

Satellite-Based Vegetation Monitoring for Sustainable Development in Plateau State

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ARTICLE INFORMATION	ABSTRACT
Article history: Published: October 2026 Keywords: NDVI MODIS Vegetation Dynamics Plateau State Remote Sensing Sustainable Development	Plateau State, in Nigeria's North-Central zone, is characterized by the Northern Guinea Savanna and the distinctive Jos Plateau forest-savanna mosaic. Its high altitude, near-temperate climate (13°C to 22°C), and role as the source of major northern rivers make its vegetation critical for biodiversity, climate regulation, and livelihoods. This vegetation, mainly open grassland with scattered trees, is increasingly transformed by mining, urbanization, agriculture, and climate change, with implications for ecological stability and food security. This study provides a systematic 25-year assessment of vegetation dynamics using Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data at 250m resolution from January 2001 to December 2025. Data were obtained from the FAO GAUL/2015 Level 1 dataset via Google Earth Engine. Cloud masking and scaling were applied, and annual dry-season mean composites were computed. Annual average NDVI, overall monthly average NDVI, and grand average NDVI were calculated to determine overall status, interannual variability, long-term trends, seasonal patterns, and periods of accelerated decline or stability. Results show moderate overall cover with a grand average annual NDVI of 0.384, indicating a balanced yet vulnerable ecosystem. Interannual variability was narrow, ranging from 0.3638 to 0.4046, reflecting resilience but high sensitivity to stress. No strong consistent linear trend was observed; vegetation oscillated around the mean, suggesting recovery after episodic stress. A net change of -0.015 between 2001 and 2025 was small and within natural variability. Strong seasonality, the heartbeat of the region, was delineated: lowest NDVI in the dry season (Jan-Mar, March: 0.2489), rapid growth in April-June (June: 0.4434), peak abundance in September-October (October: 0.5749), and decline in November-December (December: 0.3458). Episodic declines occurred in 2014-2015, 2019-2022, and 2023-2024, with lower values more frequent in recent years. The findings underscore a resilient but increasingly vulnerable ecosystem requiring adaptive management, climate-smart agriculture, water conservation, and integration of high-resolution remote sensing with ground validation.

1. Introduction

The ecological health of Plateau State, Nigeria, a region critical for both biodiversity and local livelihoods, is profoundly shaped by its vegetation cover (Ephraim, 2025), which is crucial for ecosystem health and influences climate and biodiversity. Both natural and human activities, such as mining and urbanization, drive significant land-use changes that can negatively affect biodiversity and quality of life (Fernández et al., 2025; Shang et al., 2025).

Accurate monitoring of these changes is essential for sustainable development. Global and local factors, including anthropogenic activities like mining and urbanization, drive significant changes in land use and vegetation (Wang et al., 2025; da Penha Pacheco et al., 2025). Remote sensing, particularly the Normalized Difference Vegetation Index (NDVI), provides an essential tool for monitoring these shifts. This study uses 25 years of MODIS NDVI data (2001-2025) to meticulously analyze vegetation dynamics in Plateau State, aiming to understand its overall status, interannual variability, and seasonal patterns, which are vital for sustainable development and resource management.

Plateau State is in Nigeria's North Central geopolitical zone (Wuyep & Madaki, 2020). Its ecological zone is predominantly Northern Guinea Savannah, featuring the distinctive Jos Plateau forest-savanna mosaic (One Earth, 2024; Sayre et al., 2013). The state's high altitude contributes to a unique near-temperate climate, with average temperatures ranging from 13°C to 22°C, making it much cooler than the rest of the country (Abaje & Oladipo, 2019; Yohanna et al., 2022). The vegetation consists mainly of open grassland and scattered trees, significantly altered by human activities like mining and agriculture (Dung-Gwom & Ocholi, 2021; Mwansat et al., 2011). Additionally, Plateau State is the source of several major rivers in northern Nigeria (Gyang & Pam, 2026).

This study aims to investigate the vegetation dynamics of Plateau State, its overall status, interannual variability, and seasonal patterns, which are vital for sustainable development and resource management.

