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CHARACTERIZATION OF THE DROUGHT BY THE SPI AND SPEI INDICES IN THE WEST CENTER OF CÔTE D'IVOIRE CASE OF THE LOBO BASIN

CARACTÉRISATION DE LA SÉCHERESSE PAR LES INDICES SPI ET SPEI DANS LE CENTRE OUEST DE LA CÔTE D'IVOIRE CAS DU BASSIN DE LA LOBO

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ABSTRACT

The drought observed since 1970 in Côte d'Ivoire has often had tragic consequences on water resources, the agricultural sector and the environment. The objective of this study is to characterize the meteorological drought in the Lobo River Basin with a view to raising the awareness of the population in order to take adequate adaptation measures. The method used is based on the calculation of the SPI (Standardized Precipitation Index) and SPEI (Standardized Precipitation and Evapotranspiration Index) at different time scales (3, 6 and 12 months) over the period 1979 to 2013. The results show that the entire Lobo watershed experienced a moderate type of drought, the most remarkable by their intensity and duration being recorded during the periods from 2000 to 2002 and 2005 to 2007. These drought periods were longer in the northern half of the basin according to the two indices on 3 and 6 months' time scales and longer in the extreme south of the watershed on a 12 months time scale. Drought was more slightly felt in the extreme southern half of the watershed than in the northern half of the Lobo watershed.

Keywords: characterization, drought, Lobo watershed, indices SPEI and SPI

RESUME

La sécheresse observée depuis 1970 en Côte d'Ivoire a eu des conséquences tragiques sur les ressources en eau, le secteur agricole et l'environnement. Cette étude a pour objectif de caractériser la sécheresse météorologique dans le bassin de la Lobo en vue d'une prise de conscience de la population pour prendre des mesures d'adaptation adéquates. La méthode utilisée est basée sur le calcul des indices SPI (indice standardisé de précipitation) et SPEI (indice standardisé de précipitation et d'évapotranspiration) aux différentes échelles de temps (3, 6 et 12 mois) sur la période de 1979 à 2013. Les résultats montrent que l'ensemble du bassin de la Lobo a connu une sécheresse de type modéré dont les plus remarquables par leur intensité et leur durée sont enregistrées durant les périodes de 2000 à 2002 et de 2005 à 2007. Ces périodes de sécheresses ont été plus longues dans la moitié nord du bassin selon les deux indices aux échelles de temps de 3 et 6 mois et plus longues dans l'extrême sud du bassin à l'échelle de 12 mois. La sècheresse s'est plus légèrement fait ressentie dans l'extrême sud du bassin que dans la moitié nord du bassin de la Lobo.

Mots clés : Caractérisation, sécheresse, indices SPI, SPEI, Bassin de la Lobo

INTRODUCTION

Droughts and floods are the most devastating and urgent natural disasters in the world, causing tens of billions of dollars of damage worldwide (Wilhite, 2000), and collectively affecting more people than any other form of devastating climate-related risk. Drought can be defined as a temporary natural imbalance in water availability and therefore consists of persistent below-normal rainfall that is difficult to predict, leading to a decrease in the availability of water resources (Pereira et al., 2009). It is associated with various climatic and hydrological processes such as precipitation, temperature, river flow, etc. It is also associated with a number of other factors, such as climate, water quality and water quality. (Sheffield and Wood, 2011). It is one of the most costly natural disasters in the world, affecting more people than other forms of disasters (Keyantash and Dracup, 2002). Côte d'Ivoire, like other parts of Africa, is vulnerable to the phenomenon of drought, which is linked to a lack or decrease in rainfall in a given region. Many studies (Ouédraogo, 2001; Ardoin, 2004; Kouakou et al., 2007; Kanohin, 2010) on climate variability in West Africa have shown a decrease in rainfall of 10% to 30%. This situation results in a decrease in river flows and serious water shortage problems at certain times of the year in various regions of Côte d'Ivoire and particularly in the Lobo watershed, which is an area of high agricultural activity (Doumouya et al. 2009). The consequences of droughts, as numerous as they are, require that this phenomenon be considered not only as a natural event that must be suffered, but also as a phenomenon that must be explained, known, and that, when it occurs, must be managed with the necessary effectiveness and the necessary measures taken in advance to mitigate its impact (Mehdaoui et al., 2018). This is what justifies the interest of this study which aims at characterizing the meteorological drought in the Lobo river basin using climatic indices in order to raise the awareness of the population to take adequate adaptation measures. The Expert Team on Climate Change Detection and Indices (ETCCDI) facilitated the analysis of extremes by defining a set of Sector Climate Indices (SCI-ST) updated in 2016 and a software package (ClimPact2) that calculates them. This R-based software is developed at the Climate Research Branch of the Meteorological Service of Canada (Zhang et al., 2005).

