Rainfall Variability and Vegetation Cover Dynamics in the Northern Part of the Southern Rivers: from Basse Casamance (Senegal) to Rio Gêba (Guinea Bissau).

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Abstract: **The aim of this contribution is to analyse the impact of rainfall variability on vegetation cover dynamics in the northern part of the Southern Rivers. The methodology adopted is based on the processing of rainfall data (1961-2018), Landsat satellite images and time series of Normalized Difference Vegetation Index (NDVI). The results show a highly contrasted rainfall variability, highlighted by the Standard Precipitation Index (SPI). The latter shows that annual variations in rainfall are slightly in favour of drought. The temporal profile of the NDVI revealed two periods with different rates of change. A first period from 1984 to 2000, characterised by good phenological activity, with good vegetation cover, and a second period from 2001 to 2018, marked by a significant decrease in vegetation cover. Spatial analysis of the evolution of vegetation formations reveals a north-south density gradient accompanied by an increase in dense forest and the regression of open savannah.**

***Keywords*: Rainfall variability, dynamics, vegetation cover, Southern Rivers.**

I. INTRODUCTION

The Rivières du Sud are characterised by highly contrasting rainfall variability along a south-north gradient. The importance of the climatic gradient explains to a large extent the differences in landscape and flora in the northern regions of the Rivières du Sud [1]. Rainfall decreases from the Guinean regions to the Sahel and Sahara. They are marked by frequent droughts, the most significant of which date from the 1970s, 1980s and 1990s. These droughts are remarkably severe, persistent, and widespread, and have caused major changes in natural and human systems [2]. Their impacts have been dramatic at all scales. The decrease in rainfall has been, overall, greater than in countries further away from the ocean [3]. Moreover, this drought was not only felt in the Sahelian regions of northern Senegal, but in the whole country [4]. It had a severe impact on Basse-Casamance, a region that is already in the sub-humid tropical domain. This strong decrease in rainfall has had repercussions on river flow, on the supply of groundwater and on the vegetation cover [3]. The vegetation cover of the Southern Rivers has undergone changes over the last four decades. These changes are generally linked to climate variability and change, which are becoming more and more pronounced, but also to human activities. The environment studied is home to plant formations (mangrove and forest vegetation) that are constantly under the influence of marine hydrodynamic actions. The salinity of the water plays an important role in the dynamics of the plant cover. The increase in salt content in the water and soil, linked to climatic variations, leads to the extension of saline lands and the degradation of plant formations by hypersalinity. However, the existence of rainfall variability can lead to changes that cannot always be described as degradation [1].

Spatial and temporal monitoring is carried out through the analysis of the normalized vegetation index (NDVI), which is a quantitative measure indicating vegetation dynamics [5]. It is a good indicator of vegetation activity, sensitive to spatial and temporal variations in phenological conditions of the vegetation cover [6]. Although it is the most widely used index, it has limitations related to its inability to differentiate between energy signals reflected from the canopy during senescence and bare soil. For this reason, other indices such as the SAVI type have been created. Another limitation is the overestimation of the rate of soil cover by vegetation during the growing season due to high chlorophyll activity [5].

II. METHODOLOGY

A. The study area

The area studied (figure 1) is in the southern part of the Senegalese-Mauritanian sedimentary basin of Meso-Cenozoic age, which extends from Cap Blanc in Mauritania to Cap Roxo in Guinea Bissau and the Bowé Basin, which occupies the south and south-east of the Rio Gêba. It is a transitional area between the maritime and continental domains with a relatively low topography along the coastal zone. The south-western part of the Senegal-Mauritania basin, between the Saloum delta in Senegal and Cape Mount in Liberia, is occupied by a series of coastal plains, cut by long flood valleys, shaped during the different phases of marine transgression [7]. This relief is dominated by maritime marshes constituted in their natural state by mangrove mudflats, the preferred domain of mangroves (*Rhizophora mangle* and *Avicennia africana* in particular) with finer mudflats in the southern part [8]. At the limits of the mangrove mudflats are stretches of tans that are flooded in places during the rainy season due to the flatness of the relief. The area studied is marked by the density of the hydrographic network composed of watercourses and saltwater channels constantly invaded by the tides. The climate belongs to the Libero-Guinean domain in the south [9], which is a sub-division of the tropical climate. The region is characterised by two seasons due to the alternating circulation of trade winds and the monsoon. A non-rainy season from November to April and a rainy season from May to October. Rainfall is relatively abundant (over 1000 mm per year). This abundance is essentially linked to the high potential for advected rainfall and the relief that conditions the summer shift of the intertropical convergence zone [10].