1.1 Research Gap

While general vegetation studies exist, there is a need for a systematic, long-term analysis of Plateau State's vegetation health using MODIS NDVI data to characterize interannual variability, long-term trends, and specific periods of change over 25 years (2001-2025).

1.2 Problem Statement

The vegetation of Plateau State is undergoing profound transformations, driven by human actions and climate change. These changes have significant implications for the state's ecological stability, food security, and community resilience. Despite the importance of this issue, its overall status, long-term trends, seasonal patterns, and specific periods of decline or stability over the past 25 years remain unclear. Understanding these dynamics is vital for effective environmental and resource management.

1.3. Aim and Objectives

1.3.1 Aim

This study aims to systematically analyze and evaluate the overall vegetation status and its dynamics in Plateau State using MODIS NDVI data from 2001 to 2025.

1.3.2 Specific Objectives:

1. To determine the overall vegetation status (average annual NDVI),
2. Characterize interannual variability in vegetation cover,
3. Identify long-term trends (increase, decrease, or stability) in annual average NDVI.
4. Delineate distinct seasonal patterns of vegetation,
5. Determine specific periods of accelerated decline or stability in vegetation cover.

1.4 Significance of the Study

This study provides critical insights into Plateau State's ecological resilience, agricultural potential, and vulnerability to environmental shifts. It aids in developing effective land management strategies, informing climate change adaptation, supporting food security, and ensuring the socio-economic well-being of its inhabitants.

2. Methods and Materials

2.1. Location of the Study Area

Plateau State is situated in the North-Central geopolitical zone of Nigeria, nestled between latitudes 8°24'N and 10°30'N, and longitudes 8°32'E and 10°38'E (Nanvyat et al., 2017). It shares borders with Bauchi State to the northeast, Kaduna State to the northwest, Nasarawa State to the southwest, and Taraba State to the southeast.