PRESENTATION OF THE STUDY AREA

The Lobo watershed is a sub-basin of the Sassandra River, located in the central-western part of Côte d'Ivoire between longitudes 6°05' and 6°55' West and latitudes 6°02' and 7°55' North (Figure 1). It is 355 km long and occupies an area of 12722 km² or 3.94% of the surface area of Côte d'Ivoire. The river Lobo has its source in the south of the Seguela region and flows into the Sassandra not far from the Loboville's city.

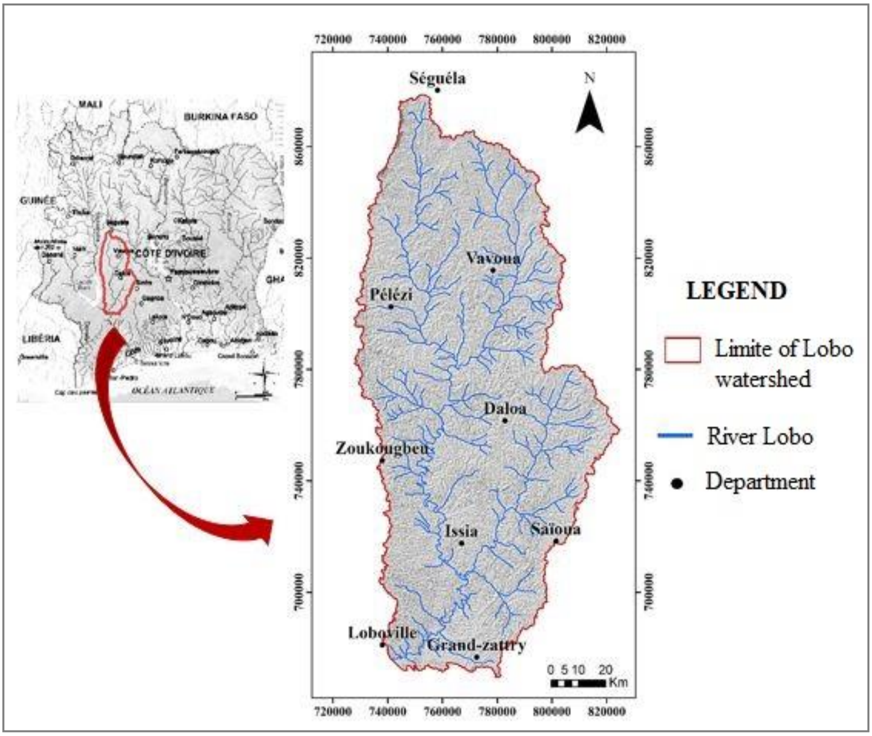

Figure 1: Localisation of the Lobo watershed (Allechy, 2020)

The major part of the watershed belongs to the upper Sassandra region, the chief town of the region is Daloa. The watershed covers the departments of Daloa, Issia, Vavoua and Zoukougbeu. The extreme North belongs to the department of Séguéla; while it overflows into the South, on the department of Soubré.

The Lobo watershed is subject to two types of climates according to the rainfall regime (Yao, 2014): the transitional equatorial attenuated climate (Baulean climate) is observed in the northern half of the basin and characterized by two seasons (one dry season and one wet season) and the transitional equatorial climate (Attiéan climate) marked by four seasons (two dry and two wet seasons), is observed in the extreme south. Two major types of relief share the basin: plains of elevation ranging from 160 m to 240 m, located in the south of the basin, and plateaus of elevations ranging from 240 m to 320 m occupying most of the basin (Yao, 2014). The Lobo basin is located in the Guinean domain and belongs to the mesophilic sector with forest areas suitable for agriculture. It is essentially made up of highly or moderately desaturated ferrallitic-type soils with modal reworking with overlay from schists and granites. The geological formations of this basin are grouped into two main entities: magmatic rocks of plutonic and volcanic types and metamorphic rocks of migmatite and shale types.

