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RESEARCH ARTICLE

SEASONAL CHANGES IN PLANT COVER IN THE AGNEBY WATERSHED (SOUTH-EASTERN COTE D'IVOIRE)

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Abstract

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With a surface area of 8450 km², the Agnéby catchment is located in the south-east of Côte d'Ivoire, in West Africa. This watershed is located in a forest environment in Côte d'Ivoire, and has undergone rapid degradation as a result of successive agro systems. It encompasses a large part of the former cocoa loop. With the decline of the cocoa economy, new plantations such as oil palm, rubber and recently cashew (in the north) have emerged. Despite the existence of numerous studies based on high spatial resolution satellite images, detailed and continuous knowledge over time of the basin's plant cover remains inadequate. However, remote sensing remains a unique tool that facilitates measurement through frequent observation of vast areas. The aim of this study is to analyse changes in vegetation cover in the Agnéby catchment using MODIS Terra high spatial resolution satellite images. The series of images used to produce the Enhanced Vegetation Index (EVI) cover the period from 2000 to 2024, with a spatial resolution of 250 m, and are taken in January, March, June and November. The methodology adopted is based on statistical processing of the vegetation index series and on spatial dispersion statistics. The spatio-temporal analysis of the indices shows that the ombrophilous sector (south of the basin) is the most anthropised, which is reflected in a strong variation in seasonal activity. In the mesophilic sector (North and Centre), the variations are smaller and smaller in a South- North gradient. The peaks observed around 2005 and 2010 are linked to climatic factors, in particular particularly wet years, favouring a larger vegetative mass. In addition, the river mouth corresponds to the greater Abidjan area (Anyama and Songon).

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Introduction:

The environmental transformations observed in recent decades, under the combined effect of human activities and climate variations, are giving rise to growing concern about the sustainability of terrestrial ecosystems (Boucka et al., 2021; Briand, 2025). Vegetation cover, a key component of these ecosystems, plays a fundamental role in maintaining biodiversity, hydrological regulation, soil stabilisation and carbon sequestration (Kamagaté et al., 2017). However, human activities such as agricultural expansion, rampant urbanisation, logging and mining are significantly altering the natural balance of the landscape (Agbanou, 2018; Assoma et al., 2021). The Agnéby catchment, in south-eastern Côte d'Ivoire, is a perfect example of this dynamic (Koné et al., 2019). This hydrosphere, characterised by a humid tropical climate and remarkable biodiversity, is an ecologically and economically important area (Brahima et al., 2024). It plays an essential role in regulating hydrological flows, maintaining water quality and supplying natural resources to local populations (Kouadio et al., 2010). However, over the decades, the basin has come under increasing pressure from human activity (Koudou et al., 2018). The expansion of agricultural crops, combined with rapid urbanisation and overexploitation of natural resources, has led to profound changes in vegetation cover (Tra Bi, 2013; Koné et al., 2022; Mir et al., 2025).

