International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

Impacts of climate variability on the spatio-temporal dynamics of plant formations in the forest-savannah transition zone: the case of the Lamto Scientific Reserve, Central Côte d'Ivoire

N'Zibla Roch-Ghislaine KOUASSI[1], N'Da Hyppolitte DIBI[2], Kouassi Kouman Noël NANAN[3], N'Guessan Olivier YAO[4]

[1]West Africa Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Graduate Research Programme on Climate Change and Biodiversity, Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

[2,3]Natural Environment Laboratory and Biodiversity Conservation, Department of Bioscience Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

[2]Center for Research and Application in Remote Sensing (CURAT), Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

[4]Laboratory of Systematics, Herbariums and Botanical Muses, National Floristic Center, Department of Bioscience Université Félix Houphouët-Boigny, 22 BP 582 Abidjan 22, Côte d'Ivoire

ABSTRACT: Understanding climatic variability's effects on land and biodiversity is vital for guiding sustainability, conservation, and climate impact predictions in fragile ecosystems like Côte d'Ivoire's forest-savanna transition zone. This study aims to analyse the impact of climate variability on the spatio-temporal dynamics of land use in the Lamto Scientific Reserve. To do this, a set of monthly climate data covering the period from 1990 to 2022 was used, including indicators such as rainfall, maximum, minimum and average temperatures, drought and standardised rainfall indices. The study also involved the classification of Landsat images dating from 1990, 2002, 2012 and 2022, enabling changes in land use to be observed. The corresponding areas were correlated with the climatic variables using a Spearman correlation test. The results show a transition from savannah to denser tree cover in the reserve. In addition, an increase in rainfall, varying between 900 and 1687 mm, suggests that Lamto could be classified as a humid region. The analysis highlights the complex interactions between climate change, particularly high temperatures, and land-use dynamics. Gallery and semi-deciduous forests show resilience in the face of rising temperatures, favouring their expansion. On the other hand, pre-forest formations, such as open forests and wooded savannahs, are more affected by these temperatures, which hinders their development. Tree savannahs also show a certain resilience, while shrub savannahs and bare land are often associated with ecological degradation processes in response to high temperatures. Finally, although rainfall plays a role, its influence seems minor, suggesting that other environmental or climatic factors, such as watercourses or microclimate, play a more significant role in land use/land cover dynamics.

KEYWORDS: Climate change, Spatio-temporal dynamics, Land Use/Land Cover, Forest-savanna transition zone, Lamto Scientific Reserve, Côte d'Ivoire.

I. INTRODUCTION

Climate change refers to variations in the properties of the Earth's climate, both over the long term and over shorter time scales, resulting from natural or anthropogenic factors **(Benarfa, 2021)**. These changes can be the result of a variety of factors, including natural processes, but since the mid-20th century, climate change has been mainly attributed to human activities, including the burning of fossil fuels, deforestation and intensive agriculture, which lead to increased greenhouse gas concentrations in the atmosphere. According to **Biagné**, **(2019)**, climate change is reflected in a noticeable increase in the intensity and frequency of extreme temperatures, including heat waves and heavy rainfall, as well as agricultural and ecological droughts in some regions, all in all by climate variability. Indeed, climate variability refers to the natural fluctuations in the climate on different time scales, ranging from a few days to decades or centuries. As per the **IPCC, (2023)**, it includes variations in climate parameters such as temperature, precipitation and winds, which can be influenced by natural factors (such as solar and volcanic cycles) and anthropogenic factors (such as greenhouse gas emissions). It is distinct from climate change, which refers to long-term changes in climate averages and is primarily caused by human activity **(IPCC, 2021).**

On a global scale, climate variability, manifested by variations in temperature, precipitation and extreme weather events, has significant impacts on ecosystems. Thus, this global phenomenon of climate change and its components spare virtually no component of life on Earth (**Smith et Hitz, 2003; Almer *et al.*, 2017; Báez et al., 2022; Fadrique et al., 2018; Báez et al., 2021; Fadrique et al., 2018**). Regarding **IPCC**, (**2022**), the rate of increase in surface temperature has generally been faster in Africa than the global average. These changes have direct impacts on the biodiversity, vegetation structure and carbon sequestration potential of intertropical ecosystems, as demonstrated by studies conducted in various regions of the continent (**UNCBD et UNEP, 2007; TEEB, 2014; Avakoudjo et al., 2022; Aka et al.,2023; Konate et al., 2023**). The consequences are manifested through desertification, changes in rainfall patterns and impacts on water resources (**Koffi et al. 2023; Niasse et al., 2004; Chen et al., 2022; Yang et al., 2022; Ndehedehe, 2022**).

Like the whole world and tropical Africa in particular, Côte d'Ivoire is not spared from the current climatic upheavals **(Brou *et al.*, 2005)**. Indeed, depending on **Diawara *et al.*,** (**2014**), The past three decades, have been marked by changes in temperature, changes in rainfall patterns and periods of drought, and an increase in evapotranspiration.

For the **GCRI (2021),** the Global Climate Risk Index indicates a level of exposure and vulnerability to extreme weather events, which countries need to understand. In this context, various studies have been carried out in Africa and Côte d'Ivoire. They were interested in the impact of climate variability on land **Sultan and Baetani, (2016); Jenkins et al., (2002); Diba et al., (2018)**, on ecosystems in Africa **(Matsumoto *et al.*, 2015; Asseh et al., 2019; Heubles et al., 2013; Belle et al., 2016; Diomande, 2024)**, about Biodiversity and ecosystem services **Achieng *et al.*, (2016)**, and on the assessment of climate variability in the forest-savannah transition zone **(Ehounou *et al.*, 2019; Kouassi et al., 2018)**. Taking different studies, the present study was initiated to evaluate the impact of climate variability on the spatio-temporal dynamics of the Lamto Scientific Reserve. In fact, the Lamto Reserve, by its location in a forest-savannah transition zone, presents a complex dynamic and a fragile balance between tropical rainforests and dry savannahs, susceptible to be influenced by climatic and anthropogenic factors. Similarly, the Lamto region has already experienced notable changes in its rainfall patterns and temperatures in recent decades **(Diawara *et al.*, 2014)**. In addition, by its status, this site is exempt from anthropogenic activities likely to have a profound impact on its dynamics. In light of these arguments, it constitutes a privileged site for the analysis of the interactions between climate variability and ecosystem dynamics. In addition, the study of the impacts of climate variability in this transition zone is of overriding importance because it will allow, among other things, to (1) assess how the transition zone adapts to climate change; which can provide valuable information for long-term conservation and adaptation management strategies in the face of future climate scenarios **;** (2) to understand ecosystem dynamics in Lamto which can help guide sustainable development policies, integrating ecological considerations into regional and national planning.

The objective of this research is to contribute to improving knowledge of the influence of climate variability on the spatio-temporal dynamics of vegetation. Specifically, it was a question of:

- Analysing the climate variability of the Lamto Scientific Reserve from 1990 to 2022**;**
- Characterizing the spatiotemporal dynamics of the Lamto Scientific Reserve from 1990 to 2022**;**
- Analysing the influence of climate variability on the spatio-temporal dynamics of the Lamto Scientific Reserve from 1990 to 2022**.**

II. MATERIAL AND METHODS

A. *Study area*

Created on 12 July 1968 by Order No. 857 AGRI/DOM of 12/07/1968, the Lamto Scientific Reserve, with an area of 2,617 ha, is located at the southern tip of the V-Baoulé, in the department of Taabo, between the coordinates 6°13' and 6°15' of latitude North and 4°06' and 5°03' of longitude West **(Gnahoré *et al*., 2018)** (Figure 1). It hosts a geophysical station and an ecological station as mentioned by **Gnahoré *et al.*, (2018)**, The vegetation of the Lamto Scientific Reserve is a mosaic of forest-savannah, made up of forest galleries bordering the Bandama River, shreds of dense semi-deciduous forests and different savannah facies with *Borassus aethiopum* **(Devineau, 1975)**.

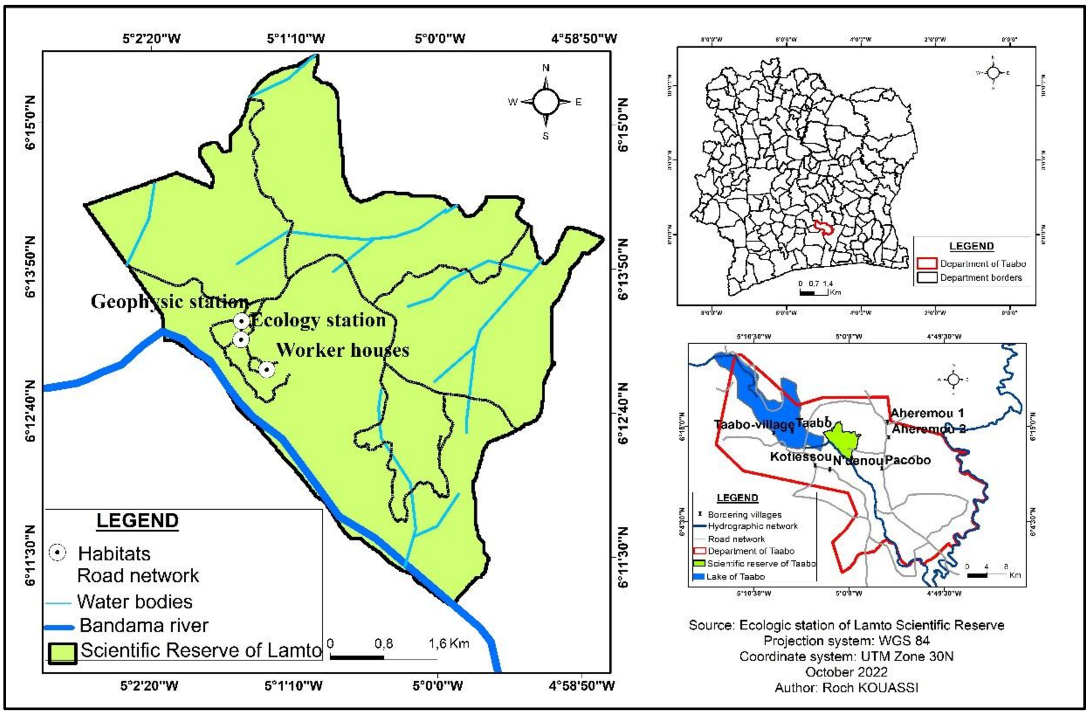

Figure 1: Location map of the Lamto Scientific Reserve

B. Study Methods

Analysis of climate variability from 1990 to 2022

Climate data collection

The climatic parameters used in this study are: Temperature and precipitation. These parameters are generally considered to be the components of climate and the environment that most influence forest fire behaviour and vegetation dynamics **(Guiguindibaye *et al.*, 2013; Ago, 2016; Vissin, 2017)**. Data related to these two climatic parameters were collected at the Lamto Reserve Weather Station, for those available. Missing data were collected on the Climate Engine website (climateEngine.org).