MATERIAL AND METHODS

Material

Data

Daily precipitation data from seventeen stations over the period 1979 to 2013 were used in this study. They come from the Centre for Climate Prediction System Reanalysis (CFSR) available at: https://globalweather.tamu.edu/#pubs.

Software

The calculation of the drought indices was carried out in the environment of the statistical software 'R', version 3.4.4, which can be downloaded free of charge from the http://www.r-project.org website. The ClimPact2 programme has made it possible to calculate these indices. It can be download free of charge from :

https://github.com/ARCCSSextremes/climpact2/archive/master.zip

Methods

Drought characterization in the Lobo watershed was carried out using the SPI and SPEI indices to scientifically determine the drought threshold on different time scales (3, 6 and 12 months). They also monitor the drought and detect it at different stages of its evolution.

Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) was developed by McKee et al .(1993). It is a statistical indicator used for the characterization of local or regional droughts. Based on a long-term precipitation history, the SPI quantifies the deviation of a period's precipitation, deficit or surplus, from the historical average precipitation for the period. The calculation of the SPI requires the adjustment of long series of precipitation data to the Gamma distribution that best represents the evolution of the rainfall series. The calculation was done according to the equation:

$$SPI = (Pi - Pm)/\sigma$$

with Pi: Precipitation in year i; Pm: Average precipitation; σ: Standard deviation.

Negative SPI values indicate a dry year, while positive values indicate wet years.

Standardized Precipitation and Evapotranspiration Index (SPEI)

The SPEI (Standardized Precipitation Evapotranspiration Index) proposed by Vicente-Serrano et al. (2010), measures the severity of drought according to its intensity and duration, and can identify the beginning and end of drought episodes. The fundamental difference between the SPI and SPEI is that the SPI is calculated only from precipitation, whereas the SPEI is based on the difference between precipitation (P) and potential evapotranspiration (PTE). Like the SPI, it has a multi-scale character, providing SPEI time scales between 1 and 48 months. The procedure for calculating the SPEI is also similar to that of the SPI, except that it uses the difference between precipitation and potential evaporation instead of just precipitation. The calculation method is described in detail in Vicente-Serrano and al. (2010). The classification of the SPI and SPEI is shown in Table 1.

Table 1: Classification of droughts according to the values values of SPI and SPEI

Value of SPI and SPEI	Drought sequence
2.0 and above	Extremely wet
from 1.5 to 1.99	Very wet
from 1.0 to 1.49	Moderately wet
from -0.99 to 0.99	Normal
from -1.0 to -1.49	Moderately dry
from -1.5 to -1.99	Very dry
-2.0 and under	Extremely dry

RESULTS

The Lobo watershed has experienced hydroclimatic variability, materialised by an alternation of wet and dry periods with regard to the evolution of the SPI and SPEI indices. Dry periods are represented by the negative values of the two indices, materialized by the colour red and wet periods by the positive values, materialized by the blue colour.

Drought characterization in a tropical regime of mitigated transition (northern half of the Lobo watershed)

Standardized Precipitation Index (SPI)

The evolution of the standardized precipitation index in the northern half of the Lobo watershed is shown in Figure 2. Figure 2.a shows that the longest drought periods according to SPI-3 months are from April 2000 to December 2001 and July 2005 to March 2007. April 2000 recorded the lowest value of SPI-3 months (-2.83), which represents an extreme dryness. The index reached its highest value (2.32) in September 1985 corresponding to an extremely wet condition. For SPI-6 months, the largest drought periods were from March 2000 to March 2002 and from September 2005 to March 2007 (Figure 2.b). Peaks in the index were recorded in July 2000 (-2.94) and August 1979 (2.10). The periods from March 2000 to June 2002 and September 2005 to June 2007 are the longest drought periods according to the SPI-12 months (Figure 2.c). The lowest and highest values of this index were observed in January 2001 (-2.43) and September 1985 (2.02), respectively. Table 2 indicates that moderate dry periods are predominant (6.75% to 10.05%) in the northern watershed according to SPI 3 and 6 months, while according to SPI 12 months, very dry periods are dominant in the northern half of the watershed.

