IMPACTS OF CLIMATE CHANGE ON DROUGHT DYNAMICS AND VEGETATION COVER IN WEST AFRICA

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***Abstract*- Global warming is exacerbating the socio-economic vulnerability of West Africa, whose economy is largely based on agriculture. Since the 1970s, the region has experienced an increase in droughts linked to a significant decline in rainfall, leading to agricultural losses, famines and forced migration. This study analyses the spatial and temporal variations in drought between 1985 and 2015 using meteorological (SPI, SPEI) and satellite (SVI) indices. The results reveal a gradual intensification of dry spells over the last two decades, with strong correlations between climate indices and plant dynamics, particularly during the transition seasons (DJF, SON). Precipitation remains the main factor controlling vegetation cover, while evapotranspiration accentuates water stress in arid areas. The analysis highlights the recurrence and spatial extent of droughts, confirming the region's persistent vulnerability and underscoring the importance of adapted agricultural strategies to strengthen resilience to hydro-climatic extremes.**

Keyword: Drought, indices, Vulnerability, West Africa.

I. INTRODUCTION

The issue of global warming is a fact that affects all regions of the world. In West Africa, global warming is affecting the rural economy, which is dominated by agricultural activity. The agricultural sector employs 70% of the total workforce [1] and accounts for between 15 and 20% of GDP.

Despite the fact that agriculture is an important sector of the sub-regional economy, it is nevertheless limited to old production practices. This situation, combined with rapid population growth, are factors that tend to exacerbate the socio-economic impact of climate change [2]. Indeed, the vulnerability of populations to change increased at the end of the 20th century with the observed reduction in rainfall (nearly 30% of rainfall in the Sahel in 40 years)[3]. Precipitation deficits have led to episodes of drought, resulting in reduced agricultural yields [4]. Drought is a natural event that occurs frequently or intermittently in almost all types of climates. It is usually the result of a natural decrease in rainfall over a period of time [5]. It is considered one of the most costly and deadly natural disasters [6–8].

The severity of drought has been felt more acutely in Africa than in any other region of the world. The continent has recorded more than 300 drought events over the last 100 years, accounting for 44% of the global total. Sub-Saharan Africa has suffered the dramatic consequences of increasingly frequent and intense climate disasters [9,10]. Since the 1970s, the region has been marked by a resurgence of major climate-related famines, which have required international aid, especially in the Sahelian regions [11]. In its forecasts, the World Bank has estimated that 216 million people could be forced to migrate by 2050 due to drought and other factors such as water scarcity, declining crop productivity, sea level rise and overpopulation [12].

The impact of drought on the production system is one of the constraints on development in West African countries, especially as they face the challenge of rapid population growth and increasing scarcity of agricultural land. In this context, it is essential to describe and understand the spatial and temporal variations of drought events in the region in order to guide agricultural strategy. The objective of this study is therefore to analyse the spatial and temporal variability of drought events in West Africa in order to better understand their impact on the agricultural production system and vegetation cover dynamics.

II. PRESENTATION OF THE STUDY AREA

The West African region is located between 5° S - 20° W and 30° N - 30° E. The population of West Africa was estimated at 386.9 million in 2019, representing 5% of the world's population, and this percentage could well reach 8% by 2050[13].

It encompasses five bioclimatic zones, namely the Guineo-Congolese, Guinea, Sudan, Sahel and Sahara zones [14]. The region covered by this study is located between latitudes 0°N and 20°N and longitude 20°W. It spans three of the five bioclimatic zones (Guinea, Sudan, Sahel). The Guinean zone consists of deciduous or semi-deciduous forests that are seasonally wet and dry. Annual rainfall ranges from 1,200 to 2,200 mm with a distinct dry season lasting 7 to 8 months. The Sudanese zone consists mainly of open forests, open wooded savannahs and wooded savannah areas with annual rainfall ranging from 600 to 1,200 mm and a dry season lasting 5 to 7 months. The Sahelian region is characterised by a mixture of steppe and savannah with short herbaceous grasses, woody plants and average rainfall of between 150 and 600 mm with a dry season lasting 8 to 9 months [14].

West Africa is one of the regions of the world that suffers dramatically from hydro-climatic extremes. Since 1968, the region has experienced a rainfall deficit that has prolonged a period of drought. Dependent on the climate, the region's economy is increasingly vulnerable [15]. The droughts of 1973-74 and 1984-85 were particularly devastating for the population. Even today, the region is regularly affected by famines due to poor rainy seasons [16].

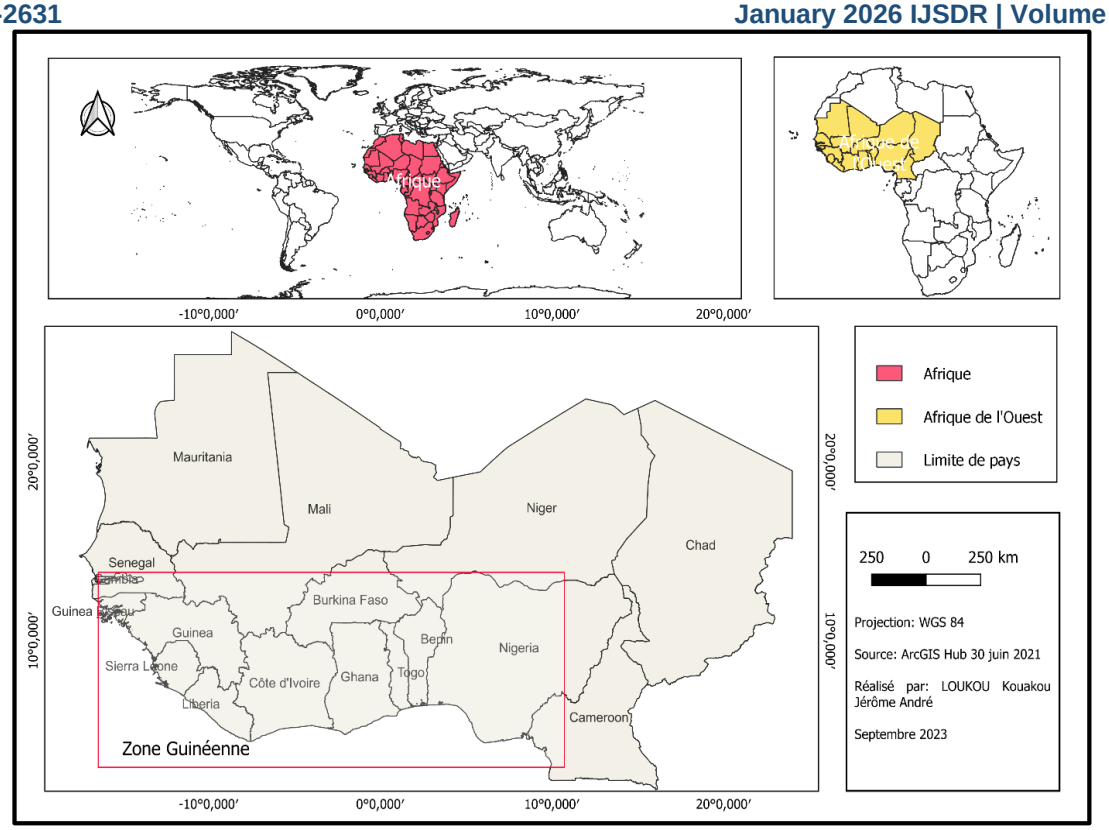

Fig 1: presentation of the study area

III. Data and Methods

3.1 Data

As part of this study, several data sources were used to characterise drought events. MYD13Q1 (Aqua) products, offering a spatial resolution of 250 m and a periodicity of 16 days, were used via the Google Earth Engine (GEE) platform. Developed by Google, this platform allows satellite images to be processed and analysed directly in the cloud, without the need for local downloading. In addition, the CHIRTS-daily (Climate Hazards InfraRed Temperature with Stations) dataset provided daily estimates of surface temperature (Tmin and Tmax) on a 0.25° (~25 km) grid, produced by the Climate Hazard Centre (CHC) at the University of California, Santa Barbara [17]. Finally, the CHIRPS (Climate Hazards Group InfraRed Precipitation with Stations) product was used to estimate quasi-daily precipitation at a resolution of 0.25°, combining infrared satellite data, local station observations and reanalyses [18]. Its temporal coverage, from 1981 to the present day, constitutes a long and homogeneous series, particularly suited to the study of climate variability and extreme rainfall events.