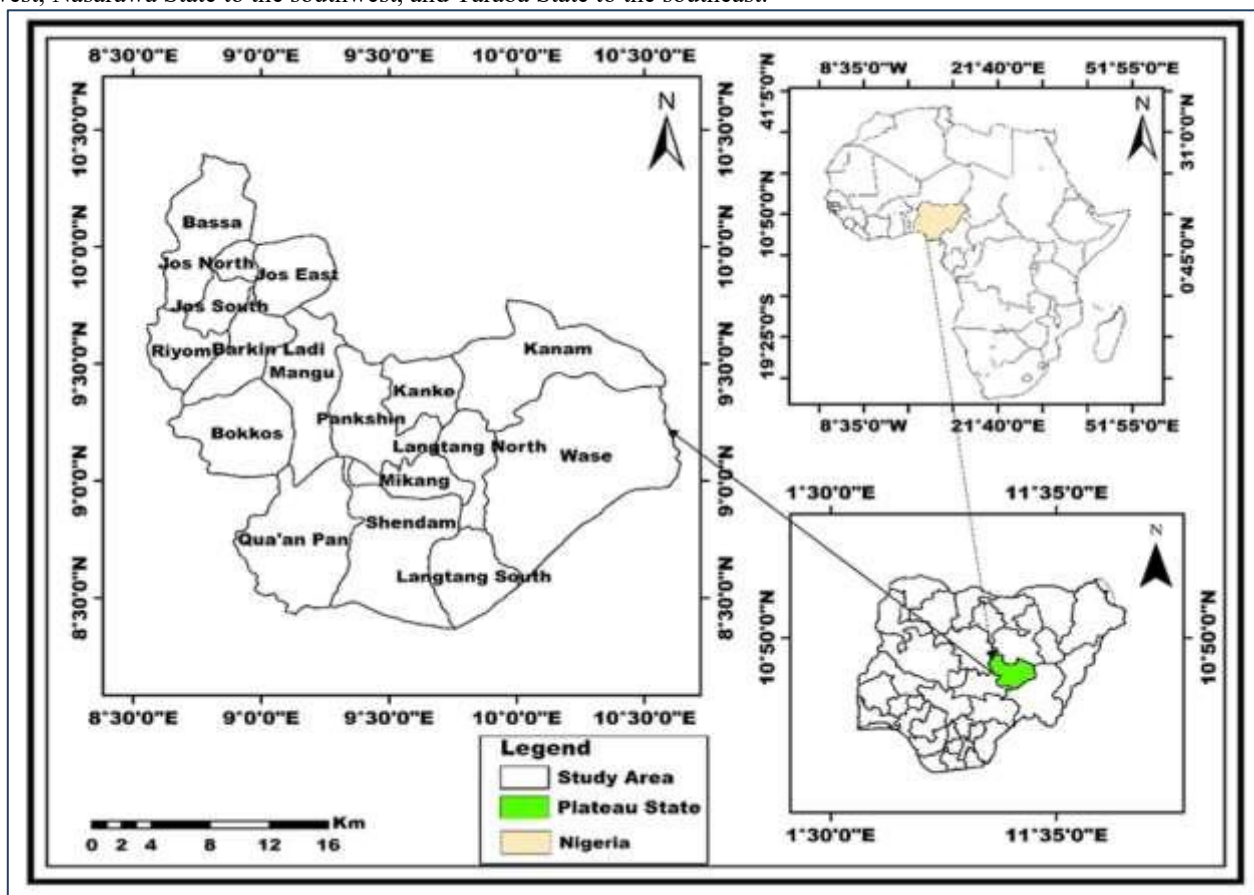


Figure 1: The map of Plateau State

2.2 Climate

The state experiences a tropical climate, characterized by two distinct seasons: a wet season (April to October) and a dry season (November to March) (Nigeria Meteorological Agency, 2022). The average annual rainfall is approximately 1,200 mm, with temperatures ranging between 18°C and.

2.3 Vegetation

The state boasts a diverse mix of savanna and montane vegetation, with the Jos Plateau supporting unique grassland types (Adeyemi et al., 2020). The vegetation consists of scattered trees, shrubs, and grasses, with areas of woodland and forest patches.

2.4 Topography and Soil

The Jos Plateau is a prominent feature, with an average elevation of 1,200 meters above sea level (Ogunmola et al., 2020). The terrain is hilly, with rocky outcrops and valleys. The soils are generally shallow, with a high concentration of tin and other minerals (Hill, 2022).

2.5 Hydrology and Drainage

The state is home to several rivers, including the Kaduna, Gongola, and Muri (Nigeria Hydrological Services Agency, 2022). The Jos Plateau is a water tower, with numerous streams and rivers draining into the surrounding lowlands.

2.6 Geology

Plateau State is underlain by Precambrian rocks, with areas of volcanic and intrusive rocks (Obi et al., 2021). The state is rich in mineral resources, including tin, coal, and granite.

2.7 Population and Socio-economic Activities

The state has a population of approximately 4.2 million people, with a mix of urban and rural communities (National Population Commission, 2021). The main economic activities are agriculture, mining, and tourism. The state is a major producer of crops such as potatoes, carrots, and vegetables (Plateau State Ministry of Agriculture, 2022).

3. Data and Materials

3.1 Data and Materials

Moderate Resolution Imaging Spectroradiometer (MODIS) satellite imagery, data at 250m resolution and coverage-km2 of January 2001 to December 31, 2025, were obtained from the FAO GAUL/2015 level 1 dataset of Google Earth Engine and used to define the study area. A cloud mask was applied, and the NDVI values were scaled. Thereafter, the annual dry-season mean NDVI composites for the state were computed, and a linear regression of the 2001-2025 NDVI time series was applied to generate per-pixel trend slope maps.

3.2 Objective details

3.2.1 Objective 1 - Overall vegetation status (average annual NDVI).

The annual NDVI was calculated as the average of the 12 monthly NDVI values for each year (2001-2025).