Figure 1: Geographical location of the area studied.

B. Climate data

The scarcity of climatic data in this region requires the reconstruction of time series using multi-source databases. Except for the Ziguinchor weather station, the other stations (Capskiring and Bissau) presented time series that were too incomplete to be reconstructed using CHIRPS (Climate Hazards Group InfraRed Precipitation with Station) data, WorldClim data and ERA-40 meteorological reanalyses from the European Centre for Medium-Range Weather Forecasts (ECMWF).

The study of rainfall variability refers to the interannual rainfall averages and the standardised precipitation index (SPI) of [11]. For a given year, this index averages the seasonal rainfall totals of the available rainfall stations. Thus, the SPI indicates whether the season can be described as surplus (if it is positive) or deficit (if it is negative).

$$\text{SPI} = \frac{Xi - \text{Xm}}{\text{Si}}$$

Where *Xi* is the cumulative rainfall for year i, *Xm* is the average rainfall for the series and *Si* is the standard deviation for the series. A SPI >1 indicates a wet year while a SPI <1 indicates a dry year. This index allows us to identify all dry and wet years in the series analysed.

The data used must meet two important criteria: firstly, the length of the time series (covering the longest possible period) and secondly, the quality of the data (fewer missing data). Three (3) rainfall stations were selected for this study: Ziguinchor, Capskiring, and Bissau. They have data series covering a period of 58 years (1961-2018) despite the scarcity of meteorological data in this region. From the calculations, a classification can be made to define the intensity of drought episodes according to the value of the index. The classification system we used (Table 1) is taken from [13].

Table I: Interpretation Scale for The Standardised Precipitation Index (Spi).

2.0 and above	Extremely wet
from 1.5 to 1.99	Very wet
from 1.0 to 1.49	Moderately humid
from -0.99 to 0.99	Close to normal
from -1.0 to -1.49	Moderately dry
from -1.5 to -1.99	Very dry
-2 and below	Extremely dry

C. Satellite data

The satellite images used (Table 2) are extracted from the Google Earth Engine (GEE) platform. It is a cloud-based platform for geospatial data analysis by giving the user the possibility to work in a geospatial Big Data infrastructure: earth observation data and cloud computing. Google Earth Engine is a multi-petabyte geospatial data archiving and parallel processing infrastructure that enables global analysis. It stores a range of geospatial data such as Landsat, Sentinel, land cover, vegetation cover, MODIS, and climate data such as CHIRPS, ERA-5, ERA-15, ERA-40, TRMM etc. GEE provides a data explorer and an application programming interface (API) based on JavaScript or Python.

Table II: Spectral And Spatial Characteristics Of The Landsat Images Used.

Sensors	Date of acquisition	Bands	Wavelengths	Resolution
MSS	1973	4-Blue	0.45-0.52 µm	60 m
		5-Green	0.52-0.6 µm	
		6-Red	0.63-0.69 µm	
		7- PIR	0.76-0.9 µm	240 m
Sensors	Date of acquisition	Bands	Wavelengths	Resolution
TM	1986	1-Blue	0.45-0.52 µm	30 m
		2-Green	0.52-0.6 µm	
		3-Red	0.63-0.69 µm	
		4- RIP	0.76-0.9 µm	
		5-SWIR 1	1.55-1.75 µm	
		7- SWIR 2	2.08-2.35 µm	

Sensors	**Date of acquisition**	Bands	**Wavelengths**	**Resolution**
ETM +.	2003	1-Blue	0.45-0.52 µm	30 m
		2-Green	0.53-0.61 µm	
		3-Red	0.63-0.69 µm	
		4-PIR	0.78-0.9 µm	
		5-SWIR 1	1.55-1.75 µm	
		7- SWIR 2	2.09-2.35 µm	
Sensors	**Date of acquisition**	Bands	**Wavelengths**	**Resolution**
OLI	2018	2- Blue	0.45-0.51 µm	30 m
		3- Green	0.52-0.60 µm	
		4- Red	0.63-0.68 µm	
		5- PIR	0.84-0.88 µm	
		6- SWIR 1	1.56-1.66 µm	
		7- SWIR 2	2.10-2.30 µm	

D. NDVI data

The study of the spatio-temporal dynamics of the vegetation cover is based on the analysis of the interannual variations of the NDVI profile extracted from the Climat Engine platform which gathers climatic data and a time series of NDVI values extracted from Landsat images, from 1984 to 2018 with a temporal resolution of eight (8) days. This is the mean NDVI reflecting the phenological variations of the vegetation formations. These Landsat image time series were chosen because of their fine spatial resolution (30 metres) and the frequency of observation of the environment. A multitude of other vegetation indices have been developed, but the best known is the NDVI. It transforms multi-spectral data into a single band image representing the distribution of vegetation. NDVI (Normalized Difference Vegetation Index) indicates the amount of green vegetation in each pixel, with higher NDVI values indicating greener vegetation.

