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Land Surface Phenology for Africa - A Case of the Republic of Ghana

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Abstract: Understanding Earth's surface phenology at different spatiotemporal scales is fundamental in evaluating the interaction between biogeographical distributions and climate dynamics. Despite remarkable achievements in remote sensing and Earth-observing technologies, there is a deficiency of African studies in land surface phenology (LSP). The article is a case of Ghana synthesizing studies of LSP between 2000 and 2024 using a systematic review and meta-analysis method. In a systemic review of the literature using the PRISMA protocol, this article critically examines methodological frameworks, spatiotemporal patterns, and drivers of LSP in diverse ecological zones of Ghana. The results indicate large discrepancies in ecological zone-based phenomenological patterns driven by climate variability, land use/cover change, and human pressures regarding deforestation, urban expansion, and agriculture expansion. Remote sensing observations using MODIS and Landsat imagery have been crucial in observing such processes, yet there is a limitation in using ground observations to gain better precision. Temperature and precipitation patterns indicate a trend in vegetation cycles such as the advancing start of the growing season and shortening vegetation duration of growth, having implications for biodiversity and agriculture productivity. In addition, extreme events in terms of heatwaves and droughts have heightened phenomenological anomalies. The article recommends more efficient remote sensing approaches, climate-resilient land management approaches, and environmentally friendly policy interventions to mitigate their impact. Future studies need to use high-resolution satellite observations in combination with local ground observations to calibrate models of LSP to provide useful information to support environmentally friendly management approaches and policy making. The article addresses knowledge gaps in African ecosystem processes and facilitates strategies to meet Sustainable Development Goals (SDGs).

Keywords Land Surface Phenology, Remote Sensing, Climate Change, Ecosystem Dynamics, Sub-Saharan Africa, Systematic Review

1 Introduction

1.1 Background of the Study

Land Surface Phenology (LSP) is one of the key areas of knowledge that yields in-depth knowledge of how various ecosystems cope with a large range of environmental transformations in reliance on remote sensing technologies to systematically monitor and assess vegetation patterns over a large period (Adole et al., 2018a; Alemu & Henebry, 2017; Cho et al., 2017). In the African continent that is home to a large range of diverse ecosystems in existence in the face of heightened anthropogenic pressures in conjunction with high climate volatility, studies that treat LSP become of great concern and paramount significance in ecological response (Cho et al., 2017; Alemu and Henebry 2017; Brown et al. 2010; Adole et al., 2017). Nevertheless, a large percentage of the existing body of work is mainly founded on datasets that comprise coarse spatial resolutions, thus sacrificing the range of precision and accuracy required to be utilized to effectively treat challenges that arise at local scales (Guan et al., 2014; Adole et al., 2018b).

Recent advancements in medium-resolution Enhanced Vegetation Index (EVI) availability and application of Moderate Resolution Imaging Spectroradiometer (MODIS) have tremendously eased the ability to undertake more advanced and detailed analysis of LSP, hence disentangling heterogeneous patterns of phenology that predominate across varied landscapes of the continent (Mechiche-Alami & Abdi, 2020; Fensholt et al., 2015; Torgbor et al., 2022; van Blerk et al. 2024). Such technologies present useful possibilities to better inform ecosystem processes, crucial in designing sustainable management strategies that can accommodate the multifaceted nature of environmental change (Shi et al., 2023). However, it is noted that there are large gaps that continue to exist in the body of work, namely in incorporating observational evidence on the ground, disentangling effects of climate change from anthropogenic drivers, as well as in the need to rectify large under-representation of ecological diversity of Africa in existing studies (Adole, 2018; Yan et al., 2017; Matongera et al., 2021).

1.2 Problem Statement

Notwithstanding its immense potential, research in Land Surface Phenomena (LSP) in the African continent is riddled with a multitude of daunting challenges that impede their progression and usefulness in offering useful knowledge (Adole et al., 2018a; Fengshan et al., 2017; Adole et al., 2017; Revermann et al., 2016). Among such challenges are methodological deficiencies like coarse-resolution datasets in particular. Such datasets present a serious challenge to a deep understanding of local vegetation patterns and patterns of variance that are fundamental in making accurate ecological inferences (Fengshan et al., 2017). Moreover, incorporating remote sensing observations with ground observations is a process of great significance in attaining a total picture of phenomena in nature; yet such a process is largely untapped owing to a multitude of technical and logistically oriented challenges that continue to prevail in the sector (Adole et al., 2018b; Shi et al., 2023). Conversely, there is a serious lacuna in knowledge concerning the complex interaction between variance in climate, land use changes, and respective patterns of phenology, a lacuna in a synoptic analysis that has been brought to the fore by Alemu and Henebry (2017) and is a lacuna in existing knowledge in respect to such related variables in nature.

The diverse ecological settings of Ghana encompassing coastal savannas, forest transition areas, and high tropical rainforest biodiversity supply a unique and enriching background to study and treat the aforementioned issues in LSP studies (Antwi et al., 2014; Osei et al., 2023; Gomez-Dans et al., 2022; Avtar et al., 2022; Oguntunde and van de Giesen, 2004; Owusu et al., 2013). With such a realistic yet diverse ecological background, this work endeavours to supply region-specific knowledge applicable not only to Ghana but also to the entire body of knowledge regarding LSP studies in the African continent.

Ordinarily, challenges in undertaking studies of LSP in Africa, in particular in consideration of the ecological diversity of Ghana, underscore the necessity of new methodological approaches and cooperative efforts to bridge existing knowledge gaps to better understand land surface dynamics.

1.3 Research Objectives, Hypotheses, and Methods Preview

This scholarly inquiry critically examines multifaceted drivers and consequential impacts associated with the dynamics of Land Surface Phenology (LSP) in the case of Ghana, a nation that is characterized by its varied ecological landscapes and climatic patterns. The specific objectives of this in-depth inquiry are set forth as follows:

Design and strictly validate sound methods to LSP, this inquiry attempts to synthesize two decades of literature review evidence between the years 2000 to 2024 seamlessly with empirical analysis of evidence in a quest to dramatically raise the precision and credibility of resulting analytical outcomes of this integrated effort.

The study attempts to estimate environmental drivers that impact LSP in a systematic analysis of multifaceted relationships and impacts of climatic variables such as precipitation patterns change and patterns of temperatures, and human forces, such as profound land use changes that impact natural vegetation growth patterns and processes of phenology.

The study also attempts to determine ecosystem impacts resulting from the effects of LSP, namely in investigating and researching ways in which such phenomenological effects impact key ecosystem services such as agricultural yields, that is key to food security, and also key conservation of biodiversity that is key to ecological resilience and sustainability.

Further to that, this inquiry attempts to design adaptive approaches that take cognizance of knowledge gained in phenomenological studies, hence deriving evidence-based propositions for resilient approaches to land management that can effectively adapt to challenges brought forth by the effects of climate change and effects of vegetation dynamics and land use.

1.4 Preliminary Hypotheses

The variability of vegetation phenology in different biomes is controlled mainly by precipitation patterns in savannas, while in forest biomes it is controlled mainly by patterns of temperatures, suggesting divergent climatic controls that determine vegetation growth and development in such different biomes.

Trends in land use, caused mainly by forest removal in processes of deforestation, heavily impact indicators of Land Surface Phenology (LSP), most obviously in transitional landscapes that occur between two different biomes, in turn altering natural timings and rhythms of vegetation decline and growth in ways that carry high ecological importance.

Synthesis of integrated observations of LSP will throw light on different seasonality patterns that are inextricably associated with the effects of climate change, more specifically in the period of the last two decades, suggesting ways in which a change in environmental circumstances is determining biological processes in different ecological contexts.