3.2 Methodology

The methodology adopted is based on a dual approach: statistical analysis of meteorological data and use of satellite measurements. Drought is assessed by the dispersion of an index relative to a pre-established critical standard [19]. Historically, observations from meteorological stations were the main source of monitoring [20], before the rise of remote sensing. Several indicators have been developed, such as the PDSI, SPI and SPEI, to detect drought at different time scales. In this study, the SPI and SPEI were chosen because of their ability to describe the short- and long-term impacts of drought [21–23].

The SPI is calculated by adjusting precipitation series to a probability distribution transformed into a normal distribution, so that its mean is equal to zero for the period studied:

$$SPI = \frac{P_i - P_m}{S} \qquad (1)$$

Where P_i : rainfall for month or year i; P_m : average rainfall for the time series in question; S: standard deviation of the series on the time scale in question.

The SPEI, meanwhile, is based on a climatic water balance defined by the difference between precipitation and potential evapotranspiration (PET). In this study, PET was calculated using Thornthwaite's formula (1948), incorporating the length of the day, the number of days in the month, the average temperature and a heat index based on monthly temperatures. SPEI is defined by the formula:

$$SPEI = W - \frac{C_0 + C_1 W + C_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \qquad (2)$$

$W = \sqrt{(p)}$ for $p \leq 0{,}5$ and p is the probability of exceeding a given value D, 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: C_0 = 2,515517, C_1 = 0,802853, C_2 = 0,010328, d_1 = 1,432788, d_2 = 0,189269 et d_3 = 0,001308.

Negative SPEI values indicate drought conditions, while positive values reflect wet conditions. A drought is considered severe when SPEI ≤ -1. The table below provides an interpretation of drought indices.

Table 1: Classes and interpretations of meteorological drought indices

SPEI value	Class	Interpretation
≥ 2.00	Extremely wet	Exceptional excess moisture
1.50 to 1.99	Very wet	Very high moisture
1.00 to 1.49	Moderately wet	Moderate moisture
-0.99 to 0.99	Normal	No significant anomaly
-1.00 to -1.49	Moderately dry	Moderate drought
-1.50 to -1.99	Very dry	Severe drought
≤ -2.00	Extremely dry	Extreme drought

At the same time, satellite data was used to supplement the analysis. Vegetation spectral indices, such as the SVI (Standardised Vegetation Index) developed by Peters et *al*,. (2002), were selected. Calculated on a weekly basis and across different seasons, the SVI highlights variations from the normal NDVI over several years:

$$Z_{IJK} = \frac{VI_{ijk} - \mu_{ij}}{\sigma_{ij}} \quad (3)$$

where Z_{IJK} is the *Z* value of pixel *i* during week j for year *k*, VI_{ij} is the weekly *VI* value for pixel *i* during week *j* for year *k*, where NDVI or EVI can be used as VI, μ_{ij} is the mean of pixel *i* during week j over *n* years, and σ_{ij} is the standard deviation of pixel i during week *j* over *n* years.

Just like weather indices, negative values indicate dry conditions, while positive values reflect wet conditions. The table below provides an interpretation of the SVI [24].

Table 2: Classes and interpretations of SVI drought indices

Valeur du SVI	Catégorie de sécheresse
≥ 0	Pas de sécheresse (conditions normales ou humides)
-0,10 à -0,94	Sécheresse légère
-0,95 à -1,44	Sécheresse modérée
-1,45 à -1,94	Sécheresse sévère
≤ -1,95	Sécheresse extrême

Finally, a Pearson correlation test was applied to assess the relationship between the SVI and the SPI/SPEI indices, providing a better understanding of the impact of weather conditions on surface conditions. A strong correlation would indicate a significant effect of drought on vegetation cover and, by extension, on agricultural activity. The correlation coefficient is defined by:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2} \cdot \sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (4)$$

where x_i, y_i: the observed values of variables X and Y; $\bar{x}$, $\bar{y}$: the means of X and Y, n : the number of observations, r: Pearson's correlation coefficient, between -1 and +1

IV. Results

4.1. Seasonal variation in the SVI drought index

Figure 28 shows the seasonal and spatial variation in the Standardised Vegetation Index (SVI) during the four seasons of the year, namely DJF, MAM, JJA and SON. The index values vary between approximately –0.6 and +0.6. Overall, the figure highlights the prevalence of drought conditions across most of West Africa, particularly in the Sahelian and Sudanian zones. This trend reflects the arid conditions facing the region, particularly in the areas between southern Mali, Burkina Faso, Niger and Chad. During the SON and DJF seasons, drought conditions are slightly more intense compared to other seasons. Index values in the vast majority of the region reach -0.6, indicating increasingly arid conditions. In contrast, the MAM and JJA seasons show a more heterogeneous structure marked by alternating drought conditions in the north and wet conditions in the far north. Overall, these results confirm that SVI dynamics remain strongly linked to the seasons, with more intense droughts during the DJF and SON transition seasons.

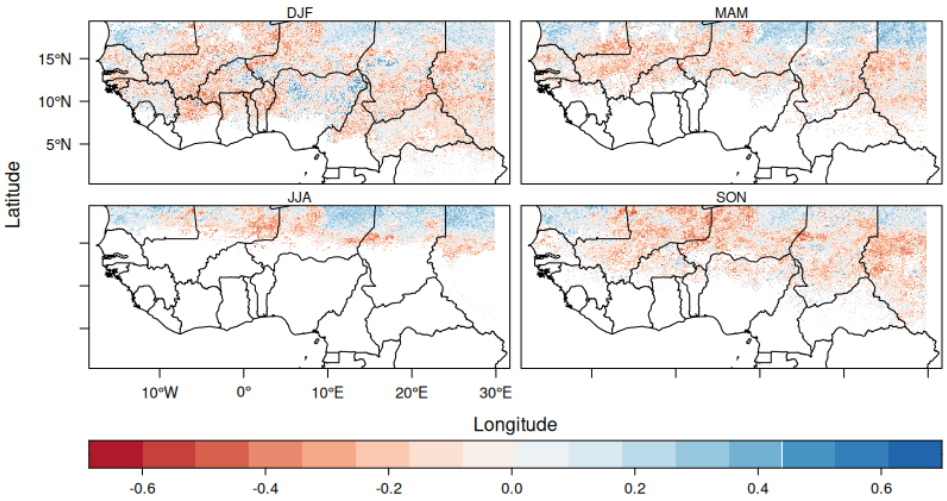

Fig 2 : Mapping seasonal variation in the SVI

4.2. Temporal variation in meteorological drought indices (SPEI, SPI) in the West African region between 1985 and 2015.

Figure 30 shows the variation in drought intensity between 1985 and 2016, assessed using the SPEI (Standardised Precipitation Evapotranspiration Index) and SPI (Standardised Precipitation Index) calculated on 3-, 6- and 12-month scales. These indices enable simultaneous analysis of the temporal variability and severity of dry spells at different climatic and hydrological scales.

