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Detection of recent changes in Gambia vegetation cover using time series MODIS NDVI

Détection des modifications récentes de la couverture végétale en Gambie à l'aide d'une série temporelle d'images MODIS NDVI

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Introduction

- 1 In West Africa, particularly in The Gambia, vegetation cover has undergone significant changes over the past five decades (Ariori and Ozer 2005; FAO, 2015; CILSS, 2016; Diedhiou *et al.*, 2020) in relation to climate variability and human actions. The former is commonly indexed as the main driver of vegetation change in West Africa (Herrmann *et al.*, 2005). It determines the zoning of the vegetation cover and the amount of plant biomass. Its role in changes in vegetation cover has been demonstrated several times (Philippon *et al.*, 2008; Hountoudji, 2008; Cisse, 2016). However, climatic variability marked by decreasing rainfall and increasing temperature has been noted in The Gambia since the drought years, that is to say the years 1970-80 (Sanneh *et al.*, 2013; Diedhiou, 2019). For the second, it is about agricultural land clearing, firewood and charcoal cutting, overgrazing, and the advance of the urban front (Diedhiou, 2019; Bah *et al.*, 2019; Fent *et al.*, 2019).
- 2 Thus, in order to participate in the production of knowledge in achieving Goal 15 of the Sustainable Development Goals on the preservation and restoration of terrestrial ecosystems, monitoring of changes in vegetation cover is necessary. For a State such as The Gambia and for the United Nations Development Program (UNDP), such monitoring is a major interest for better resource and environmental management. This monitoring takes on a particularly interesting dimension through the identification, description and analysis of the ongoing process. It is all the more interesting

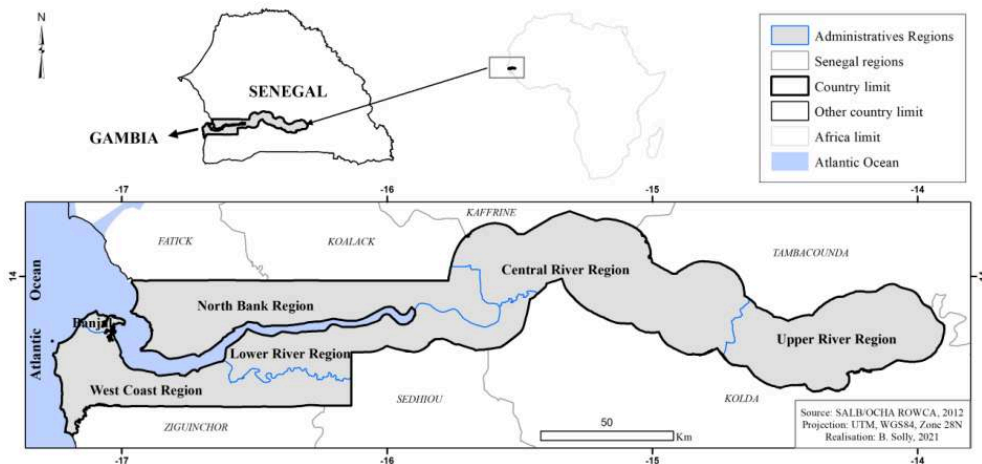
considering that the literature on the issue throughout the Republic of The Gambia is very little, if not scarce. Most of the studies conducted there have focused on adaptation to climate change and agricultural production (Akon-Yamga *et al.*, 2011; Yaffa, 2013; Sanneh *et al.*, 2014; Sonko *et al.*, 2019; Jarju *et al.*, 2021). A few rare studies have focused on the dynamics of land use and changes in vegetation cover both in wetlands and land, either at the zonal, regional or national scale (Andrieu and Mering, 2008 ; CILSS, 2014; Diedhiou, 2019; Bah *et al.*, 2019; Fent *et al.*, 2019; Diedhiou *et al.*, 2020; Dieye *et al.*, 2021). Studies carried out at the West African or Sahel scale have paid little attention to the analysis of results at The Gambia scale (Herrmann *et al.*, 2005; Dardel *et al.*, 2014; Leroux *et al.*, 2014; Brandt *et al.*, 2016).