1.5 Statistical Methods

The research approach used in this work is characterized by a mixed-methods design that brings together different analytical methods to support each other, hence strengthening the credibility of the results.

Time-Series Analysis: The results gained during the literature review will be thoroughly analysed using harmonic regression methods, which allow for easy identification of key phenological indicators, namely the Start of the Study (2000) and End of the Study (2024), to provide a better picture of vegetation dynamics over different time scales.

Multivariate Regression: The complex interactions between observed indicators of Land Surface Phenology (LSP) and various climatic in addition to anthropogenic variables will be explored systematically to shed more light on how different variables affect vegetation phenology over different landscapes.

Visual Analysis: The use of graphical representations and plots will allow for easy visualization of phenological patterns over different geographic areas, hence enabling the identification of particular hotspots in areas of notable changes in vegetation phenology resulting from environmental or anthropogenic variables.

1.6 Study Design

The study's design will deliberately concentrate on three different biological zones: rainforests, transitional forests, and coastal savannas. These areas together include a wide range of habitats that are essential to comprehending vegetation dynamics. To precisely document changes over time, the research will use sophisticated quantitative vegetation indices data to carefully record the various data on plant development. Additionally, local knowledge and viewpoints will be incorporated into the study framework through the complete documentation of land-use practices that may influence vegetation health and growth.

1.7 Research Significance

This thorough study carefully looks at and aims to fill important gaps in the field of Land Surface Phenomena (LSP) research, while also significantly advancing sustainable environmental management practices both within Ghana's borders and with wider international implications: In the field of Climate Adaptation, the analytical framework offered by LSP research is essential for strengthening the ability to build resilience because it skilfully identifies and clarifies the complex dynamics of climate-sensitive vegetation, which are essential for comprehending ecological responses to environmental changes (Adole et al., 2018a; Shi et al., 2023).

In the context of food security, the crucial knowledge gained from crop phenology research greatly enhances the precision of agricultural yield forecasting and guides strategic agricultural planning, thereby successfully reducing the different risks brought on by climatic variability and fluctuations (Mechiche-Alami & Abdi, 2020). Regarding Ecosystem Conservation, the results of this study provide crucial direction for safeguarding biodiversity and promoting sustainable resource use, both of which are becoming more and more crucial in light of international ecological preservation initiatives (Fensholt et al., 2015). In terms of policy development, the study's evidence-based recommendations offer priceless insights that are crucial for shaping climate and land-use policies, which in turn impact national and regional decision-making processes. This is essential for sustainable development and efficient governance (Brown et al., 2010).

All things considered, this study's diverse contributions not only fill in the gaps in the literature but also provide a strong basis for further investigation and real-world applications that might improve environmental sustainability and resilience in the face of persistent global issues.

1.8 Scope and Contributions

To derive nuanced insights into Land Surface Phenology (LSP) that can be applied not only within Ghana but also in various other contexts across the African continent, this extensive academic investigation is primarily focused on the rich and varied ecological diversity found within Ghana's geographical boundaries. The research's two-decade temporal framework, from 2000 to 2024, allows for the identification and analysis of important long-term ecological trends, and the data gathered from a literature review carried out during that time frame guarantees that the findings have a high level of current relevance and applicability to the state of the environment today. Coordinating the spatial resolutions of ground-based and satellite-derived datasets and effectively resolving any discrepancies in the definitions of phenological events are two important logistical issues that arise during the research process and are specifically addressed by the methodological strategies used for data integration. By systematically addressing these intricate problems inherent in the research, this work not only improves methodological rigor within the profession but also significantly contributes to the corpus of knowledge about Land Surface Phenology for the greater African setting.

1.9 Structure of the Paper

Introduction: This part outlines the overall background of the study, explains the main goals, and highlights the importance of the investigation to the larger scholarly conversation. It creates a thorough framework that places the study in the context of the body of knowledge already in existence, emphasizing its applicability and potential for advancement.

Literature Review: In this section, the existing literature on Land Surface Phenology (LSP) studies is thoroughly reviewed, with an emphasis on the unique opportunities and challenges that are characteristic of the African context. This helps to identify gaps in the literature that need more investigation and analysis.

Methodology: To provide a strong basis for the empirical investigation and guarantee the validity and reliability of the research findings, this section carefully explains the complex integration of various methodologies, such as the use of the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) and the application of sophisticated statistical models.

Results and Discussion: To close the gap between theoretical understanding and real-world applications, the study critically discusses the implications of its empirical findings for efficient ecosystem management and relevant policy formulation while also presenting them in an organized manner.

Conclusions and Recommendations: This last section provides a concise summary of the research's main findings and several practical suggestions tailored to stakeholders, promoting well-informed policymaking and decision-making concerning the study's main topics.

Thus, every element of the study framework is deeply entwined to form a coherent story that emphasizes how crucial it is to address the particular dynamics of the African setting within the larger LSP discourse. By using an all-encompassing approach, the research hopes to make a significant contribution to both academic literature and real-world applications, with the ultimate goal of advancing knowledge and promoting favorable results within the designated field.

1.10 Conceptual Framework and Methodology Connection

By providing a thorough connection between land surface processes (LSP), the different environmental factors that impact these processes, and the services provided by ecosystems, the theoretical framework depicted in Figure 1 highlights and emphasizes the complex and interconnected roles that each of these elements plays in influencing ecological dynamics. According to the academic publications of Adole et al. (2018b) and Fensholt et al. (2015), this conceptual framework offers a methodical approach to the selection of pertinent variables, such as precipitation patterns and changes in land use, while also directing the application of statistical analyses and field-based methodologies. These approaches together guarantee a comprehensive and multidimensional investigation of the topic. The importance of this paradigm ultimately rests in its capacity to promote a more thorough comprehension of the intricate relationships between environmental variables and ecosystem services, therefore advancing our understanding of environmental research and management.

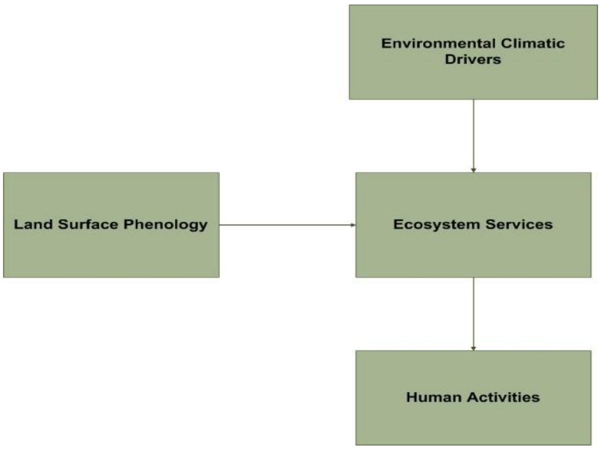

Figure1. Conceptual Framework of the Study

2 Study Area

2.1 Geography of Ghana

With the country of Côte d'Ivoire to the west, the landlocked nation of Burkina Faso to the north, the country of Togo to the east, and finally the vast waters of the Gulf of Guinea to the southernmost portion of its territory, Ghana, as depicted in Figure 2, holds a prominent geographic position in the West African region. The country's geographic coordinates, which determine its position on the earth, can be roughly defined as falling between 6 degrees North and 10 degrees 30 minutes North in latitude and between 4 and 1 degree 30 minutes West in longitudinal positioning. Ghana has a total landmass of about 23,853,900 hectares, which is a significant amount that indicates its size and potential for a variety of land uses, especially in agriculture. According to a study by Botwe et al. (2012), it is significant because around 57% of this enormous land area is categorized as arable land, highlighting the nation's potential for agricultural output and food security. This substantial share of fertile land highlights the value of Ghana's agriculture industry and how it contributes to the livelihoods of a sizable section of the populace. Therefore, conversations about regional economic growth, resource management, and environmental sustainability require a grasp of Ghana's physical setting, including its boundaries and land usage. In conclusion, Ghana's geographic location and terrain features offer both benefits and difficulties that must be taken into account in any thorough study of West African countries.