Climate data analysis

The analysis of the climate data focused on the evaluation of the dynamics of temperature, rainfall and the evaluation of drought indices which are: the Standardized Precipitation Index (SPI) and the Palmer Drought Severity Index (PDSI).

Temperature is considered one of the main factors influencing the rate of plant development. Higher temperatures predicted by climate change and the risk of more extreme thermal events will impact plant productivity **(Hatfield et Prueger, 2015)**. According to **Hatfield et Prueger, (2015)**, The latter dries them out and weakens them facing of water stress.

Hence, the maximum, minimum and average temperatures were taken into account (monthly) in our assessment through a descriptive approach.

Standardised Precipitation Index (SPI)

To highlight periods of water deficit in the study area, precipitation dynamics were assessed from 1990 to 2022 using the Standardized Precipitation Index or Nicholson Index (SPI) and the Palmer Drought Severity Index (PDSI).

The standardised precipitation index (SPI) was developed by **McKee, Doesken and Kleist (1993)**. It is a statistical indicator used for the characterisation of local or regional droughts. It therefore makes it possible to determine the degree of humidity or dryness of the environment **(Bergaoui and Alouini 2001)**. Based on a long-term rainfall history (minimum 30 years), it quantifies the deviation of a period's rainfall, deficit or excess, from the historical average rainfall of the period. This can be normal, wet, or dry. It also makes it possible to interpret the dynamics of vegetation cover with the evolution of precipitation (**McKee, Doesken, and Kleist, 1993**). The SPI was evaluated using the following equation:

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

$$PI = \frac{P_i - P_{mean}}{\sigma} \quad (1)$$

SPI = Rainfall index of the year *i* ; P_i = the cumulative rainfall for a year *i* ; P_{mean} = Mean annual rainfall observed over the entire series; σ = Standard deviation of annual rainfall observed for a given series.

The interpretation of the results of the SPI calculation was made according to the SPI classes and their degree of dryness or humidity (Table I).

Table I: Classification of drought according to values SPI (Mckee, Doesken et Kleist (1993).

SPI Class	SPI>2	1.5<SPI<1.99	1.0<SPI<1.49	-0.99 <SPI<0.99	-1<SPI<-1.49	-1.5<SPI<-1.99	SPI<-1.99
Degree of dryness or humidity	Extremely wet	Severely wet	Moderately wet	Near normal	Moderately drought	Severaly drought	Extremely drought

Palmer Drought Severity Index (PDSI)

The PDSI is a drought index that characterises the cumulative deviation of local average soil moisture conditions based on a simplified water balance calculation. Therefore, it is classified as an index of meteorological drought and quantifies the departure of water from the soil surface (**Svoboda and Fuchs, 2016**). It is commonly used around the world to quantify observed droughts and drought projections (**Ficklin *et al.*, 2016**).

PDSI is calculated based on the water balance parameters of (T**hornthwaite et Mather,1955)**. The interpretation of the PDSI is mentioned in (Table 3) Descriptive and trend analyses were evaluated in the same way monthly over the period (1990-2022) through time series data. The PDSI can be formulated as the following equation:

$$X_{(i)} = \frac{z_{(i)}}{\sigma} + \beta X_{(i-1)} \quad (2)$$

$X_{(i)}$ is the result of the PDSI in the tenth month, $z_{(i)}$ is the humidity anomaly index in the *th* month, $X_{(i-1)}$ is the amount of the PDSI for the previous month, α et β are the climate coefficients of the PDSI.

Table II: PDSI Categorization of Drought Severity (Palmer 1965).

PDSI Value	Drought category
4.00 or more	Extremely wet
3.00 to 3.99	Severely wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient dry spell
-1.00 to -1.99	Mild drought

-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
-4.00 or less	Extreme drought

C. *Analysis of the spatiotemporal dynamics of vegetation*

Satellite images and software

The vegetation dynamics of the Lamto reserve were carried out over 30 years (from 1990 to 2022). The satellite images used are from the years 1990, 2002, 2012 and 2022. They come from the 196-56 scene and sensors (Landsat TM for 1990, Landsat ETM+ for 2002 and 2012 and Landsat OLI-TIRS for 2022). They date from the period of the long dry season when the rate of cloudiness and cloud cover are lowest (**Chatelain, 1996**). In addition, they were acquired simultaneously to reduce the problems of solar angles, phenological changes in vegetation and differences in soil moisture.

Image pre-processing

The objective of the pre-processing is to improve the satellite images for a good spectral discrimination of the different types of land cover of the landscape (**N'Da *et al.*, 2008, Sangne, 2009**). As the images from the years 1990, 2002 and 2012 were level 1, the pre-processing carried out concerned only atmospheric and radiometric corrections, to extract information from the signal that is independent of the effects of the atmosphere and converting the luminances into reflectances (**Caloz et Collet, 2001**). This was followed by the extraction of the study window, which focused on the Lamto Scientific Reserve.

Satellite image processing

Three main operations were performed on the insulated window. First, it is a question of calculating the biophysical indices resulting from the Tasseled cap transformation of the ENVI 5.3 software, from the raw bands. These indices are:

- The Brightness Index (BI), which highlights the level of cover or the density of vegetation cover;
- The Wetness Index (WI), which highlights the level of moisture in vegetation or subsoil;
- The Normalize Vegetation Difference Index (NDVI), is used to highlight the intensity of photosynthetic activity.

Afterwards, a principal component analysis was performed on the raw bands (visible, near-infrared and mid-infrared). It aims to improve the visual quality of each original band and to obtain new images in which certain characteristics are accentuated and enhanced.

Finally, the third operation consisted of executing a coloured composition, by associating the three primary colour channels (red, green and blue) with raw bands.

Thus, the images obtained, from the coloured compositions, were visually interpreted to discriminate the different land uses. Images from the PCA and vegetation indices were used as a reference for this discrimination based on colouration and spectral characteristics. The land uses discriminated against at this stage are the classes: gallery forest/dense semi-deciduous forest, open forest/wooded savannah, arboreal savannah/shrub savannah, water body and bare soil/habitat.

This step was followed by the choice of training points whose coordinates were recorded in a GPS for their recognition and description during the validation mission.

This was also attended by the actual classification. Based on proven knowledge in the field, we opted for supervised classification with the maximum likelihood algorithm to produce classified images. It is the most suitable for the thematic study of vegetation mapping (**N'Da *et al.*, 2008**).

The classifications of previous years (1990, 2002 and 2012) used the same technique. As the Land Use/Land Cover (LULC) of the different dates did not change, the training and control points of 2022 were used for the classification of the earlier dates. However, as the spatial dynamics of Land Use/Land Cover (LULC) are evolving, only the points at the level of the areas that remained stable during the period have been retained for these dates.

Hereafter, the classifications of the Land Use/Land Cover (LULC) maps of the different dates were generated using the software ArcGIS 10.8.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

The mapping performance was evaluated through three parameters: the confusion matrix, the overall accuracy and the Kappa coefficient.

D. Method for analysing the links between climatic variables and vegetation dynamics

A correlation analysis between the variables was performed to assess the influence of climatic parameters (Temp_Min, Temp_Mean, Temp_Maxi, Precipitation mm), PDSI values and SPI values on vegetation dynamics expressed through the areas of each land cover by period (1990-2002, 2002-2012, 2012-2022), through Spearman's correlation.

Spearman's correlation, or Spearman's correlation coefficient (ρ), is a statistical measure that evaluates the strength and direction of a monotonic (increasing or decreasing) relationship between two variables (**Sokal *et al*, 2012).**

III. RESULTS

A. Climate variability of the Lamto Scientific Reserve from 1990 to 2022

Temperature fluctuation from 1990 to 2022

Minimum, mean and maximum temperatures present various trends over the study period (Figure 2). As for the mean temperature, the curve presents growth along the chronosequence, marked by upward or downward fluctuations at times. We have therefore gone from 24.5° in 1992 to 27° in 2021, i.e. an overall growth of 2.5° over 30 years. This chronosequence is marked by two decisive dates, the years 1992 and 2021. The year 1992 recorded the lowest average temperature (22.38°C), while the year 2021 saw the highest warming with an average value of 27°C.

Nevertheless, there is a discontinuity in the dynamics of temperature. Hence, the period 1992 to 2002 is marked by an increase in mean temperature from 24.5° to 26°C, i.e. a warming of 1.5°. The period from 2002 to 2015, on the other hand, was marked by very low overall growth. The mean temperatures fluctuated between 25° and 25.5°C. From 2015 to 2021, the mean temperature rose from 25.5° to 27°C. During this period, we witnessed a global warming of 1.5°C.