- 3 Techniques for monitoring recent changes in vegetation cover at the national or West African band level includes remote sensing, through the analysis of trends in time series of MODIS images, is positioned as an effective means (Andrieu, 2018; Zoungrana *et al.*, 2018; Gansaonre *et al.*, 2020). These time series provide the most appropriate data for analyzing the trend of changes related to natural and human phenomena (Hamimina *et al.*, 2013). Using the Normalized Difference Vegetation Index (NDVI), they identify land degradation and regeneration (Eckert *et al.*, 2015; Solly *et al.*, 2021). This index provides information on photosynthetic activity, leaf water content, soil moisture, phytosanitary quality, primary productivity, biomass, etc. It can detect changes in vegetation productivity through changes in vegetation cover (Guo *et al.*, 2018). In addition, it is strongly correlated with rainfall in many West African countries (San Emeterio *et al.*, 2011), especially in areas that record less than 1000 mm per year (Nicholson *et al.*, 1990). Differences or changes in species types, the presence of disturbed vegetation in an area with a similar vegetation type, and evolutionary factors may also be reflected through NDVI (Yengoh *et al.*, 2015).
- 4 The objective of this study is therefore to determine changes in vegetation cover in The Gambia, through the use of time series of NDVI MODIS images over the period 2000-2019.

Study area

- 5 The Republic of The Gambia is located in the West African zone between latitudes 13°30 and 13°49 N and longitudes 16°48 and 13°47. Except on the Atlantic coast, the country is bordered on all sides by the Republic of Senegal. The country is about 480 km long and varies in width from 48 km in the river estuary to 24 km inland (Ministry of Environment, 2018). It covers an area of 11,259 sq.km spread over six administrative regions (Fig. 1).

Figure 1. Location of the study area.



- 6 Land use and land cover are composed of 14 main classes: forest, gallery forest, woodland, mangrove, savannah, wooded to shrub savannah, cultivation areas, irrigated crops, plantations, settlements, bare soils, sandy surfaces, water bodies and swampy and floodplain grasslands (CILSS, 2016; Ministry of Environment, 2018). From a climatic point of view, the year is characterized by two seasons. The dry season, which usually starts from November to May, and the rainy season from June to October. Average annual rainfall varies from 600 to 900 mm, and seasonal temperatures vary between 32°C and 34°C and are generally higher in the eastern part of the country (Loum and Fogarassy 2015; Bojang *et al.*, 2016). The population is estimated at 1,867,000 inhabitants in 2013 and is mainly concentrated in the Greater Banjul Area, with 1,390,000 inhabitants in 2016 (CIESIN, 2005). The main economic activities revolve around agriculture (rice, maize and peanut), cutting and marketing of firewood and service, and fishing. These are also the main activities that affect the development of vegetation cover in The Gambia.

Data and method

Data used

- 7 To detect changes in vegetation cover in The Gambia, we used MODIS NDVI data. The MODIS satellite has the advantage of providing images over 16 days available since the second half of February 2000 with a spatial resolution of 250 m. In terms of the long NDVI time series (>10 years), it is the most spatially resolved series that exists today. Compared to NOAA AVHRR data, MODIS data showed better performance for such a study (Fensholt, 2004). The images are uploaded to <https://search.earthdata.nasa.gov/> as granules. The products are provided in the Hierarchical Data Format for NASA's Earth Observing System (HDF-EOS) format and are composed of several bands, including NDVI. The series used here runs from 2000 to 2019, from version 6 of the vegetation indices of the Terra medium resolution imaging spectrometer (product MOD13Q1).