2.2 Geology of Ghana

With a wealth of geological mineral resources at its disposal, Ghana has a strikingly diverse geophysical terrain that adds to the country's overall geological complexity and diversity. Geographically speaking, the nation is located inside the West African Craton, a major geological structure that has shaped the region's geological history and evolution over millions of years. Ghana's main geographical divisions include the vast Volta Basin, the vast Northern Plains, the historically significant Ashanti-Kwahu area, which encompasses Kumasi, and the Coastal Plains, which are notably situated near the capital, Accra. According to the academic work of Lemenkova (2021), each of these discrete geological regions offers a different set of geological traits, topographical features, and varied landscapes that together affect significant geophysical parameters, such as but not limited to gravitational variations. Understanding the relationship between these geological formations and their physical characteristics is essential to comprehending the larger geophysical phenomena that take place on the land, which in turn offers important insights into the natural processes that control the geological behaviour of the area. Therefore, the complicated interrelationship between Ghana's mineral riches and its diverse geological and geophysical environments emphasizes the value of thorough geological research in clarifying the intricacies present in this West African country.

2.3 Climate of Ghana

Ghana's climate can be described as tropical equatorial, with a variety of variances that are visible in various geographical locations. The southern regions typically experience bimodal rainfall patterns, whereas the northern regions usually experience unimodal monsoon climatic patterns. The presence of the Harmattan winds, which are hot, dry, and dusty, and come from the northeast, as well as the tropical marine air mass that winds in from the southwest, greatly affects this complex climate system and the overall atmospheric dynamics in the area. There is significant variation in Ghana's annual precipitation, with rainfall ranging from 1015 millimeters to 2300 millimeters, and the country's average temperature is a notable 30 degrees Celsius with an average relative humidity of about 80 percent (Botwe et al., 2012). According to recent scholarly research, there is a worrying pattern of steadily rising temperatures and falling precipitation, which together could trigger severe weather conditions, like protracted droughts, which would disproportionately affect the agricultural sector and jeopardize food security and livelihoods (Asare-Nuamah et al., 2019; Issahaku et al., 2016; Asante and Amuakwa-Mensah, 2015).

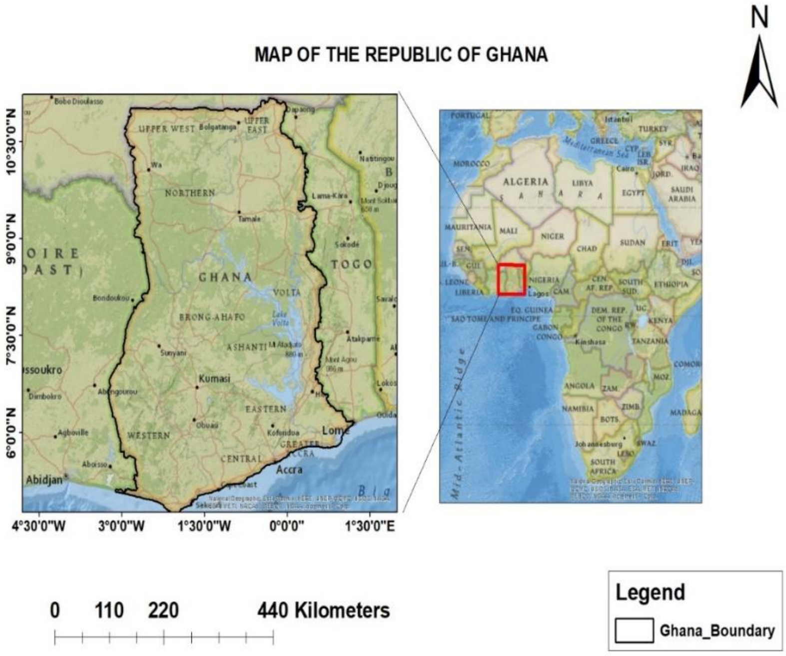

Figure 2. Study area location map

2.4 Environment of Ghana

Due in large part to the combined effects of rapid urbanization and the broader effects of climate change, Ghana is currently facing numerous urgent environmental issues, many of which are especially severe in its urban centers (van der Geest, 2011; Arndt et al. 2015). In addition to several other problems that have become more widespread in recent years, such as widespread deforestation, pollution in many forms, and the disturbing degradation of land, the nation is experiencing a concerning depletion of its natural resources. Several factors, including rapid population growth that puts further strain on already scarce resources, poor urban planning that cannot keep up with the growing demands of urban populations, and the widespread cycle of poverty that many citizens experience, all contribute to these serious problems. Furthermore, natural disasters like floods and droughts have exacerbated Ghana's environmental problems. According to Cobbinah et al. (2017) and the UNDP (2022), these events have not only had a devastating impact on local communities but have also fundamentally changed the geography of urban environments.

In addition to these difficulties, research by Ampadu (2021) and Asante and Amuakwa-Mensah (2015) has shown that the variability in rainfall patterns and temperature fluctuations has important ramifications for important industries like agriculture, the distribution and availability of water resources, and ultimately, public health. In summary, Ghana's geological and geographical features, along with its climate and environmental conditions, are characterized by a wealth of mineral resources, a diverse range of landscapes, and a tropical climate that is highly variable. These factors all contribute to the urgent environmental issues that the country is currently facing. Together, these complex elements have a significant impact on the nation's overall development trajectory and highlight the urgent need for coordinated strategies that successfully address the numerous effects of climate change and environmental degradation.

3 Materials and Methods

3.1 Search Strategy

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards, which were supported by Slayi et al. (2024), served as the foundation for the systematic review that was conducted in this study. A PRISMA framework has been included to clarify the study selection process. To ensure a comprehensive and open review process, a full PRISMA checklist was also used. We made every effort to adhere to the highest standards of systematic review technique, even though the research was not listed in a database that was open to the public. Previous evaluations have confirmed that using the PRISMA framework significantly improves the research process's clarity, accuracy, and reproducibility (Slayi et al., 2024). The two main stages of the review were the methodical search and selection of relevant literature and the careful handling and examination of the information gleaned from the selected research. This systematic methodology guaranteed a thorough assessment and laid the groundwork for further studies that aim to duplicate and expand on the results. The research technique flowchart is shown in Figure 3.

3.2 Relevance and Current State of the Investigated Topic

Following the technique described by Bettany-Saltikov (2010), this study aimed to find research that was by the Population, Exposure, and Outcomes (PEO) components of the inquiry. This first stage was essential to guaranteeing the topic's applicability and documenting the present status of land surface phenology (LSP) research.