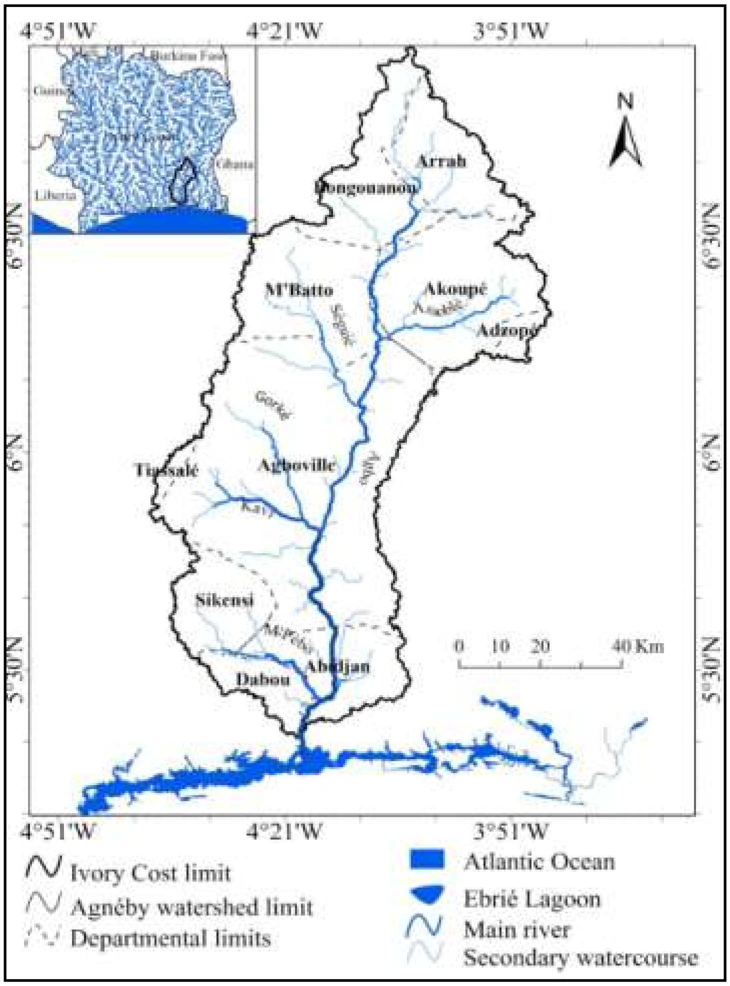
In this context, the use of modern tools for monitoring and analysing transformations is crucial. Satellite data, in particular that provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors aboard NASA's Terra and Aqua satellites, offers a unique opportunity (Chen et al., 2021; Toribio et al., 2022 and, 2025). These sensors provide continuous, high temporal resolution information on changes in vegetation cover (Areffian et al., 2021). They are therefore a valuable tool for understanding landscape dynamics and assessing the impact of human activities and climate variations on ecosystems (Badreldin et al., 2014; Lunetta et al., 2022).

The aim of this article is to analyse changes in vegetation cover in the Agnéby catchment using MODIS data. The study will focus on changes in vegetation, identifying the areas most affected by human activities. The methodological approach combines remote sensing techniques and statistical analysis to provide a comprehensive assessment of the spatiotemporal dynamics of vegetation cover (Filipponi et al., 2018; Pradhan et al., 2024). This analysis will provide valuable information to local decision-makers in their efforts to conserve and sustainably manage natural resources.

Material and Methods:-

Presentation of the study area:

The Agnéby is one of Côte d'Ivoire's main coastal rivers. The river basin lies between latitudes 5°25' and 6°50' North and longitudes 3°45' and 4°35' West. It covers an area of 8450 km² up to its mouth in the Ébrié lagoon (Koudou et al., 2018) **(Figure 1)**. The Agnéby basin lies entirely within the predominantly mesophilic forest zone of south-eastern Côte d'Ivoire (Girard, 1963). In the northern fringe of the forest massif, strongly or moderately altered ferralitic soils are present, including hydromorphic soils (Koné et al., 2022). It is underlain by Precambrian formations belonging to the Birimian period, characterised by weak metamorphism (Girard, 1963). According to Kamagaté et al. (2017), these formations consist mainly of Arkosic schists to the north of and around Bongouanou and to the south of Agboville. They are associated with isolated or intrusive granitic formations (metagranites, granitoids and granodiorites) covering the area studied (Konin et al., 2022). The lower sedimentary part, of Tertiary and Secondary formation, is made up of sandy and clayey sediments as well as Quaternary coastal sediments occupying the downstream bed (Goula et al., 2009)



Source: SRTM 2014 Author: Ahou Sabine, June 2023
Figure1: Location of the Agnéby catchment area

Study Materials and Methods:

Materials:-

This study was based on MODIS-Terra/EVI satellite images. These data have a spatial resolution of 250 m and a temporal resolution of 16 days, collected over a period from 2000 to 2024 in the months of January (start of the dry season), March (start of the main rainy season), June (peak of the main rainy season) and November (plant maturation month). A total of 24 images per month were downloaded (https://www.EarthExplorer.usgs.gov) for this study. The reference scene used in the study is the MOD13Q1V6.1 image **(Table 1)**, composed of 36 spectral bands with a precision covering a range from 0.4 to 14.4 µm (Huete et al., 2010)

Table1: Characteristics of the MODIS images used

MODIS sensors	Spatial/temporal resolution	Multiplier Scaling factors	Use
MOD13Q1V6.1	250m\16 days	0,0001	Improved Vegetation Index

Source: https://www.EarthExplorer.usgs.gov

Analysis methods:

Enhanced Vegetation Index (EVI):

The analysis focused on the Enhanced Vegetation Index (EVI), an essential bioclimatic indicator for studying vegetation cover (Toribio et al., 2022) and (Doughty et al., 2025). The EVI is characterised by its increased sensitivity to variations in vegetation structure and phenology, as well as to environmental stress (Gong et al., 2024). This index is used to assess photosynthetic activity based on the analysis of satellite images (Mercier, 2017). It offers superior accuracy by improving vegetation monitoring through a reduction in atmospheric effects and attenuation of the background canopy signal (Areffian et al., 2021). EVI has been developed to optimise the vegetation signal with improved sensitivity in high biomass regions and better vegetation monitoring through canopy background signal slicing and reduction of atmospheric influences (Zhigang et al., 2007) and (Zhao et al., 2024). EVI values vary between

-1 and +1, with healthy vegetation generally showing values between 0.2 and 0.8. In this study, the formula proposed by Huete et al. (1997) to calculate the EVI is:

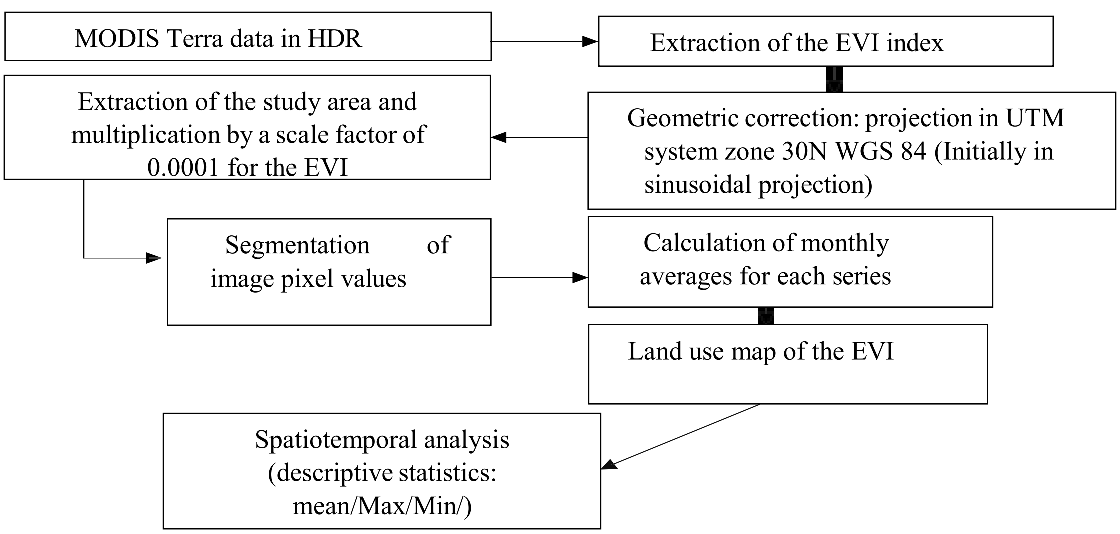
$$EVI = \frac{2.5\,(NIR - RED)}{(NIR + (C1 + RED) - (C2 + BLUE) + L)} \quad \text{(Eq1)}$$