Annual Average NDVI (Year X) = (NDVI_Jan + NDVI_Feb + ... + NDVI_Dec) / 12 Eqn 1. Secondly, the overall monthly average NDVI was calculated by averaging the NDVI for each specific month across the entire 25-year period.

Overall Monthly Average NDVI (Specific Month) = (NDVI_SpecificMonth_Year1 + NDVI_SpecificMonth_Year2 + ... + NDVI_SpecificMonth_Year25) / 25 Eqn 2

And thirdly, overall vegetation status was determined by computing a grand average annual NDVI over the 25 years to characterize the region's vegetation cover.

Grand Average Annual NDVI = (Annual Average NDVI_2001 + Annual Average NDVI_2002 + ... + Annual Average NDVI_2025) / 25 . Eqn 3

3.2.2 Objective 2 - Interannual Variability in vegetation cover

The interannual variability was identified by noting the minimum and maximum annual average NDVI values. Minimum and maximum annual average NDVI values, along with their corresponding years, were identified to quantify year-to-year fluctuations. Minimum Annual Average NDVI was quantified by finding the lowest value among all the calculated Annual Average NDVI values (from 2001 to 2025), and the Maximum Annual Average NDVI by finding the highest value among all the calculated Annual Average NDVI values (from 2001 to 2025).

3.2.3 Objective 3 - Long-Term Trend Observation (increase, decrease, or stability) in annual average NDVI

Long-term trends were qualitatively assessed by visually inspecting the annual NDVI time series for consistent changes to identify the presence or absence of a strong, consistent linear trend (increasing or decreasing). Emphasis was placed on observing oscillations around the overall mean.

3.2.4 Objective 4 - Distinct seasonal patterns of vegetation

The distinct seasonal patterns of vegetation were delineated using overall monthly average NDVI values to identify periods of distinct seasonal phases: lowest vegetation (dry season), vegetation growth, peak vegetation (rainy season), and subsequent decline. This involved observing the Overall Monthly Average NDVI for each month to identify Growth, which are Months where the value is consistently increasing; Peak, the month(s) with the highest value; and Decline, Months where the value is consistently decreasing.

3.2.5 Objective 5 - Specific Change Analysis in vegetation cover

The specific changes were analyzed by comparing the 2001 and 2025 annual average NDVI. The annual average NDVI of the initial year (2001) was compared with that of the final complete year (2025) to determine the magnitude and direction of change.

Change = Annual Average NDVI (2025) - Annual Average NDVI (2001)Eqn 4

The calculated magnitude of change was qualitatively assessed against the observed interannual variability. This involved a judgment regarding the likelihood of the change representing a true trend versus natural fluctuations.

1. Comparing the "Change = Annual Average NDVI (2025) - Annual Average NDVI (2001)" value with the range of "Minimum and Maximum Annual Average NDVI" to see if the change falls within the usual year-to-year fluctuations.

2. Judging whether the change is significant enough to indicate a real trend or if it's likely just part of the natural variability observed over the 25 years.

Periods of accelerated vegetation decline (sharp decreases over consecutive years) and periods of relative stability (minor fluctuations) were assessed by comparing annual average NDVI values. To identify accelerated decline, consecutive years where annual average NDVI values show a significant and consistent decrease were looked for, and relative stability was identified by looking for consecutive years where annual average NDVI values show only small, irregular fluctuations.

4. Results and Discussion

4.1. Results

This section presents results of our analysis of annual NDVI data, which reveal key insights into Plateau State's vegetation dynamics

4.1.1 Determination of the Overall vegetation status (average annual NDVI).

The annual NDVI showed that Plateau State has moderate vegetation cover (an average annual NDVI of 0.384), indicating a balanced yet vulnerable ecosystem.

4.1.2 Characterization of Interannual variability in vegetation cover.

Annual averages showed fluctuation within a narrow range (0.3638 to 0.4046), reflecting climatic sensitivity and ecosystem resilience.

4.1.3 Identification of long-term trends (increase, decrease, or stability) in annual average NDVI

Observation of Long-Term Trend showed no strong, consistent linear trend (increase or decrease) over the 25 years. Vegetation values oscillate around the mean, suggesting episodic environmental stresses followed by recovery.