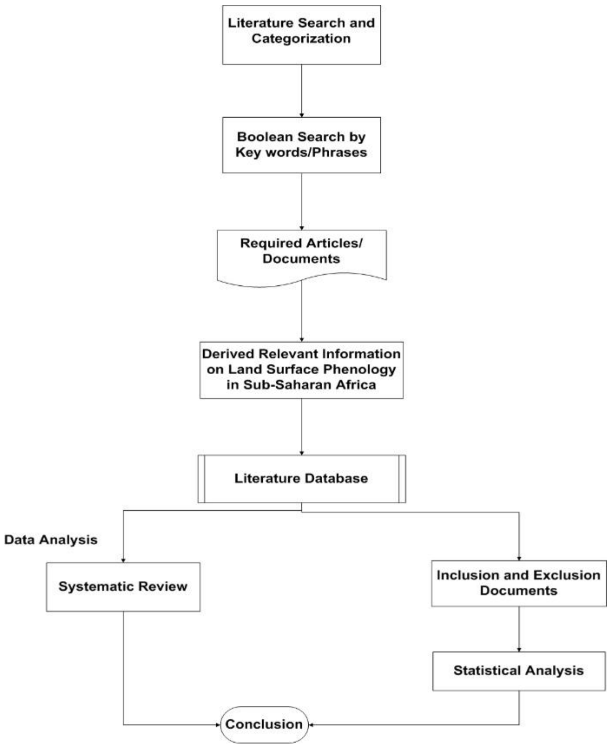

Figure 3. Literature review building, article categorization, and data analysis were adopted in this study.

To guarantee the inclusion of highly relevant research, eligibility criteria were developed. The LSP studies that looked at land degradation (LD) in sub-Saharan Africa (SSA), an area where vegetation dynamics, ecosystem resilience, and land use practices are crucial for environmental sustainability and food security, were the special focus of this review. Key causes of LD as identified by LSP measures, such as vegetation decrease brought on by soil erosion, drought, overgrazing, and issues with land tenure, were the focus of the exposure criterion. The chosen studies had to include findings about how LD affected land productivity, including changes in grazing capacity, ecosystem functionality, and phenological markers (e.g., plant green-up and senescence phases). By excluding studies that had no direct relationship to LSP techniques or were not within the SSA context, our stringent selection procedure guaranteed a targeted and pertinent synthesis. The work improves our knowledge of how vegetation dynamics reflect the causes and effects of LD by incorporating land surface phenology into this evaluation. This helps us better understand land-use changes and the sustainability of ecosystems in SSA.

3.3 Historical Literature Search

To find academic works that focus on the causes and effects of LSP in SSA, the historical literature review for this systematic study was conducted using the Web of Science, African Journal Online (AJOL), Scopus search, and Google Scholar search engines, as well as Academia.edu and ResearchGate, which are extensive multidisciplinary databases. In all, 394 papers were used in this investigation. Using the Population, Exposure, and Outcomes (PEO) paradigm, a search method was developed. "Land surface phenology," "land surface phenology in Africa," and "land surface phenology in Ghana" were the main search terms. To guarantee a comprehensive examination of the topic, these phrases were combined. Filters were applied to select only peer-reviewed journal articles, conference publications, book chapters, and review papers published in the English language to narrow down the search results, with a focus on fields related to the social sciences, agricultural and biological sciences, and environmental science. To integrate the most recent research findings, the search was further limited to papers published between 2000 and 2024. Exporting the search results to Mendeley reference management software (v1.19.8) for further screening was part of the search process. First, we carefully examined abstracts and titles in light of predetermined inclusion and exclusion standards. The full texts of the remaining publications were assessed for pertinence, and studies that did not meet these requirements were excluded. Our evaluation focused on studies that specifically looked at how LSP affects ecosystem biodiversity in Africa, Sub-Saharan Africa, the Republic of Ghana, and globally for in-depth analysis. We next extracted and assessed the quality of the data from the chosen studies to make sure the final literature compilation was reliable and relevant to the study question. According to the search investigation, some of the variables influencing LSP dynamics in Africa include both climatic and non-climatic (Adole et al., 2018a; Antwi et al., 2014; Adole et al., 2017; Adole et al., 2018b). For LSP research, data from satellite sensors was suggested as the data source.

3.4 Inclusion Criteria

To ensure the quality and relevance of the research reviewed, we carefully defined the inclusion and exclusion criteria for the selection of review articles, as shown in Table 1. To improve readability and guarantee alignment with the researchers' language competency, we limited our inclusion to English-language articles. Geographically, the review focused solely on SSA-related literature, purposefully we included other research from other areas to maintain the systematic review's emphasis. There were certain restrictions because the articles included in this study had to be completely available for download. While we acknowledge that many references are available through different online platform catalogues, access limitations did limit our ability to incorporate several potentially relevant research. Furthermore, these databases' abstracts and keywords might also provide insightful information. We recommend that a broader range of international sources be examined in future research projects to complement the typology of the subjects examined. Only studies that examined the causes and effects of LSP in the context of SSA countries and global studies were included in the analysis. Works that only focused on crops and didn't use LSP weren't included. We excluded Gray literature, such as reports and theses, unless they provided significant empirical evidence to support and confirm the study's integrity. Instead, we only included peer-reviewed journal articles, conference proceedings, book chapters, and review articles.

Table 1. Inclusion and Exclusion Criteria for the LSP Review Articles in the Order of Selection

Criteria	Included	Excluded	Justification
Language use	English	All other languages	To enhance readability and due to authors' preference
Country or Location of Study	Africa, Sub-Saharan, and Global LSP related studies	Non-LSP related studies	To be in line with the objective of the study
Article availability	Fully available articles using the Web of Science, Google Scholar search engine, Academia.edu, and ResearchGate platforms	Article not accessible	To cite the authors correctly
Date of publication	Articles published between the years (2000-2024)	1999 and below	To have the current contemporary perspective on LSP in Africa and global studies
Research Focus	Studies that included LSP	Studies focusing on solely agriculture and livestock	To be in line with the focus of the study
Type of Article	Peer-reviewed research journal articles, conference papers, book chapters, and review papers	Gray literature, including reports and thesis, unless they provided substantial information about the subject matter	To increase the validity of the research investigations

3.5 Data Extraction and Analysis

To find recurrent patterns and trends in land surface phenology (LSP) study, the data analysis employed a thematic technique. A thorough assessment of the major variables affecting LSP dynamics, their effects on land production, and the efficacy of several adaptation methods was made possible by this methodical approach. Furthermore, using terms taken from paper abstracts, a co-occurrence network and link analysis were used to investigate linkages between knowledge domains (Slayi et al., 2024). The size of the labels and circles in this framework that represented certain phrases matched their significance, which was established by how frequently they appeared in the literature. The interconnections across knowledge areas are depicted by the linkages between terms; greater correlations are indicated by concepts that are closely positioned. To capture phenological changes across multiple ecosystems, the investigation also highlighted several methodological frameworks used to evaluate LSP, taking into account various temporal and geographical dimensions. Key patterns in LSP dynamics were shown by the findings, which showed changes in vegetation cycles brought about by anthropogenic activities, land use changes, and climate change. Additionally, the study discovered important environmental factors that have a major influence on LSP patterns, including variations in temperature, precipitation, and soil moisture. Despite significant progress in LSP research, there are still significant gaps, especially in the areas of enhancing predicting models for phenological transitions and incorporating high-resolution remote sensing data. To improve land management techniques and refine mitigation solutions, these gaps must be filled.

4 Results and Discussion

4.1 Results

4.1.1 Overview of Selected Studies

Only climatic factors, such as temperature, precipitation, and vegetation photoperiod, can adequately explain patterns of land surface phenology at the continental scale (Adole et al., 2018b, Adole et al., 2016; Guan et al., 2014). However, there is considerable local variation in the timing of foliage display within biomes that cannot be attributed exclusively to the abiotic environment.