$$\mathrm{NDVI} = \frac{PIR - \mathrm{R}}{\mathrm{PIR} + \mathrm{R}}$$

The normalised vegetation index (NDVI) is established by subtracting the red channel (where mineral surfaces have high reflectance) from the infrared channel (where vegetation cover has high reflectance). The resulting neochannel shows an increasing gradient of vegetation activity from black (no cover) to white (very high chlorophyll activity). The result of an NDVI takes the form of a new image, with the value of each pixel ranging from 0 (bare soil) to 1 (maximum vegetation cover) [12].

III. RESULTS

A. Interannual variability of rainfall

Interannual rainfall totals at the stations in Bissau, Ziguinchor and Capskiring are characterised by a regressive spatio-temporal variability from south to north. The area studied is characterised by two climatic domains marked by an unequal distribution of annual rainfall. The Guinean regions receive the greatest amounts of precipitation recorded during nearly 60 years of measurements (Figure 2). The maximum of the series is noted in Bissau in 2017 with 2814 mm. This year remains the wettest insofar as it records the highest rainfall amounts in all stations with 2306 mm in Ziguinchor and 2249 mm in Capskiring.

The analysis of the interannual variability of the rainfall totals shows a rainy period that began in 1961 and lasted until 1969. This period is common to all three observation stations. The 1970s marked the advent of a series of increased droughts which lasted until the 1980s or even 1990s and which were manifested by a dramatic decline in annual rainfall amounts. These droughts are evidenced by all the climate stations studied. The minimum is observed at the Ziguinchor station with 723 mm, well below the average of 1364 mm. It was 1310 mm in Bissau in 1977 and 823 mm in Capskiring in 2003. Analysis of inter-annual rainfall variability shows that after a long drought, rainfall conditions have improved, although they are lower than in the 1960s.

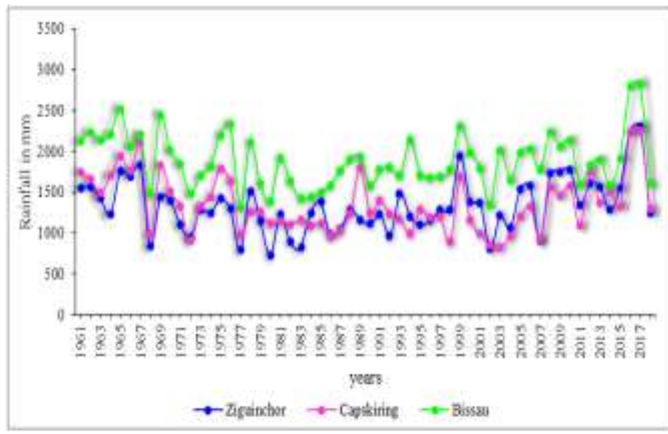

Figure 2 : Interannual variation in rainfall at Ziguinchor, Capskiring and Bissau stations between 1961 and 2018.

B. The Standardised Precipitation Index (SPI)

The analysis of the time series of annual precipitation recorded at the stations selected for this study reveals the existence of dry and wet periods. The study carried out is generally based on the values of the standardised precipitation index calculated over the 50-year observation period. The rainfall data derived from the calculation of this index (SPI) by station show that the annual variations in precipitation are slightly in favour of drought (Table 3).

Table III: Proportions (%) Of Dry And Wet Years At The Selected Stations.

Interpretation	SPI classes	Ziguinchor	Capskiring	Bissau
Extreme dryness	-2 and below	0	0	0
Very Dry	from -1.5 to -1.99	10	4	8
Moderately dry	from -1.0 to -1.49	10	18	10
Close to normal	from -0.99 to 0.99	66	58	64
Moderately humid	from 1.0 to 1.49	10	12	14
Very wet	from 1.5 to 1.99	2	6	2
Extremely wet	2.0 and above	2	2	2

Over a period of 50 years, very dry years represent 10% for the Ziguinchor station, 4% for the Capskiring station and 8% for the Bissau station. Moderately dry years account for 10% in Ziguinchor, 18% in Capskiring and 10% in Bissau. There are no years in which rainfall is well below normal, which are otherwise classified as extremely dry years. Years with near-normal rainfall dominate the series but are still below average. These years account for 66% of the total at the Ziguinchor station, 58% at the Capskiring station and 64% at the Bissau station. This deficit period was observed between 1970 and 2008 at all the stations and throughout the series studied, despite a few years of high surplus. This period is slightly dry with a probability of occurrence of once every 3 years [13]. The geographical location of this part of the Southern Rivers in relation to the equator gives it a good rainfall despite its spatio-temporal variability during the period studied.