Treatment method

- 8 The methodological approach began with the creation of the time series (TSF) from the module “Earth Trends Modeler” on Idrisi TerrSet, using all the images (2000-2019). After this step, we corrected the images by replacing the erratic values (especially related to clouds and missing lines) with interpolated values using the Preprocess function (Denoise).
- 9 We then calculated the correlation of Kendall or Kendall’s tau through linear regression, first on the 227 NDVI values (23 syntheses x 10 years) for the period 2000-2009, then on the 230 NDVI values for the period 2010-2019, and finally on the 457 NDVI values for the period 2000-2019 (Solly *et al.*, 2021). Two parameters were considered here. This is the correlation coefficient “tau” and the significance “p”. The correlation coefficient (S) highlights the trend in the vegetation index. It is given by equation 1 and 2:

$$S = \sum_{i=1}^{x-1} \sum_{j=i+1}^x \text{sign}(x_i - x_j)$$

and

$$\text{sign}(x_i - x_j) = \begin{cases} 1 & \text{if } x_i - x_j < 0 \\ 0 & \text{if } x_i - x_j = 0 \\ -1 & \text{if } x_i - x_j > 0 \end{cases}$$

- 10 where n is the length of the data series studied, and the observations made on date, i and j respectively. For all $i = nj = n-1$.
- 11 The Kendall trend rate (τ) is obtained through equation 3:

$$\tau = \frac{2s}{n(n-1)}$$

- 12 with s the correlation coefficient of Kendall and n the length of the series of data studied.
- 13 The correlation coefficient varies between -1 and +1, and measures the relationship between two sets of variables to determine the degree to which a trend increases, decreases or remains unchanged (Wessels *et al.*, 2012).
- 14 The estimation of the significance of the correlation “tau” is given by equation 4:

$$p = 2[1 - \Phi(|Z|)]$$

- 15 Z follows a standard normal distribution, and a positive value of Z means an upward trend, and a negative value means a downward trend.
- 16 The significance value highlights the significance of the trend (Neeti and Eastman 2011) in that it represents the measure of the need to reject a null hypothesis ($p=0$). The threshold used here for the test is 10% ($p<0.1$). It may vary by author by 0.1 (Andrieu, 2018; Solly *et al.*, 2021) to 0.001 (Neeti and Eastman, 2011) to 0.01 (Mishra and Mainali, 2017), and 0.05 (Eckert *et al.*, 2015; Zoungrana *et al.*, 2018; Guo *et al.*, 2018; Gansaonre *et*

al., 2020), and according to the estimator used (p , slope TS, Z, TS Intercept). The 0.1% threshold is used here because, at 0.05% which is the most used, we have almost no significance in the trends. In this study the estimator used is p .

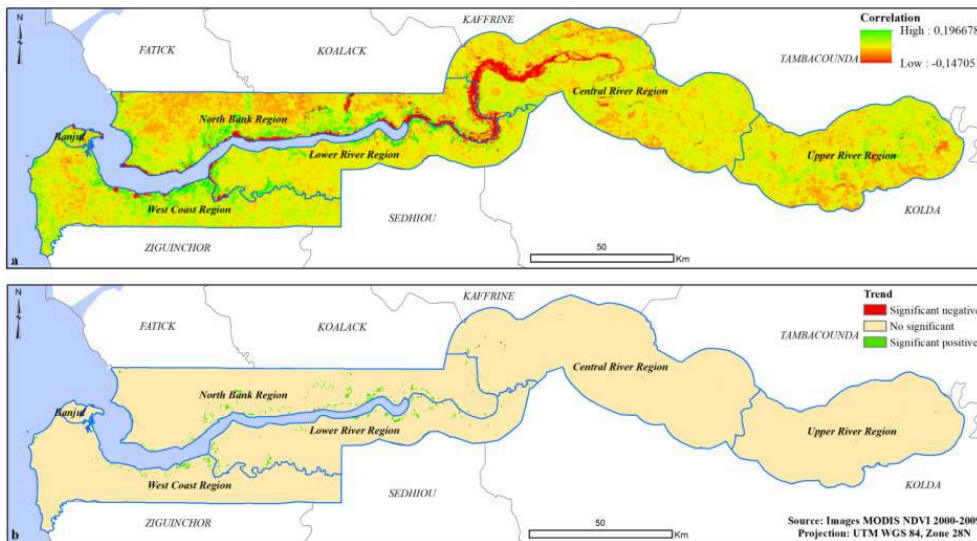
- 17 The result made it possible to detect the different trends (positive and negative) of the NDVI and their significance, presented in the rest of the work. A positive value indicates an upward trend while a negative value indicates a downward trend. The trend is significant positive when ≥ 0.1 ; significant negative when ≤ -0.1 .