4.1.2 Literature search and study selection

Google Scholar databases covering the years 2000–2024 were searched for peer-reviewed literature. To provide a set of studies conducted across multiple continents and, consequently, provide a comparison with the set of studies in Africa, a combination of the search terms and keywords "Phenology" and "Vegetation Phenology" were used. The results were further refined with keywords such as "Africa," "Asia," "Australia," "North America," "South America," and "Europe," as well as keywords representing the major countries in the world, such as "Ghana," "USA," "UK," and "China." The papers for this review were chosen based on the following criteria:

- Publications in English
- Printed in scientific journals with peer review
- The third is the essay needs to include a main or secondary assessment of vegetation phenology.

The study's year of publication, study area, phenological assessment techniques, spatial and temporal scale, sensor types, and vegetation indices and parameters were all determined by reviewing some peer-reviewed literature on Ghanaian and African vegetation phenology based on the conceptual framework. Through a study of the literature included in the reference lists of previously included publications that assessed the vegetation phenology of Africa and met the aforementioned criteria, more studies were added to the overall collection of research.

4.1.3 Geographical distribution of studies

The first search phrases and keywords, "Phenology" and "Vegetation phenology," yielded about 394 articles. Using additional keywords to refine by geographic distribution, such as the names of continents and significant nations worldwide, Europe generated the most articles (195), followed by North America (60) and Asia (84). Only 35 papers from Africa were chosen for this evaluation since they met the previously mentioned requirements, compared to 93 and 55 articles from South America and Africa, respectively (Figure 4).

4.1.4 Publication year

Given that more than 75% of the articles were published between 2010 and 2022 (Figure 5), the findings seem to corroborate the assertion that phenological research has increased dramatically during the last ten years. Since plant phenology has been demonstrated to have a substantial correlation with climate change, this rise can be ascribed to a heightened awareness of climate change concerns on a worldwide scale. The rise in land surface phenology since 2010 is seen in this figure 5. This could be a result of growing awareness and attention to climate change throughout time

4.2 Discussions

4.2.1 Temperature Averages and Their Impact on Land Surface Phenology in Ghana

Overview of Temperature Trends (2000–2022)

The given dataset displays average temperatures from 2000 to 2022 (Figure 6), exhibiting clear patterns and trends consistent with the effects of climate change worldwide. With only minor inter-annual fluctuation, the data shows a steady rise in mean yearly temperatures. In particular, the years 2000–2010 saw mild temperatures, averaging between 26.36°C and 27.15°C every year. There were few extremes in this rather tranquil time. Temperature averages showed a significant increase trend from 2011 to 2022, rising by around 0.66°C year on average when compared to the early 2000s. This range's hottest years were noted in particular years that corresponded with more intense global warming. Ghana's land surface phenology is significantly impacted by these temperature shifts. The timing and duration of phonological events like as leaf-out, blooming, and senescence (the natural aging process of plants) can be altered by even small temperature fluctuations since vegetation development cycles are highly reliant on temperature.

4.2.2 Implications for Land Surface Phenology

An essential source of information for comprehending phenological variations is the temperature data from 2000 to 2022. The timing of phenophases is probably influenced by the interaction of higher temperatures with other climatic conditions, such as rainfall patterns. The timing of important plant life phases, such as leaf emergence and senescence, is accelerated by warmer temperatures, which causes a discrepancy between Ghana's traditional agricultural calendars and plant development cycles.

Spring Onset (Green-Up): Budburst, leaf-out, and flowering can all occur earlier in the year when temperatures are warmer in late winter and early spring. In temperate and boreal locations, where plants depend on temperature cues like cumulative growing degree days to break dormancy, this is especially noticeable (Richardson et al., 2013).

Leaf Fall (Autumn Senescence): Leaf coloring and shedding occur in fall as plants prepare for dormancy due to cooler temperatures and fewer daylight hours. By delaying senescence, warmer fall temperatures can prolong the growth season (Piao et al., 2019).

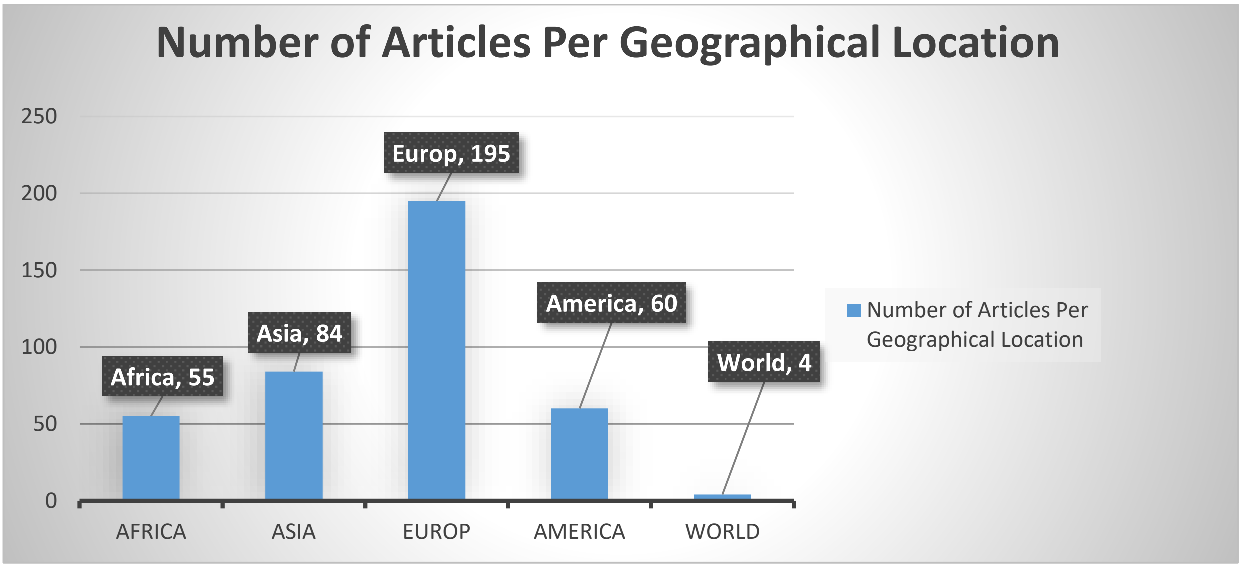

Figure 4. Number of Articles per geographical location

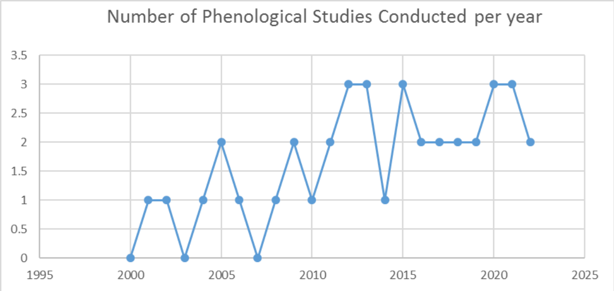

Figure 5. Plotting the number of land surface phenology papers across time in years.