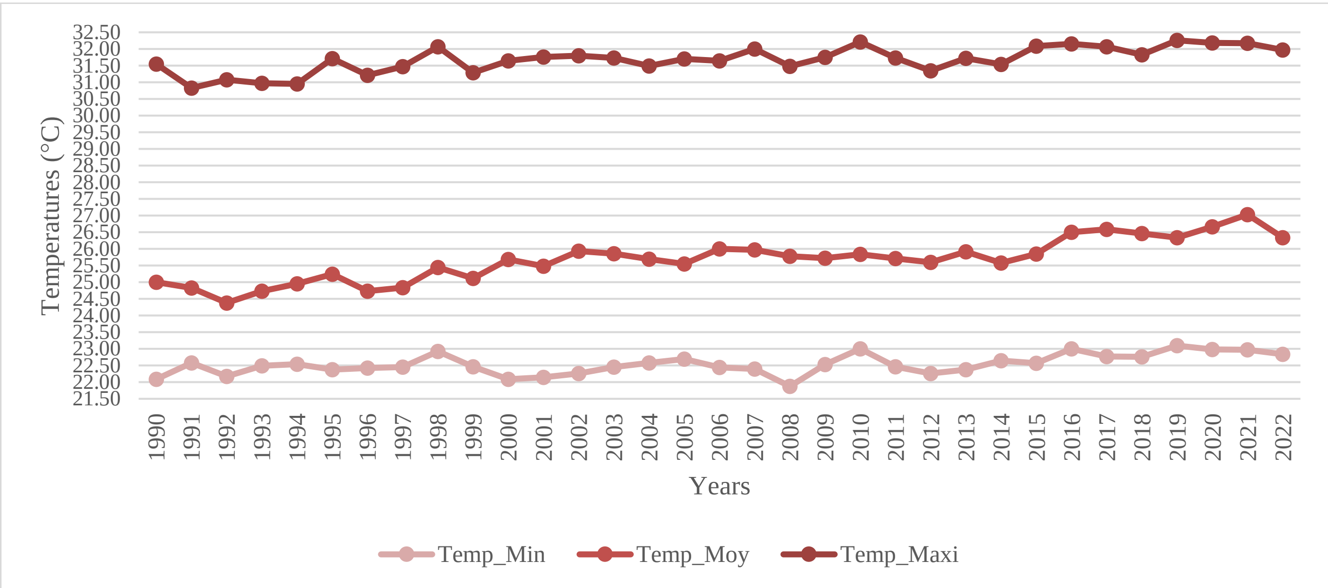

Figure 2: Trend curves for temperature variables in the Lamto Scientific Reserve from 1990 to 2022

Precipitation Dynamics from 1990 to 2022

The precipitation values for the three decades of study vary between 900 mm and 1687 mm, respectively for the years 1992 corresponding to the least rainy year and 2021 equivalent to the year with the most rainfall (Figure 3). The years 1990, 1992 and 1997 were the years with the lowest rainfall, with values of 1100 mm, 907 mm and 1040 mm, respectively. In contrast, the years 2003, 2010 and 2021 recorded the highest amounts of rainfall with values of 1638 mm, 1676 mm and 1687 mm respectively.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

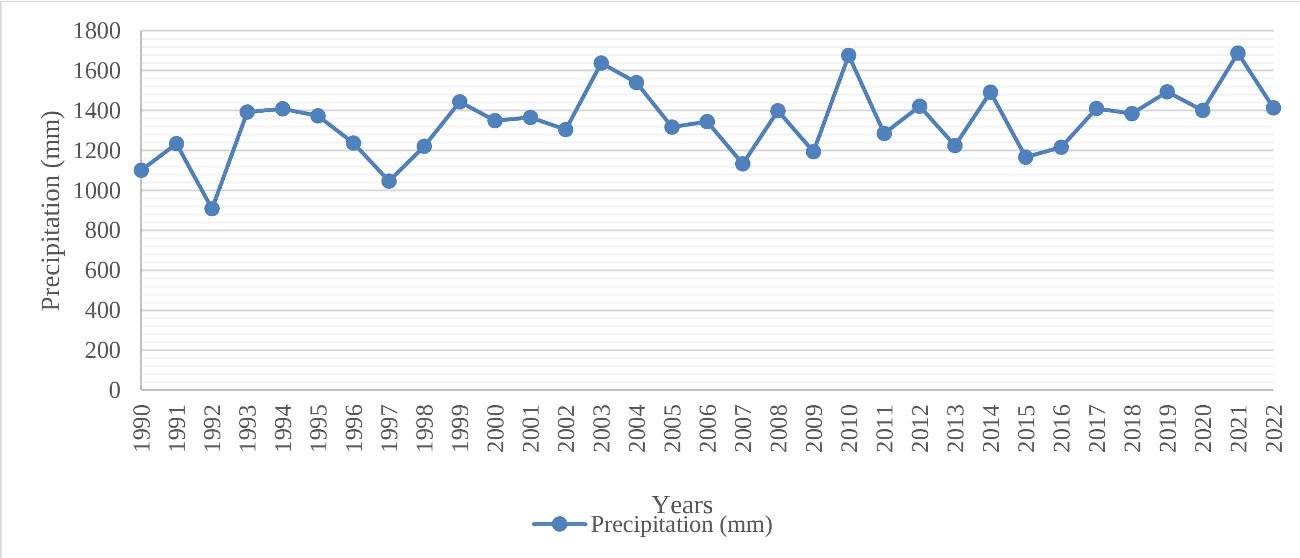

Figure 3: Lamto Scientific Reserve's precipitation fluctuation curve, 1990 to 2022

Periods of wetness and drought

The Standardized Precipitation Index (SPI) and Palmer Drought Severity Index (PDSI) were used to assess periods of moisture and drought during the study period.

Under SPI, the study period (1990-2022) expresses two trends: dry and wet periods (Figure 4). As a result, the years 1990, 2007 and 2015 were characterised by moderate drought, while 1997 was characterised by a high drought and 1992, an extreme drought. In contrast to these dates, the year 2004 experienced an episode of moderate wetness, the years 2003 and 2010, high wetness and the year 2021 extreme wetness.

At the level of the Palmer Drought Severity Index (PDSI), both trends are also observed (Figure 5). Yet, there was a dominance of the drought episode during the study period (Table III). Nearly 67% of the study period was marked by a drought episode while 12% of this period was marked by a period of wetness. For the drought episode, moderate drought and mild drought were more observed (18%).

For the moisture category, the light moisture that occurred over 9% of the study period is the most important.

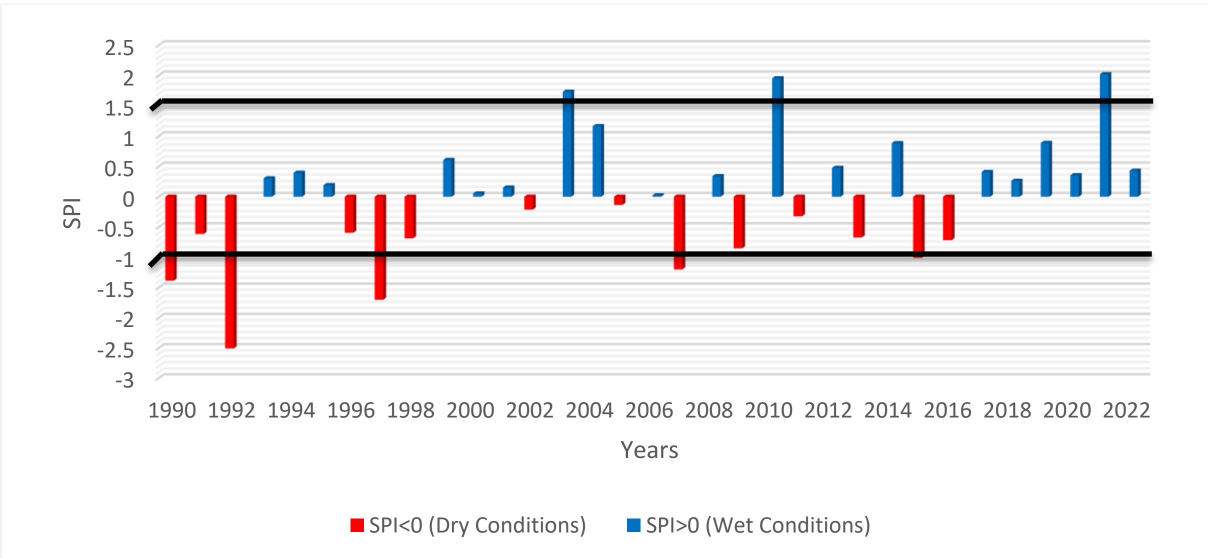

Figure 4: Lamto Scientific Reserve's SPI trend line from 1990 to 2022

Table III: Distribution of study years based on PDSI categories

PDSI Value	Slight wet	Incipient wet spell	Near normal	Incipient dry spell	Mild drought	Moderate drought	Severe drought	Extreme drought
Years	1991 1995 2010	2019	1994 1996 2001 2003 2004 2005 2008	2011	2002 2007 2009 2014 2015 2018	1990 1993 1999 2000 2006 2012	1992 1997 2013 2017 2020	1998 2016 2021 2022
Number of years	3	1	7	1	6	6	5	4
Proportion	9.09	3.03	21.21	3.03	18.18	18.18	15.15	12.12

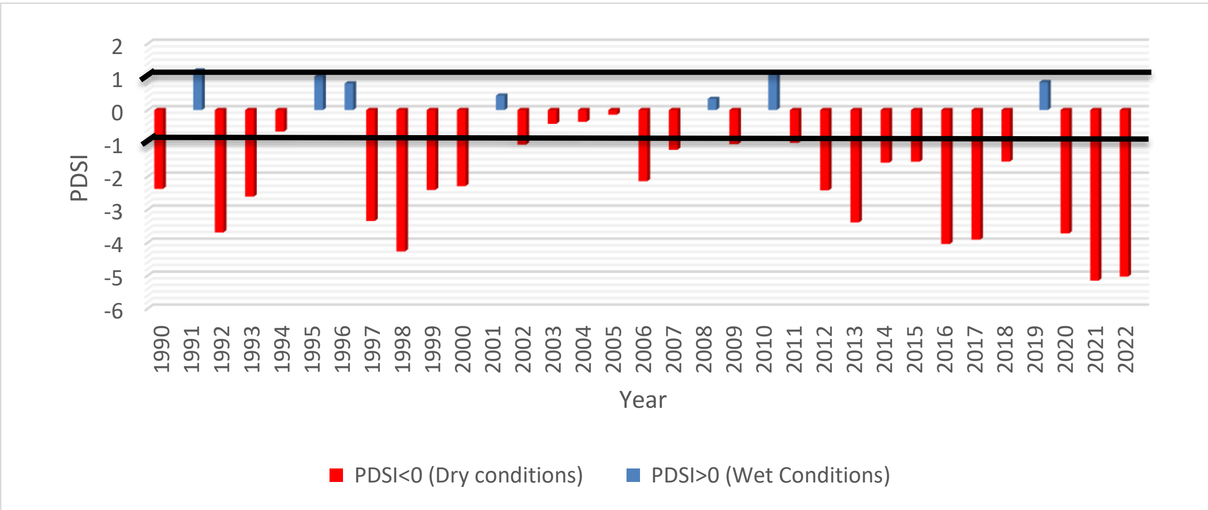

Figure 5: Lamto Reserve's PDSI trend line from 1990 to 2022

B. Spatio-temporal dynamics of vegetation in the Lamto Scientific Reserve from 1990 to 2022

Land Use Land Cover Mapping of the Lamto Scientific Reserve

The mapping of the Land Use Land Cover of the vegetation of the Lamto Reserve discriminated 6 classes of Land Use/Land Cover (LULC) for the different dates of study (Figure 6). These are the semi-deciduous dense forest/gallery forest class, the open forest/wooded savannah class, the arboreal savannah class, the shrub savannah class, the water body class and the bare soil/habitat class. The different classifications were evaluated by the confusion matrix through the calculation of the overall accuracy of classifications and the Kappa coefficient. These matrices show overall cartographic accuracies of 98.66%, 99.83%, 98.32% and 98.32% for Landsat TM, 7 ETM, 7 ETM and OLI-TIRS. The Kappa coefficients are valued at 0.98; 0.99; 0.98 and 0.97 respectively for images from 1990, 2002, 2012 and 2022.

