ISSN: 2641-1784

Research Article

Advance in Environmental Waste Management & Recycling

Use of the standardized precipitation and evapotranspiration index (SPEI) from 1961 to 2019 to characterize the drought trend in northern Senegal: Study of the spatio-temporal dynamics in the Ferlo watershed

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Submitted: 14 Oct 2021; **Accepted**: 19 Oct 2021; **Published**: 29 Oct 2021

Citation: *Sidy Dièye, Cheikh Faye, Ababacar Fall and Pierre Corneille Sambou (2021) Use of the standardized precipitation and evapotranspiration index (SPEI) from 1961 to 2019 to characterize the drought trend in northern Senegal: Study of the spatio-temporal dynamics in the Ferlo watershed. Adn Envi Was Mana Rec, 4(3):232-244.*

Abstract

The study and analysis of the dynamics of the earth's climate is one of the scientific themes that has developed mostly at the recent years. This mobilized several scientists to study, describe or characterize the climate through several methods. These methods derived from climate science have given convincing results of high scientific significance, and above all through the appreciable quality of the indicators provided. In this context, and in order to appreciate this drought trend, we are using in the framework of this study of the Standardized Index of Precipitation and Evapotranspiration (SPEI) during the period 1961-2019. Indeed, the frequency and recurrence of drought are harmful events for the traditional production system in the Sahel region. Thus, the objective of this study is to identify the multiscale distribution of droughts. The results obtained define different types of droughts as well as their prevalence. These generally indicate the prevalence of slightly wet and slightly dry traits and are followed by moderately dry and moderately wet indices over all the stations studied. However, it should be noted a periodic occurrence of more or less long droughts which resulted in the preponderance of meteorological and agricultural droughts with occurrences mainly located in the periods 1974-1989 at Linguère station (1974-1989 and 1993-2009), in Louga, between 1962-1973 and 1974-1982 in Podor, and, at the end between 1961-1970, 1974-1985 and 1993-2000 in Matam. In addition, the drought sequences are manifested earlier at the level of the stations of Matam and Podor. On other hand, at Linguère and Podor stations, the extreme drought indices were higher for all time scales chosen (SPI_1months, SPI_3 months and SPI_12 months).

Keywords: Analysis, Drought Dynamics, Trends, Characterize, Indicators, SPEI, Watershed Ferlo, Senegal

Introduction

The Senegalese Sahel has been confronted for several decades with the problem of drought and its impact on the environment and especially on the lives of populations. This situation is all the more worrying given that the context, the manifestations of climate change are expressed through certain elements: salinization of the land, strong winds, disappearance of certain plant and wildlife species, reduction in waves of migratory birds, the increase in of temperatures, the shortening or prolongation of the rainy seasons [1]. Droughts are usually classified by type (meteorological, agricultural and hydrological) and differ among themselves according to their intensity, duration and spatial coverage. Meteorological drought is usually accompanied by below normal precipitation and above normal temperatures [2]. The monitoring or surveillance of this phenomenon has made use of a number of methods, including the normalized precipitation index (WMO, 2012). In fact, the cycle of drought that began at the end of the sixties manifested itself with more or less persistence and severity depending on the years, times and stations within the Sahelian zone itself. This has often led to dire situations. These climatic crises have particularly affected the northern zone of Senegal, the most Sahelian part of the country is regularly subject to severe droughts. The most worrying in these conditions, is its quasi-chronic character since the end of the seventies with rainfall totals lower than the 1931-1960 normal. They have become the rule, with the rainy season tending more and more to shorten. Suddenly, the north of Senegal is facing a crisis situation. This drought has led to socioeconomic and environmental consequences [3-11].

The consequences are all the more worrying as the persistence of the drought over a long range, November-May, as well as the poor distribution of precipitation and the high evapotranspiration (ETP) over more than half of the year, reduce the chances of a good development of agricultural activities, breeding which occupies a good part of the populations of the sylvopastoral zone. In fact, in the sylvopastoral zone, production activities are subject to the rainfall regime. Under these conditions, the life of the populations is divided between adaptation and resilience to the vagaries of the climate, even if we observe a climatic situation characterized by an alternation of dry and wet years. However, extreme but rare situations of humidity are noted. These generally correspond to phases of return to a normal rainfall rate and by extension to a better serenity in the daily life of the populations. In fact, in the Sahelian zone and particularly in the north of Senegal, the rainfall deficit has been less marked over the past twenty years compared to the period 1970-2000. The modification of the climatic cycle and the severity of the climatic conditions have been fatal to ecosystems: surface water, surface water tables, soils and vegetation are sometimes irreversibly affected (Bovin P. and Mougenot B., 1998). Work carried out in the sylvopastoral found negative variations extended to socioeconomic activities [12-14]. This is how drought is described as "an insidious plague that results from a drop in rainfall from levels considered normal (WMO, 2012)" and is one of the most disastrous natural hazards with destructive impacts.

In this study, our first objective is to provide a complete analysis of the drought conditions in the Ferlo basin during the period 1961-2019. This is an index meeting the constraints or limitations of the SPI which did not take temperatures into account in the study of droughts. It is for this reason that found the solution by taking temperature into account in the calculations of the new index which they call the Standardized Precipitation and Evapotranspiration Index (SPEI) [15]. Mathematically, the SPEI is similar to the SPI, but it incorporates temperature data for the calculation of potential evapotranspiration. Therefore, it combines the sensitivity to change in evapotranspiration demand (caused by fluctuations and trends in air temperature) with the multi-temporal nature of SPI [16]. It is therefore a question here of studying the series of SPEI for different temporal scales by following different multiscale models, in order to have on the one hand new information on drought and on the other hand, to deepen our knowledge on trends in the spatio-temporal manifestation of drought in the Ferlo basin.