Results

Vegetation trends in The Gambia between 2000 and 2009

- 18 During the decade 2000-2009, the average Kendall correlation generally indicates a positive trend of NDVI on 98.37% of the study area. However, this trend is not significant (Fig. 2). Correlation values range from 0.2 to -0.15.

Figure 2. (a) Trends in NDVI between 2000 and 2009; (b) Significance of p at 10% threshold.



- 19 From a spatial perspective, positive correlation values are observed in all administrative regions. The southern part of the North Bank Region and the northern part of the West Coast Region and the Lower River Region had the most significant positive correlations with a significant trend at $p \geq 0.1$. Otherwise, negative but not significant correlations values were also observed. In these three regions, the positive trends represent 20.33%, 16.21% and 13.82% respectively (Table 1).

Table 1. Trends in NDVI by region (in percentage) between 2000 and 2009.

Regions	Positive trend	Negative trend
Banjul	0,62	0,05
West Coast Region	16,21	0,12

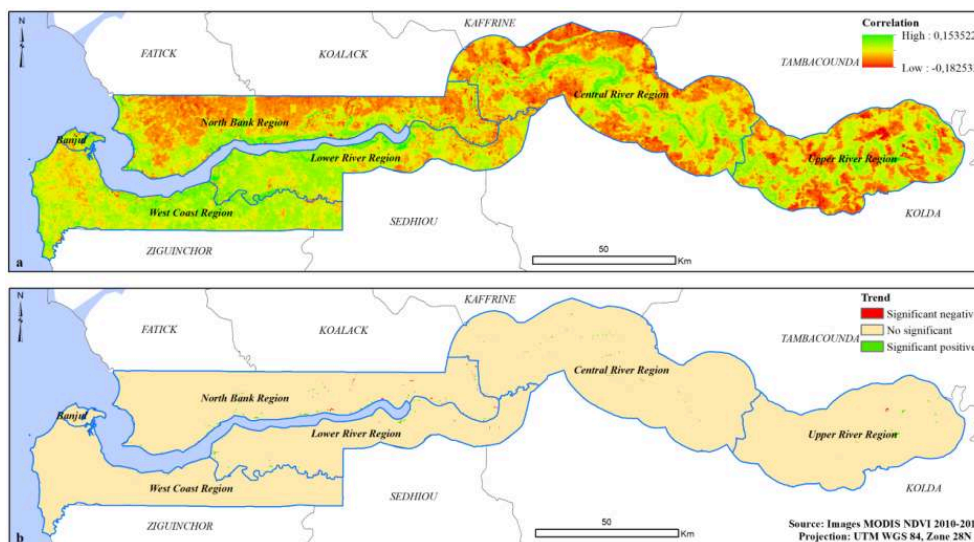
North Bank Region	20,33	0,86
Lower River Region	13,82	0,15
Central River Region	27,89	0,46
Upper River Region	19,48	0,00
Total by trend	98,37	1,63
Total all trends	100	

- 20 However, more than a quarter of the positive trends in vegetation productivity in the Republic of The Gambia during this decade are recorded in the Central River Region, although this is also the region with the most pixels of significant negative trends.
- 21 The percentage of significant positive trend (at the 10% threshold) is 1.57%. The significant negative trend is 0.04% and is mainly observed in the northeastern part of the Central River Region.