The spectra of Land Use/Land Cover proportions vary from one date to another (Figure 7). In 1990, the vegetation of the Lamto Scientific Reserve was dominated by shrub savannahs with a proportion of 46% while wooded savannahs were the least represented vegetation formation with a proportion of 3%.

In 2002, the trend was the same for the dominant plant formations in terms of surface area. However, there has been an increase in the area of shrub savannahs, the proportion of which is estimated at 52%. Secondly, a reduction in the size of the open forest/wooded savannah class, which fell from 23% to 14%. At that time, the dominance of savannah formations increased from 49% to 58% of the reserve's surface area.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

In 2012, there was a regressive trend in shrub savannahs, which remain the most dominant type of vegetation with a proportion of 41%, and an evolutionary trend in arboreal areas, which occupy 22% of the reserve's surface area. There is an appearance of bare soil/habitat, with a proportion of 1%.

In 2022, the trend is marked by the dominance of wooded savannahs, which occupy 30% of the reserve. There has been an evolution of the open forest/wooded savannah class, with a proportion of 17%, and a decline in shrub savannahs, which occupy only 25% of the reserve's surface.

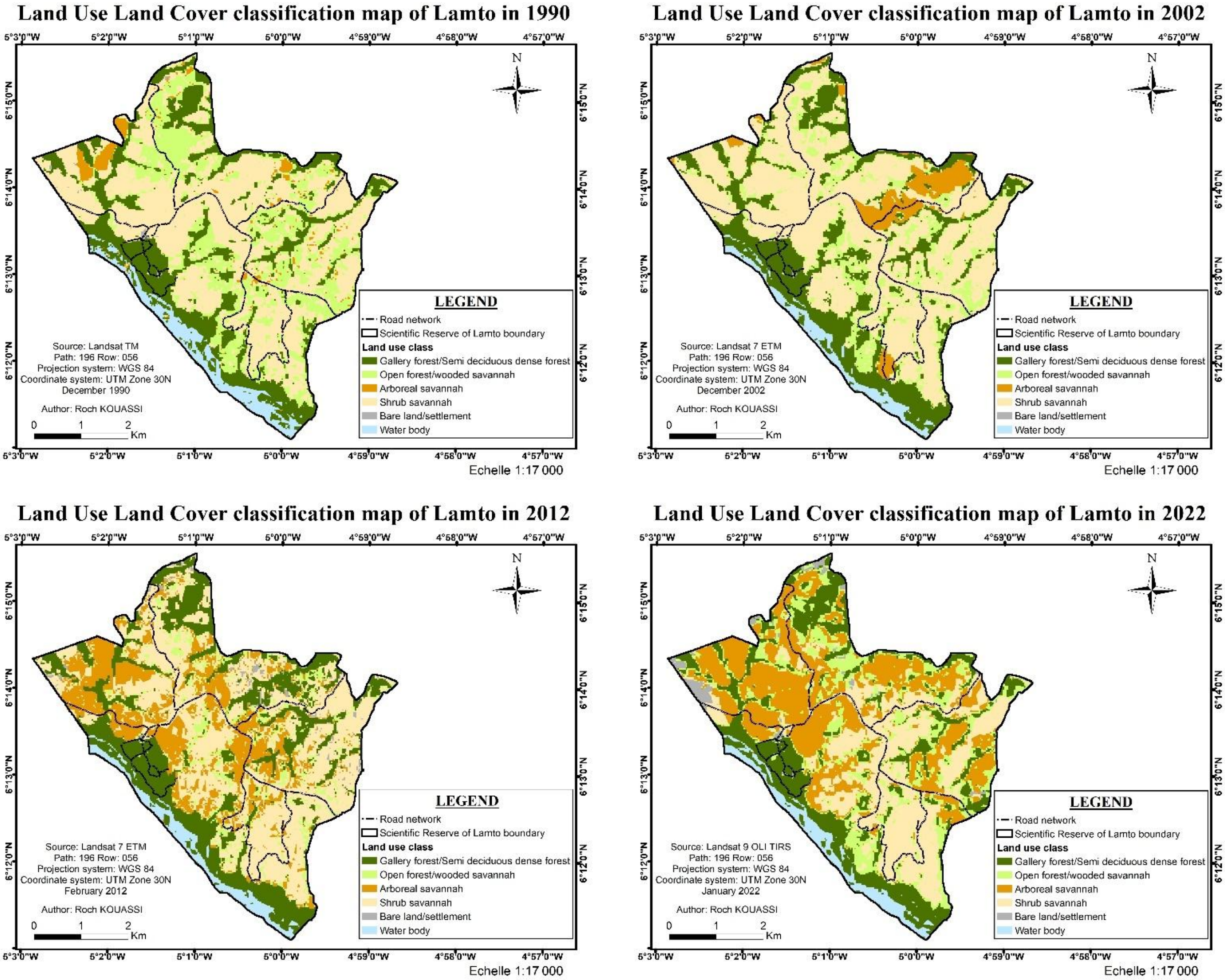

Figure 6: Land Use/Land Cover (LULC) maps of the Lamto Scientific Reserve from 1990, 2002, 2012, 2022

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

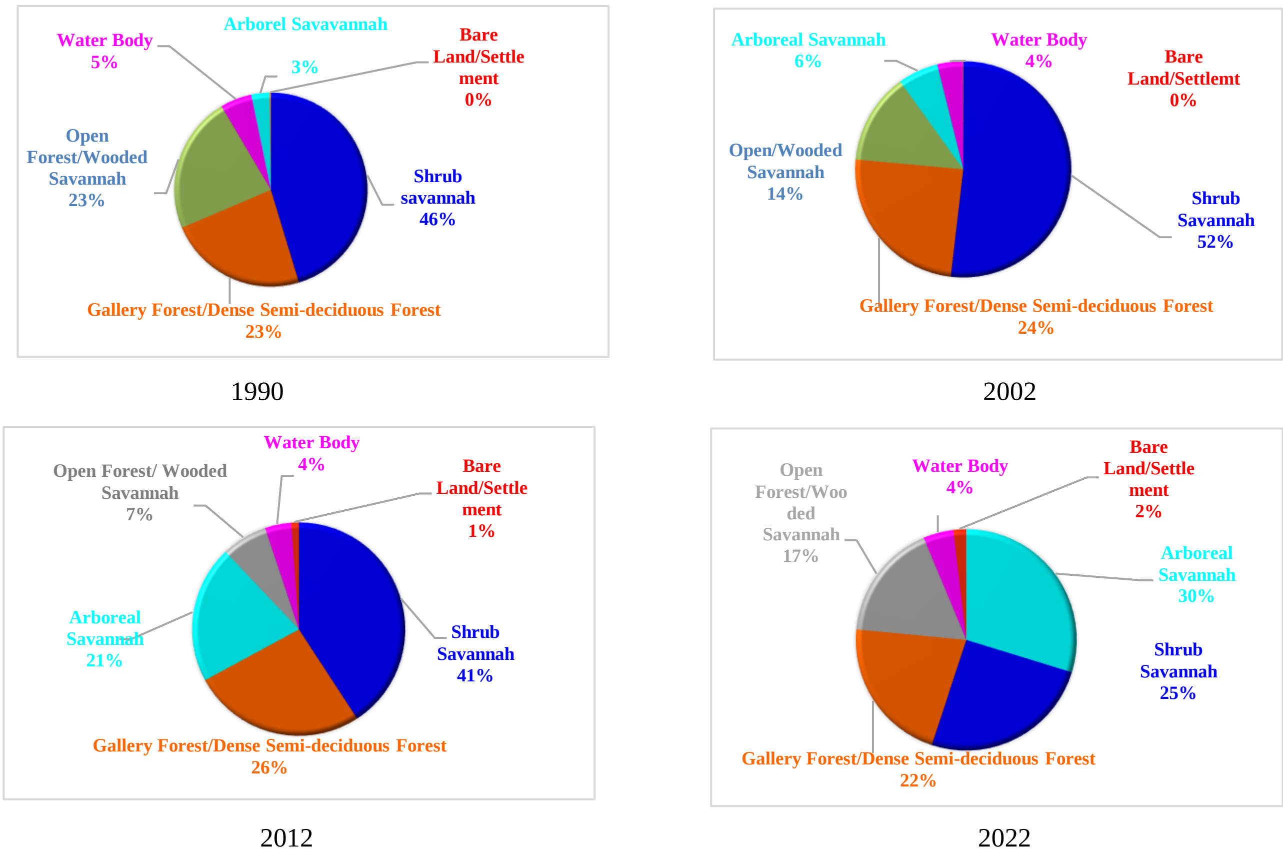

Figure 7: Spectrum of Land Use Land Cover proportions of different study periods

Land Use Land Cover Trends in the Lamto Scientific Reserve

Land Use Land Cover in the Lamto Reserve has changed in different ways during the observation period of the study (Figure 8). The forest formations (dense semi-deciduous forests and galleries forests) and pre-forest formations (open forests and wooded savannahs) have experienced an opposite dynamic. Moreover, during the first two decades (1990-2002 and 2002-2012), pre-forest formations experienced an increase in area while forest formations declined. Conversely, the period from 2012 to 2022 was characterised by a reduction in the area of pre-forest formations and a gain in forest formations. The flat water and bare soil/habitat classes have undergone the same evolution, with a gain in surface area during the first decade (1990-2002) and a loss of surface area during the last two decades of study. As for the shrub savannah class, it has declined over the 30 years, with a peak in loss during the period 2002-2012. The wooded savannahs have lost surface area during the period 1990-2002 and have gained in size over the last two decades.