Presentation of the study area

The study area is limited to the Ferlo Valley, located in northern Senegal between latitudes 14 ° 30 'and 16 ° 10' north and longitudes 12 ° 50 'and 16 ° 30' west. It constitutes the downstream extension of the depression occupied by Lake Guiers beyond the earthen dike of the village of Keur Momar Sarr, built in 1957. The Ferlo watershed extends over part of the administrative regions of Louga, Matam and Saint-Louis and covers a total area of 43,700 km^2 (Figure 1). It is bounded to the north by the Senegal River Valley and to the south by the eco-geographic zone of the Groundnut Basin. The Ferlo watershed is characterized by the presence of vast dune plateaus intersected by the network of the Ferlo fossil valley and its tributaries, and a fairly monotonous relief. The soils are of the hydromorphic isohumic type in the Ferlo valley, sandy-clayey, gravelly and with lateritic outcrops [17].

From a climatic point of view, this zone belongs to the Sahelian zone and more particularly to the Ferlo region. It is thus subjected to a dry tropical climate with a rainy season which goes from June to October. Precipitation varies between 200 and 500 mm per year following a north-south gradient and is characterized by pronounced spatio-temporal variability. The annual mean temperature is 29.6 ° C with an annual mean amplitude of 7.6 ° C. The thermal regime is bimodal in nature, showing two maxima (May and October) and two minima (January and August). From a hydrological point of view, we note the presence of deep aquifers, called the Maestrichtian and Eocene aquifers, and the surface aquifers or aquifers of the Terminal Continental and Quaternary [18]. The surface waters of the Ferlo region are represented by the Lac de Guiers, a shallow natural depression (2 to 3.5 m in the north and 1 to 1.5 m in the south covering 300 km2 at its maximum extent) It extends into the lower Ferlo Valley by a network of temporary water points, made up of ponds of variable size, developed or natural located in the valley bottoms. are, in the rainy season, only puddles of water of a few tens of square meters, others can spread over hectares [19]. Indeed, the Ferlo basin belongs to the sylvopastorale (ZSP), the main region of This region is geomorphologically made up of a landform formed by a flat and monotonous surface which gradually sinks towards the west and north-west. networks of dead valleys whose ramifications cut the plateaus into a series of strips of very variable surfaces and with scalloped contours [20]. Overall, it is subdivided into two zones, one in the east, dominated by a sandy substrate, and the other in the west, dominated by a ferruginous substrate [21].

The rainy season is from June to October. It is characterized by low precipitation (100 to 600 mm / year) with a north-south gradient and pronounced spatio-temporal variability. Two out of three years, August is the rainiest month of the year. Light rains, known as Heug, can also be noted in the cold dry season. The annual mean temperature is 29.6 ° C with an annual mean amplitude of 7.6 ° C. The thermal regime is characterized by a bimodal evolution, revealing two maximum temperatures (May and October) and two minimum (January and August). The annual aérages relative humidity is 47% and it is marked by a unimodal evolution, with a maximum occurring in August (73%) and a minimum in February (29%) [22]. As for the plant cover, it is made up of a herbaceous carpet predominantly of annual species (Cenchrus biflorus, Schoenefeldia gracilis, Zornia glochidiata, etc.), covering the ground incompletely, and a sparsely dense shrub layer dominated by Balanites aegyptiaca, Boscias enegalensis, Acacia senegal, etc., in the sandy part, and Pterocarpus lucanes in the ferruginous part (Stancioff et al, 1986; 21].

From a socio-economic point of view, this is an essentially agricultural and pastoral region. It is home to a herd of cattle, small ruminants, equines and donkeys. The cattle in the area are mostly zebu Gobra breed. The population is made up of Fulani who constitute the dominant ethnic group, Ouolofs, Moors and Serer scattered throughout the area. However, livestock is the dominant production system in the ZSP, depending on the sub-zones, it is associated with agricultural activities such as the cultivation of millet (Pennisetum typhoides), peanuts (Arachis hypogaea), cowpea (Vignas inensis) sorghum (Sorghum bicolor) béref (Citrulus lanatum) and bissai (Hibiscus sabdariffa) or to forestry activities such as logging, gum arabic, fruits of Balanites aegyptiaca and Zizyphus mauritiana. Depending on the importance of these activities, we can distinguish five subsystems: silvopastoral, agrosilvopastoral, agropastoral, lower Ferlo valley and peri-urban [23].