The analysis of the SPI shows three phases of evolution (Figure 3). The first phase, whose evolution is almost identical for the three stations sharing the same observation period from 1961 to 2010, is marked by a low contrast variability with a frequency of wet years between 1961 and 1969. The second phase begins in the 1970s and extends over a long period of drought, commonly called the climatic break, until 2007, despite a few years when the index is positive. The third phase is marked by an improvement in rainfall and runs from 2008 to 2018. It is considered by researchers as a return to better rainfall conditions if not an anomaly in the succession of deficit years noted previously.

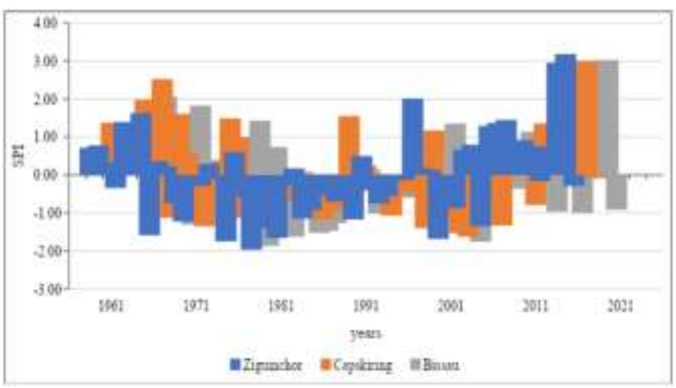

Figure 3 : Standardised precipitation index (SPI) calculated over the period 1961-2018 at the Ziguinchor, Capskiring and Bissau stations.

Climate change is now widely recognised by the scientific community [14]. The inter-annual evolution of rainfall in the Southern Rivers is very contrasted. It is subject to spatio-temporal variability in the image of the standardised precipitation index. On an international scale, the World Meteorological Organization [14], predicts a probable increase in rainfall over a short period of time and according to geographical areas. This increase is due to the acceleration of the hydrological cycle because of high temperatures.

The calculation of this index allows us to understand the impact of rainfall variability on the spatio-temporal evolution of coastal ecosystems. The analysis of the SPI reveals that from the years 1969 to 1970, as mentioned in several scientific documents written in the field, there has been a rainfall deficit characterised by a succession of dry years corresponding to the onset of drought. This observation concerns all the rainfall stations selected for this study. However, we note a uniform trend at the start of observations in 1961 for the three stations (Ziguinchor, Capskiring and Bissau).

The graphical representation of the standardised precipitation index (SPI) has made it possible to highlight the succession of periods of dry years and wet years. In general, the moving average curves, which are a good indicator of large interannual fluctuations, show three distinct periods, which we have detailed above.

This rainfall variability is an element that partly conditions the dynamics of the physical environment. The impact of rainfall variability on coastal areas can be seen in the salinisation of the land, which affects agriculture and agricultural production, the reduction in the flow and drying up of rivers, the rise of the saltwater table and flooding of coastal areas, and the salinisation of the water table, which alters the quality of drinking water on the coast. This variability affects the dynamics of the coastal morphological units that we will study in the next chapter and is also manifested by an acceleration of coastal erosion that we can observe along the coast in Lower Casamance. Vegetation species such as mangroves, which play a protective role for the coastline, are threatened by an increase in salt concentration, rising temperatures and rising sea levels.

C. Spatial and temporal dynamics of the vegetation cover

Examination of figure 4 shows a highly contrasted interannual variability in vegetation cover between 1984 and 2018. It shows a regression in the vegetation cover of the area, as shown by the trend curve, despite a few years with a very active phenological stage. The temporal profile revealed two periods with different rates of evolution. The first period, from 1984 to 2000, is characterised by good phenological activity, although it begins at the end of the resounding droughts experienced by West Africa in the 1970s and 1980s. This period reflects the high vegetation cover that characterises this environment and is much cited in the literature. The maximum NDVI is noted in 1990 with a value of 0.54. It should be remembered that for a spatio-temporal analysis of NDVI, it is necessary to work with the true reflectance values. This means that the satellite images must be radiometrically and atmospherically corrected. The second period extends from 2001 to 2018, where a significant decrease in vegetation cover is clearly observed, with the minimum value in the series being recorded in 2017. This regression may be linked to variations in climatic conditions or to anthropic pressure. The coastal areas of the Rivières du Sud are attracting more and more people who are settling there permanently because of the many advantages that these environments offer. The latter exert pressure on the physical environment through the expansion of cultivated land and the cutting of wood for both energy and commercial purposes.