The enhanced vegetation index (EVI) includes the coefficients C1 and C2, designed to correct for the diffusion of aerosols in the atmosphere, and the coefficient L, which adjusts for soil and canopy effects. For NASA's MODIS sensor, specifically designed for EVI, the standard values are C1 = 6, C2 = 7.5 and L = 1 (Ambadkar et al., 2024). EVI is particularly suitable for analysing chlorophyll-rich areas such as tropical forests. However, its use is recommended in regions with low relief in order to minimise topographical effects, particularly in mountainous areas. Finally, the coefficient of variation (CV) was calculated, making it possible to visualise the variations in vegetation in the study area. The formula is:

$$CV = \frac{\text{écartype}\ \ (x \ldots xn)}{moyenne\ \ (x \ldots xn)} \quad \text{(Eq2)}$$

Processing MODIS bioclimatic data to analyse changes in vegetation cover:

The processing of satellite images began with the downloading of MODIS Terra data: EVI (250 m/16 days). The EVI bands were then converted from HDR to TIFF format using QGIS 2.18.15 software. After this conversion, the main processing was carried out using GIS. To finalise this process, the EVI values were adjusted by applying scale factors: 0.0001 for the EVI, using the BAND MATH function. This step was followed by the extraction of the study area (Figure 2).



Source: Ahou Sabine, November 2024

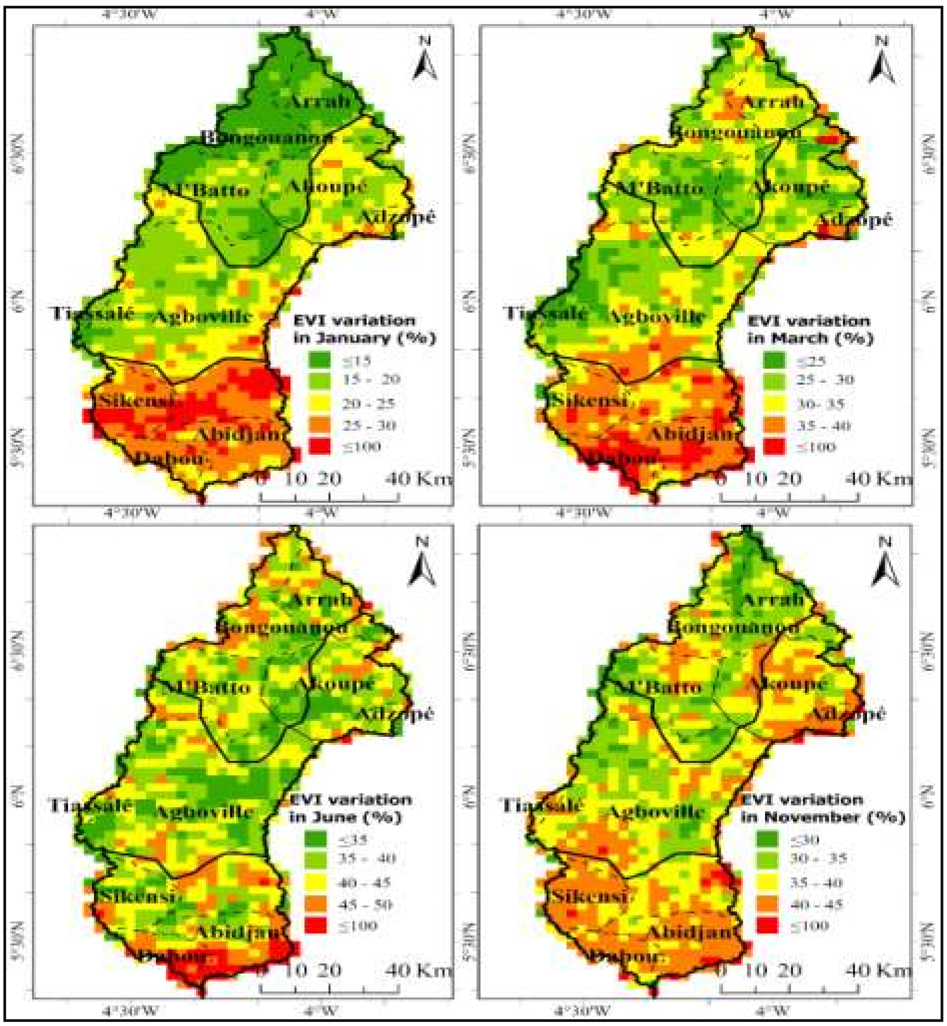
Figure2: MODIS image processing stages

Mapping was carried out by segmenting the mean values of the EVI pixels over the period 2000-2024, using the "Zonal statistics" tool available in the Arcgis software. By extracting the pixel values corresponding to each sector, it was possible to analyse the EVI time series.

Results:-

Vegetation cover marked by the impact of agriculture in the Agnéby catchment area:

In order to gain a better understanding of the spatiotemporal dynamics of changes in EVI, an additional analysis was carried out by calculating the coefficient of variation. This approach focused on four months representative of climatic contrasts - two dry months (January and November) and two rainy months (March and June) - with the aim of highlighting seasonal fluctuations and spatial heterogeneities in vegetation. This mapping of the coefficient of variation highlights the variability of the EVI in the different areas of the Agnéby catchment, particularly in the southern, central and northern sectors. The maps below illustrate this variability for each of the months selected. In January, the areas with low EVI dominance (<15%) are located in the northern and central sectors of the basin, indicating relatively stable vegetation. On the other hand, the south of the basin, particularly around Abidjan (Anyama and Songon) and Dabou, showed greater variations (>25%). In March, these variations increased overall in the central and southern areas of the basin. Coefficients of variation remain high in June in the south (>40%), but a relative stability of vegetation cover is visible in the north and some central areas (<35%). In November, variations are more noticeable in the southern and eastern sectors (>35%) of the basin. As for the central and southern parts, slight variations are visible (<30%).



Source: MODIS Terra/EVI ,2000 to 2024

Figure3: Spatial and temporal variation of the EVI in the Agnéby catchment area

Table 2 below presents the descriptive statistics of the EVI from 2000 to 2024 for the months of January, March, June and November. Analysis of this table highlights the different characteristics of the variations in EVI during these four selected months.

Table 2: Descriptive statistics for EVI from 2000 to 2024

Parameters	Minimum	Maximum	Mean	Standard deviation	Coefficient of variation (%)
January	**6.98**	70.22	18.68	4.33	**23.18**
March	10.32	73.56	25.33	4.3	16.98
June	16.43	107.14	**38.87**	5.48	14.09
November	11.63	**131.45**	32.25	5.4	16.73