In order to assess the variation in drought sequences in West Africa in greater detail, the analysis covered the period 1985-2015. Drought indices were calculated at three-time scales: 3, 6 and 12 months. The figures below show the temporal variations in the SPEI and SPI indices. Observation of the SPEI at different scales shows that the region as a whole experienced few dry episodes during the first decade (1985-1995), with only two significant short-term events. The following decades were marked by the recurrence of longer-lasting dry episodes, reflecting a gradual intensification of regional drought.

Similar to the SPI, the trends observed vary depending on the time scale. The SPI-3 shows frequent alternation between dry and wet sequences throughout the study period, indicating high short-term variability. In contrast, the 6-month SPI shows a predominance of dry episodes during the first decade, followed by an alternation between dry and wet periods, with the latter generally being more intense than the former. The 12-month SPI trends are similar to those of the 6-month SPI. There were two long dry spells and a prolonged wet phase during the first decade, followed by a succession of dry and wet episodes over almost two decades before a relatively wet period began between 2005 and 2013. These different trends reflect the variability of short-term drought (SPI-3).

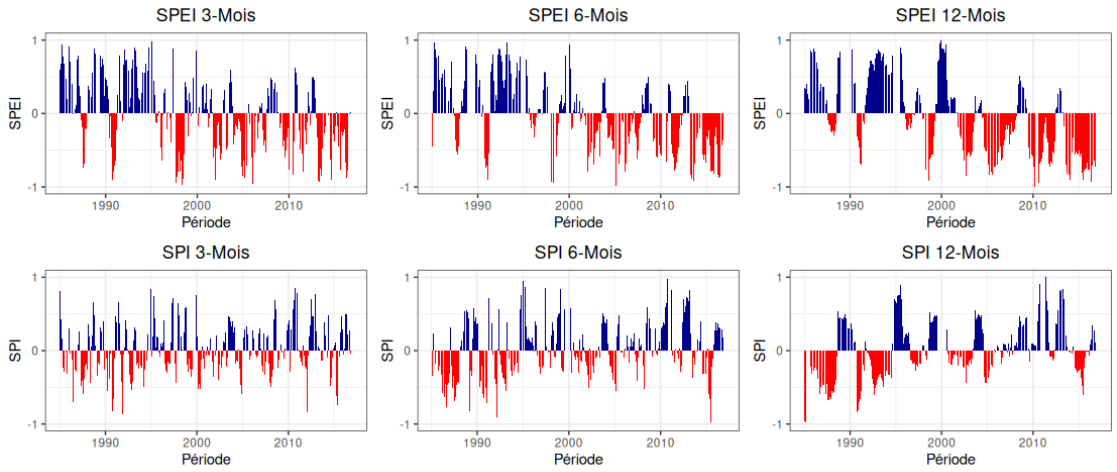

Fig 3 : Variation in drought intensity using the SPEI and SPI indices for 3, 6 and 12 months in 1985 and 2016.

Figure 32 shows the frequency and intensity of drought episodes over the period 1985–2016 according to the SPEI (Standardised Precipitation Evapotranspiration Index) and SPI (Standardised Precipitation Index) indices, calculated on three time scales (3, 6 and 12 months). These two indicators highlight the dynamics of meteorological drought while comparing their evolution at different time scales.

The SPEI-3 shows a recurrence of moderate drought episodes between 2005 and 2016. During this period, there were just over seven drought episodes, including one sequence in 2005, three in 2010, two in 2015 and one in 2016. The SPEI-6 reveals a more marked intensity over the entire period, with eleven moderate episodes, including four in 2010, a year also characterised by a severe drought episode. Under SPEI-12, the intensity is moderate, with a total of eight moderate episodes spread over three years, including three episodes in 1998, four in 2010 and one episode in 2016. The joint interpretation of the SPEI-3, SPEI-6 and SPEI-12 indices indicates an increase in the frequency and intensity of drought episodes over the last two decades. In addition, the results observed from the SPI clearly show a different dynamic, marked by more isolated occurrences of moderate episodes. The SPI-3 and SPI-6 each reveal a single sequence over the entire period, in 2015 and 1985 respectively, while the SPI-12 identifies two sequences in 1985. In summary, the SPEI indices indicate an increase in the frequency and intensity of droughts between 2005 and 2016, with a

marked peak in 2010. Conversely, the SPI indices suggest more sporadic variability in drought episodes, with isolated episodes in 1985 and 2015.

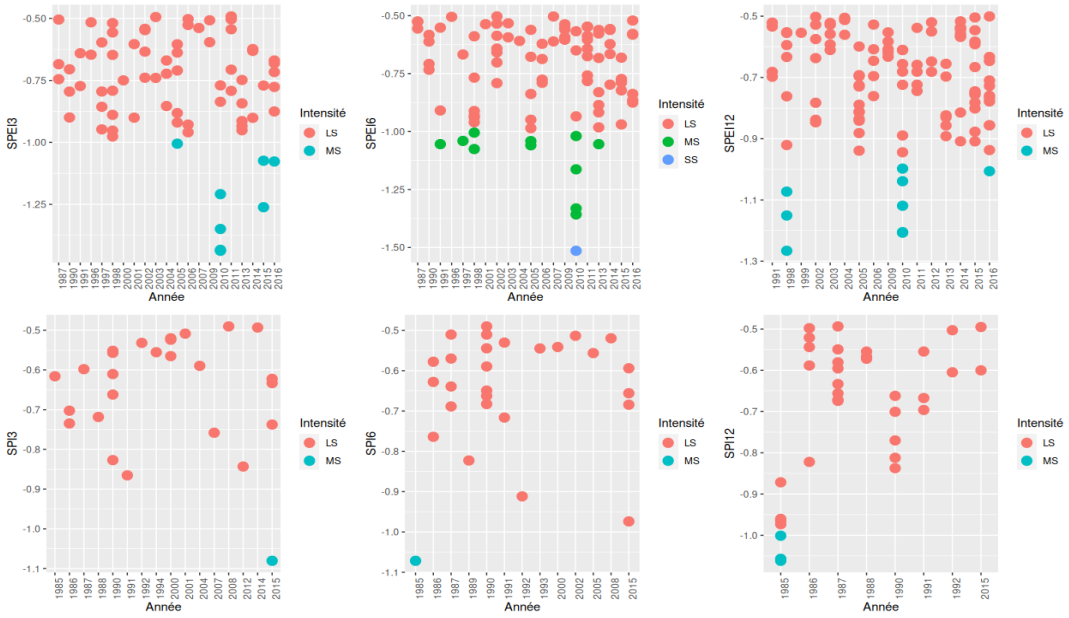

Fig 4 : Frequency of drought episodes using the SPEI and SPI indices for 3, 6 and 12 months between 1985 and 2016.