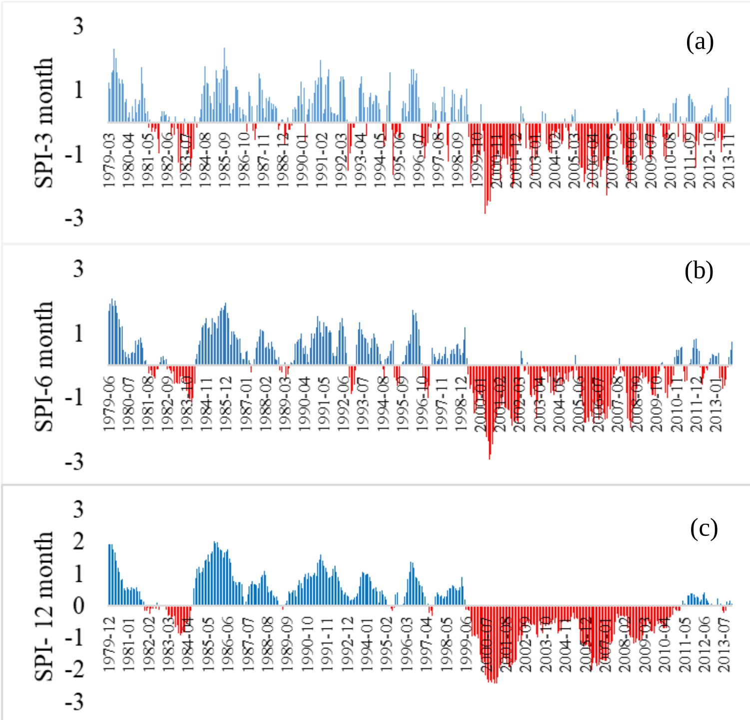

Figure 2: SPI evolution of 3, 6, 12 months in the northern half of the watershed

Table 2: Frequencies of different drought classes according to SPI in the northern half of the Lobo watershed

Drought sequence		**SPI (%)**					
		3 months		6 months		12 months	
Wet periods	Extremely wet	0.72	14.11	0.48	14 .22	0.24	12.72
	Very wet	3.83		4.10		4.4	
	Moderately wet	9.57		9.64		8.07	
Normal periods	Normal	70.6	70.6	71.6	71.6	72.86	72.86
Drought periods	Moderately dry	10.05	15.31	6.75	14.22	4.4	14.13
	Very dry	3.59		6.27		6.6	
	Extremely dry	1.67		1.20		3.46	

Standardized Precipitation and Evapotranspiration Index (SPEI)

Figure 3 shows the change in the SPEI in the northern half of the Lobo watershed. SPEI-3 months shows that the longest periods of drought were those between April 2000 and December 2001, and between July 2005 and March 2007, although they showed an alternation with the "normal" months (Figure 3.a).

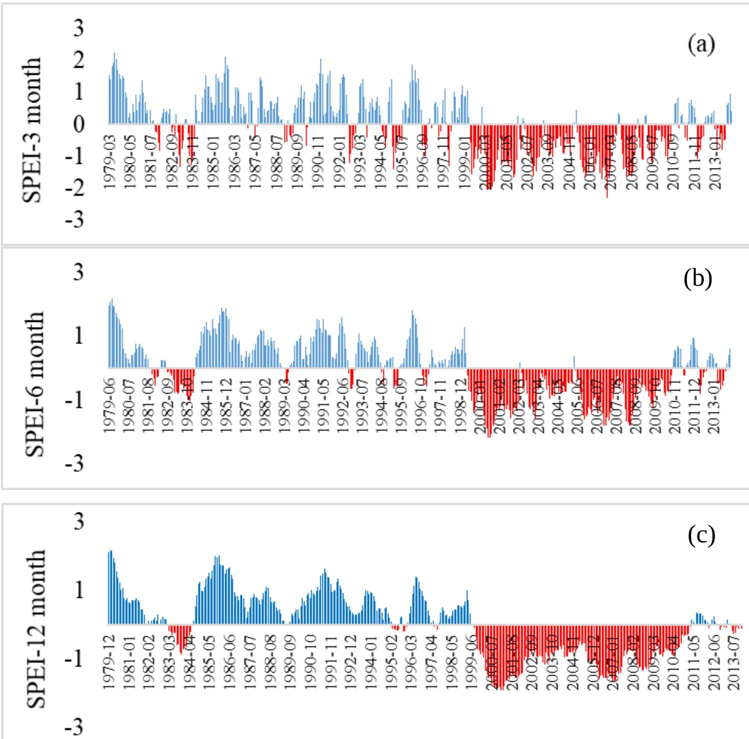

Figure 3: Variation in 3, 6 and 12-months SPEI in the northern half of the watershed