Vegetation trends in The Gambia between 2010 and 2019

- 22 During the decade 2010-2019, we generally see a decreasing trend in vegetation productivity (Fig. 3a) compared to the decade 2000-2009, but not significant in the pValue test (Fig. 3b). Only a few pixels with a significant positive trend are observed; they are dispersed throughout all administrative regions except the West Coast Region. This region was also the one with the largest increase in NDVI with 13.87% of the study area (Table 2).

Figure 3. (a) Trends in NDVI between 2010 and 2019; (b) Significance of p at 10% threshold.



- 23 During this decade the correlation values vary between +0.15 and -0.18. The percentage of positive correlation is 56%, and the percentage of negative correlation is 44%. The

latter mainly concerns the North Bank Region (with 12.87%) and the Central River Region (with 15.7%).

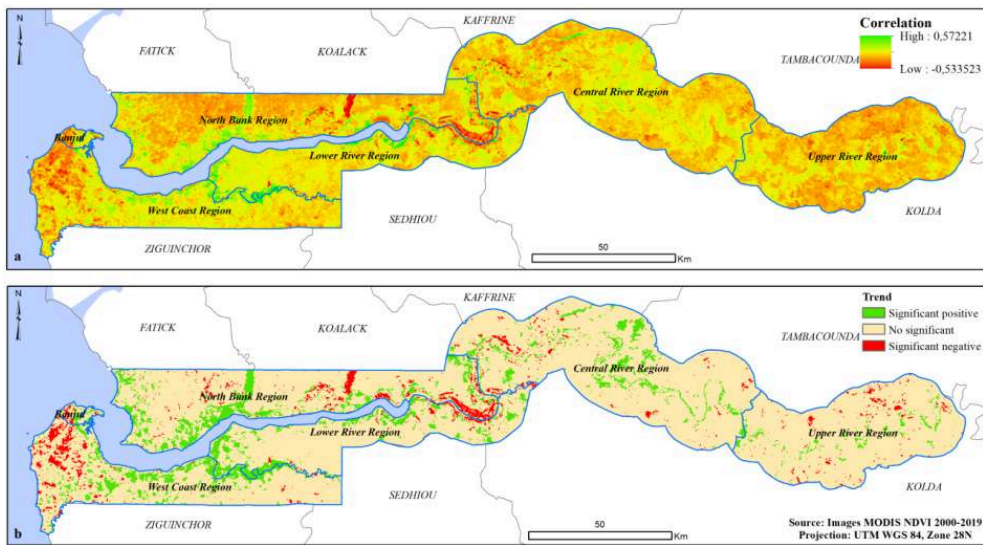
Table 2. NDVI Trends by Region (Percent) Between 2010 and 2019.

Regions	Positive trend	Negative trend
Banjul	0.45	0.22
WestCoast Region	13.87	2.45
North Bank Region	8.28	12.87
Lower River Region	10.84	3.14
Central River Region	12.68	15.7
Upper River Region	9.87	9.63
Total by trend	55.99	44.01
Total all trends	100	

Vegetation trends in The Gambia between 2000 and 2019

- 24 During these two decades, the average of the Kendall correlation indicates that 61.86% of the national territory is marked by a positive trend and 38.14% by a negative trend (Fig. 4a; Table 3). However, the southern part of the North Bank Region, and the northern part of the West Coast Region and the Lower River Region, are the ones that have recorded the strongest trends in increasing vegetation productivity. These trends are also significant overall at the p test (figure 4b). The Central River Region also recorded a significant positive trend in NDVI.

Figure 4. (a) Trends in NDVI between 2000 and 2019; (b) Significance of p at 10% threshold.