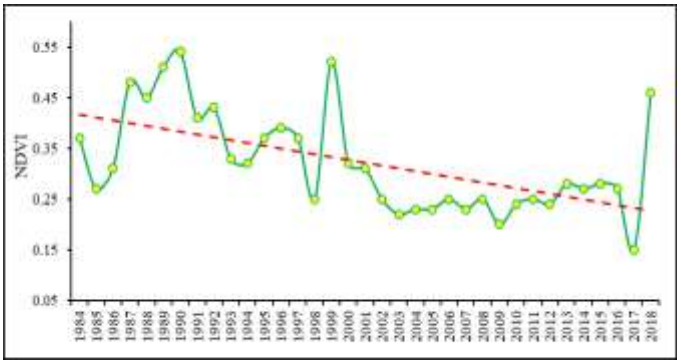

Figure 4: Interannual evolution of the average NDVI of the study area from 1984 to 2018.

The vegetation index is a widely used parameter nowadays in studies mainly related to climate change impacts. The relationships between NDVI and climate parameters are not yet fully established and are the subject of numerous studies, [15]. However, it remains a good indicator for assessing the impacts of climate change on vegetation cover. Naturally, favourable climatic conditions lead to the development of vegetation cover and the regeneration of degraded areas. Figure 5 shows the interannual evolution of NDVI and cumulative rainfall in the study area from 1984 to 2018.

NDVI is an index that quantifies the amount of vegetation activity. It is the normalised difference between luminance in the near infrared (NIR) band and luminance in the late visible band, known as the red band (R). Temporal analysis allows the detection of changes in vegetation [1]. The classifications carried out on Landsat images have limitations for assessing vegetation dynamics insofar as the images are chosen according to a time interval varying between 14, 15 and 17 years. The Landsat NDVI time series make it possible to understand the dynamics of the vegetation cover on a fine scale, unlike the NOAA series.

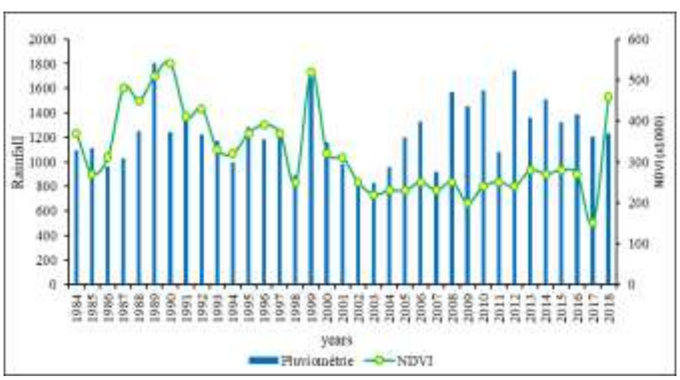

Figure 5: Interannual evolution of NDVI and cumulative rainfall in the study area from 1984 to 2018.

The analysis of figure 5 shows two phases of evolution of the vegetation cover in the area studied. A first phase where the NDVI evolves at the rate of rainfall and which goes from 1984 to 2003 and a second phase where we observe a regression of the vegetation cover compared to the first one despite the favourable rainfall conditions, evolving between 1200 mm and 1800 mm per year. These changes can be attributed to two factors:

- The impact of climate change on the environment. According to the IPCC (2014) predictions, precipitation can be expected to decrease or increase, but over a short period of time and poorly distributed spatially and temporally. As a result, large amounts of precipitation may be recorded without positively affecting the state of the vegetation cover.
- The other element that is often mentioned in the literature is the anthropic pressure on plant resources. The expansion of saline lands has led farmers to conquer mangrove soils and other fertile forest lands. Systematic cutting of Rhizophora wood to meet household energy needs and the development of coastal settlements may contribute to the decline in vegetation cover. The multitude of services offered by the mangrove domain is increasingly attracting people who find their livelihoods there.

Given all the elements that govern the dynamics of the vegetation cover, it is difficult to correlate NDVI with rainfall. However, climate and especially rainfall play a key role in the regeneration and development of plant formations. A lack of annual rainfall weakens plant formations and disrupts their seasonal phenological cycle. The cumulative annual rainfall is correlated with the mean annual NDVI value to see the relationship between these two variables (figure 6). The correlation is made over two periods. A first period where the evolution of the NDVI follows in parallel that of rainfall and a second period where the opposite is observed. The correlation coefficient between cumulative annual rainfall and the normalized difference vegetation index is 0.68 for the first period. This means that 68% of the variation in vegetation cover is explained by the amount of annual rainfall recorded. However, no correlation is observed in the second period. The decrease in vegetation cover can be linked in this case to the anthropogenic pressure detailed above.