4.3. Spatial variation of SPI and SPEI indices

4.3.1. Spatio-temporal variation of drought using the 3-month SPI index

Figure 32 shows the spatial and temporal variations in drought in West Africa over the period 1985–2015, assessed using the three-month standardised precipitation index (SPI-3). Analysis of this series reveals that the region has experienced multiple episodes of drought, with SPI values below -1, reflecting significant water deficits. These droughts are distributed unevenly in time and space, but their occurrence remains almost continuous over the three decades studied. Thus, during the period 1985-1994, the region showed signs of a more or less widespread drought, with peaks observed in 1986, 1990 and 1987. Almost all regions, except for the south-east, recorded SPI-3 values below -1.5, reflecting severe drought. During this decade, some countries in the centre of the region, including Mali and Burkina Faso, experienced severe drought in 1985, while drought hit the south hard in 1992, particularly in the coastal countries of the Gulf of Guinea. The trend remains marked by contrasting drought conditions during the decade 1994-2003. The most critical years (values less than or equal to -1.5) of this decade were 1996, when the entire Sahel was affected, and 2000, when virtually all localities were affected. The last years of the time series show increased variability in drought conditions, with a resurgence of dry spells. The year 2004 in this series shows widespread drought, particularly marked in the east with values reaching -1.5, indicating severe drought. In 2007, the water deficit intensified in the north-west and south-east, then again in 2011 (except for the countries on the Gulf of Guinea coast) and 2015 (in the south), years of severe drought across the region. In other years, drought occurred sporadically and severely in the east in 2008 and 2009, on the west coast in 2013 and finally in 2014 in the northwest. In summary, despite some mitigation in certain years, the trend shows that the region has suffered from recurrent drought, marked by severe and widespread episodes throughout the period. This reflects West Africa's vulnerability to persistent drought conditions, particularly in the Sahel and coastal areas.

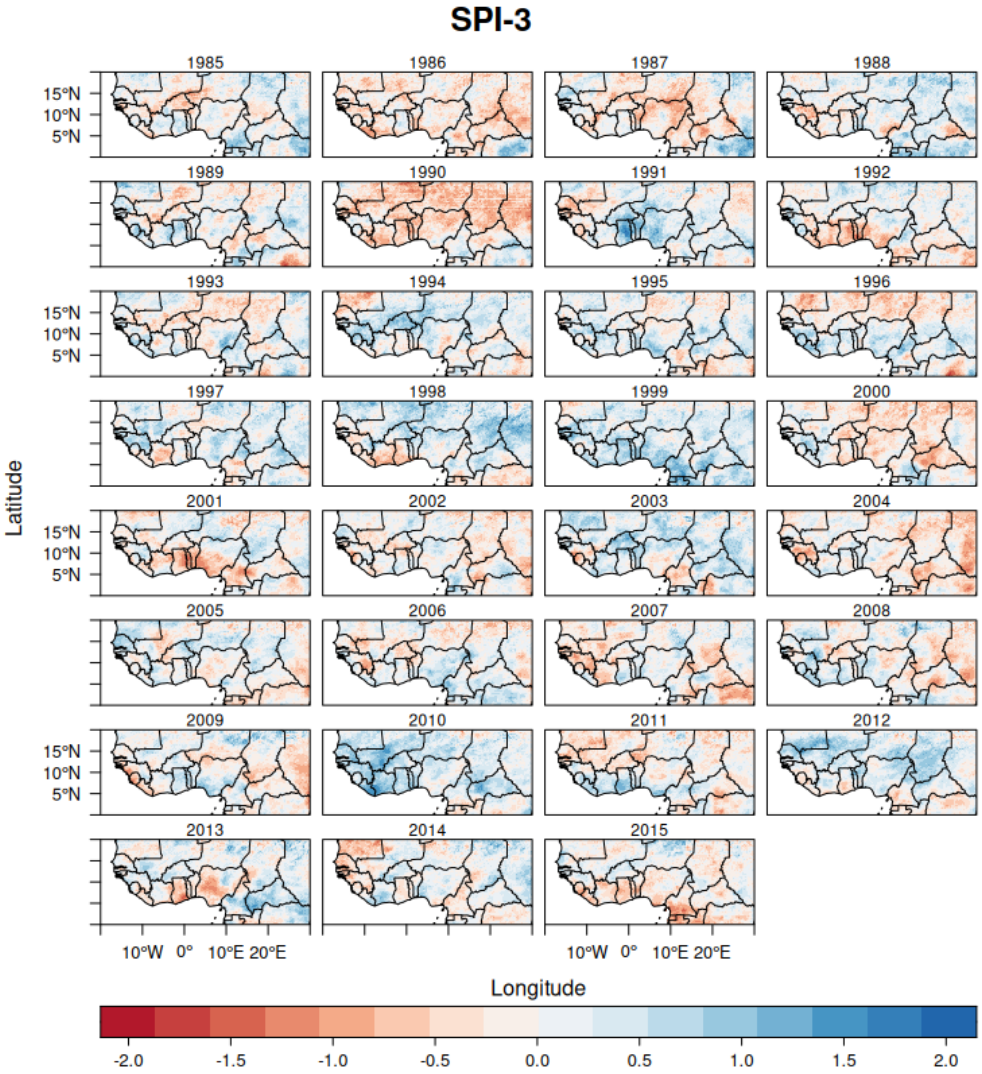

Fig 5 : Spatio-temporal variation in drought between 1985 and 2015 using the SPI 3 drought index

4.3.2. Spatio-temporal variation in drought using the 6-month SPI index

Spatio-temporal variations in drought assessed using the SPI-6 index are shown in Figure 33. Like the SPI-3 index, the **SPI**-6 shows that the West African region is generally exposed to severe drought with values between -1 and -2, but this general trend varies according to period and geographical area.

During the decade from 1985 to 1994, the region experienced intense drought during the first three years, with the northern areas being the most affected, while the south remained relatively less affected. Between 1990 and 1992, the drought persisted but in a more localised manner, concentrating on the northern regions in 1990, spreading to the north-west in 1991 and 1993, and affecting the western and eastern areas more in 1992. The year 1994 saw a generalised spread of the phenomenon to all countries, with Côte d'Ivoire being almost entirely affected. From 1995 to 2004, the region experienced a relative improvement with a net reduction in the intensity of dry spells, although some years continued to see fairly critical drought conditions. As a result, in 1997, 2001 and 2002, the drought spread across much of the territory, affecting both northern and southern localities. In addition, more localised episodes can be observed in certain years, notably in the south-east in 1995, in the north in 1996 and then in the west and east in 1998 and 2003. Similarly, the period 2005-2015 shows a more widespread drought, specifically in 2005 and 2006, with SPI values between -1 and -2, indicating a severe drought. The severity of the drought in 2007 and 2008 can also be seen in the north-west and south-east regions. As in previous years, in 2009 the phenomenon appears to have intensified in the west, particularly in southern Sudan, Chad and throughout the Central African Republic. During the period 2010-2013, severe drought was also observed in the south-east and on the coast of the Gulf of Guinea. In recent years (2014 and 2015), drought has tended to become more widespread across the entire region, with the most pronounced effects occurring in the east and in coastal countries. In summary, the analyses reveal a succession of dry spells and periods of relief, reflecting the high variability of drought in the West African region. Northern localities remain more vulnerable, but the phenomenon is gradually spreading to coastal regions.