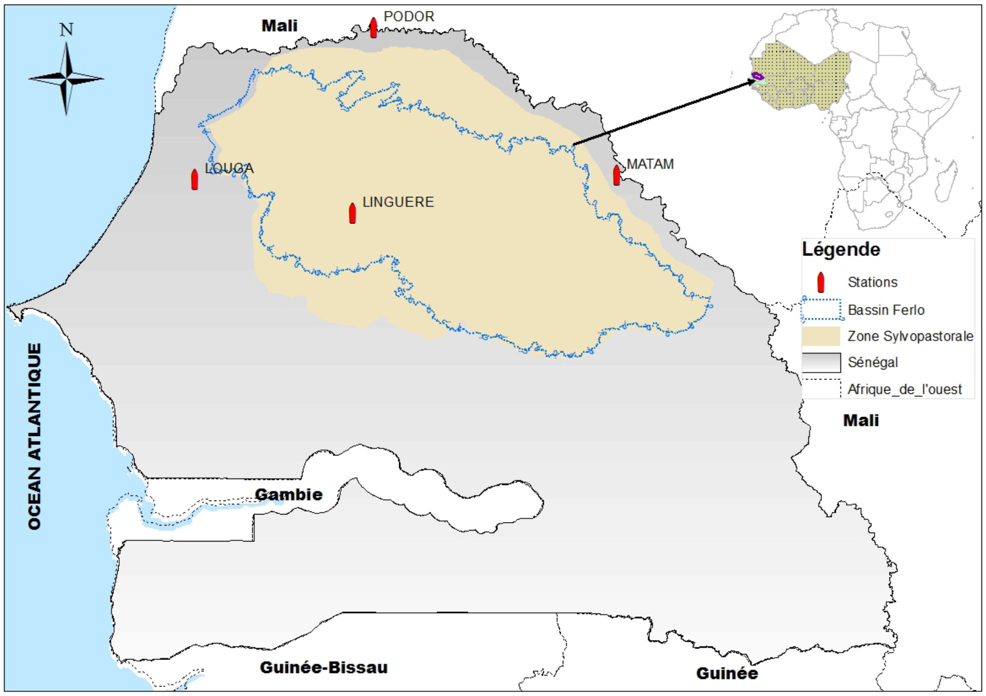


Figure 1: Location of the Sylvopastoral Zone

Today, the area is strongly impacted by the repeated rainfall deficits of recent decades. This situation has also prompted the Senegalese public authorities, in recent years, to opt for the establishment of a program to improve the availability of surface water oriented towards the management of water points and the restoration of the area. middle through the Great Green Wall [24].

Materials and methods

Standardized precipitation and evapotranspiration index (SPEI) data

In this study, the SPEI is used to monitor and quantify the drought over the Ferlo basin, and an additional comparison was made with the SPI to test its performance. The data is taken from the Global Drought Monitor SPEI: http://spei.csic.es/index.html. The calibration period for the SPEI goes from January 1961 to December 2019. The SPEI values are calculated with temperature and precipitation data from ANACIM measured in-situ on how many stations four stations (Louga, Linguère, Podor and Matam). They are therefore well suited for analysis at the local level. The SPEI is considered to be an improved drought index, particularly suitable for analyzing the effect of global warming on drought con [25,26,27]. The calculation of the SPEI in this study follows the method mentioned in the study by [15]. It is based on a climatic water balance which is determined by the difference between Precipitation (P) and potential evapotranspiration (ETP) for month i:

$$D_i = P_i - ETP_i$$

Di provides a simple measure of the excess or deficit of water for the month analyzed. PET is calculated using the Thornthwaite equation [28]. The calculated values Di are aggregated at different time scales, following the same procedure as that for the SPI. The difference, Dki, j in a given month j and year i depends on the chosen timescale, k. For example, the difference accumulated during a month of a given year, with a time scale of 12 months, is calculated according to the following formula:

Xki, j = +, if j <k, and
Xki, j =, if j ≥ k,

Where Di, j is the difference in P-FTE of the lth month of year i, in mm.
And then the log-logistic distribution is selected to normalize the D-series to obtain the SPEI. The probability density function of the log-logistic distributed variable is expressed as follows:

$$= () -1 [1+ () \boldsymbol{\beta}] -2$$

Where α, β, and γ are the scale, shape, and origin parameters, respectively, for D values in the range (γ> D <∞).

Thus, the probability distribution function of the series D is given by:

$$= [1+ () \boldsymbol{\beta}] -1$$

With F (x), the SPEI can easily be obtained as normalized values of F (x). For example, after the classical approximation of [18].

Where for p 0.5 and p is the probability of exceeding a determined D value, p = 1 - F (x). If p> 0.5, p is replaced by 1 - p and the sign of the resulting SPEI is reversed. The constants are t: C0 = 2.515517, C1 = 0.802853, C2 = 0.010328, d1 = 1.432788, d2 = 0.189269 and d3 = 0.001308. Positive values of SPEI indicate above-average humidity conditions, while negative values indicate drought conditions. A drought event is defined when the value of SPEI is less than or equal to -1 during a certain period. The drought categories according to the SPEI values are presented in Table 1. The SPEI indices calculated from the monthly precipitation and temperature data over the period 1961-2019.

Tableau 1 : Catégorisation du degré de sécheresse / d'humidité en fonction des indices standardisés de précipitations et d'évapotranspiration

Valeurs SPEI	Séquences de sécheresses	Valeurs SPEI	Séquences humides
SPEI < -2,00	Extrêmement sèche	2,00< ISP	Extrêmement humide
-1,50< ISP <-1,99	Sévèrement sèche	1,50< ISP <1,99	Sévèrement humide
-1,00< ISP <-1,49	Modérément sèche	1,00< ISP <1,49	Modérément humide
0,00< ISP <-0,99	Légèrement sèche	0,00< ISP <0,99	Légèrement humide

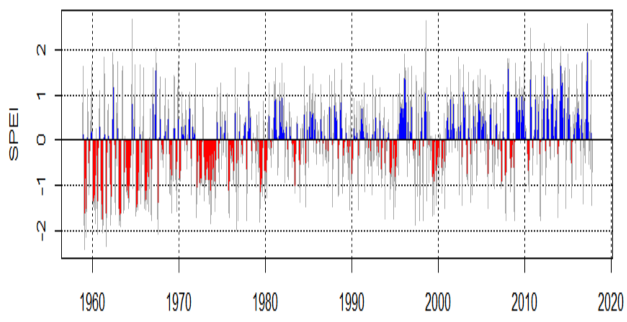
Results and discussion

Multi-scale drought models

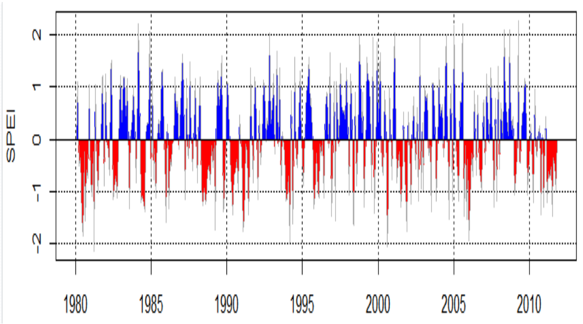
According to the aforementioned methodological approach, the monthly SPEI was calculated from 1950 to 2018 at 5 time scales (1, 3 and 12 months) for the subdivided study area. These SPEI series were averaged in order to characterize the dry or wet conditions in the Ferlo basin (figure2: a1, a2, a3; b1, b2, b3; c1, c2, c3; d1, d2, d3).

