamane Konaré, Thierry Pellarin, Ahmed Balogun, Nadine Dessay, Bamory Kamagaté, Issiaka Savané, and Arona Diédhiou. 2015. "Changes in Vegetation and Rainfall over West Africa during the Last Three Decades (1981-2010)." Atmospheric and Climate Sciences 05(04):367–79. doi: 10.4236/acs.2015.54028.

Barbé, L. Le, and T. Lebel. 1997. "Rainfall Climatology of the HAPEX-Sahel Region during the Years 1950–1990." Journal of Hydrology 188‐ 189:43‐ 73. doi: 10.1016/S0022-1694(96)03154-X.

Bodian, Ansoumana. 2012. "Rainfall-flow modeling approach to regional knowledge of water resources: application to the upper Senegal River basin". Physio-Geo. Physical Geography and Environment (Volume 6):3–5. doi:10.4000/physio-geo.2561.

Bodian, Ansoumana. 2014. "Characterization of the recent temporal variability of annual precipitation in Senegal (West Africa)". Physio-Geo. Physical geography and environment (Volume 8):297–312. doi:10.4000/physio-geo.4243.

Buishand, T. A. 1982. “Some Methods for Testing the Homogeneity of Rainfall Records.” Journal of Hydrology 58(1-2):11-27. doi: 10.1016/0022-1694(82)90066-X.

Camberlin, P., R. Okoola, M. Diop, and P. Valimba. 2003. “Identification of start and end dates of the rainy season: Applications to East Africa and Senegal”. International Association of Climatology Publication 15:295–303.

Chappell, Adrian, and Clive T. Agnew. 2004. “Modeling Climate Change in West African Sahel Rainfall (1931–90) as an Artifact of Changing Station Locations.” International Journal of Climatology 24(5):547-54. doi: 10.1002/joc.1021.

Dacosta, Honoré, Konate Yaye Kandia, and Raymond Malou. 2002. “Spatio-temporal variability of precipitation in Senegal over the past century”. P. 499‐ 506 in IAHS-AISH publication.

Descroix, Luc, Aïda Diongue Niang, Gérémy Panthou, Ansoumana Bodian, Youssouph Sane, Honoré Dacosta, Moussa Malam Abdou, Jean-Pierre Vandervaere, and Guillaume Quantin. 2015. “Recent changes in rainfall in West Africa across two regions: Senegambia and the Middle Niger Basin”. Climatology 12:25–43. doi: 10.4267/climatology.1105.

Diagana, Bocar, and Adrien Mankor. 2008. “Sustainable agriculture and poverty reduction in the Senegal peanut basin: Results of the Tradeoffs analysis model, Reflections and perspectives”. 44.

Diallo. 2021. “Pluviometric variability and agricultural activities in the peanut basin of the Thiès region from 1961 to 2016: impacts and adaptation strategies of the populations”. Single doctoral thesis/Department of Geography/Faculty of Letters and Human Sciences/Doctoral School Study of Man and Society.

Diallo, Souleymane, MBagnick Faye, and Hassan Bismarck Nacro. 2022. “Rainfall variability and its impacts on yields and cultivated areas in the peanut basin of the Thiès region (Senegal)”. VertigO - the electronic journal in environmental sciences. doi:10.4000/vertigo.34710.

Diello. 2007. “Climate – man – environment interrelation in the Sahel of Burkina Faso: impacts on surface conditions and hydrological modeling”. Accessed June 17, 2023 (https://www.documentation.ird.fr/hor/fdi:010056120).

Faye, Cheikh, Amadou Abdoul Sow, and Jean Baptiste Ndong. 2015. “Study of rainfall and hydrological droughts in tropical Africa: characterization and mapping of drought by indices in the upper basin of the Senegal River”. Physio-Geo. Physical geography and environment (Volume 9):17–35. doi:10.4000/physio-geo.4388.

Goula, Bi Tié Albert, Issiaka Savane, Brou Konan, Vamoryba Fadika, and Gnamien Béatrice Kouadio. 2006. “Impact of climate variability on the water resources of the N’Zo and N’Zi basins in Ivory Coast (humid tropical Africa), VertigO - the electronic journal in environmental sciences”. 7(1).

Hubert, Pierre, Jean Pierre Carbonnel, and Ali Chaouche. 1989. “Segmentation of hydrometeorological series — application to precipitation and flow series in West AfricaEast ". Journal of Hydrology 110(3):349-67. doi: 10.1016/0022-1694(89)90197-2.

Jung, Gerlinde. 2006. “RegionalClimate Change and the Impact on Hydrology in the Volta Basin of West Africa.” WissenschaftlicheBerichte FZKA 7240:1‐ 147.

Kouassi, Amani Michel, Assoko, Adjoa Victoire Sandrine, Dje, Kouakou Bernard, Kouakou, Koffi Eugene, Kouame, Koffi Fernand, and Biemi, Jean. 2017. “Analysis of the persistence of drought in

West Africa: Characterization of the recentclimatevariability in Ivory Coast”. Environmental and Water Sciences, public Health and Territorial Intelligence Journal 1(2):47-59.

Kouassi, Amani Michel, Koffi Fernand Kouamé, Yao Blaise Koffi, Kouakou Bernard Dje, Jean Emmanuel Paturel, and SekoubaOulare. 2010. “Analysis of climatevariability and its influences on seasonalrainfallregimes in West Africa: case of the N’zi (Bandama) watershed in Côte d’Ivoire”. Cybergeo: European Journal of Geography 513. doi: 10.4000/cybergeo.23388.