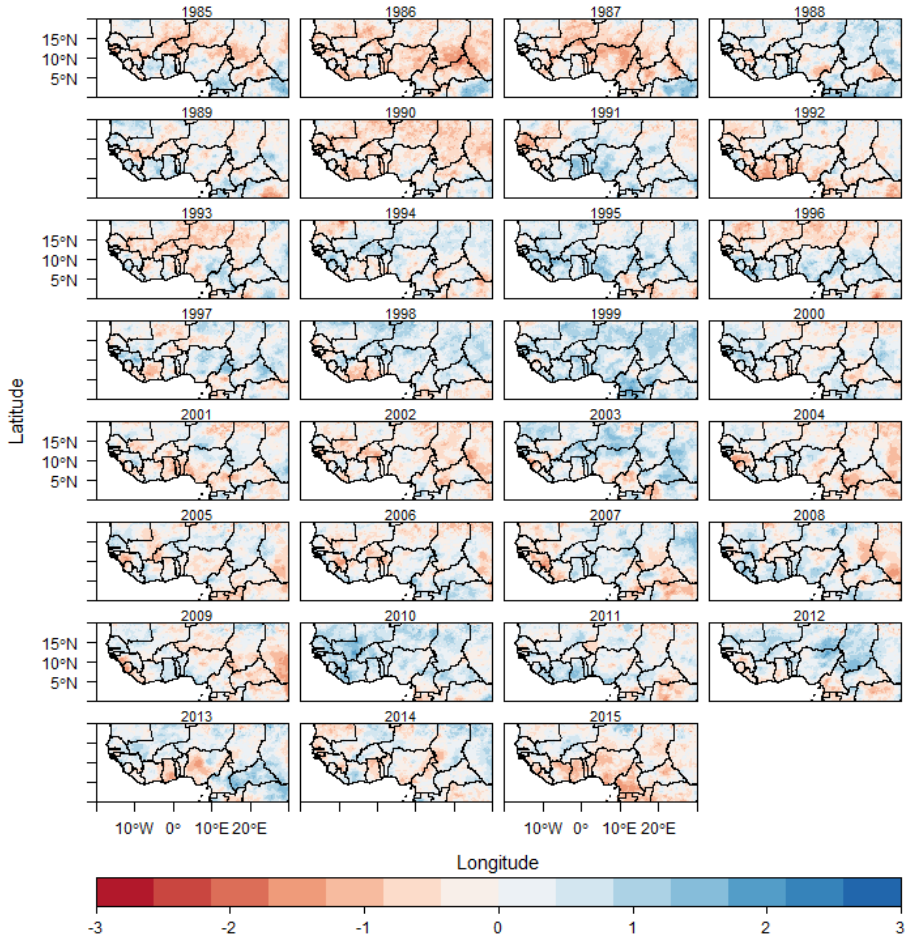

Fig 6 : Spatio-temporal variation in drought between 1985 and 2015 using the SPI 6 drought index

4.3.3. Spatio-temporal variation in drought using the 12-month SPI index

Figure 34 illustrates the spatial and temporal variations in drought across West Africa using the SPI-12 index. Like the indices analysed previously, this index shows that the region has been exposed to episodes of severe drought overall, with notable differences depending on the period and geographical area.

During the period 1985-1994, the region experienced severe to extreme drought with index values between -2 and -3, reflecting a very pronounced rainfall deficit. The years 1985 to 1987 appear to have been the most critical, mainly affecting the northern Sahelian areas, while the southern regions were relatively less affected. Between 1990 and 1992, the drought intensified again, concentrating in the north and north-west in 1991 and 1993 before spreading to the whole of West Africa in 1992, indicating a major regional episode. In 1994, several localities were still experiencing significant drought, although the situation had improved slightly.

During the decade 1995-2004, the hydrological situation improved slightly, reflecting a partial recovery in rainfall after the previous long droughts. Nevertheless, isolated episodes of drought persisted in 1997, 2001 and 2002, with almost all countries still experiencing significant water deficits affecting both the north and south. Some droughts remained localised, particularly in the south-east in 1995, in the north in 1996 and then in the west and east in 1998 and 2003, reflecting high drought variability without any real stabilisation of the climate regime.

Between 2005 and 2015, droughts were more varied, alternating between very dry years and wetter periods. The years 2005 and 2006 were marked by very severe drought across a large part of the region, with SPI-12 values between -3 and -2. In 2007 and 2008, rainfall deficits mainly affected the north-west and south-east, while in 2009 the eastern part experienced the most arid conditions. Between 2010 and 2012, drought persisted in the south-eastern areas before moving in 2013 and 2014 to certain locations on the southern coast, particularly the Gulf of Guinea. In 2015, dry conditions extended from southern Mauritania to northern Congo, reflecting a particularly severe coastal and southern drought. Overall, the period 1985-2015 was characterised by high climate variability dominated by recurrent drought episodes. After the critical decades of the 1980s and 1990s, a slight improvement emerged from the mid-1990s onwards, but without a lasting return to normal conditions.

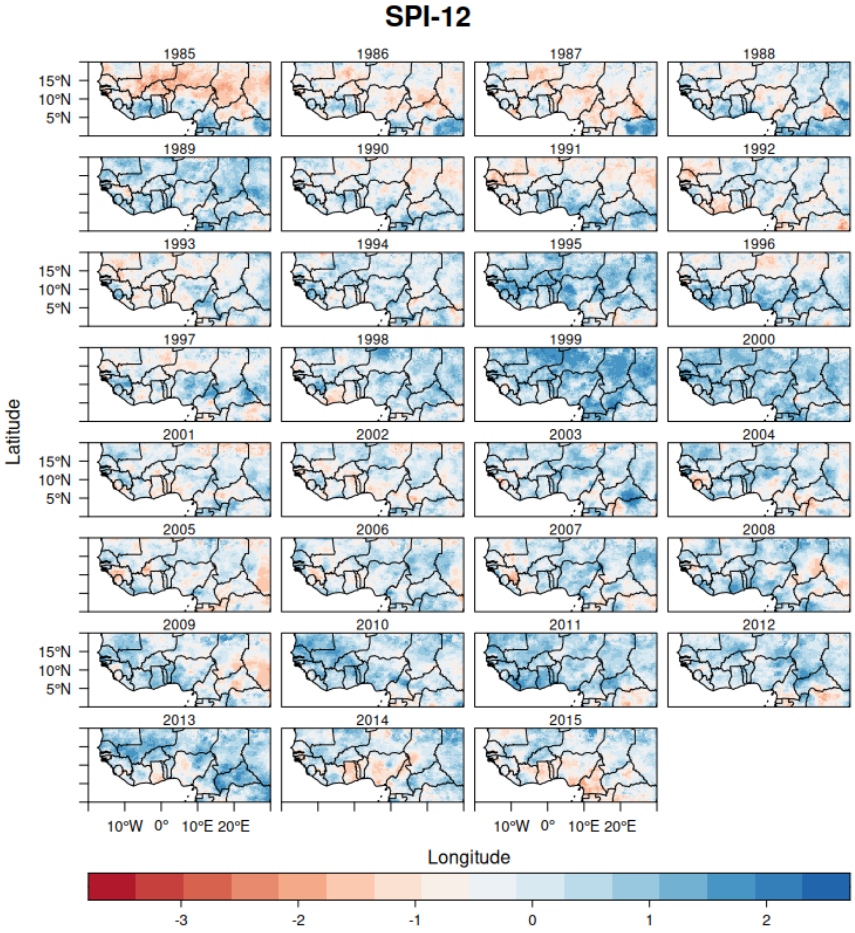

Fig 7 : Spatio-temporal variation in drought between 1985 and 2015 using the SPI 12 drought index

4.3.4. Spatio-temporal variation in drought using the 3-month SPEI index

Figure 35 illustrates the spatial and temporal variation of drought in West Africa between 1985 and 2015, analysed using the SPEI-3 index, derived from CHIRPS data for precipitation and CHIRTS data for temperatures.

During the decade 1985-1994, West Africa experienced a relatively wet period according to the 3-month SPEI indices. However, despite this general trend, several episodes of drought were observed. The most significant ones occurred in 1990 in the western part of the study area (Ghana, Côte d'Ivoire, Liberia, Guinea, Sierra Leone, Gambia, Mali, Senegal, Mauritania and Burkina Faso) and in 1987 along a horizontal strip stretching from Mauritania to Gabon. These droughts remained moderate. Mild droughts were also recorded in 1986 and 1988 in the south-east, in 1991 in several locations in the west and east, and in 1992 in the southern areas, from Guinea to Togo.