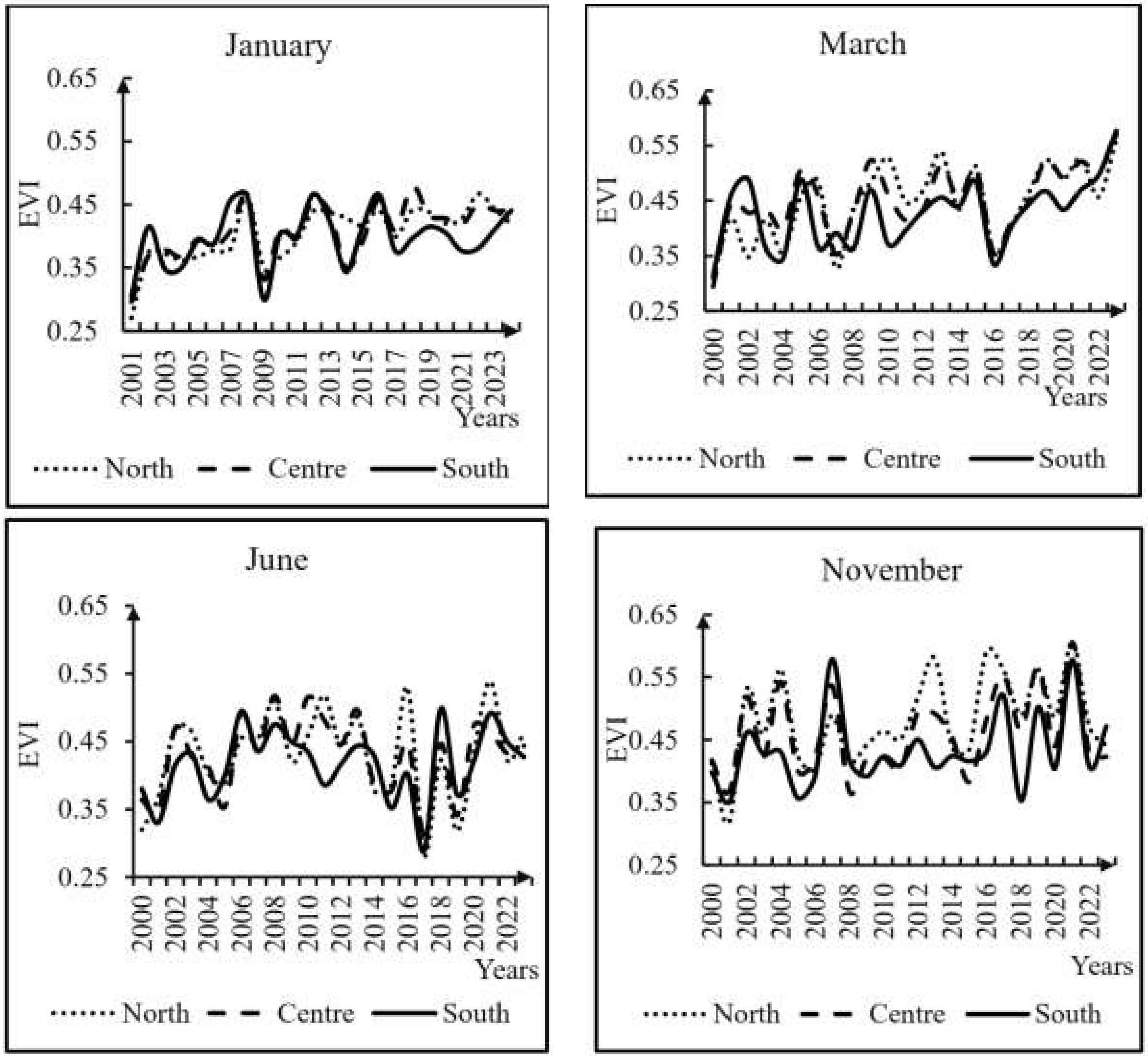
Source: MODIS Terra EVI, 2000 to 2024

Firstly, in January, the EVI shows a relatively moderate variation, with a coefficient of variation of 23.18%, indicating a relative stability of the vegetation in terms of density, although the EVI values are low overall, leading to a decrease in chlorophyll activity, which reflects the conditions of the dry season. Then, in March, the mean EVI increased to 25.332, while the coefficient of variation was 16.98%, reflecting a more homogeneous vegetation density marking the start of the rainy season in the said catchment. The monthly average of the EVI series in June peaked at 38.87, indicating particularly dense vegetation. The coefficient of variation (14.09%) is the lowest of the months studied, reflecting the great uniformity of vegetation in June, the month of the main rainy season. Finally, November's coefficient of variation (16.73%) reflects a slight increase in the variability of plant density, due to the transition to the dry season. This month corresponds to a vegetation maturation phase in the Agnéby catchment, with a partially high average EVI (32.248).