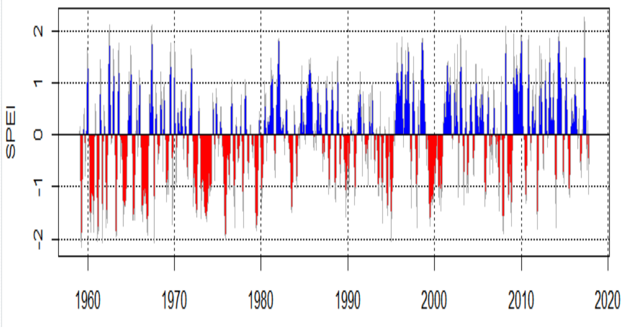
Analysis of the different situations indicates a succession of drought and wet sequences in the Ferlo basin. However, the SPEI series at different time scales show quite contrasting values from one station to another. This drying out is however much more apparent at the level of the 3 and 12 month timescales which show episodes of drought, especially over the period 1970-1980. However, before 1970, the episodes of drought were severe in Matam and Linguère. Thus, extreme droughts have really started since 1970, while light to moderate droughts were already Beng felt from the 1960s at the level of the Matam and Podor stations. At the end a second phase of manifestation of droughts occurred in the period 1990-2000, even if it is less severe than that of the period 1970. This last phase of the dry sequence is followed by a period of return to l. humidity 2010-2019.

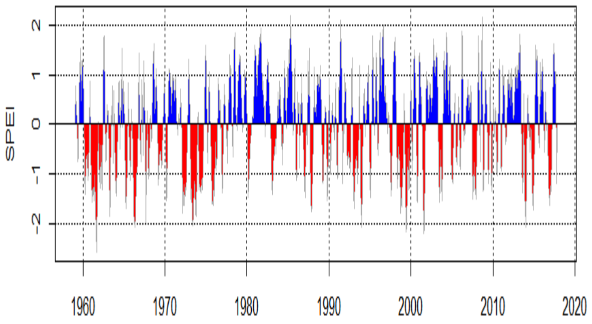
Station Matam(a1SPEI1, a2SPEI3,a3 SPEI12)

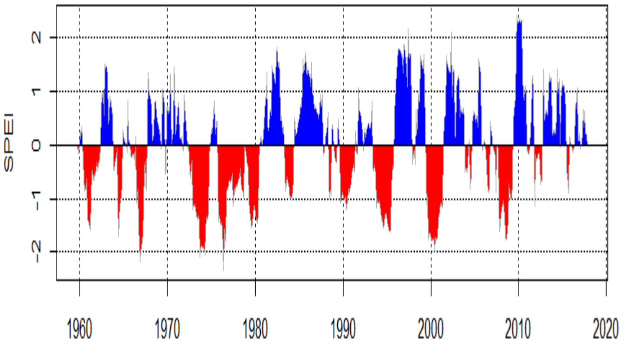


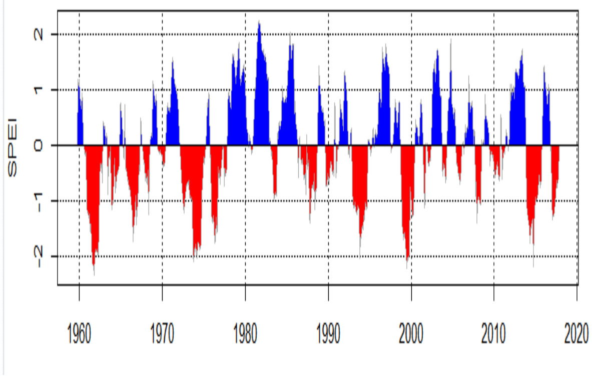
Station Podor (b1SPEI1, b2SPEI3, b3SPEI12)





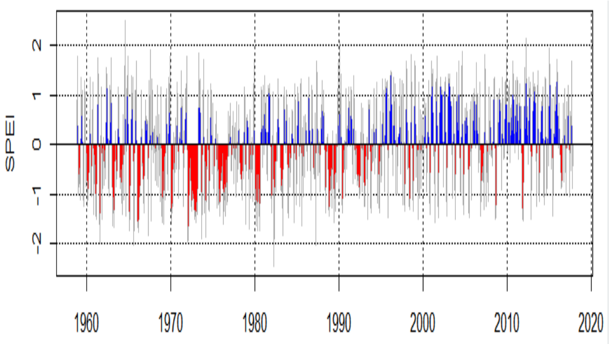


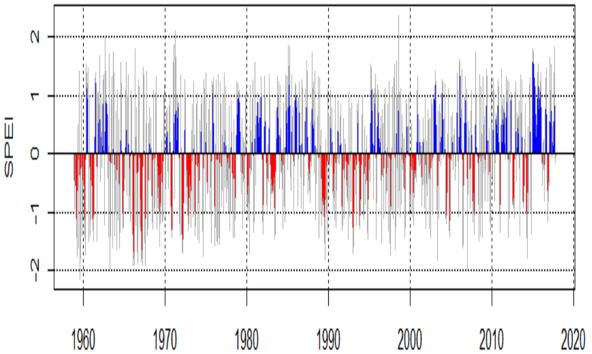


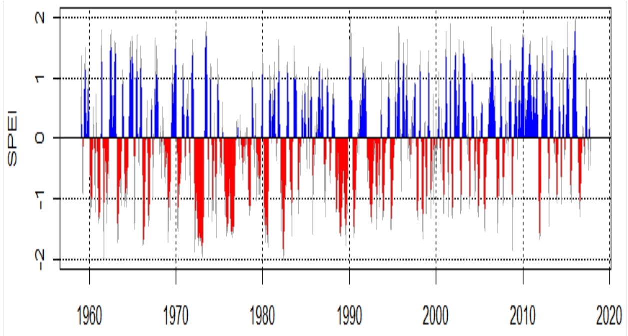


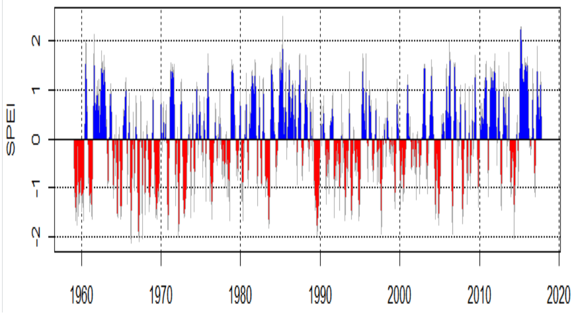
Station (c1SPEI1, c2SPEI3, c3SPEI12)

station (d1SPEI1, d2SPEI3, d3SPEI12)