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

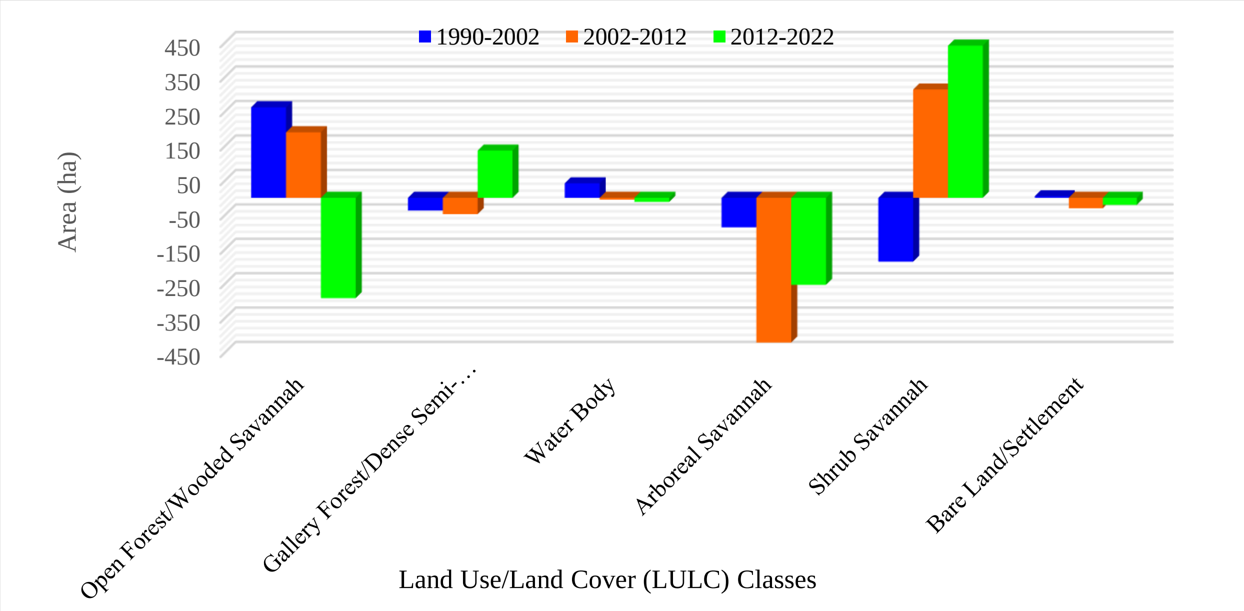

Figure 8: Land Use Land Cover trends over the periods 1990-2002, 2002-2012 and 2012-2022

Influence of climate variability on the vegetation dynamics of the Lamto Scientific Reserve from 1990 to 2022

The correlation implemented through the Spermann test indicates that there are links between the dynamics of certain land uses and climatic variables. The variables that significantly explain the dynamics of the different land uses are: the severity index, the Palmer Drought Severity Index (PDSI), the mean and maximum temperatures (Figure 10). The PDSI reveals a positive and mean correlation (0.48) with dense semi-deciduous and gallery forests. Consequently, a harsher drought would encourage the development of this type of plant formation. In contrast to this observation, the PDSI index is negatively correlated with the open forest/wooded savannah class. This implies that a reduction in drought, or even wetter periods, would lead to the regression of open forests and wooded savannahs (Table IV).

Mean temperature is the climatic variable that has the greatest influence on Land Use Land Cover dynamics and is the strongest in its relationship. Accordingly, the temperature rise strongly favours the increase in the areas of wooded savannahs, bare soils and average water bodies, with correlation values of 0.816, 0.811 and 0.699 respectively (Table IV). In contrast to these Land Use Land Cover, the mean temperature, with a correlation value of -0.811, has a very negative influence on the expansion of shrub savannahs. Like the mean temperature, the minimum temperature has the same effects on vegetation dynamics, but with a lesser influence. Indeed, the increase in the minimum temperature moderately supports the expansion of wooded savannahs, bare soils and water bodies. The correlation values are 0.591, 0.602, and 0.533. Nonetheless, the augmentation in this variable hinders the expansion of shrub savannahs. The value of this link is -0.602 (Table IV).

In general, precipitation and associated indices (SPI, PDSI) do not have a significant correlation with most vegetation or land cover types in this analysis.

Table IV: Summary of the correlations of the Spearmann test between climatic variables and Land Use Land Cover

Variables		Gallery forest/ Semi deciduous _dense forest	Open forest/ wooded savannah	Arboreal savannah	Shrub savannah	Bare_land/ settlement	Water body
Precipitation	Correlation value	-0.018	-0.043	0.343	-0.297	0.297	0.180
	P-Value	*0.923*	*0.813*	*0.051*	*0.093*	*0.093*	*0.314*

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

Variables		Gallery forest/ Semi deciduous _dense forest	Open forest/ wooded savannah	Arboreal savannah	Shrub savannah	Bare_land/ settlement	Water body
	Coefficient of Determination	0.000	0.002	0.118	0.088	0.088	0.033
PDSI Value	Correlation value	0.478	-0.470	-0.256	0.278	-0.278	-0.302
	P-Value	*0.005*	*0.006*	*0.150*	*0.117*	*0.117*	*0.087*
	Coefficient of Determination	0.228	0.221	0.065	0.077	0.077	0.091
SPI Value	Correlation value	-0.018	-0.043	0.343	-0.297	0.297	0.180
	P-Value	*0.923*	*0.813*	*0.051*	*0.093*	*0.093*	*0.314*
	Coefficient of Determination	0.000	0.002	0.118	0.088	0.088	0.033
Minimum Temperature	Correlation value	-0.253	0.241	-0.084	0.106	-0.106	-0.107
	P-Value	*0.155*	*0.177*	*0.641*	*0.556*	*0.556*	*0.551*
	Coefficient of Determination	0.064	0.058	0.007	0.011	0.011	0.012
Mean Temperature	Correlation value	-0.314	0.245	0.816	-0.811	0.811	0.699
	P-Value	*0,075*	*0,170*	*<0.0001*	*<0.0001*	*<0.0001*	*<0.0001*
	Coefficient of Determination	0.099	0.060	0.665	0.657	0.657	0.489
Maximum Temperature	Correlation value	-0.079	0.041	0.591	-0.602	0.602	0.533
	P-Value	*0.662*	*0.822*	*0.000*	*0.000*	*0.000*	*0.002*
	Coefficient of Determination	0.006	0.002	0.349	0.363	0.363	0.284

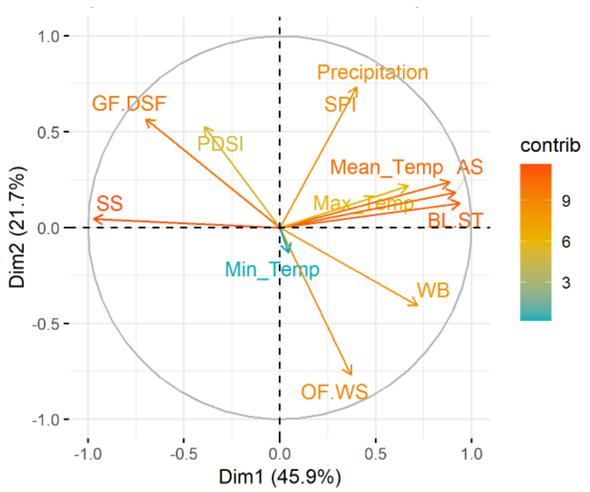

Figure 9: Correlation circle between climatic variables and Land Use/Land Cover (LULC) in Lamto

International Journal of Current Science Research and Review
ISSN: 2581-8341
Volume 07 Issue 12 December 2024
DOI: 10.47191/ijcsrr/V7-i12-32, Impact Factor: 7.943
IJCSRR @ 2024
www.ijcsrr.org

IV. DISCUSSION

Climatic variables of Lamto reserve

The study on climate variability indicated a very perceptible dynamic of the climatic variables of the Lamto reserve in 30 years of study. Thus, in terms of the average temperature (Tm), an overall increase of 2°C was observed. The year 2021 recorded the highest Tm and the period from 2015 to 2022 saw the fastest growth. The growth trend pointed out by this study shows that the Lamto Scientific Reserve is not exempt from the increase in global temperature as mentioned by **IPCC (2021)**. According to **Niang et al., (2014)**, **Bary et al., (2018)**, and **IPCC, (2021)** Africa is experiencing a temperature increase higher than the world average. This result obtained in the Lamto Reserve is not singular because authors such as **Douffi et al., (2021)**, have noted this general increase in temperature in Côte d'Ivoire in general and in the Lamto Scientific Reserve in particular **(Diawara et al. 2014; Kouame et al., 2019; Bigot et al., 2004)**.

In fact, three trends in temperature variations were observed over the overall period of the three decades considered in this study. From 1992 to 2002, temperatures increased by 1.5°C, followed by a stagnation phase between 2002 and 2015 and a new phase of warming from 2015 to 2021.

The increase of 1.5 °C during this period can be seen as a response to the global climate changes affecting the Lamto Scientific Reserve. **WHO, (2024)**, and **Sylla et al., (2016)**, studies show that West Africa is vulnerable to these variations, influenced by climatic phenomena such as El Niño and La Niña. **Sarr et al., (2008)** observed that warming periods are often linked to fluctuations in precipitation patterns, thus affecting regional climate systems. Rising temperatures may also be linked to changes in atmospheric circulation that influence climatic conditions on the African continent such as the Walker, Hadley and monsoon circulations **(Ibebuchi, 2024; Sarr et al., 2008; Nicholson, 2013)**. Moreover, the trade winds, blowing from subtropical regions towards the equator, are also affected by these circulation systems. Changes in the strength and direction of the trade winds can alter the availability of moisture and influence temperatures in West Africa, particularly the Lamto zone **(Sarr et al., 2008, Singh et al. 2023)**.