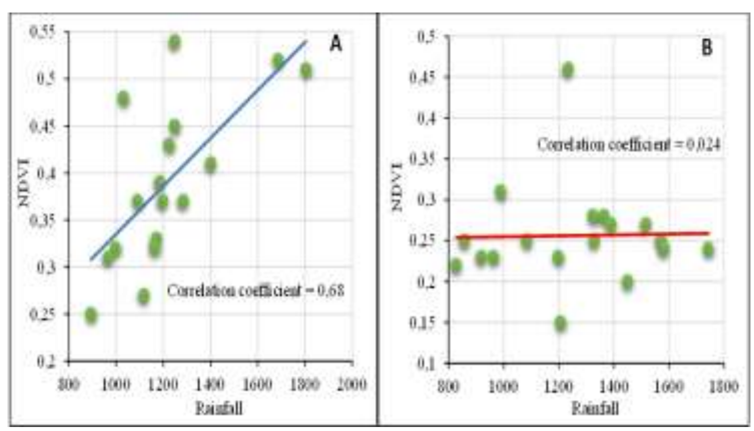

Figure 6: Statistical relationship between NDVI and cumulative annual rainfall from 1984 to 2000 (A) and from 2001 to 2018 (B).

D. Seasonal dynamics of the vegetation cover

The Normalized Difference Vegetation Index (NDVI) not only allows to characterize the spatio-temporal dynamics of the vegetation cover of a given area, but it can be used to assess the climatic variability through the calculation of drought indices. Several indices such as the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI) are proposed in this sense to see in a geographical area if the drought conditions are met or not. Two indicators evaluate the situation of the NDVI in relation to the situation that represents dry conditions. It is the minimum value of the NDVI that indicates a less favourable vegetation condition, whereas for temperature, it is the maximum temperatures that indicate water stress conditions [16].

These drought indicators are calculated based on NDVI and brightness temperatures (TB). This also justifies the close link between the spatio-temporal dynamics of vegetation and climatic conditions. The NDVI time series statistics are derived from Landsat data at the 30 m scale. However, the frequency of observations as well as the spatial accuracy led us to choose the NDVI data from MODIS which are nine (9) day summaries with a spatial resolution of 250 m, which is the finest among satellites with high temporal repeatability. These are medium spatial resolution images that are very suitable for monitoring spatial cover.

The analysis of Figure 7 highlighted the annual vegetation cycle of the area studied in 2018. These results confirm the conclusions of the time series from the Landsat data. They also show the relationship between the vegetation cover dynamics and the annual rainfall cycle. A decrease in vegetation is observed in the dry season, in the absence of herbaceous vegetation cover, particularly between February and June. In July, with the arrival of the rainy season, the regeneration of the herbaceous cover is observed from the south of the region, which records the first rainfall. Between July, August and September, some places on the continent experienced a negative NDVI due to the importance of rainwater. This phenomenon is observed especially in the Guinean region between July and August. These rainfall conditions are favourable to the development of the vegetation cover and maintain its phenological growth until January.

The NDVI does not differentiate between herbaceous and tree or shrub vegetation. The estimates are generalised, but the index allows the characterisation of the rainy season and the determination of its start and end dates. The principle assumes that plant chlorophyll activity increases throughout the rainy season, resulting in increased vegetation index values [15]. As the non-rainy season approaches, the herbaceous vegetation tends towards senescence, chlorophyll activity decreases and consequently vegetation index values fall. From February onwards, the NDVI values decrease progressively until March, indicating the seasonal contrast of the vegetation cover. This regression is linked not only to the lack of rainfall but also to the high temperatures recorded in the non-rainy season, which drastically impact soil moisture.

At the coastal fringe, the overflow of marine waters and stagnant waters in the rainy season occupy a lot of space and strongly influence the estimates of vegetation cover. These surface conditions appear in black on the spatial NDVI, particularly in estuaries and their margins. These are mixtures of water and vegetation that are difficult to separate due to the spatial resolution of the images used. The classification of a pixel as vegetation or non-vegetation is always in favour of the dominant spatial entity within it, as the spatial resolution does not allow for pure pixels in the region studied.