25 However, in the north-western part of the Central River Region, we notice large pixels of significant negative values. The same is true in the western part of the West Coast Region and Banjul, at the eastern end of the North Bank Region along the river and the Upper River Region. Lower River Region had the lowest negative NDVI trends (2.69% of the study area). For Banjul and the North Bank Region, the percentage of positive trends is relatively equal to the negative percentages.

Table 3. NDVI Trends by Region (Percent) Between 2000 and 2019.

Regions	Positive trend	Negative trend
Banjul	0.34	0.32
West Coast Region	11.39	4.94
North Bank Region	10.24	10.87
Lower River Region	11.32	2.69
Central River Region	17.52	10.87
Upper River Region	11.05	8.45
Total by trend	61.86	38.14
Total all trends	100	

26 In sum, over the last 20 years, the percentage of significant negative trend is 4% and the positive 10% at the 10% threshold.

Discussion

- 27 Vegetation cover has undergone significant changes over the last two decades in The Gambia. Positive NDVI trends observed through the Mann-Kendall correlation indicate the stability of the vegetation cover and its regeneration in places. While negative trends indicate degradation of the vegetation cover. Trends from NDVI are consistent with findings from several studies. The trends observed from the MODIS NDVI in The Gambia are consistent, in terms of change in vegetation cover from the Landsat images (LULCC), with the findings from several studies.
- 28 According to CILSS (2016), more than a century ago, the majority of The Gambia was covered by clear forests, wooded savannas and gallery forests. Today, most of the still forested landscapes are to the south of the river, with increasing density from east to west. Our results also showed that most of the positive trends are observed along the river, where the gallery forest is located, and the mangrove, which increased by 1,111 ha between 2000 and 2016 (Diedhiou, 2019). This progression of the mangrove along the river was also noted by Dieye *et al.* (2021) over the period 2000-2018 through a mapping of the evolution of the mangrove. Our results also showed that positive trends are more important in the west (which corresponds to the estuarine part) than in the east (which corresponds to the mainland) where the Upper River Region is located. In this region, the low positive trends in vegetation productivity, and even the decreasing trends noted, can be explained by its proximity to the Kolda region (Senegal), where the advance of agricultural land and the abusive and illegal cutting of wood resulted in a loss of 41,668 ha of vegetation cover between 1999 and 2018 (Solly *et al.*, 2021). Faced with this situation, enormous efforts must be made by the decision-makers to achieve a greening of vegetation in Upper River Region.
- 29 In the Central River Region, Bah *et al.*, (2019) reported that the area of cropland, halophyte vegetation, and stand expanded between 1984 and 2017 to the detriment of irrigated crops, mangroves, shrub savanna and wooded savanna. For our part, we also noted a downward trend in vegetation productivity during the 2010-2019 decade, in the whole not significant to the test of p to 10%.
- 30 For Banjul and the western part of the West Coast Region, the urban expansion of Banjul would be the main factor explaining (CIESEN, 2005) the significant downward trend in NDVI noted especially in the west façade between 2000 and 2019. This situation shows the importance of the degradation of the vegetation cover in this area; hence the urgency for the Gambian authorities to act. In fact, in these two administrative regions, Diedhiou (2019) had reported an increase in very open woodlands at the expense of denser formations which can be seen as an indicator of the importance of pressures on forest resources.
- 31 In addition to the results on a thematic level, methodologically, this study showed the importance of the approach used to study changes in vegetation cover. Indeed, using the contextual test of Mann-Kendall, Neeti and Eastman (2011) obtained a very significant result in the detection of trends in relatively short time series. Using Kendall's correlation test or Kendall's "tau" for vegetation kinematics in Ivory Coast (Andrieu, 2018) and for detecting areas of degradation and regeneration of vegetation cover in southern Senegal (Solly *et al.*, 2021), these authors obtained significant correlations at $p < 0.1$. This threshold used in this study also provided us with

satisfactory results. However, it should be noted that trends may vary depending on the series used; this is why it is important to interpret the results carefully.