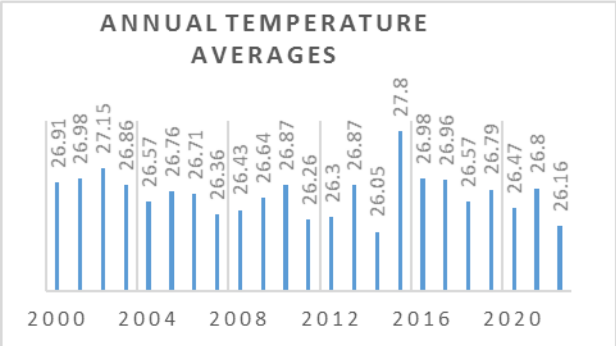

Figure 6. The chart above is the temperature annual averages from 2000 to 2022 (Source: NASA Climatic data website/https://power.larc.nasa.gov/data-access)

The dynamics of the land cover may change as a result of the dominance of some plant species that are better suited to heat stress and the decrease of others that are more susceptible to it. Reduced Productivity The temperature data shows an increase in the frequency of hot extremes and extended dry spells, which might lower net primary production (NPP) throughout Ghana's ecosystems, impacting agriculture and biodiversity. Impacts on Humans and the Environment, Agriculture Phenological changes brought on by temperature can have an impact on agricultural methods, insect dynamics, and crop production. For instance, increased spring temperatures have been associated with earlier blooming in crops like maize and wheat (IPCC, 2021). Ecosystems Phenological mismatches, such as those between pollinators and plants, might interfere with biodiversity and ecological interactions. Research on the interactions between pollinators and plants has shown.

4.2.3 Regional Variations within Ghana

The average temperature in Ghana does not rise consistently in every region. Different reactions to temperature variations are seen in savannah, woodland, and coastal zones. Although the ocean's effect somewhat reduced temperature rises in coastal zones, lengthier dry spells might still occur there. The Atlantic Ocean's moderating effect is the cause of these comparatively steady temperatures. However, extended dry spells have increased in frequency, resulting in deficiencies in soil moisture that affect wetland and mangrove plants (Owusu & Waylen, 2009). Shorter peak greenness phases and postponed green-up times are examples of phenological changes. Temperature increases have a direct effect on forest phenology, causing faster leaf-out or blooming events in forest zones that are more susceptible. more susceptible to changes in temperature, with blooming and leaf-out occurring more quickly in warmer climates (Frimpong et al., 2020). The species composition of trees has also changed as a result of increased precipitation, favouring drought-resistant species (Acheampong et al., 2014). Savannah areas. especially susceptible to warming, as rising temperatures worsen water stress and slow the regeneration of plants after rains (UNDP, 2013). This climate variability is characterized by sharp rises in temperature and intermittent precipitation (IPCC, 2021). Water stress is made worse by these circumstances, which delays the regeneration of plants after rainfall. Shorter growth seasons and more instances of plant browning have been seen in the area (Yengoh et al., 2010).

4.2.4 Inter-Regional Comparisons

Comparing Ghana's land surface phenology changes to those of other African locations dealing with comparable climatic pressures can help us better understand them:

West African Sahel: Like northern Ghana, the Sahel has seen more unpredictable rainfall and temperature swings (Taylor et al., 2002). In contrast to the parched Sahel, Ghana's coastline and woodland regions offer more consistent vegetation conditions.

Rainforests in Central Africa: The deeper rainforest canopies of Central Africa are more resilient to temperature change than the forest zone of Ghana, where phenological shifts are becoming more apparent; nonetheless, phenological stability has started to be impacted by more frequent dry spells (Ouedraogo et al., 2022).

Semi-Arid Regions of Southern Africa: Similar to Ghana's savannah, these regions experience shorter growth seasons as a result of heat stress. Phenological disturbances have been somewhat lessened, nonetheless, by conservation initiatives and adaptive farming practices.

These parallels imply that Ghana's diverse temperature zones make it a singular case study for comprehending phenological changes brought on by climate change, highlighting the necessity of specialized adaptation plans for each of its areas.

4.2.5 Seasonal and Annual Phenological Shifts in Ghana

Changing Seasons of Growth, the tropical savannah and woodland regions are where Ghana's flora mainly grows. An examination of temperature data points to a clear correlation between changes in the commencement of growing seasons and rising temperatures. For example:

Early Growth Season Initiation, particularly in areas where grasslands and crops predominate, the earlier arrival of higher temperatures in recent years (2015–2022) has probably caused earlier leaf-out and blooming events (IPCC Sixth Assessment Report (AR6, 2021).

Reduced Growth Times, it's possible that prolonged heat waves during hotter years caused moisture stress, which caused crops and natural flora to prematurely senescence. This pattern may help to explain why there have been variations in natural vegetation production and agriculture output in some years.

Influence on the productivity of vegetation, Elevated temperatures have the potential to decrease soil moisture availability by speeding up evapotranspiration, or the loss of water from plants and soil. According to satellite-based phenological research, Ghana's lower vegetation greenness indices (NDVI) correspond with certain years of excessive heat, as indicated by the temperature data on the chart.

4.2.6 Summary of Key Findings on Temperature (2000–2022)

Ghana's temperature averages from 2000 to 2022 show a slow warming trend, which has important ramifications for the phenology of the land surface. Changes in vegetation cycles, such as earlier growing season start, shorter growth periods, and increased vegetation stress in hotter years, are probably the result of rising temperatures. These results demonstrate how important it is to include temperature information in phenological models to forecast future vegetation dynamics and create flexible agricultural and environmental management plans for Ghana.

4.2.7 Precipitation Averages and Their Impact on Land Surface Phenology In Ghana

Based on yearly averages, the graph shows Ghana's precipitation patterns from 2000 to 2022 (Figure 7). Important findings include: Overall Increasing tendency: The numbers indicate a general upward tendency over time, which may be the result of climatic changes causing changes in phenological patterns. Periods of Stability and Fluctuation: From 2000 to 2005, for example, there were periods of relative stability. After 2017, there are notable increases that peak in 2022. Recent Surge: The sharp increase in values between 2018 and 2022 may point to a more severe climate change, which may be caused by modifications to the environment or policies.

4.2.8 Implications for Land Surface Phenology in Ghana

Plant Growth: In general, more precipitation promotes plant growth, which influences land surface phenology, including productivity and greening phases. Risks of Flooding Increased precipitation might cause floods, which would affect natural ecosystems and agricultural land. Correlation with Climate Change: The increased tendency may be consistent with more general climate changes, which highlights the significance of keeping an eye on such changes.

4.2.9 Summary of Key Findings on Precipitation (2000–2022)

Overall Trend of Increase, Throughout the research period, Ghana's precipitation has generally increased, with major increases occurring after 2017, which may indicate climate changes. Times of Stability, relatively stable periods, as those from 2000 to 2005, show that rainfall patterns varied little throughout that time. Recent Increases, Precipitation increased significantly between 2018 and 2022, reaching a high in that year. Increased climatic dynamics or policy changes may be the cause of this spike. Influence on phenology, Changes in vegetation growth cycles and other phenological shifts are in line with the rising rainfall. In water-stressed areas, the combination of higher temperatures and more precipitation may cause growing seasons to begin sooner or recovery to be delayed (IPCC, 2021). Variability by Region, Different reactions to variations in precipitation are seen in the savannah, woodland, and coastal zones: Savannah zones have a slower rate of vegetation regrowth after rains and are extremely susceptible to changes. Increased rainfall helps forest zones, although temperature-driven phenological changes still have an impact.

4.2.10 Correlation of Precipitation and Temperature Trends

Earlier Growing Seasons: As precipitation increased after 2017, rising temperatures probably accelerated the emergence of warmer conditions. The timing of vegetation phenophases like blooming and leaf-out may have changed as a result.

Reduced Growing Times: Extended heat waves during hotter years coupled with erratic precipitation may cause moisture stress, which might hasten senescence.