As for the stagnation of temperatures recorded between 2002 and 2015, it can be interpreted as a stabilization phase due to interannual climatic fluctuations, but also to meteorological conditions specific to the region. According to Zhou *et al.*, (2016), periods of temperature stagnation can occur in regions where atmospheric systems find a temporary equilibrium. This could suggest that the region has experienced phases of climate adaptation, where temperature fluctuations have been offset by changes in precipitation patterns, resulting in a stabilization of measured temperatures.

While the warming phase observed between 2015 and 2021, may indicate a response to global climate change, where extreme weather events are becoming more frequent. **Kouadio *et al.*, (2021)**; **Rome *et al.*, (2019)** mention that temperature increases can be exacerbated by phenomena such as heat waves, which are becoming more frequent in tropical regions. The **IPCC, (2021)** also reported that temperatures in Africa continue to rise at a worrying rate, which may be reflected in weather data recorded at weather stations like the one at the Lamto geophysical station.

The analysis of wet and dry periods in the Lamto Scientific Reserve, based on the Standardised Precipitation Indices (SPI) and the Palmer Drought Severity Index (PDSI), reveals worrying trends that highlight the climatic vulnerability of this region. The prevalence of droughts could be attributed to several factors, including global climate change, which is intensifying climate variations at the regional scale.

Indeed, studies indicate that increases in global temperatures and changes in atmospheric circulation patterns can lead to decreased precipitation and worsening droughts **(IPCC, (2021) ; Zeng *et al.*, (2020))**.

Mapping and dynamics of land use and land cover

In terms of vegetation dynamics, the forest class increased slightly during the observation period of the study. This increase could be explained by the fire established at the edge of the forest area which protects it from the influence of seasonal fire, which would allow this class to develop more easily. This expansion in the forest class is mainly located along the Bandama River rather than within the savannah areas. The open forest/wooded savannah and shrub savannah classes were the most unstable during the observation period of the study. This instability could be explained first by its transitory nature, which supports its conversion towards the gallery forest/semi-deciduous forest class, which constitutes the climax state of the vegetation of the environment. Eventually, the arboreal savannah class was the one that recorded a large increase in its area during the study period. This growth is explained by the influence of fire. Indeed, as this class is mainly made up of pyrophytic species, the seasonal fire in Lamto makes it possible to break the dormancy of these species whose seeds are stored in the soil and which germinate following the first rains after the passage of the fire. This afforestation of the savannahs could lead to a regeneration of forest formations, which would prove that the ecosystem of the forest-savannah transition would tend towards a forest climax, as opposed to savanization **(Koulibaly et al., 2010, Koulibaly et 2016)**. This regeneration phenomenon is corroborated by several studies. **Chazdon (2008)** points out that tropical forests can recover effectively under favourable conditions, thus contributing to biodiversity and carbon storage. Likewise, **Poorter et al., (2021)** and **N'Guessan et al., (2019)** have shown that these forests can regenerate in just 20 years when they do not suffer deforestation or other forms of anthropogenic degradation. This rapid resilience is essential to maintain the ecological integrity and ecosystem services of forests.

Climatic variable interaction and vegetation dynamics

The study of the interactions between climatic variables and the dynamics of the Land Use/Land Cover (LULC) in the Lamto Scientific Reserve has shown that temperatures are the variables that most influence the dynamics of the different ecosystems. Precipitation and associated indices (SPI, PDSI), nevertheless, do not have a significant correlation with most vegetation types or Land Use/Land Cover (LULC), generally expressing. However, there is specificity in the links between habitats and climatic variables. Thus, forest formations (gallery and semi-deciduous forest) and pre-forest formations (open forest and wooded savannah) are only related to the Palmer Drought Severity Index (PDSI), so with the precipitation. Similarly, temperatures only influence savannah formations (arboreal and shrub savannahs), bare soils and water bodies.

As far as the PDSI and therefore drought is concerned, it favours the expansion of gallery and semi-deciduous forests and leads to a regression of pre-forest formations. This expansion of forests during periods of drought could be explained by the resilience of certain plant species present in this habitat. In point of fact, the location of the study area in the transition zone favours the establishment of species that can withstand a certain threshold of water stress. In addition, this study has shown that periods of drought, even when they occur, rarely extend over several consecutive years, which could lead to impacts deeper on the flora. Authors such as **Rammig et al., (2010)** et **Dja et al., (2018)** addressing in the same vein, have proven that tropical forests can be resilient to dry periods and maintain their biodiversity by adjusting to the specific adaptation of species.

Unlike forests, pre-forest formations are vulnerable to drought. In truth, a more increased drought will accentuate the water deficit at ground level, which will negatively affect the flora and consequently the vegetation. On the other hand, drought makes these habitats more vulnerable to the passage of seasonal fire, caused each year to maintain the balance between forest and savannah, which will accordingly lead to their degradation and therefore the reduction of their surface area. **Adjonou *et al.*, (2009),** in a similar approach, showed that the decrease in rainfall resulting from climate change has a negative impact on the dynamics of woody trees in open forests in Togo.

As far as temperature is concerned, its enhancement favours a gradual dynamic, arboreal savannahs, water bodies and bare soils. **Trenberth and Shea (2005)** and **IPCC (2021)** have demonstrated that increasing temperature stimulates evapotranspiration which promotes rainfall. The increase in rainfall will promote the development of vegetation, in the case of the arboreal savannah, and the gain in surface area for the water body. The regression of shrub savannahs, on the other hand, could be explained by the transformation of this habitat into an arboreal savannah when it is subjected to heavy rainfall. This explains the regression of shrub savannahs and the progression of arboreal savannahs. As for bare soils, their increase cannot be justified by rainfall. On the other hand, the rise in temperature will dry out the grassy layer more, especially in the savannah facies with very little woody cover. As this stratum is very dry during the period December to January, the seasonal fires applied during this period will eliminate it completely, revealing bare soil. The lack of vegetation cover after these fires could lead to soil erosion during the harmattan period and reduce their water retention capacity, impacting the regeneration of herbaceous plants during the wet seasons. In addition, exposure of bare soils to high temperatures can affect germination processes and compromise the resilience of the savannah ecosystem in the context of climate change.

V. CONCLUSION

The study highlighted the complexity of climate-ecosystem interactions in an ecological transition zone while emphasizing the importance of appropriate management and conservation strategies to preserve these evolving landscapes. Spatio-temporal monitoring of Land Use/ Land Cover (LULC) reveals a marked trend towards densification of arboreal cover, indicating a transition from savannahs to denser forest formations. This dynamic of "afforestation" can be seen as a response to climate change in this region of forest-savannah transition. The study shows that, although precipitation has increased over the years (from 900 mm to 1687 mm), high temperatures strongly influence vegetation dynamics. Gallery and semi-deciduous forests show increased resilience to high temperatures, while other formations, such as shrub savannahs, are associated with signs of ecological degradation, often linked to higher temperatures. The different types of plant formation react differently to climatic factors. While some forest formations tend to strengthen under current climate change, other vegetation types, such as shrub savannahs and bare land areas, appear to be more vulnerable, which could exacerbate ecological degradation processes. The analysis demonstrates that precipitation plays a minor role in some changes in vegetation cover. This suggests that factors such as rivers, microclimate, or other specific local conditions also play an important role in the evolution of the reserve's landscapes.

REFERENCES

1. Achieng, J., Boucher, T. & Owende, P., 2016. 'The effects of climate variability on biodiversity and ecosystem services in West Africa', *Ecosystem Services*, vol. 23, pp. 103–112. doi:10.1016/j.ecoser.2016.11.007.
2. Adjonou, K., Ahlfeldt, K. & Koutouan, R., 2009. 'Impact de la pluviométrie sur la dynamique des ligneux dans les forêts claires au Togo', *Tropical Forest Ecology*, vol. 45, no. 2, pp. 123–137.
3. Adjonou, K., Ahlfeldt, K. & Koutouan, R., 2009. 'Impact de la pluviométrie sur la dynamique des ligneux dans les forêts claires au Togo', *Tropical Forest Ecology*, vol. 45, no. 2, pp. 123–137.
4. Ago, E.E., 2016. *Dynamique des flux de carbone entre l'atmosphère et des écosystèmes Ouest-Africains : cas des forêts et savanes sous climat soudanien au BENIN*. Thèse de Doctorat, Université de Liège Gembloux Agro Bio Tech, Bruxelles. 184 p.
5. Aka, K.S.R., Akpavi, S., Dibi, N.H., Kabo-Bah, A.T., Gyilbag, A. & Boamah, E., 2023. 'Toward understanding land use land cover changes and their effects on land surface temperature in yam production area, Côte d'Ivoire, Gontougo Region, using remote sensing and machine learning tools (Google Earth Engine)', *Frontiers in Remote Sensing*, vol. 4, p. 1221757. doi:10.3389/frsen.2023.1221757.
6. Almer, C., Laurent-Lucchetti, J. & Oechslin, M., 2017. 'Pénurie d'eau et émeutes : preuves désagrégées provenant d'Afrique subsaharienne', *Journal de l'économie et de la gestion de l'environnement*, vol. 86, pp. 193–209.
7. Asseh, E.E., Ake-Assi, E. & Koffi, K.J., 2019. 'Diversité biologique et influence des changements climatiques sur la distribution géographique de quelques espèces d'Acanthaceae en Côte d'Ivoire', *International Journal of Biological and Chemical Sciences*, vol. 13, no. 2, pp. 676–692.
8. Avakoudjo, H.G.G., Mensah, S., Idohou, R. et al., 2022. 'Effects of climate and protection status on growth and fruit yield of *Strychnos spinosa* Lam., a tropical wild fruit tree in West Africa', *Trees*, vol. 36, pp. 1117–1129. doi:10.1007/s00468-022-02276-2.
9. Báez, J.C., Gimeno, L. & Real, R., 2021. 'North Atlantic Oscillation and fisheries management during global climate change', *Reviews in Fish Biology and Fisheries*, vol. 31, pp. 319–336. doi:10.1007/s11160-021-09645-z
10. Báez, S., Fadrique, B., Feeley, K. & Homeier, J., 2022. 'Changes in tree functional composition across topographic gradients and through time in a tropical montane forest', *PLoS ONE*, vol. 17, no. 4, e0263508. doi:10.1371/journal.pone.0263508.
11. Barry, A.A., Caesar, J., Klein Tank, A.M.G., Aguilar, E., McSweeney, C., Cyrille, A.M., Nikiema, M.P., Narcisse, K.B., Sima, F., Stafford, G., Touray, L.M., Ayilari-Naa, J.A., Mendes, C.L., Tounkara, M., GarGlahn, E.V.S., Coulibaly, M.S., Dieh, M.F., Mouhaimouni, M., Oyegade, J.A., Samboup, E., Laogbessi, E.T. 2018. West Africa climate extremes and climate change indices. International Journal of Climatology, DOI: 10.1002/joc.5420
12. Belle, E.M.S., Burgess, N.D., Misrachi, M., Arnell, A., Masumbuko, B., Somda, J., Hartley, A., Jones, R., Janes, T., McSweeney, C., Mathison, C., Buontempo, C., Butchart, S., Willis, S.G., Baker, D.J., Carr, J., Hughes, A., Foden, W., Smith, R.J. & Kingston, N., 2016. *Climate Change Impacts on Biodiversity and Protected Areas in West Africa: Summary of the main outputs of the PARCC project, Protected Areas Resilient to Climate Change in West Africa*. UNEP-WCMC, Cambridge, UK.
13. Benarfa, H., 2021. *La variabilité climatique dans la wilaya de Tébessa*. Mémoire de Master 2, Université de Larbi Tébessi, Algérie. 55 p.