The highest and lowest values of the 3-month SPEI index were in July 1979 (2.23) and January 2007 (-2.31), respectively. According to SPEI-6 months, the most intense periods of drought include the periods from March 2000 to March 2002 and October 2005 to May 2007 (Figure 3.b). August 1979 and July 2000 are the months with the highest (2.17) and lowest (-2.19) values, respectively. For 12-month SPEI, the periods from March 2000 to June 2002 and October 2005 to July 2007 are the longest periods of drought (Figure 3.c). Peaks were recorded in January 1980 (2.16) and February 2001 (-1.93). According to the SPEI, the northern half of the watershed experienced moderate periods of drought (9.29% to 10.05%), followed by very dry periods (3.86% to 4.55%) and very low extremely dry periods (0% to 1.2%) (Table 3).

Table 3: Frequencies of different drought classes according to SPEI in the northern half of the Lobo watershed

Drougth sequence		SPEI (%)					
		3 months		6 months		12 months	
Wet periods	Extremely wet	0.96	14.59	0.48	13.98	1.22	
	Very wet	4.07		4.82		3.67	12,96
	Moderately wet	9.57		8.67		8.70	
Normal periods	Normal	69 .6	69 .6	70.6	70.6	71.4	71.4
Drought periods	Moderately dry	10.05	15.79	10.60	15.42	9.29	15.65
	Very dry	4.55		3.86		6.36	
	Extremely dry	1.20		0.96		00	

Drought characterization in tropical transition regime (extreme south of the Lobo watershed)

Standardized Precipitation Index (SPI)

Figure 4 shows the variation of index SPI the southernmost part of the watershed. The longest and strongest periods of drought according to SPI-3 months in the extreme southern watershed were from March 2000 to March 2001 and December 2007 to June 2008 (Figure 4a). During the first of these periods, the SPI reached a value of -3.14 in April 2000 and its highest value of 2.87 was recorded in September 1985. For SPI-6 months, the longest dry periods were from March 2000 to March 2001 and December 2006 to July 2007 (Figure 4b). The lowest (-3.04) and highest (2.22) values of the index were observed in July 2000 and September 1985, respectively. SPI-12 months shows that the longer dry periods include March 2000 to September 2002 and March 2006 to August 2007 (Figure 4.c). The lowest value of the index (-2.36) was found in the first period in February 2001 and the highest value (2.39) was found in September 1985. The frequency of the drought classes according to SPI is presented in Table 4. On the three time scales of the SPI, the southern watershed experienced moderately dry periods ranging from 9.33% to 13.45%, very dry periods ranging from 1.47% to 3.11%, and extreme dry periods ranging from 1.67% to 2.2%.

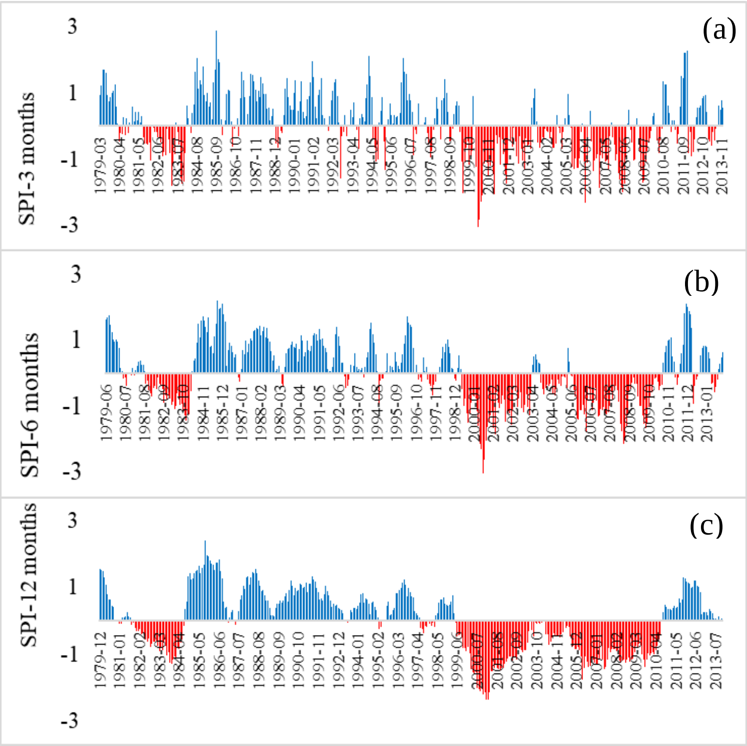

Figure 4 : Variation of 3, 6 and 12 month SPI in the extreme south of the watershed