Between 1995 and 2004, drought tended to spread across the entire region, despite a generally wet year in 1999. Overall, drought remained moderate, but 1998 stood out with severe drought in the west, with values approaching -2. In the other years of the period, drought remained moderate in most countries.

During the period 2005-2015, drought tended to spread to most parts of the region. However, milder drought conditions were observed in 2008 and 2012, in the east and north-east respectively. This trend was also observed during the years 2005 to 2007 and 2014 in the northeast, which was marked by widespread moderate drought episodes (values between -1 and -1.5). During the rest of the observation period, severe droughts prevailed, with some localities showing a gradual drying of the regional climate.

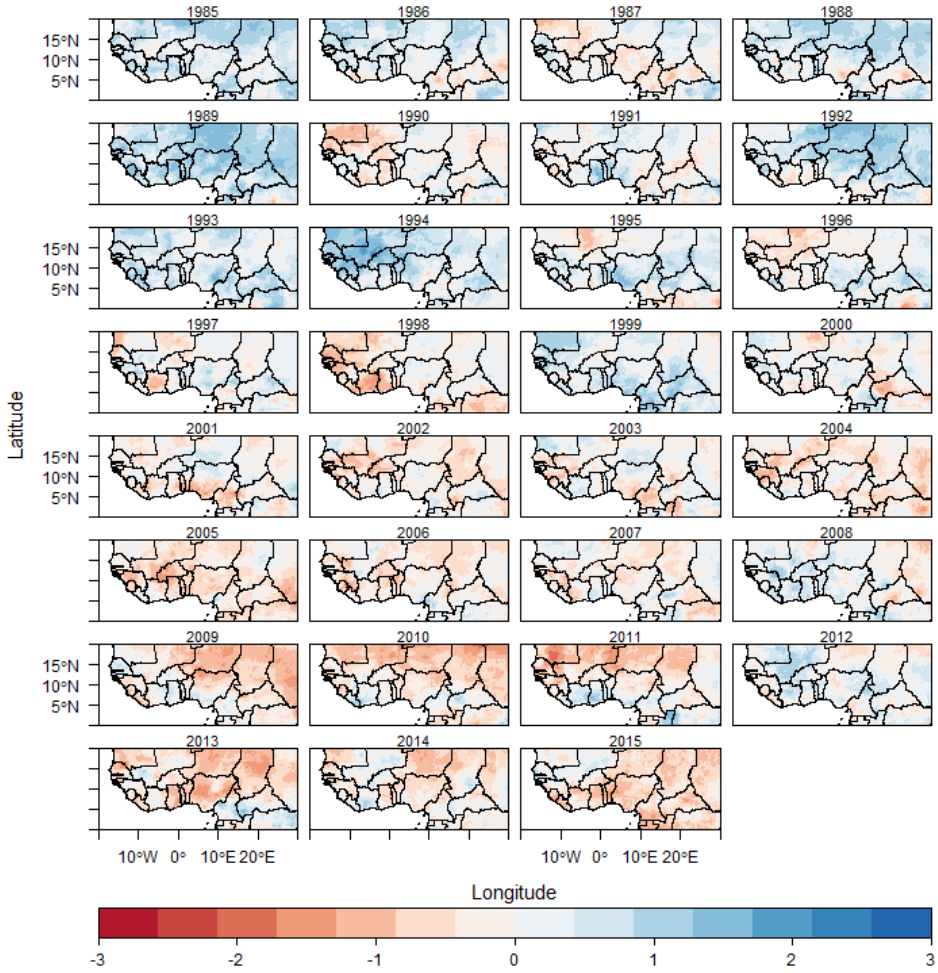

Fig 8 : Spatio-temporal variation in drought between 1985 and 2015 using the SPEI 3 drought index

4.3.5. Spatio-temporal variation in drought using the 6-month SPEI index

Figure 36 shows the spatial and temporal variation in drought in West Africa over the period 1985–2015, assessed using the SPEI-6 index derived from CHIRPS (precipitation) and CHIRTS (temperature) data.

The SPEI-6 drought index shown in the figure indicates that between 1985 and 1994, West Africa experienced a generally wet period, although some years were marked by localised droughts. The maps for 1986, 1987, 1990 and 1991 highlight the most intense episodes. In 1986, the drought mainly affected the south, while in 1987, a dry strip stretched from southern Mauritania to Cameroon. In 1990, the western part of the region was particularly affected, and in 1991, water deficits appeared simultaneously in the east and west. Other more limited episodes were observed in 1988 in south-eastern Nigeria and eastern Central African Republic, and in 1992 in the south, between Liberia and Ghana. The maps also show a resurgence and intensification of drought episodes across the region during the period 1995 to 2004. The most critical years were undoubtedly 1998, 2002 and 2004, during which the severity of the drought was more widespread. The index values during these years fluctuated between -1 and -1.5, indicating severe drought. In 1996, the most severe droughts were concentrated in the north-west, while in 2001, droughts were slightly more localised in coastal countries, the east and Mali. In 2003, the situation was similar, with the exception that the areas affected remained the west and south-east. Similarly, the period 2005-2015 shows a dry trend that is both dominant and persistent. Apart from 2008 and 2012, when drought conditions were moderate in some localities, drought spread and reached intense and severe levels, affecting almost all parts of the region. These indicators clearly illustrate the progressive aridification of the West African climate, caused by the increasing frequency and intensity of dry spells since the 2000s.

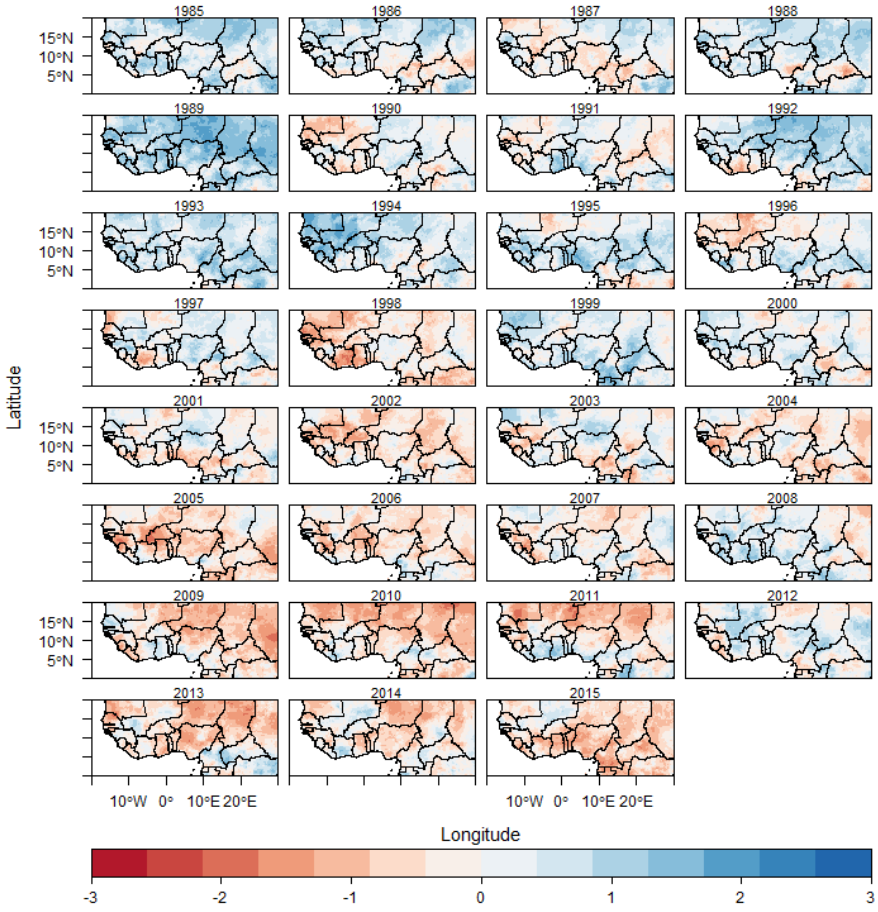

Figure 9 : Spatio-temporal variation in drought between 1985 and 2015 using the SPEI 6 drought index