14. Bergaoui, M. & Alouini, A., 2001. ‘Caractérisation de la sécheresse météorologique et hydrologique : Cas du bassin versant de Siliana en Tunisie’, *Sécheresse*, vol. 12, no. 4, pp. 205–213.
15. Biagné, M.R., 2019. *Dynamique, structure et diversité floristique de la végétation du département de Dimbokro (Centre-Est de la Côte d’Ivoire)*. Thèse de Doctorat, Université de Cocody-Abidjan, Côte d’Ivoire. 147 p.
16. Bigot, S., Oszwald, J., Brou Yao, T., Diedhiou, A., Konaré, A., Fofana, M. & Assamoi, P., 2004. ‘Le suivi des variations climatiques et écologiques en Afrique de l’Ouest : le rôle de la station géophysique’, dans *AIC 2004, « Climat, mémoire du temps… » Thème 2 : « Le Climat : son évolution et ses excès »*, Lamto, Côte d’Ivoire, pp. 127–130.
17. Brou, Y.T., Akindès, F. & Bigot, S., 2000. ‘La variabilité climatique en Côte d'Ivoire : entre perceptions sociales et réponses agricoles’, *Cahiers Agricultures*, vol. 14, no. 6, pp. 533–540.
18. Caloz, R. & Collet, C., 2001. *Précis de télédétection : Traitements numériques d’images de télédétection*. Sainte-Foy : Presses de l’Université de Québec et AUF. 386 p.
19. Chatelain, C., 1996. *Possibilités d’application de l’imagerie satellitaire à haute résolution pour l’étude des transformations de la végétation en Côte d’Ivoire forestière*. Thèse de Doctorat, Université de Genève, Suisse. 158 p.
20. Chazdon, R.L., 2008. ‘Beyond deforestation: Restoring forests on degraded lands’, *Science*, vol. 320, no. 5882, pp. 1458–1460. doi:10.1126/science.1152626.
21. Chen, Z., Zhou, T., Chen, X., Zhang, W., Zhang, L., Wu, M. & Zou, L., 2022. ‘Observationally constrained projection of Afro-Asian monsoon precipitation’, *Nature Communications*, vol. 13, p. 2552. doi:10.1038/s41467-022-30106-z.
22. Devineau, J.L., 1975. *Etude quantitative des forêts galeries de Lamto (moyenne Côte d’Ivoire)*. Thèse de Doctorat (3e cycle), Université de Paris VI. 190 p.
23. Diawara, A., Yoroba, F., Kouadio, K.Y., Kouassi, K.B., Assamoi, E.M., Diedhiou, A. & Assamoi, P., 2014. ‘Climate Variability in the Sudano-Guinean Transition Area and Its Impact on Vegetation: The Case of the Lamto Region in Côte D’Ivoire’, *Advances in Meteorology*, vol. 2014, Article ID 831414, 11 pages. doi:10.1155/2014/831414.
24. Diba, I., Camara, M., Sarr, A.B. & Diedhiou, A., 2018. ‘Potential impacts of land cover change on the interannual variability of rainfall and surface temperature over West Africa’, *Atmosphere*, vol. 9, no. 10, p. 376. doi:10.3390/atmos9100376.
25. Diomande, E.B.I., 2024. ‘Climate trends and changes in biodiversity in the Comoé National Park (North-East Côte d’Ivoire)’, *European Journal of Science, Innovation and Technology*, vol. 4, no. 4, pp. 328–338. Disponible à : https://www.ejsit-journal.com/index.php/ejsit/article/view/522.
26. Dja, A.A., Koné, M. & Yao, M., 2018. ‘Résilience des forêts tropicales aux périodes sèches’, *African Journal of Ecology*, vol. 56, no. 2, pp. 235–244. doi:10.1111/aje.12445.
27. Douffi, K.G-C., Yao1, A.C., Koffi, K.J., Traoré, A.S., Koné1, M. 2021. Afforestation in Response to Thermal Change in the Forest-Savannah Transition of the Lamto Scientific Reserve, Côte d’Ivoire, *European Journal of Forest Engineering*, 7(2):45-56
28. Ehounou, J.-N., Brou, K., Tahi, M.G., Kassin, E.K., Dékoula, C.S., Yao, G.F., Kouadio, H.K., N’guessan, A.E.B. & Soro, N., 2019. ‘Impact of local global warming on rainfall and annual cocoa water requirements in the regions of Lôh-Djiboua and Gôh in west-central Côte d’Ivoire’, *International Journal of Environment and Climate Change*, vol. 9, no. 9, pp. 503–517. doi:10.9734/IJECC/2019/v9i930135.
29. Fadrique, B., Báez, S., Duque, Á., Malizia, A., Blundo, C., Carilla, J., Osinaga-Acosta, O., Malizia, L., Silman, M., Farfán-Ríos, W., Malhi, Y., Young, K.R., Cuesta, F.C., Homeier, J., Peralvo, M., Pinto, E., Jadan, O., Aguirre, N., Aguirre, Z. & Feeley, K.J., 2018. ‘Widespread but heterogeneous responses of Andean forests to climate change’, *Nature*, vol. 564, pp. 207–212. doi:10.1038/s41586-018-0715-9.
30. Ficklin, D.L., Robeson, S.M. & Knouft, J.H., 2016. ‘Impacts des changements climatiques récents sur les tendances des débits de base et des écoulements pluviaux dans les bassins versants des États-Unis’, *Geophysical Research Letters*, vol. 43, no. 10, pp. 5079–5088. doi:10.1002/2016GL068734.
31. Global Climate Risk Index (GCRI), 2021. *Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2019 and 2000–2019*. Germanwatch e.V., 47 pages. Available on: <www.germanwatch.org>.

32. Gnahoré, E., Missa, K., Koné, M., Gueulou, N. & Bakayoko, A., 2018. 'Dynamique et structure de la flore de la Savane Protégée des Feux dans la Réserve Scientifique de Lamto (Centre de la Côte d'Ivoire)', *European Scientific Journal*, vol. 14, no. 36, pp. 432–451.
33. Guiguindibaye, M., Belem, M.O. & Boussim, J.I., 2013. 'Caractéristiques des feux dans un incendie en savane soudanienne au Tchad', *Revue internationale des sciences biologiques et chimiques*, vol. 7, no. 3, pp. 1147–1156.
34. Hatfield, J.L. & Prueger, J.H., 2015. 'Températures extrêmes : Effet sur la croissance et le développement des plantes', *Extrêmes météorologiques et climatiques*, vol. 10, pp. 4–10.
35. Heubes, J., Schmidt, M., Stuch, B., García Márquez, J.R., Wittig, R., Zizka, G., Thiombiano, A., Sinsin, B., Schaldach, R. & Hahn, K., 2013. 'The projected impact of climate and land use change on plant diversity: An example from West Africa', *Journal of Arid Environments*, vol. 96, pp. 48–54. doi:10.1016/j.jaridenv.2013.04.008.
36. Ibebuchi, C.C., 2024. 'Predictability of the atmospheric circulation patterns in Africa, south of the equator, using variations of the Southern Annular Mode and ENSO', *Theoretical and Applied Climatology*, vol. 155, pp. 4641–4651. doi:10.1007/s00704-024-04898-7.
37. IPCC, 2021. *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S.L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M.I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J.B.R., Maycock, T.K., Waterfield, T., Yelekçi, O., Yu, R. & Zhou, B. (eds.)]. Cambridge: Cambridge University Press. doi:10.1017/9781009157896.
38. IPCC, 2022: *Climate Change 2022: Impacts, Adaptation, and Vulnerability.* Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.
39. IPCC, 2023. *Climate Change 2023: Synthesis Report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. Geneva, Switzerland: IPCC, pp. 35–115. doi:10.59327/IPCC/AR6-9789291691647.
40. Jenkins, G.S., Adamou, G. & Fongang, S., 2002. 'The challenges of modeling climate variability and change in West Africa', *Climatic Change*, vol. 52, no. 3, pp. 263–286. doi:10.1023/A:1013741803144.
41. Koffi, B., Brou, A.L., Kouadio, K.J.O., Ebodé, V.B., N'Guessan, K.J.-Y., Yangouliba, G.I., Konaté, Y., Brou, D. & Kouassi, K.L., 2023. 'Impact of climate and land use/land cover change on Lobo reservoir inflow, West-Central of Côte d'Ivoire', *Journal of Hydrology: Regional Studies*, vol. 47, p. 101417. doi:10.1016/j.ejrh.2023.101417.
42. Konate, D., Didi, S.R., Dje, K.B., Diedhiou, A., Kouassi, K.L., Kamagate, B., Paturel, J.-E., Coulibaly, H.S.J.-P., Kouadio, C.A.K. & Coulibaly, T.J.H., 2023. 'Observed changes in rainfall and characteristics of extreme events in Côte d'Ivoire (West Africa)', *Hydrology*, vol. 10, no. 104. doi:10.3390/hydrology10050104.
43. Kouadio, L. & Tohé, E., 2020. 'Impact de l'augmentation de la température sur les écosystèmes en Côte d'Ivoire : Étude de cas à la réserve scientifique de Lamto', Ecological Indicators, vol. 109, Article 105823. doi:10.1016/j.ecolind.2019.105823.
44. Kouamé, K.R., Dibi Kangah, P.A., Koli Bi, Z. 2019. Variabilité climatique dans le centre-est de la Côte d'Ivoire : indicateurs, scénarii actuels et futurs. *Revue de Géographie Tropicale et d'Environnement*, 1:7- 20
45. Kouassi, J.-L., Wandan, N.E. & Mbow, C., 2018. 'Assessing the Impact of Climate Variability on Wildfires in the N'Zi River Watershed in Central Côte d'Ivoire', *Fire*, vol. 1, no. 3, p. 36. doi:10.3390/fire1030036.
46. Koulibaly, A., Kouamé, D., Groga, N., Kouassi, K.E., Bakayoko, A. & Porembski, S., 2016. 'Floristic characteristics of the mosaic and how forest progresses on savanna in the Lamto reserve region (Côte d'Ivoire)?', *International Journal of Development Research*, vol. 6, no. 5, pp. 7792–7799.
47. Koulibaly, A., Kouamé, N.F., Traoré, D. & Porembski, S., 2010. 'Structure et régénération de la végétation ligneuse, le long de transects forêts-savanes, dans la région de la Réserve de Lamto (Côte d'Ivoire)', *Annales de Botanique de l'Afrique de l'Ouest*, vol. 6, pp. 56–72.