Table 4 : Frequencies of different drought classes according to SPI in the extreme south of the Lobo watershed

Drought sequences		**SPI (%)**					
		3 months		6 months		12 months	
Wet periods	Extremely wet	1.91	13.88	0.96	15.66	0.24	15.65
	Very wet	3.59		4.58		3.91	
	Moderately wet	8.37		10.12		11.49	
Normal periods	Normal	72.01	72.01	69.64	69.64	67.24	67.24
Drought periods	Moderately dry	9.33	14.11	9.88	14.7	13.45	17.11
	Very dry	3.11		2.89		1.47	
	Extremely dry	1.67		1.93		2.20	

Standardized Evapotranspiration and Precipitation Index (SPEI)

The change in the 3, 6 and 12-month SPEI in the extreme southern part of the Lobo watershed is shown in Figure 5.

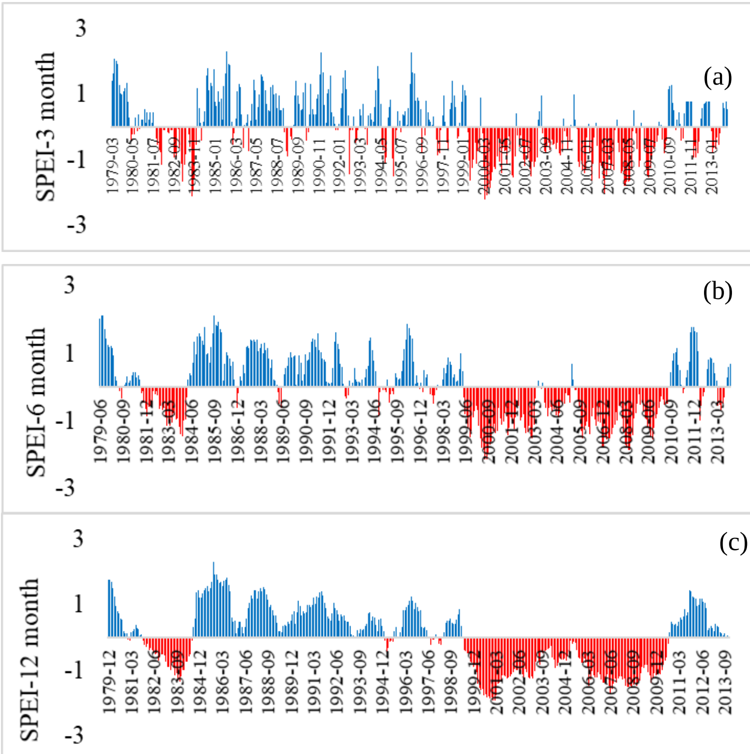

Figure 5 : Variation in 3, 6 and 12-month SPEI in the southernmost part of the watershed

At the 3-month scale, SPEI presents the periods from March 2000 to March 2001 and September 2006 to July 2007 with an alternation of normal months as the longest periods of drought (Figure 5.a). Peaks in the index are observed in April 2000 (-2.21) and September 1985 (2.31). At the 6-month scale, the longest periods of drought are from March 2000 to March 2001 and August 2006 to August 2007 with an alternation of one normal month in the second period (Figure 5.b). September 1985 recorded the highest value (2.13) of the index and July 2000 recorded the lowest value (-2.15). According to the 12-month SPEI, the periods from February 2000 to February 2002 and April 2006 to February 2009 are considered the longest periods of drought (Figure 5.c). Extreme values of 12-month SPEI were observed in September 1985 (2.32) and February 2001 (-1.93). Table 5 shows that moderately dry periods are preponderant (from 10.05% to 17.11%) in the southern watershed, followed by very dry periods (between 3.11% and 4.78%) and extreme dry periods (varying from 0% to 1.44%).