Interannual evolution of the improved vegetation index (EVI):

Figure 4 shows the EVI (Enhanced Vegetation Index) interannual evolution curves from 2000 to 2024 in the Agnéby catchment area, derived from the processing of MODIS Terra / Vegetation Index / 250m /16days images. Our analyses were sectorised. Firstly, in January, in the northern sector, the EVI shows a general upward trend, with significant fluctuations around the years 2005 and 2010. After 2015, the index stabilised at around 0.45. In addition, the EVI for the Centre sector has also risen, with marked instability in 2008. Since 2015, the trend has been more stable, with values close to those in the North. As for the South sector, it shows more pronounced and less stable variations than the North and Centre sectors, with more pronounced peaks and falls. In March, in the northern sector, the EVI shows an increasing trend, with notable fluctuations, especially between 2005 and 2010. A clearer increase is observed after 2020, reaching a peak in 2023. In the Centre sector, as in the North, the EVI in the Centre follows an increasing trend with similar fluctuations. It also peaks in 2023. The Southern sector shows more marked variations, but the general trend is also upwards, reaching its peak in 2023 with a value of 0.41.

Analysis of the EVI in June in the North sector shows an overall upward trend, with significant fluctuations around 2010 and 2015. Since 2020, the index appears to have fallen slightly. The EVI in the Centre follows a similar trend to that in the North, with a gradual increase, although fluctuations are also present. The EVI in the South in June shows notable variability, with values peaking in 2005 and 2015, but a more stable trend. Finally, for the month of November, significant peaks in EVI values are observed in certain years, particularly around 2004, 2008, 2012 and 2016, especially in the North and South sectors. Decreases in EVI values were also observed, particularly around the years 2002, 2010 and 2018. A slight decrease in EVI values is observed in all sectors from 2018 to 2022.Finally, an examination of these figures reveals significant fluctuations in EVI over the years, with more pronounced variations in the South than in the North and Centre. All sectors show a general upward trend in EVI, although the values reach different peaks depending on the month. The Centre is the most stable sector in terms of EVI fluctuations, followed by the North, while the South is the most unstable. Peaks and troughs differ from month to month, with higher values generally observed in March and June than in January.



Source: MODIS Terra EVI ,2000 to 2024
Figure 4: Interannual variation in EVI in the Agnéby catchment area

Discussion:-

The methodological approach adopted highlights various aspects of the physiognomy and biology of the vegetation using the improved vegetation index calculated (Huete et al., 1997; Yin et al., 2014; Doughty et al., 2025). The EVI was used to distinguish between variations in vegetation as a function of photosynthetic activity, water stress levels during January, March, June and November and ground cover density. This approach was developed in the work of (Kouamé et al., 2015) on land cover in the Bandama catchment and in the book chapter of Lunetta et al. (2022) on the detection of land cover change using multi-temporal MODIS NDVI data. The north-south gradient is marked by increasing variation in EVI. The northern and central parts of the basin, characterised by denser and less disturbed forest cover, show smaller variations, indicating greater resilience of the vegetation to seasonal and anthropogenic changes (Jiang et al., 2024). In contrast, the southern sector, where urban areas (Anyama and Songon) and intensive agricultural activities are concentrated, shows much lower variations. This reflects a more disturbed vegetation, subject to rapid dynamics of degradation. The high variations in the southern sector reflect the influence of human activities, in particular deforestation (logging), agricultural expansion and urbanisation. This assertion is consistent with the work of Koné et al (2022) and field observations in the Agnéby catchment. These pressures lead to vegetation instability, which can be seen in the variations in EVI. These results are in line with those of Garroutte et al. (2016) in their article on the use of NDVI and EVI to map spatiotemporal variations in biomass and forage quality for migratory elk in the Greater Yellowstone Ecosystem. The northern sector, which is less subject to these pressures, has more stable vegetation. However, transition zones in the centre (such as Agboville and Tiassalé) are beginning to show moderate variations, suggesting a gradual expansion of human activities towards these localities (Ahoussi et al., 2013). The seasonality of rainfall in this tropical hydrosphere has a strong influence on variations in EVI (Lizaga et al., 2022). The months of January and November, corresponding to the dry season, show more marked variations in some areas, due to the temporary loss of vegetation cover (Domingo-Marimon et al., 2024). In June, rainfall favours more uniform vegetation cover, except in heavily urbanised areas. These results confirm that the Agnéby catchment is subject to contrasting environmental dynamics, influenced by climatic seasonality and anthropogenic pressures, in line with the findings of Koné et al. (2022). They are also in agreement with those of Jacquin et al, (2010) on the assessment of vegetation cover degradation in the Madagascan savannah using MODIS images. With regard to inter-annual variations, during the growing season (March to June), the EVI increases, illustrating a period of maximum vegetative growth with high chlorophyll activity. On the other hand, during the dry season, corresponding to the months of January and November, the EVI observed is low, reflecting the drop in chlorophyll activity density under drier climatic conditions.