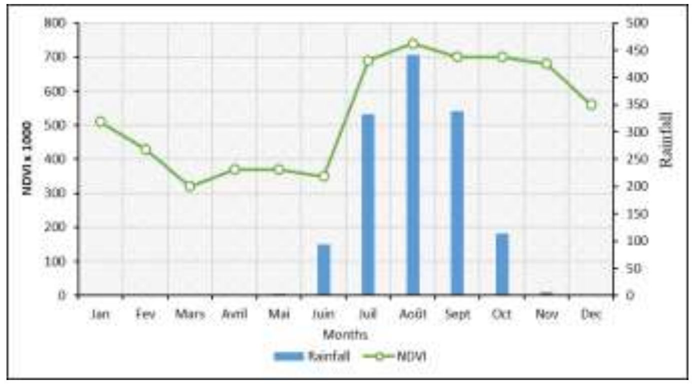

Figure 7: Monthly evolution of vegetation cover compared to monthly cumulative rainfall in the study area.

E. Spatial and temporal dynamics of the vegetation cover

The observation of the physiognomy of the vegetation in the field made it possible to distinguish three (3) plant formations highlighted by the cartographic results (figure 8). Diachronic mapping made it possible to quantify the dynamics of the vegetation formations. The results show that in 1973, the dense forest occupied 4.49% or 218034 hectares. With the resurgence of droughts during the 1970s, a regression of 1.5% was observed in 1986, as one moves away from the coast and the wetlands. The dense forest is observed at the limit of the mangrove vegetation, especially in the Guinean part. The mangrove vegetation that occupies all the estuaries of the Casamance, Rio Cacheu, Rio Mansoa and Rio Gêba covers an area of 336450.96 hectares, i.e., 6.93% of the area studied. In 1986, the surface area occupied by mangroves fell from 336450.96 ha in 1973 to 263563.38 ha, i.e., a regression of 72887.58 ha. This strong decrease can be linked to the recrudescence of drought episodes during this period and to the increase of the salt content in the water and the soil.

Land use statistics show a predominance of open savannah, which represents 24.74% of the area studied. Mangrove increased slightly between 1986 and 2003, from 6.56% to 6.63%, before rising to 7% in 2018. This increase can be linked to the return of better rainfall conditions in recent decades. Open savannah has seen a gradual decrease in its area since 1973, while dense forest has seen an increase in its spatial coverage of 3.6% in 2018 despite rainfall variability. This can be linked to high soil moisture content and the depth of the water table.

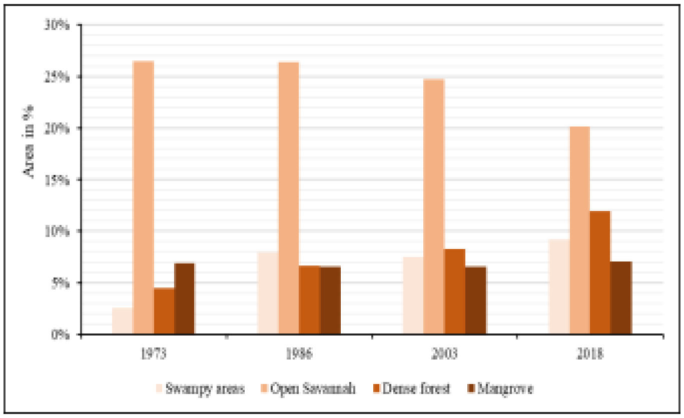

Figure 8: Evolution of vegetation formations between 1973 and 2018.

However, spatial analysis of the changes has shown that there are areas where vegetation cover has declined. These areas are in the north of the Department of Ziguinchor, between the Casamance estuary and the Rio Cacheu estuary, particularly on the outskirts of the Cacheu marine protected area. Increases are observed to the south of the Rio Gêba, to the north of the Rio Mansoa, all in the Guinean region (Figure 9). This growth is linked to the expansion of cashew nut plantations, which is currently the main export product of Guinea-Bissau. However, the density of forests is decreasing more and more from north to south following the rainfall gradient but also due to the extension of saline lands in the north.