Table 5 : Variation in the frequencies of different drought classes according to SPEI in the extreme south of the Lobo watershed

Droughts sequences		SPEI (%)					
		3 months		6 months		12 months	
Wet periods	Extremely wet	1.22	16.75		17.35		16.38
				0.96		0.26	
	Very wet	4.78		5.06		4.65	
	Moderately wet	10.77		11.33		11.49	
Normal	Normal		69 .62	66.02	66.02	62.59	62.59
periods		66.99					
Drought	Moderately dry	10.05	16.27	11.57	16.63	17.11	21.03
periods	Very dry	4.78		4.58		3.11	
	Extremely dry	1.44		0.48		00	

DISCUSSION

The objective of this study was to characterize droughts in the Lobo watershed in the central-western part of Côte d'Ivoire. Daily precipitation data over the period 1979 to 2013 from the Climate Prediction System Reanalysis Centre (CSFR) were used in this study. The CFSR was designed and implemented as a coupled atmosphere-ocean-land-sea-ice system surface to provide the best estimate of the state of these coupled domains over this period. Authors Mo et al, 2011; Najafi et al, 2012; Dile and Srinivasan, 2014 have conducted several studies with CFSR data and indicate their validity. According to Fuka, et al (2013), these data have the advantage of better translating the rainfall event measured by the satellites. Indeed, his studies on the use of climate prediction system reanalysis data as meteorological input for watershed models demonstrated that CFSR data could be reliably applied to watershed modelling in a variety of hydroclimatic regimes and other watersheds. The work of Saleh (2000) in the upper northern part of the Bosque River watershed reached the same conclusion.

The methodological approach was based on the calculation of the SPI (Standardized Precipitation Index) and SPEI (Standardized Precipitation and Evapotranspiration Index) indices. These indices measure the severity of drought according to its intensity and duration, and can identify the beginning and end of drought episodes. They define wet, dry and normal years and are used to monitor droughts (Botai et al., 2016). Their main advantage over other drought indices is their multiscalar nature, i.e. they can be calculated on different time scales from 1 month to 48 months. Moreover, they are comparable in time and space. Because they are robust and have shown prohibitory results, SPI and SPEI have been widely used for drought studies in different regions. Bonaccorso et al (2003), Tsakiris et al (2004), Vicente-Serrano et al (2005) and Daniel Lopez N. et al (2006) used the SPI respectively in Italy for spatial variability of drought, in Greece for characterization of drought sequences in the State of Chihuahua at various time scales, in Spain for a hydrological response to different time scales of climatological drought and in Mexico for a drought monitoring system. Although SPEI has only recently been developed, the index has also been used in studies related to drought variability (Li et al., 2012; Paulo et al., 2012), climate change (Abiodun et al., 2013; Yu et al., 2013), drought monitoring systems (Fuchs et al., 2012). The present work generally shows that moderately dry periods are the most frequent (about 9% to 17%) in the entire Lobo watershed. These results are similar to the work of N'Guessan bi et al (2018) in the Marahoué region in central Côte d'Ivoire, and Bohn and Piccolo (2018) in the regions of El Trébol (11.16%) and Olavarría (12.07%) in Argentina. According to the indices studied at different time scales, the longest and most intense periods of drought are observed during the periods from 2000 to 2002 and 2005 to 2007. Potop and Mozny (2011), Bedoum et al (2014) and Mehdaoui et al (2018) reached the same conclusion. Indeed, in their work on the application of a new drought index - a standardized index of precipitation and evapotranspiration in the Czech Republic, Potop and Mozny (2011) indicated that drought periods corresponding to the periods 1981 to 1990, 1991 to 2000 and 2000 to 2010. Bedoum et al (2014) in their study on the impact of rainfall variability and drought in Southern Chad showed that the drought is of moderate type and that the most remarkable periods of drought in terms of intensity are the periods from 1965 to 1967 and 2002 to 2005. Mehdaoui et al (2018) have shown at the Hassan Adakhil dam station in the Ziz watershed in South-Esy of Morocco that the moderately dry periods are the periods from 1995 to 2006.

CONCLUSIONS

The study carried out in the Lobo watershed is based on SPI and SPEI values calculated over the study period (1979-2013), i.e. 35 years of observations. The high variability of these indices has made it possible to highlight periods of drought with greater precision. Thus, the entire Lobo watershed has experienced a moderate type of drought, the most remarkable of which were recorded during the periods from 2000 to 2002 and 2005 to 2007. These periods were most intense in the northern half of the watershed on both the 3 and 6 month time scales and in the extreme southern half of the watershed on the 12 month time scale. The extreme south of the Lobo watershed was more affected by drought than the northern half of the watershed.

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