4.1.4 Delineation of distinct seasonal patterns of vegetation

Results showed evidence of a strong seasonal pattern.

Dry Season (Jan-Mar): Lowest NDVI (e.g., March: 0.2489), minimal cover, hardship; Growth Period (Apr-Jun): NDVI increases rapidly (e.g., June: 0.4434), onset of rains, planting; Peak Season (Sep-Oct): Highest NDVI (e.g., Oct: 0.5749), lush cover, abundance; Decline (Nov-Dec): NDVI declines (e.g., Dec: 0.3458), transition to dry season.

4.1.5 Determination of specific periods of accelerated decline or stability in vegetation cover. A slight decrease of -0.015 in annual average NDVI was noted between 2001 and 2025, which is qualitatively assessed as small and likely within natural variability.

Temporal Patterns showed that vegetation health is subject to episodic declines (e.g., 2014-2015, 2019-2022, 2023-2024), interspersed with periods of stability or recovery. Lowest NDVI values are more frequent in the latter half of the study period.

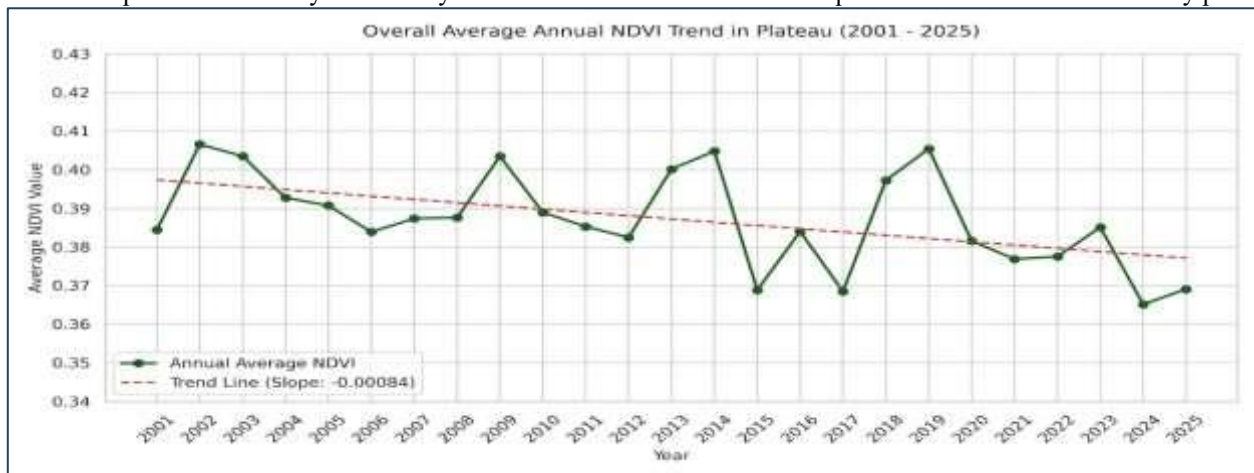


Figure 3.1: Overall vegetation status of Plateau State (2001 - 2025)