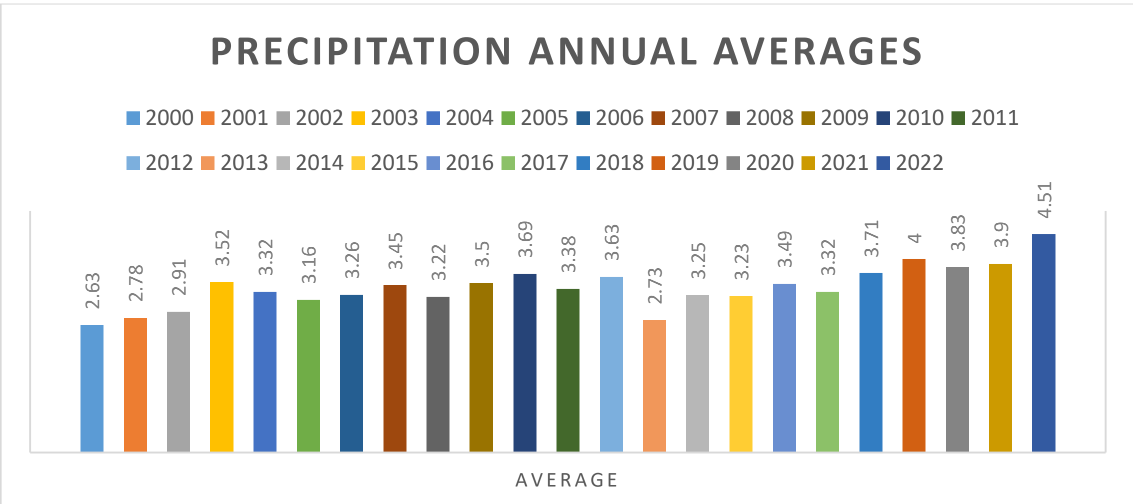

Figure 7. The chart above shows the temperature annual averages from 2000 to 2022. (Source: NASA Climatic data website/https://power.larc.nasa.gov/data-access)

Increased Evapotranspiration: Warmer temperatures may have caused plants and soil to lose water more quickly, requiring more precipitation to support vegetation. These consequences may have been lessened in part by the increase in rainfall after 2017.

Regional Impacts: Ghana's savannah, woodland, and coastal regions show different reactions. Savannah zones are especially susceptible to the combined impacts of rising temperatures and erratic precipitation, which slows the regrowth of plants following precipitation. Phenological changes in forest zones are closely related to variations in rainfall and temperature.

Vegetation production: Net primary production (NPP) is impacted by the interaction of increasing temperatures and varying rainfall. For instance, vegetative stress and lower greenness indices might result from hot spells and little precipitation.

Indicators of Climate Variability: The recent increase in precipitation may indicate climate system shifts that are connected to regional or global atmospheric dynamics.

4.2.11 Other Phenological Patterns

SOS and EOS Trends: In wooded areas, the SOS has advanced by an average of 1.5 days per ten years, but in savannah regions, the SOS has advanced by an average of 2 days every decade. Overall, the LOS was prolonged due to a modest expansion of the EOS in the savannah regions (Jönsson et al., 2010).

Peak Greenness: Peak NDVI values showed a 3% decrease in agricultural fields and a 5% rise in forested regions, indicating deterioration in managed lands but enhanced vegetation productivity in natural ecosystems (Cai et al., 2017).

Across the whole nation, we found a broad correlation between photoperiod and LSP characteristics. One reason for this might be because the most reliable environmental signal from year to year is photoperiod (Borchert et al., 2005; Jolly et al., 2005). Because of this consistency, plants could be more likely to control their development by relying on certain day-duration signals (Kouressy et al., 2008). According to (Adole, 2018), preseason photoperiod increases of more than 12 hours are often linked to later SOS and earlier EOS, whereas increases of more than 10 hours were linked to earlier SOS and later EOS.

Similarly, earlier SOS and later EOS were linked to lower preseason photoperiods of less than 12 hours throughout Africa. Therefore, a longer day length of more than 12 hours may be thought to delay the start of the vegetation growing season and induce dormancy, whereas a shorter day length of less than 12 hours but more than 10 hours may cause SOS and postpone EOS. There have been prior reports of this noticeable shift in how plants react to little variations in photoperiods of two hours or less (Borchert & Rivera, 2001; Rivera & Borchert, 2001; Rivera et al., 2002).

An "endogenous time-keeping mechanism called the circadian clock" (Jackson, 2009) and photoreceptors' detection of light signals have been credited with plants' exceptional capacity to sense light and estimate time (Singh et al., 2017). However, as suggested by Richardson et al. (2013) and Way & Montgomery (2015), further research is necessary to fully understand how this mechanism functions, particularly in various plant species.

4.2.12 Socio-economic factors that influence land surface phenology

The results show that logging, population expansion, deforestation, overgrazing, urbanization, and infrastructure development are the socioeconomic drivers influencing land surface phenology in Ghana. These results align with those of earlier research conducted in Ghana. One important human activity that significantly contributes to Ghana's declining forest cover is logging. Chainsaw logging can have far more detrimental effects on biodiversity and forest cover than traditional logging. To protect the woods, chainsaw logging was outlawed in Ghana in 1998.

Additionally, the conversion of forest cover to other land cover classes is significantly impacted by population growth, especially in sub-Saharan Africa. This is because the need for fuel wood and agricultural land rises in tandem with population growth. Deforestation is another contributing reason. 60% of all tropical deforestation activities are thought to be caused by the development of farmland. Another important factor contributing to deforestation was identified as slash-and-burn agriculture. To boost Ghana's economic independence, the bulk of its forest areas have been removed for cocoa farming and wood exploitation. This has significant ramifications for the nation's woods' biotic and social integrity. The majority of responders also cited overgrazing as a contributing cause. Although it may be difficult in wooded places to peel tree bark for animal feed or fodder, this is not the main reason why trees are felled. The social phenomenon known as the "tragedy of the commons" makes overgrazing worse. The rural population tries to improve the forestlands by raising as many animals as they can while also distributing them. As a result, there are more animals than the land can support.

To prevent grasslands from becoming barren ground, the animals remove the plants, and the winds finish the job by sweeping away the topsoil. One socioeconomic factor contributing to Ghana's changing land surface phenology is urbanization and infrastructure development. To provide the infrastructure necessary to support the growing population, developing villages and towns surrounding the forest reserve require land, which is typically accomplished by clear-cutting. Road building opens up the area to development and attracts a large number of people to the woodland boundary. To access the forest for subsistence land, these immigrants typically build a colony there by using newly constructed roads or logging routes. Because the removal of internationally significant carbon sinks from tropical forests contributes to 20% of anthropogenic carbon emissions, the expansion of infrastructure projects is a cause for concern on a worldwide scale.

4.2.13 Land Cover Change Impacts

Significant phenological changes, such as delayed SOS and lower peak NDVI values, were brought about by agricultural growth, especially in northern Ghana (Yengoh et al., 2010). Higher peak greenness and better SOS were two benefits of reforestation activities in the southern zones (Acheampong et al., 2014).

4.2.14 Extreme Weather Events and Their Impact

Extreme weather occurrences, including heat waves, droughts, and periods of heavy precipitation, have become more frequent in Ghana (Peprah, 2022). The following are some important ways that these events affect land surface phenology (Figure 8):

Heatwaves: Extended hot weather speeds up evapotranspiration, which lowers soil moisture and stresses plants. Crop productivity and biodiversity are impacted by this early senescence (Zhang et al., 2013).

Droughts: Prolonged dry spells, especially in the northern and savannah areas, interfere with regular phenological cycles, reducing growth seasons and delaying green-up.