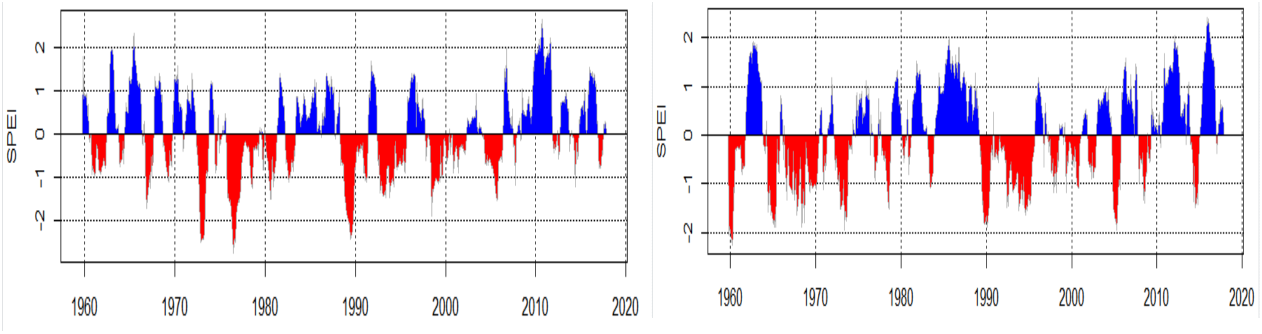
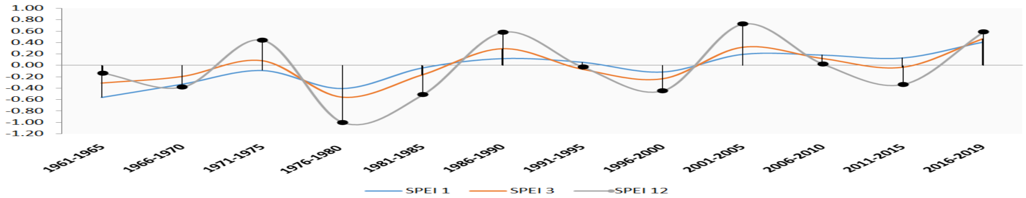
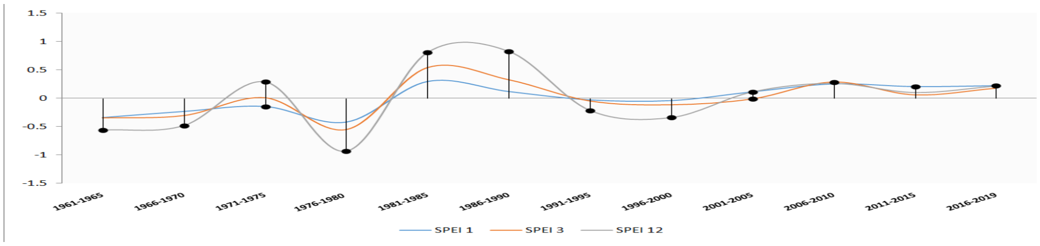


Figure 2 : Evolution temporelle des valeurs SPEI sur des échelles de temps 1, 3 et 12 mois de 1961 à 2019 sur le bassin du Ferlo.

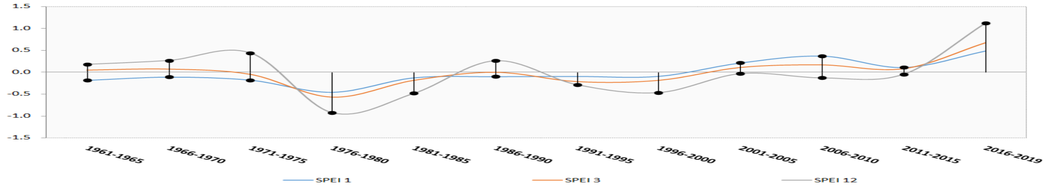
The information given by the different situations at the level of the stations studied corroborates the work of the authors which suggests the end of the Sahelian drought during the 1990s [7,29,30]. As for figure 3 (aa, bb, cc, dd), it shows the five-year evolution of SPEI on time scales 1, 3 and 12 months. The most severe drought was recorded between 1970 and 1980 with several monthly SPEI averages approaching -1.5. Thus, the five-year evolution of the SPEI values on time scales 1, 3 and 12 months from 1961 to 2019 in the Ferlo basin makes it possible to further highlight the succession of more or less marked periods of dry years and wet years (Figure 3: aa for Matam; bb for Podor; dd for Linguère and cc for Louga). The 5-year moving average curves showed a succession of wet and dry periods with a last wet five-year period which confirms the work of on the return to humid conditions and by a greater interannual variability of precipitation [7,30,31].