These results are in line with those of Badreldin et al. (2014) evaluating the spatiotemporal dynamics of vegetation cover as an indicator of desertification in Egypt using multi-temporal MODIS satellite images. The inter-annual dynamics of the EVI show general upward trends in all sectors, indicating an overall improvement in vegetation cover over the years (Cheng et al., 2024) This increase is attributed to several factors, including a resurgence of agrosystems, a local reduction in anthropogenic disturbance and changes in agricultural practices, such as the introduction of agroforestry. However, there are marked fluctuations, particularly in the southern sector, reflecting increased instability due to intense anthropogenic pressures, such as rapid urbanisation, intensive agriculture and deforestation. In the northern and central sectors, the EVI is generally more stable, suggesting vegetation that is less exposed to human disturbance. The peaks observed around 2005 and 2010 are linked to climatic factors, in particular particularly wet years with more than 1,500 mm (Koné et al., 2019)

Conclusion:-

The analysis of changes in vegetation cover in the Agnéby catchment, carried out using MODIS satellite data, has highlighted the complex dynamics and major transformations affecting this humid tropical catchment in south-eastern Côte d'Ivoire. The results reveal significant changes in vegetation cover over time, mainly attributed to increasing anthropogenic pressures such as agricultural expansion, logging and urbanisation. These pressures, combined with the effects of climate change, are contributing to the degradation of local ecosystems. The use of MODIS data has proved particularly relevant for the spatiotemporal monitoring of landscape transformations, thanks to its high temporal resolution and its ability to cover vast areas repeatedly. These data have not only made it possible to quantify changes in vegetation cover, but also to identify the most vulnerable areas and the factors driving these changes. This approach contributes to a better understanding of the processes of environmental degradation and provides a solid basis for developing strategies for the sustainable management of natural resources. However, the study also highlights the urgent need for action to preserve the ecosystems of the Agnéby catchment.

In the face of growing challenges, it is essential to promote initiatives aimed at reconciling socio-economic development and environmental conservation. This includes the adoption of sustainable agricultural practices, reforestation, the implementation of integrated catchment management policies and raising awareness among local communities of the importance of preserving natural resources. First and foremost, this study demonstrates the importance of remote sensing tools, such as MODIS data, for monitoring landscape change in tropical areas. It also highlights the central role played by these analyses in the planning and implementation of appropriate environmental management strategies. Ultimately, these efforts will help not only to preserve biodiversity and ecosystem services in the Agnéby catchment, but also to strengthen the resilience of communities in the face of future ecological and climatic challenges. This research also paves the way for further studies, including the integration of data at higher spatial and temporal resolution, and the analysis of interactions between the dynamics of the vegetation cover and human activities. These future investigations could further enrich our understanding of environmental change and support sustainable management policies on a larger scale.

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Author contribution:
KB and DA defined the framework for the article. KAS conducted the study. The satellite images were downloaded from the Copernicus website by KAS and KES. KAS and KES wrote the manuscript with contributions from all co-authors.

Competing interests:
The manuscript was written independently, and no state, private or institutional body funded this research. We declare that there are no conflicts of interest related to this manuscript.

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