According to satellite-based phenological research, the increased frequency of drought occurrences corresponds with drops in NDVI (Funk et al., 2015). The Ministry of Food and Agriculture reports that 435,872 farmers who cultivate an estimated 8871,745 hectares have been adversely affected by the drought. The most impacted crops in the country's north were major crops such as maize, rice, groundnuts, soybeans, sorghum, millet, and yam. Furthermore, farmers have reported losses of GHC 3.5 billion, with a potential loss of GHC 10.4 billion in revenue. Approximately 62% of the nation's yearly grain output comes from the northern region. Approximately 4.45 million acres, or 1.8 million hectares, of land, are in danger. Bryan Acheampong, the then-minister of agriculture, responded by declaring a temporary restriction on the export of grains, including rice, soybeans, and maize, that would take effect immediately. At a press briefing on August 26, 2024, Bryan Acheampong said, "We are forecasting a significant shortfall in grain availability, without any interventions this could lead to a nationwide food shortage" (General News, Tuesday, 27 August 2024; www.ghanaweb.com).

Flooding and Heavy Rainfall: Although more precipitation can promote the development of flora, too much rainfall damages roots and causes soil erosion. Flooding events have disrupted seasonal greening cycles in low-lying forest regions and along the coast. In places like Accra and Tamale, there is severe flooding that interferes with people's ability to move around and disturbs their daily routines in several ways (Figure 9). The influence on road and transportation infrastructure is examined first, followed by the everyday mobility issues that inhabitants encounter and, finally, the coping and adaptation measures that they employ. Road and transportation infrastructure disruption the mobility patterns and activities of urban dwellers are significantly influenced by the state of the roads and the kind of transportation infrastructure. Prior research has demonstrated how floods impact the road network, leading to disruptions in mobility and service. The most frequent obstacles to mobility for low-income urban dwellers are flooded surfaces and impassable roadways. The majority of flood-related injuries and fatalities happen when people try to cross the water, either on foot or in a car.

Figure 8. Images showing drought-affected areas in northern Ghana (Source Ghanaweb.com)

Figure 9. Images showing flood event and High flood line evident on buildings in study communities in Accra (Source: Amankwah et al., 2022)

4.2.15 Uncertainty in Temperature and Precipitation Trends

Data Collection Methods: Disparities in measuring methods, sensor kinds, and satellite resolutions lead to variability in temperature and precipitation data (Hersbach et al., 2020). Temporal and Spatial Coverage: Incomplete datasets may result from biases or gaps in climate records, especially in distant locations. Annual Variability Between Years, El Niño and La Niña are examples of natural climatic oscillations that cause changes that make trend analysis more difficult.

4.2.16 Uncertainty in Phenological Projections

Sensitivity of the Model to Inputs: Phenological models depend on NDVI, temperature, and precipitation data, all of which are prone to measurement mistakes. Plant Response Variability: Predictive models become more complicated as a result of the distinct ways that various plant species and ecosystems respond to changes in the environment (Richardson et al., 2013). Prospective Climate Situations: Long-term projections are unclear as they rely on greenhouse gas emission pathways and climate policy decisions (IPCC, 2021).

4.2.17 Statistical and Methodological Uncertainties

Limitations of the Vegetation Index: According to Yengoh et al. (2010), NDVI and other remote sensing indices might not accurately reflect changes in biomass or plant health. Changes in Land Use: Additional factors that impact phenology are introduced by anthropogenic activities like urbanization and deforestation. Feedback Loops: Complex feedback processes that may not be completely understood are a part of climate-vegetation interactions (Piao et al., 2019).

5 Conclusion and Recommendations

5.1 Conclusion

5.1.1 Key Findings

Summary of Key Findings:

The study shows notable inter-zonal variations in land surface phenology (LSP) throughout Ghana, which are caused by anthropogenic pressures, land-use changes, and climate variability. Remote sensing data, especially from MODIS and Landsat, has been crucial in tracking phenological dynamics, but there are still issues integrating ground-based observations with satellite data. Trends in temperature and precipitation from 2000 to 2022 indicate a gradual warming trend and increasing rainfall variability, which have caused changes in vegetation cycles, including earlier growing season onset and shorter growth periods.

LSP has been greatly impacted by socioeconomic issues, especially in savannah and woodland areas, such as logging, population increase, deforestation, and urbanization. Phenological changes have been made worse by extreme weather events, such as heat waves, droughts, and heavy rains, which have an effect on ecosystem health and agricultural output.

Implications for Environmental Monitoring:

The results highlight how crucial it is to continuously monitor LSP in order to comprehend how human activity and climate change affect vegetation dynamics. Improved monitoring can aid in forecasting changes in growing seasons, which is essential for food security and agricultural planning.

The study emphasizes the necessity of adaptive land management techniques to lessen the impact of climate change on ecosystems, especially in areas that are already at risk, such as Ghana's northern regions and the savannah.

Methodological Aspects:

To evaluate LSP dynamics, the study used a mixed-approaches strategy that included time-series analysis, multivariate regression, and visual analysis. Although data from remote sensing provide insightful information, integrating ground-based observations is still difficult, especially in areas with little infrastructure. More localized research is required to capture fine-scale fluctuations, although the accuracy of LSP forecasts can be increased by using high-resolution satellite data and sophisticated statistical models.

5.2 Recommendations

5.2.1 Research Gaps

Integration of Ground-Based and Satellite Data: To increase the precision of LSP models, further research is required that combines ground-based observations with satellite data. Effect of Socioeconomic variables: To measure the influence of socioeconomic variables such urbanization, deforestation, and agricultural growth on LSP, further study is required.

Long-Term Phenological Trends: To comprehend the combined effects of land-use changes and climate change on LSP throughout many biological zones, further long-term research is needed. Extreme Weather Events: Research should focus on the unique implications of extreme weather events, such as droughts and floods, on phenological patterns and vegetation health.

5.2.2 Research Directions

Localized investigations: Future study should focus on localized investigations to capture fine-scale differences in LSP, particularly in locations with considerable ecological variety.

Cross-Regional Comparisons: Comparative research across different African areas can give insights on how LSP reacts to comparable climate stresses in different ecological contexts. Phenological measures: To increase comparability and consistency in LSP investigations, phenological measures that can be used in many environments must be developed and standardized.

Climate-Resilient Agriculture: To guarantee food security, research should examine the creation of climate-resilient farming methods that adapt to changing phenological patterns.

5.2.3 Methodological Improvements

Ground-Based Validation: Adding more ground-based observation stations, especially in remote and understudied regions, can improve the validation of satellite-derived LSP data.

High-Resolution Remote Sensing: Using high-resolution satellite data, like Sentinel-2, can improve the precision of LSP monitoring, especially in heterogeneous landscapes.

Advanced Statistical Models: Adding machine learning and artificial intelligence to LSP models can improve the ability to predict phenological shifts under various climate scenarios.

Temporal and Spatial Scaling: Creating methods that can efficiently scale LSP data from local to regional levels will be essential for more comprehensive ecological assessments.

5.2.4 Policy Implications

Sustainable Land Management: To lessen the negative effects of urbanization, overgrazing, and deforestation on LSP, policymakers should give priority to sustainable land management techniques.

Climate Adaptation methods: In order to adjust to changing phenological patterns, the results of this study can help design methods for climate adaptation, especially in agriculture.

Environmental Monitoring Programs: To help guide policy choices, governments and environmental organizations should fund long-term environmental monitoring initiatives that study LSP and its drivers.

Community Engagement: Policies ought to promote community involvement in conservation initiatives, especially in areas where regional customs have a major influence on LSP.

Disaster Preparedness: Policies should prioritize disaster preparedness and resilience-building, especially in sensitive areas like northern Ghana, given the rising frequency of extreme weather occurrences.

Declaration

Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article

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