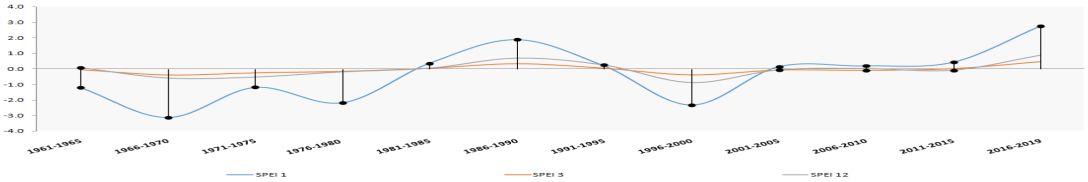
(aa) Matam



(bb)Podor



(cc)Linguère



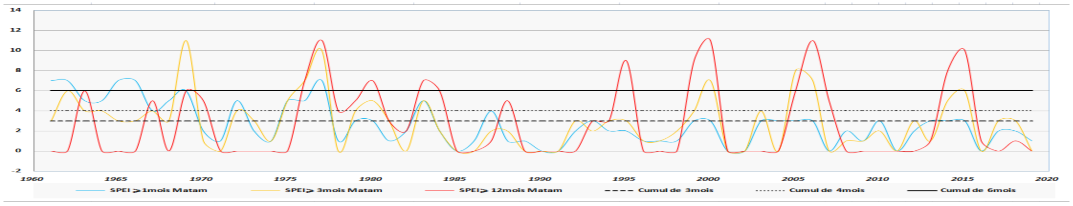
(dd)Louga

Figure 3: Five-year evolution of SPEI values on time scales of 1, 3 and 12 months from 1961 to 2019 in the Ferlo basin.

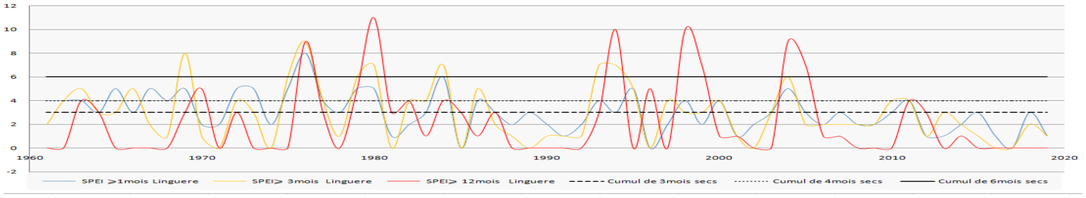
Overall, the results of Figures 2 and 3 confirm the research carried out by many authors who have already reported this severe drought in West Africa and in Senegal indicating that the 1970s, 1980s, and 1990s were dry periods marked by a strong rainfall deficit [32-37]. Thus, the drying conditions are more remarkable if we consider longer delays. In terms of SPEI (SPI_12: a3, b3, c3 and d3) where the drying trends are sharper.

The temporal and spatial extent of the drought Time span

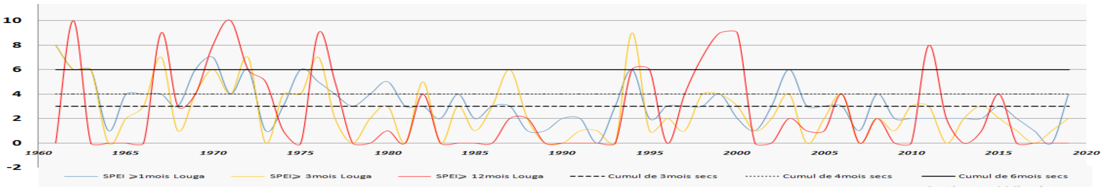
In this part, the duration of drought episodes (defined as SPEI ≤ -1) was calculated for each year. The duration is expressed in number of months. Figure 4 shows the average number of dry months per year from 1961 to 2019 for each station according to the different SPEI time scales taken into account in this study. If generally the number of dry months (SPEI ≤ -1) did not exceed 4, it increased considerably during the years 1964, 1969, 1977 in Podor, 1962, 1971 in Louga, 1980, 1994, 1998 in Linguère, 1977, 2000, 2006 and 2015 in Matam with in particular annual accumulations greater than or equal to 10 months at long time scales (that is to say for SPEI_12). However, the different indices, at the different SPEI timescales presented less severe drought conditions during certain periods with relatively low frequencies of dry months during the period 1980-1995 at the level of all the stations.



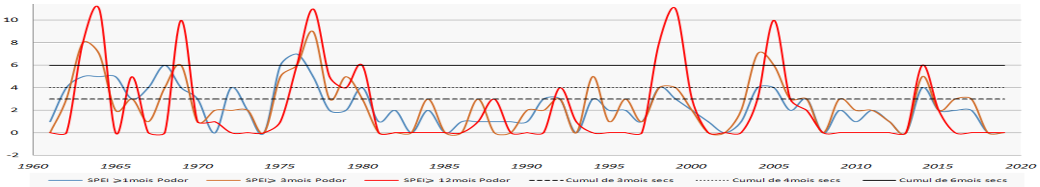
Matam



Linguere



Louga



Podor

Figure 4 : Average number of dry months (SPEI ≤ -1) by sub-periods on time scales of 1, 3 and 12 months from 1961 to 2019

The SPEI with one month reflects the meteorological drought. On the 3 to 6 month time scales, we have agricultural drought, while the 6 to 12 month scales correspond to a hydrological drought index, useful for monitoring surface water resources [38,39].

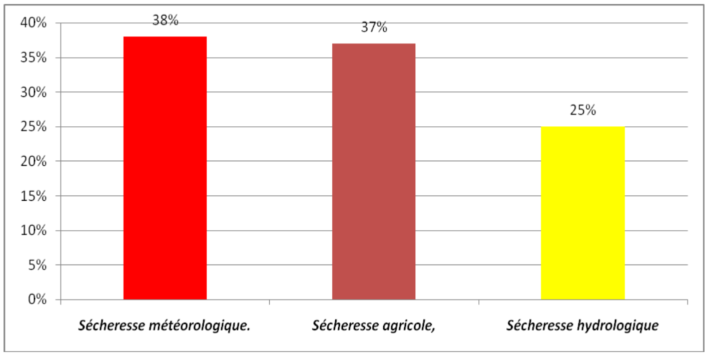


Figure 5 : Frequency of different types of drought (SPEI ≤ −1) at time scales of 1, 3 and 12 months from 1961 to 2019

Thus in the Ferlo basin, meteorological (38%) and agricultural (38%) droughts are much greater than hydrological droughts. This is relatively opposed to the Situation in Casamance where the two drought situations (meteorological and agricultural) are considered to be slightly more severe [40].