Conclusion

- 32 Changes in land cover are often used as indicators of land degradation or regeneration. Thanks to a time series of MODIS NDVI images, this study attempted to determine changes in vegetation cover in The Gambia over the period 2000-2019. The results showed an increasing trend in vegetation productivity between 2000 and 2009 in almost all regions. It is also significant from north to south along the river. In contrast, in the decade 2010-2019, there was a general downward trend in productivity in 44.01% of the study area, but less pronounced in the western part of the Lower River Region, West Coast Region and Banjul. The calculation of the Kendall correlation over the period studied indicated that 59.2 per cent of the national territory was marked by a positive trend and 40.8 per cent by a negative trend. Over the entire study period (2000-2019), the Kendall correlation calculation indicated that 59.2% of the national territory is marked by a positive trend and 40.8% by a negative trend. The percentage of significant positive trend is 10%, the negative one is 4%.
- 33 This study is important in that it brings new knowledge to decision makers in relation to the existing knowledge on changes in vegetation cover in The Gambia. It allows for more accurate identification of the different trends that are taking place and the main determinants of these trends, which are necessary for the development of effective forest resource management policies. However, despite the effectiveness of the methodological approach used, it would be useful in the future to include, field data, land use and land cover data, and spatialized precipitation data in the analysis.

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ABSTRACTS

In The Gambia, the vegetation cover has undergone significant changes over the past two decades. To assist policy decision-making, this study seeks to detect trends in changes over the past two decades using a time series of NDVI MODIS images. The methodological approach is based on the calculation of the correlation of Kendall (τ) associated with the p-significance test at the 10 % threshold. The results showed a trend of increasing vegetation productivity during the decade 2000-2009 (98.37% of the study area) in almost all administrative regions. This trend is more significant along the river. In contrast, during the decade 2010-2019, it was noted overall significant downward trend in productivity (44.01% of The Gambia) in all administrative regions except West Coast Region and Banjul, however not significant. The result showed that, over the whole period (2000-2019), 61.86% of the national territory was characterized by a positive trend and 38.14% by a negative trend; and that the significant positive trend percentage is 10%, the significant negative trend percentage is 4%. Significant positive trends are observed much more along the river and central of the Central River Region; significant negative trends are observed mainly in the western part of West Coast Region and Banjul, at the eastern end of the North Bank Region and in the Upper River Region.

En Gambie, la couverture végétale connaît d'importantes modifications depuis les deux dernières décennies. Pour aider les politiques dans leur prise de décision, cette étude cherche à détecter les tendances des changements au cours de cette période à l'aide d'une série temporelle d'images MODIS NDVI. L'approche méthodologique est basée sur le calcul de la corrélation de Kendall (τ) associé au test de significativité de p au seuil de 10 %. Les résultats ont montré une tendance à l'augmentation de la productivité de la végétation durant la décennie 2000-2009 (98,37 % de la zone d'étude) dans quasiment toutes les régions administratives. Cette tendance est plus significative le long du fleuve. Par contre, durant la décennie 2010-2019, on a noté globalement d'importantes tendances à la baisse de la productivité (44,01 % de la Gambie) dans toutes les régions administratives excepté la West Coast Region et Banjul, toutefois non significatives. À l'échelle de toute la période étudiée (2000-2019), 61,86 % du territoire national est marqué par une tendance positive et 38,14 % par une tendance négative. Le pourcentage de tendance positive significative est de 10 %, celui significativement négatif de 4 %. Les tendances positives significatives sont le plus souvent observées le long du fleuve et dans le centre de la Central River Region, celles significativement négatives principalement dans la partie ouest de la West Coast Region et de Banjul, à l'extrémité Est de la North Bank Region et de la Upper River Region.

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Mots-clés: MODIS-NDVI, analyse des tendances, tau de Kendall, couverture végétale, Gambie

Keywords: MODIS-NDVI, trend analysis, Kendall tau, vegetation cover, The Gambia

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