4.3.6. Spatio-temporal variation in drought using the 12-month SPEI index

Figure 37 illustrates the spatial and temporal variation of drought in West Africa between 1985 and 2015, based on the SPEI-12 index calculated using CHIRPS (Climate Hazards Group InfraRed Precipitation with Station data) data for precipitation and CHIRTS (Climate Hazards Centre InfraRed Temperature with Stations) data for temperature. This index, which incorporates both rainfall anomalies and the effects of potential evapotranspiration, makes it possible to assess cumulative water conditions on an annual scale and to characterise fluctuations in the regional climate regime.

Between 1985 and 1994, the SPEI-12 index shows West Africa to be generally wet, with values often above +1 and locally above +2, indicating a significant water surplus. However, some years show dry spells. In 1986, the southern regions had values around -1.5, indicating moderate drought. In 1987, a wide band from southern Mauritania to Cameroon reached values below -2, corresponding to severe drought. In 1990, the north-western zone recorded anomalies close to -1 to -2, while in 1991 the eastern and western zones showed similar deficits. In 1988, south-eastern Nigeria and eastern Central African Republic showed values close to -1, and in 1992 the coastline between Liberia and Ghana showed a comparable deficit.

The period 1995-2004 was marked by intense and widespread drought, which intensified as shown in the maps. The droughts during 1998, 2002 and 2004 showed a more intense trend, reaching -2.5 to -3 in most locations in the area. Indeed, the droughts observed in 1996 in the north-west show values close to -1.5, signs of severe drought, while in 2000 the coastal countries and Mali suffered the worst droughts with values close to -2. In 2003, localities in the west and south-east showed intensities close to -1.5, reflecting severe drought.

From 2005 to 2014, the frequency and intensity of droughts increased sharply. Values regularly fluctuated between -1.5 and -3 over most of the territory. In 2005, 2006 and 2011, the Sahelian and central areas exceeded -2, while the coastal regions locally maintained surpluses close to +1. In 2008 and 2012, the anomalies remained localised but reached -2 in some regions. From 2013 onwards, red tones dominate the map, with values between -1 and -2.5 covering almost all of West Africa. This trend reflects a gradual drying of the climate, with droughts becoming more frequent, longer lasting and more widespread, affecting both the Sahelian and coastal regions.

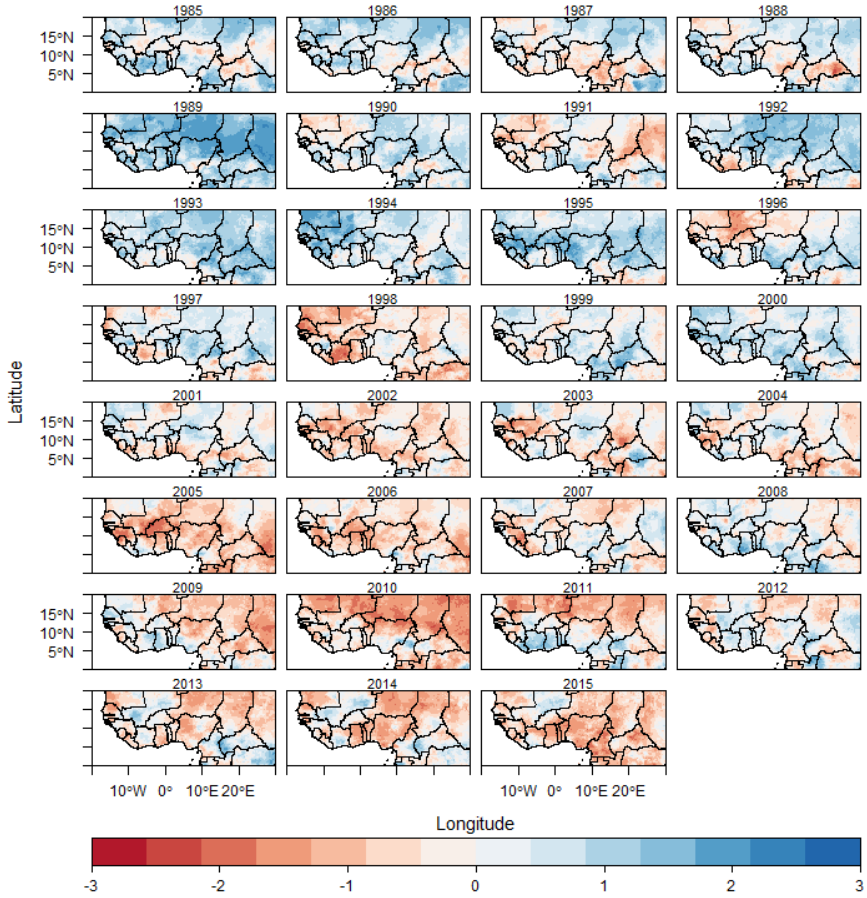

Fig 10 : Spatio-temporal variation in drought between 1985 and 2015 using the SPEI 12 drought index

4.4. Sensitivity of meteorological drought to vegetation cover

Figure 27 shows the correlation maps between the Standardised Vegetation Index (SVI) and two climatic drought indices, the Standardised Precipitation Index (SPI) and the Standardised Precipitation Evapotranspiration Index (SPEI). These correlations were established at different time scales of 3, 6 and 12 months and for four representative seasons: DJF (December to February), MAM (March to May), JJA (June to August) and SON (September to November). In general, the vast majority of the region showed a predominance of positive correlations (greater than 0.5), indicating a good agreement between the SPEI and SPI indices and the SVI index. These indicators reflect the sensitivity of vegetation to water conditions in the region, confirming that precipitation remains the main factor controlling the SVI at the regional scale. However, the SPEI induces a slight modulation linked to evapotranspiration, which is particularly noticeable in arid environments. Furthermore, not all seasons necessarily show the same levels of correspondence between the index categories. During the DJF and SON seasons, the correlations are stronger, showing a clearer relationship between plant dynamics and water conditions. This behaviour shows that during the wet season, accumulated at the end of the cycle, and during the dry season, vegetation remains less responsive to climatic variations when water stress intensifies. During the MAM and JJA seasons, the correlations are weaker, showing rapid growth conditions in which the vegetation cover is well localised. Overall, the figure indicates a close link between SVI and regional water conditions, marked by particularly pronounced responsiveness during the DJF and SON seasons, which are crucial periods for assessing vegetation resilience and recovery in response to moisture variations.