Table 2: Frequency rate of the average number of dry months (SPEI ≤ −1) by sub-periods on time scales of 1, 3 and 12 months from 1961 to 2019

	SPEI 1 (Matam)	**SPEI 3 (Matam)**	**SPEI 12 (Matam)**
1961-1970	35%	25%	14%
1971-1980	21%	24%	22%
1981-1990	11%	8%	15%
1991-2000	11%	16%	22%
2001-2010	11%	14%	14%
2011-2019	10%	13%	13%
	SPEI 1 (Linguère)	**SPEI 3 (Linguère)**	**SPEI 12 (Linguère)**
1961-1970	22%	20%	12%
1971-1980	25%	23%	24%
1981-1990	15%	14%	15%
1991-2000	15%	20%	28%
2001-2010	15%	14%	15%
2011-2019	9%	8%	6%
	SPEI 1 (Louga)	**SPEI 3 (Louga)**	**SPEI 12 (Louga)**
1961-1970	29%	29%	33%
1971-1980	17%	18%	7%
1981-1990	20%	23%	37%
1991-2000	20%	17%	9%
2001-2010	13%	13%	14%
2011-2019	29%	29%	33%
	SPEI 1 (Podor)	**SPEI 3 (Podor)**	**SPEI 12 (Podor)**
1961-1970	29%	24%	28%
1971-1980	24%	25%	27%
1981-1990	7%	5%	3%
1991-2000	17%	17%	21%
2001-2010	13%	18%	14%
2011-2019	10%	11%	6%

The results of Table 2 indicate that 40 to 50% or even more of the dry months are located in the first two decades with a strong predominance of the decade 1960-1970 on all the time scales, with the exception of the stations of Linguère and Matam in France. '12-month time scale. These two stations show 12% and 14% respectively on the SPEI_12 timescale. Likewise, it should be noted the particularity of the Louga station which presents the most remarkable drought frequencies during the decade 1981 to 1990 with 20% at the time scale SPEI_1, 23% at the time scale SPEI_3 and 37% at the time scale. the SPEI_12 timescale. Indeed, the water deficit of previous periods being accumulated during the calculation of SPEI with longer time scales, is an indicator to assess the lack of humidity caused the meteorological and agricultural drought and aggravated the hydrological drought [40]. Before 1980, the average number of dry months being quite frequent on the different SPEI time scales (Table 5). On the other hand, between 2011 and 2019, droughts experienced a significant drop in their frequency, with the exception of Louga station where they are still quite severe with frequencies of 29% and 33%. At the Linguere level, they reach their lowest values (6%) at SPEI_12 timescales.

Spatial extension

To always assess the severity of the drought, spatialization makes it possible to assess the spatial extent of the drought. To characterize the spatial extent of the drought, the mean values of SPEI_12 months for the period 1961-2019 were spatialized over the Ferlo Basin. The results of the SPEIs are shown in Table 3 and in Figure 5. Their analysis shows the persistence of drought from 1980 to 2019, regardless of the geographical area indicated, compared to the period from 1950 to 1970.

Table 3 : Average SPEI values on the 12-month time scale by subperiods at different stations in the Ferlo Basin from 1961 to 2019

UTM	Latitude UTM	Longitude UTM	1961-1970	1971-1980	1981-1990	1991-2000	2001-2010	2011-2019
Matam	686104.9375	1731140.75	-0,27	-0,28	0,04	-0,23	0,38	0,08
Linguère	487736.90625	1702337.375	0,23	-0,24	-0,11	-0,38	-0,08	0,47
Louga	368641.75	1727982.875	-0,29	-0,36	0,37	-0,32	-0,02	0,34
Podor	503556.5	1842032.625	-0,52	-0,32	0,82	-0,28	0,19	0,15

However, the most apparent drought is localized at the Podor station, the northernmost station. On the other hand, the Matam station generally maintains less severe drought conditions. In addition, the sequences (1981-1990 and 1991-2000 and 2001-2010 at the Linguère station were the most marked severity of droughts at the SPEI_12 scale. On the other hand, they were present earlier and more pronounced at the level of level of Podor stations (Figure 5).

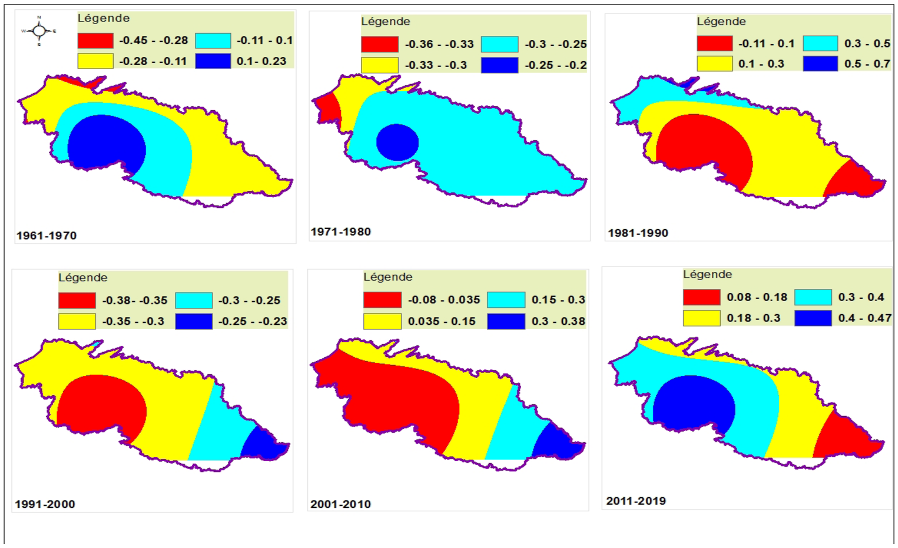


Figure 6: Spatial evolution of SPEI_12 values by periods in the Ferlo basin

The results in Figure 5 are consistent with those in Table 2 which show a fairly random distribution of droughts in magnitude, magnitude and extent at different time scales of analysis. Thus, the particular situations noted at the level of each station reflect hydro-climatic conditions specific to each station.