48. Matsumoto, K., Aida, M. & Imada, A., 2015. 'The impacts of climate variability on the ecosystems in Africa: A review', *Environmental Monitoring and Assessment*, vol. 187, no. 5, pp. 1–20. doi:10.1007/s10661-015-4441-1.
49. McKee, T.B., Doesken, N.J. & Kleist, J., 1993. 'La relation entre la fréquence et la durée des sécheresses et les échelles de temps', dans *Actes de la 8e Conférence sur la climatologie appliquée*, vol. 17, no. 22, pp. 179–183.
50. N'da, D.H., Adou, Y.C.Y., N'Guessan, K.E., Koné, M. & Sangne, Y.C., 2008. 'Analyse de la diversité floristique du Parc National de la Marahoué, Centre-Ouest de la Côte d'Ivoire', *Afrique Science*, vol. 4, no. 3, pp. 552–579.
51. N'Dri, A.B., Gignoux, J., Dembele, A., Konate, S. 2012. Short term effects of fire intensity and fire regime on vegetation dynamic in a tropical humid savanna (Lamto, central Côte d'Ivoire) *Natural Science*, 4(12): 1056-1064.
52. Ndehedehe, C., 2022. 'Drought Events', dans *Satellite Remote Sensing of Terrestrial Hydrology*, Springer, Cham. doi:10.1007/978-3-030-99577-5_11.
53. N'Guessan, A.E., N'dja, J.K., et al., 2019. 'Drivers of biomass recovery in a secondary forested landscape of West Africa', *Forest Ecology and Management*, vol. 433, pp. 325–331. doi:10.1016/j.foreco.2018.11.027.
54. Niang, I., Ruppel, O.C., Abdrabo, M.A., Essel, A., Lennard, C., Padgham, J. & Urquhart, P., 2014. 'Africa', dans *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects*. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., Field, C.B., Dokken, D.J., et al. (eds.)]. Cambridge: Cambridge University Press, pp. 1199–1265.
55. Niasse, M., Afouda, A. & Amani, A. (éds.), 2004. *Reducing West Africa's vulnerability to climate impacts on water resources, wetlands and desertification: Elements for a regional strategy for preparedness and adaptation*. Gland, Switzerland & Cambridge, UK: IUCN.
56. Nicholson, S.E., 2013. 'The West African Sahel and the Sudan: Climate and Context', *Annual Review of Earth and Planetary Sciences*, vol. 41, pp. 177–199. doi:10.1146/annurev-earth-040809-152833.
57. Palmer, W.C., 1965. *Meteorological drought*. U.S. Weather Bureau Research Paper No. 45. 58 p.
58. Poorter, L., Craven, D., et al., 2021. 'Multi-dimensional resilience of tropical forests', *Science*, vol. 372, no. 6538, pp. 97–102. doi:10.1126/science.abh3629.
59. Rammig, A., Jupp, T., Thonicke, K., Tietjen, B., Heinke, J., Ostberg, S. & Cox, P., 2010. 'Estimation du risque de dépérissement de la forêt amazonienne', *New Phytologist*, vol. 187, pp. 694–706. doi:10.1111/j.1469-8137.2010.03318.x.
60. Rome, S., Pohl, B., Oueslati, B., Moron, V., Raymond, F., Janicot, S. & Diedhou, A., 2019. 'Durée et fréquence des vagues de chaleur en Afrique tropicale septentrionale selon 5 indices de chaleur', *HAL-SHS*, pp. 250–264. Disponible à : https://hal.science/hal-02189450.
61. Sangne, Y.C., 2009. *Dynamique du couvert forestier d'une aire protégée soumise aux pressions anthropiques : cas de la forêt classée de Téné dans le département d'Oumé (Centre-Ouest de la Côte d'Ivoire)*. Thèse de Doctorat unique, UFR Biosciences, Laboratoire de Botanique, Université de Cocody-Abidjan, Côte d'Ivoire. 220 p.
62. Sarr, B., Mbow, C. & Sultan, B., 2008. 'Impact des fluctuations des régimes de précipitations sur les savanes de l'Afrique de l'Ouest', *Climatologie régionale d'Afrique de l'Ouest*, vol. 32, pp. 204–217.
63. Secretariat of the Convention on Biological Diversity (UNCBD), 2008. *Year in Review 2007*. Montreal, Canada: Secretariat of the Convention on Biological Diversity. 52 p.
64. Singh, M., Ouedraogo, M. & Kagabo, D., 2023. *El Niño 2023-2024 status and its possible impact on food security in the African continent*. Alliance Bioversity International & CIAT, Dakar, Senegal. 6 p.
65. Smith, J. & Hitz, S., 2003. 'Estimation des impacts mondiaux du changement climatique', *Document d'information*. Organisation de coopération et de développement économiques (OCDE), Paris. Available on : http://www.oecd.org/dataoecd/9/60/2482270.pdf or http://www.oecd.org/env/cc.
66. Sokal, R.R., Oden, N.L. & Thomson, B.A., 2012. 'A Problem with Synthetic Maps', *Human Biology*, vol. 84, no. 5, pp. 609–621. doi:10.1353/hub.2012.a503922.
67. Sukhdev, P., Wittmer, H. & Miller, D., 2014. 'The Economics of Ecosystems and Biodiversity (TEEB): Challenges and Responses', dans Helm, D. & Hepburn, C. (éds.), *Nature in the Balance: The Economics of Biodiversity*. Oxford: Oxford University Press, pp. 1–15.

68. Sultan, B. & Gaetani, M., 2016. 'Agriculture in West Africa in the twenty-first century: Climate change and impacts scenarios, and potential for adaptation', *Frontiers in Plant Science*, vol. 7, p. 1262. doi:10.3389/fpls.2016.01262.
69. Svoboda, M.D. & Fuchs, B.A., 2016. *Manuel d'indicateurs et d'indices de sécheresse*, vol. 2. Genève, Suisse : Organisation météorologique mondiale. 53 p.
70. Sylla, M.B., Nikiema, P.M., Gibba, P., Kebe, I. & Klutse, N.A.B., 2016. 'Climate Change over West Africa: Recent Trends and Future Projections', dans *Adaptation to Climate Change and Variability in Rural West Africa*, Yaro, J. & Hesselberg, J. (eds), *Springer, Cham.* doi:10.1007/978-3-319-31499-0_3.
71. Thornthwaite, C.W. & Mather, J.R., 1955. 'The water budget and its use in irrigation', dans *Water—Yearbook of Agriculture 1955*, A. Stefferud (éd.), U.S. Department of Agriculture, pp. 346–358.
72. Trenberth, K.E. & Shea, D.J., 2005. 'Relationships between precipitation and evaporation', *Journal of Climate*, vol. 18, no. 21, pp. 4890–4902. doi:10.1175/JCLI3562.1.
73. United Nations Environment Programme (UNEP), 2007. *Annual Report 2007*. Nairobi: United Nations. 82p.
74. Vissin, E.W., 2017. *Impact de la variabilité climatique et de la dynamique des états de surface sur les écoulements du bassin béninois du fleuve Niger*. Thèse de Doctorat, Université de Bourgogne. 258 p.
75. World Health Organisation (WHO), 2024. *El Niño Southern Oscillation (ENSO)*. World Health Organisation. Online Access on 29/11/204 https://www.who.int/news-room/fact-sheets/detail/el-nino-southern-oscillation-%28enso%29?utm_source=chatgpt.com
76. Yang, Z., Gao, X., Lei, J., Meng, X. & Zhou, N., 2022. 'Analysis of spatiotemporal changes and driving factors of desertification in the Africa Sahel', *CATENA*, vol. 213, p. 106213. doi:10.1016/j.catena.2022.106213.
77. Zeng, X., Lu, H. & Zhang, J., 2020. 'Impacts of Climate Change on African Precipitation Patterns', *Climate Dynamics*, vol. 54, pp. 3951–3965. doi:10.1007/s00382-019-05188-2.
78. Zhou, C., Yu, Y. & Li, J., 2016. 'Temperature plateau in East Asia: Dynamics and Implications', *Climatic Change*, vol. 134, no. 2, pp. 349–361. doi:10.1007/s10584-016-1594-x.