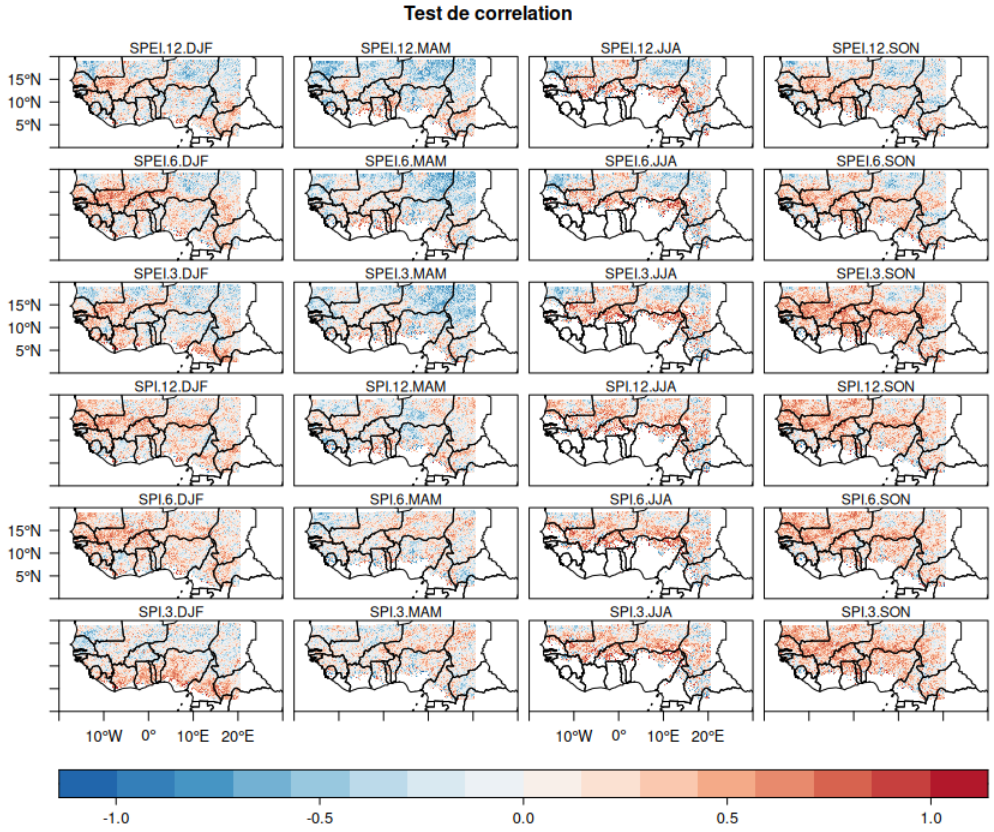

Figure 11 : Spatial correlation of the SVI and drought index

V. Discussion

The combination of meteorological indices (SPI, SPEI) and satellite indices (SVI) represents a major methodological advance in drought assessment in West Africa. The SPI and SPEI indices, widely used in the literature [21,22], are used to characterise rainfall variability and the climatic water balance. The SPI, based solely on precipitation, is recognised for its simplicity and robustness in detecting rainfall anomalies [25]. The SPEI, by incorporating potential evapotranspiration, better captures water stress conditions, particularly in arid areas [26].

At the same time, satellite indices such as the SVI, derived from the NDVI, reflect the ecological response of vegetation to climatic fluctuations[27]. Integrating these two approaches allows atmospheric and surface dynamics to be cross-referenced, which enhances the reliability of the results. This complementarity is also highlighted by several studies that emphasise the need for a multi-indicator approach to understand the complexity of drought [20,23].

The results reveal strong seasonal variability in the correlations between drought indices and soil moisture. During the wet seasons (MAM and SON), the correlations are higher, reflecting a direct response of the soil to precipitation. In contrast, during dry seasons (DJF and JJA), correlations are low, suggesting that surface conditions depend more on local conditions and water reserves [28]. Spatially, the Sahelian and Sudanian zones appear to be the most vulnerable, with recurrent water deficits. These results corroborate previous observations highlighting the fragility of the Sahel in the face of persistent droughts [29]. The southern regions, particularly the coastal countries of the Gulf of Guinea, show more contrasting variability, alternating between dry and wet periods. This spatial heterogeneity reflects the complexity of the West African climate, marked by north-south gradients and oceanic influences [30].

The temporal analysis highlights a gradual intensification of dry spells since the 2000s. The first decade (1985–1995) was relatively less marked, while the following decades saw an increase in droughts, peaking in 2010. This finding is consistent with the work of Dai (2011)[31], which shows a global trend towards aridification in tropical regions. The contrast between SPI and SPEI is also instructive: SPI reflects sporadic variability, with isolated episodes, while SPEI reveals a more persistent and cumulative dynamic linked to evapotranspiration [22]. This difference highlights the importance of integrating thermal processes in order to understand drought in its entirety. The results thus confirm that drought in West Africa is not only a rainfall deficit, but a multidimensional phenomenon influenced by temperature and evaporative demand [32].

The results have major implications for natural resource management and agricultural planning. The sensitivity of vegetation cover to water conditions, particularly during the DJF and SON seasons, shows that these periods are crucial for assessing ecosystem resilience [27]. Prolonged dry spells directly affect agricultural productivity, food security and water availability [33].

The spatial redistribution of soil moisture, with marked drying in the north and relative improvement in the south, could accentuate regional disparities. The already vulnerable Sahelian zones are likely to experience intensified water crises, while southern regions could face increased pressure from climate migration and resource demand [34]. These findings highlight the urgent need to strengthen early warning systems and adapt agricultural practices to new climatic conditions.

Although the study provides robust results, certain limitations should be noted. The SPI and SPEI indices are based on precipitation and temperature data that may be subject to uncertainty, particularly in areas where weather stations are scarce [20]. Furthermore, satellite indices such as the SVI, although effective in capturing plant dynamics, do not always reflect the complexity of soil-plant-atmosphere interactions [35]. To improve understanding, it would be useful to incorporate other indicators, such as the Vegetation Condition Index (VCI) or thermal remote sensing data, in order to better understand water stress [36]. Furthermore, the

analysis could be extended beyond 2015 to assess recent developments, particularly in light of SSP-2.4.5 climate scenarios and the adaptation policies that have been implemented [34].

The discussion highlights that drought in West Africa between 1985 and 2015 was characterised by a gradual intensification of dry spells, high seasonal variability and increased vulnerability of Sahelian areas. The complementarity of the SPI, SPEI and SVI indices makes it possible to cross-reference climatic and ecological dynamics, providing an integrated view of the phenomenon. These results confirm the trends observed in the literature[29–31] and highlight the urgent need to strengthen early warning systems, adapt agricultural practices and develop sustainable water resource management strategies to cope with an increasingly extreme climate.

VI. Conclusion

The drought in West Africa between 1985 and 2015 was characterised by gradual intensification, marked seasonal variability and increasing spatial extent, reflecting structural climate instability that is having a lasting impact on the region. The SPI, SPEI and SVI indices reveal a dynamic in which dry spells are becoming not only more frequent but also more severe, directly impacting soil moisture and vegetation cover vitality. This trend confirms the existence of a sustained aridification process that is increasing the vulnerability of West African ecosystems and societies. The analysis highlights that the wet seasons, particularly MAM and SON, reflect a more direct response of soils and vegetation to rainfall, while the dry seasons, DJF and JJA, reveal an increased dependence on local water conditions and fragility in the face of rainfall deficits. In terms of time, the first decades appear to be relatively less affected by dry spells, but since the 2000s, the frequency and intensity of droughts have increased, with a particularly pronounced peak in 2010, confirming a trend towards a more extreme climate. Spatially, the Sahelian and Sudanian zones remain the most vulnerable, but the spread of droughts towards coastal regions highlights the extension of the phenomenon to the whole of West Africa. Ultimately, this study demonstrates that drought has become a structuring factor in the regional climate and that it is necessary to strengthen integrated monitoring systems, develop robust early warning mechanisms and promote adaptation and regional cooperation strategies in order to preserve the food, water and socio-economic security of populations in the face of future climate challenges.

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