Statistical approach to variability using the rupture test method

In order to understand long-term data trends and determine trends, the series (SPEI_1, SPEI_3 and SPEI_12) were analyzed using KhronoStat software (IRD, 1998) in order to detect a possible break related to a non -stationarity. A break can be generally defined by a change in the probability law of the time series at a given instant, most often unknown [41]. For all of these tests, the null hypothesis H0 corresponds to the absence of a break at the 1% threshold. These tests are particularly sensitive to a change in mean and, if the null hypothesis of homogeneity of the series is rejected, they provide an estimate of the break date [42]. Among the rupture tests grouped together in KhronoStat, three were selected for this study, namely the Pettitt test, the Lee and Heghinian test and the Hubert segmentation method. As pointed out by these tests are renowned for their robustness and power and have been the subject of several applications in different regions of Africa Only Hubert's method can detect several breaks, if they exist, in a time series of data [42-51].

Table 4: Breakdown dates in time-scale series (SPEI_1, SPEI_3 and SPEI_12) for the period 1961-2019

Ruptures selon les Tests (12mois)								
	Pettitt				***Lee et Heghinian***		***Hubert***	
	1eres ruptures	**2èmes ruptures**	**3èmes ruptures**	**4ème rupture**			**1eres ruptures**	**2nds ruptures**
Matam	1971		2001		1999		1962	
Linguère	1976		2005		2015		1962	
Louga	1971		2000		1962		1962	
Podor	1964		1986	2005	1964		1962	
Ruptures selon les Tests (3mois)								
	Pettitt				***Lee et Heghinian***		***Hubert***	
Matam	1964		2011		1998		1961	
Linguère	1970		1986	2001	2015		1961	
Louga	1972		1994		1972		1961-1972	1973-2019
Podor	1964		1989	2005	2005		1961	
Ruptures selon les Tests (1mois)								
	Pettitt				***Lee et Heghinian***		***Hubert***	
Matam	1966	1977	2007		1966		1961-1969	1970-2019
Linguère	1971	1986	2006		2018		1961	
Louga	1961	1965	1977	1994	1961		1961	1961-2019
Podor	1965	1977	1989	2010	1977		1961	

The application of three tests (Pettitt, Lee and Heghinian, Hubert) at the level of standardized index of precipitation and evapotranspiration (SPEI_12) on all the stations (Matam, Linguère, Louga and Podor) shows two significant breaks (Table 4). According to Pettitt's test, the first ruptures occurred between 1961 and 1976, the second ruptures between 1977 and 1986, the third ruptures between 1977 and 2007, while the fourth and last occurred between 1994 2010. According to De Lee methods and Heghinian and De Hubert, the ruptures were earlier at Louga on the different time scales with respectively in 1962 for SPEI_12,1972 for SPEI_3 and 1961 for SPEI_1). On the other hand, they were later at Linguère and took place in 2018 for SPEI_1 and 2015 for both SPEI_3 and SPEI_12. Also, it should be noted, by analyzing the stations independently, the frequent occurrence of breaks on the time scales (SPEI_1 and SPEI_3) at the level of the Louga and Podor stations. Finally at the level of Hubert's segmentation method, the phased advent of ruptures are noted on the time scales (SPEI_1 and SPEI_3) of Louga and Matam, while only the Louga station is interested in this phasing situation in the manifestation of ruptures on the SPEI_3 scale [52-55].

Conclusion

In this study the SPEI, calculated with the temperatures and precipitations was used to test the recent evolution of drought. They were compared with research results in order to better characterize the drought and its different trends in the Ferlo basin. The multiscale models, the extent and the spatiotemporal character of the SPEI were used and then analyzed in this work. These different approaches made it possible to detect a drying trend over practically the entire Basin from the 1970s and a gradual return to a relatively wet period in the decade 2010 to 2019. They also revealed disproportionate manifestations of drought in the different regions. stations with more acute cases of severity (Podor station), more apparent precocity at Matam and Podor and a constant periodic frequency in the period 1970-1980.

The results of the test (Pettitt, Lee and Heghinian, Hubert) indicated that the mean values of SPEIs at the three time scales (1, 3 and 12). The information obtained made it possible to highlight the succession of periods of rupture, and, in general, they served to highlight major trends. This is how they showed the worsening conditions of the drought at the Podor station to examine the spatio-temporal extent.

In addition, because of the sensitivity of the growth of vegetation to droughts, with the increase in temperature, the SPEI index should be compared more with indicators of measures of vegetation behavior in order to better understand the consequences of drought. in this region. However, the SPEI index used in this study is also used to monitor drought as it is an improved index that takes into account both precipitation and temperature. Its multi-temporal characteristic made it possible to analyze the different types of drought at different time scales. However, other widely used drought indices such as the Standardized Precipitation Index (SPI) created by could be used as a benchmark for further research to gain a better understanding of the evolution of droughts in this region [38,56].

Overall, the results of this study have provided new knowledge on drought in the Ferlo Basin. They constitute a plus in the analysis of the evolution of the temporal cycles of manifestation of periods of drought in terms of frequency of appearance, cessation, length of the season, etc. The finding is similar when the analysis is applied to the results taken individually at the scale of each station. However, an analysis based on a regional synthetic index could provide more information on the general behavior of drought in this northern region of Senegal and at the same time serve as à basis for comparative studies involving several climatic zones.

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