Leroux, Marcel. 1996. The dynamics of weather and climate. Editions Masson.

Lubes-Niel, H., J. Masson, J. Paturel, and E. Servat. 1998. “ClimateVariability and Statistics.” Simulation study of the power and robustness of some tests used to verify the homogeneity of chronicles. Revue des sciences de l’eau / Journal of Water Science 11(3):383-408. doi:10.7202/705313ar.

Lubès-Niel, Hélène, Luc Séguis, and Robert Sabatier. 2001. “Study of stationarity of the characteristics of rainyevents at the Niamey station over the period 1956–1998”. Comptes Rendus de l’Académie des Sciences-Series IIA-Earth and Planetary Science 333(10):645-50.

Mahé, Gil, and Jean-Claude Olivry. 1995. “Variations of precipitation and runoff in West and Central Africafrom 1951 to 1989”. Science and global change / Drought 6(1):109- 17.

Mahé, Gil, and Jean-Emmanuel Paturel. 2009. “1896–2006 SahelianAnnualRainfallVariability and RunoffIncrease of Sahelian Rivers.” Comptes Rendus Geoscience 341(7):538- 46. doi: 10.1016/j.crte.2009.05.002.

McKee, Thomas B., Nolan J. Doesken, and John Kleist. 1993. “The Relationship betweenDrought Frequency and Duration and Time Scale.” Proceedings of the 8th Conference on AppliedClimatology (Anaheim, California) 179-84.

Ndong, Jean-Batiste. 1995. “The evolution of rainfall in Senegal and the consequences of the recentdrought on the environment”. Géocarrefour 70(3- 4):193- 98. doi: 10.3406/geoca.1995.4212.

Nicholson, S.E., B. Some, and B. Kone. 2000. “An Analysis of RecentRainfall Conditions in West Africa, Including the Rainy Seasons of the 1997 El Niño and the 1998 La NiñaYears.” Journal of Climate 13(14):2628- 40. doi: 10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2.

Nicholson, Sharon E. 1983. “Sub-SaharanRainfall in the Years 1976–80: Evidence of ContinuedDrought.” MonthlyWeatherReview 111(8):1646- 54. doi: 10.1175/1520-0493(1983)111<1646:SSRITY>2.0.CO;2.

Nicholson, Sharon E. 2001. “Climatic and Environmental Change in Africaduring the Last Two Centuries.” ClimateResearch 17(2):123–44. doi:10.3354/cr017123.

Olivry, J.C., and J. Sircoulon. 2005. “Evolution of hydrologicalresearch in partnership in sub-SaharanAfrica: the example of French-speaking countries”. Revue des sciences de l’eau 11:61–75. doi:10.7202/705330ar.

Ozer, Pierre, Yvon-Carmen Hountondji, and Ousmane LaminouManzo. 2009. “Evolution of rainfallcharacteristics in eastern Niger from 1940 to 2007”. Geo-Eco-Trop: International Review of Tropical Geology, Geography and Ecology 33:11-30.

Panthou, G., T. Vischel, and T. Lebel. 2014. “Recent Trends in the Regime of ExtremeRainfall in the Central Sahel.” International Journal of Climatology 34(15):3998-4006. doi:10.1002/joc.3984.

PATUREL, J. E., E. SERVAT, M. O. DELATTRE, and H. LUBES-NIEL. 1998. “Analysis of long-termrainfallseries in non-Sahelian West and Central Africa in a context of climatevariability”. Hydrological Sciences Journal 43(6):937-45. doi:10.1080/02626669809492188.

Paturel, J. E., E. Servat, B. Kouame, J. F. Boyer, and H. Lubes Niel. 1996. “Procedures for identifying “breaks” in time series-modification of rainfallregime in non-Sahelian West Africa. In Tropical hydrology: geoscience and tool for development”. IAHS Publ. (238): 99-110.

Pettitt, A. N. 1979. “A Non-ParametricApproach to the Change-Point Problem.” Journal of the Royal Statistical Society: Series C (AppliedStatistics) 28(2):126-35. doi:10.2307/2346729.

Sagna, Pascal. 1995. “The recentevolution of rainfall in the Grande-Côte region of Senegal and the Cap-Vert archipelago”. Géocarrefour 70(3- 4):187- 92. doi: 10.3406/geoca.1995.4211.

Sambou, Saly, HonoréDacosta, and Jean-Emmanuel Paturel. 2018. “Spatio-temporalvariability of rainfallfrom 1932 to 2014 in the Kayanga/Gêba river watershed (Republic of Guinea, Senegal, Guinea-Bissau)”. Physio-Geo. Physical geography and environment (Volume 12):61–78. doi:10.4000/physio-geo.5798.

Sarr Mamadou Adama. 2009. “Recentevolution of climate and vegetation in Senegal: case of the Ferlo watershed”. Doctorate: Geography and planning: Lyon 3: 2009 - Geography and planning: Cheikh Anta Diop University: 2009 (co-supervision), Jean Moulin University (Lyon); Cheikh Anta Diop University of Dakar.

Scheffé, Henri. 1999. The Analysis of Variance. WileyClassics Library Edition published 1999.

Servat, É., J. E. Paturel, H. Lubès-Niel, B. Kouamé, J. M. Masson, M. Travaglio, and B. Marieu. 1999. “Different aspects of rainfallvariability in non-Sahelian West and Central Africa”. Journal of Water Sciences 12(2):363-87. doi:10.7202/705356ar.