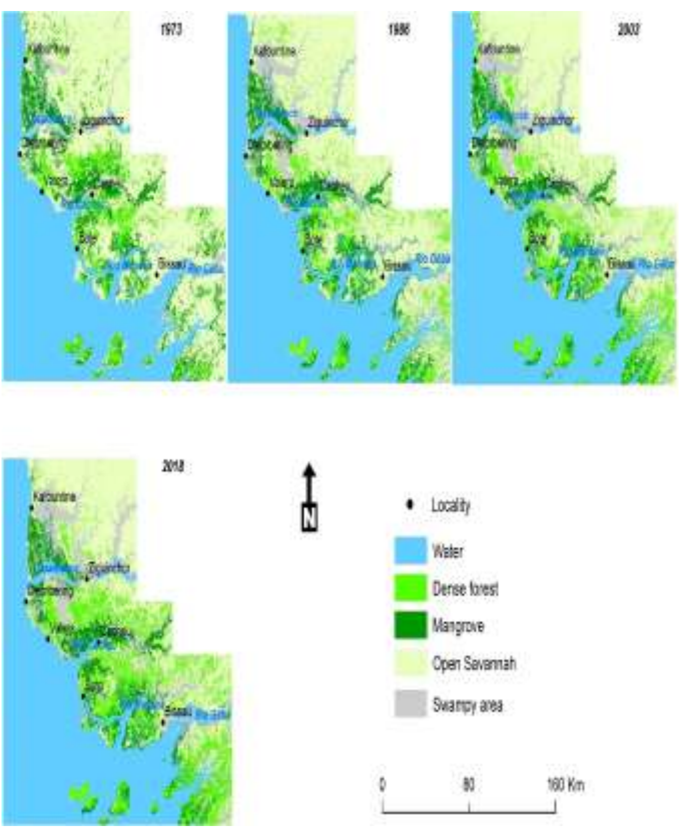

Figure 9: Spatio-temporal dynamics of vegetation cover in the study area from 1973 to 2018.

IV. DISCUSSION

The analysis of rainfall time series showed that the area studied has experienced very marked rainfall variability. The analysis of cumulative rainfall shows a downward trend, particularly in the Sahelian zone. The IPCC projections (2007 and 2014) predict an increase in drought events. The drought of the 1970s is the main cause of mangrove degradation. This drought led to an increase in the salinity of saltwater channels, characteristic of coastal areas [17] of the Southern Rivers. This climatic variability influences the dynamics of the vegetation cover, whose density and greenness follow a north-south gradient. Rainfall has evolved sequentially in the Sahelian zone, while in the Sudanian region, it is subject to slight interannual variability. Since the 1950s and 1980s, there has been a general trend for isohyets to shift south/southwest. This evolution reflects a clear and generalized decrease in annual rainfall over the whole of West Africa [18]. The deterioration of the climate in recent decades, accompanied by an uninterrupted succession of dry years, explains the remarkable extension of the tidal flats at the expense of the mudflats, particularly in the outer parts of the Saloum estuaries, as well as the rise, far upstream, of the salinity front of certain rivers such as the Casamance [8]. This climatic variability has had an impact on the plant formations of the northern part of the Southern Rivers. The resurgence of droughts in the 1970s and 1980s led to the mortality of woody species in sensitive ecosystems [19], [20]. The effects of drought in savannah environments are observed through variations in woody cover, which are highly indicative of climate change at the local scale [20], [21], [22]. Mangrove formations are the most impacted by these climate fluctuations. These results are in line with those of [17], who identified rainfall deficit as the determining factor in mangrove regression. The average NDVI of all plant formations has regressed since the 2000s while rainfall conditions have improved. This means that other factors, such as anthropic pressure, impact the dynamics of the vegetation cover in the studied area. The results of the correlation between NDVI and rainfall are a perfect example and agree exactly with those of [1] who found the same correlation coefficient (0.68) between 1984 and 2000. The evolution of the monthly NDVI, compared to the duration of the rainy season, shows that the vegetation cover has a response time of one month between the arrival of the first rains and the greatest foliar development [1]. The vegetation activity curve follows the rainfall curve with a one-month lag. However, the supervised classification method, combined with observations of the physiognomy of the vegetation in the field, made it possible to classify the images into five (5) classes using the maximum likelihood algorithm. The diachronic analysis of the vegetation formations showed a development of the dense forest, a reduction of the open savannah and a stable evolution of the mangrove formations.

V. CONCLUSION

The objective of this study was to analyse the impact of rainfall variability on vegetation cover dynamics in the northern part of the Southern Rivers. The methodological approach adopted consisted of the processing of time series of rainfall, normalized difference vegetation index (NDVI) and digital processing of Landsat MSS, TM, ETM+ and OLI satellite images. The results of this methodological approach showed a very marked rainfall deficit from 1970 until the 1990s before suggesting a return to better rainfall conditions. This climatic variability is partly correlated with the dynamics of the vegetation cover in the area studied. The evolution of the NDVI between 1984 and 2018 showed two phases of vegetation cover evolution. A first phase where the NDVI evolves at the same rate as rainfall, from 1984 to 2003, and a second phase where we observe a regression of the vegetation cover in relation to the first phase despite favourable rainfall conditions, evolving between 1200 mm and 1800 mm per year. The spatial analysis shows a North-South density gradient of vegetation cover with the development of dense forest and the regression of open savannah.

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