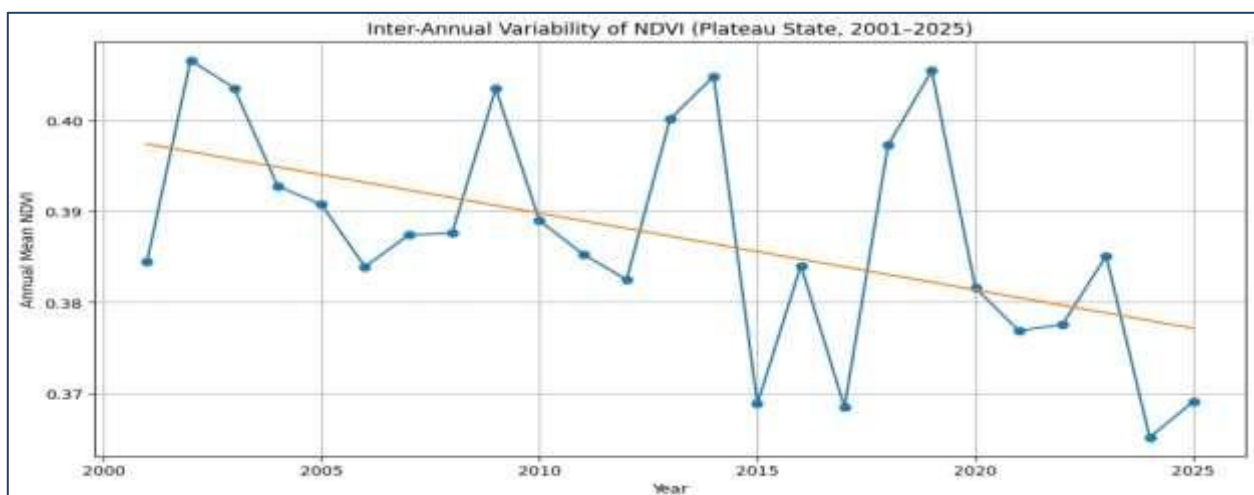


Figure 3.2a: Interannual variability in vegetation cover of Plateau State (2001 - 2025)

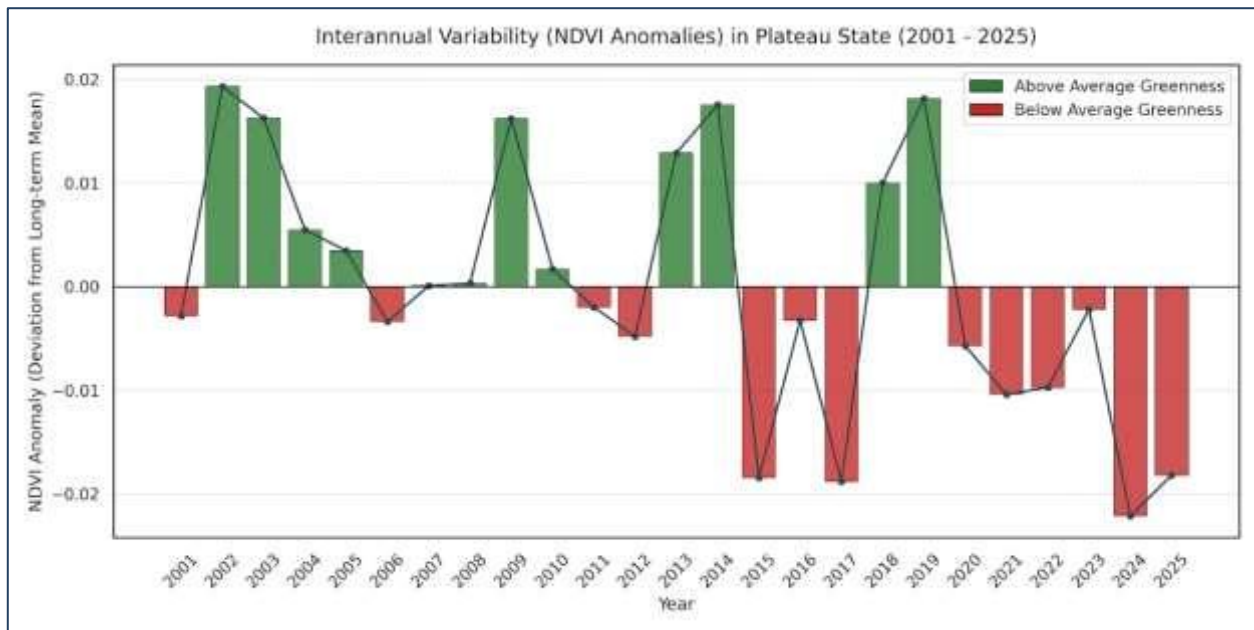


Figure 3.2b: Interannual variability in vegetation cover of Plateau State (2001 - 2025)

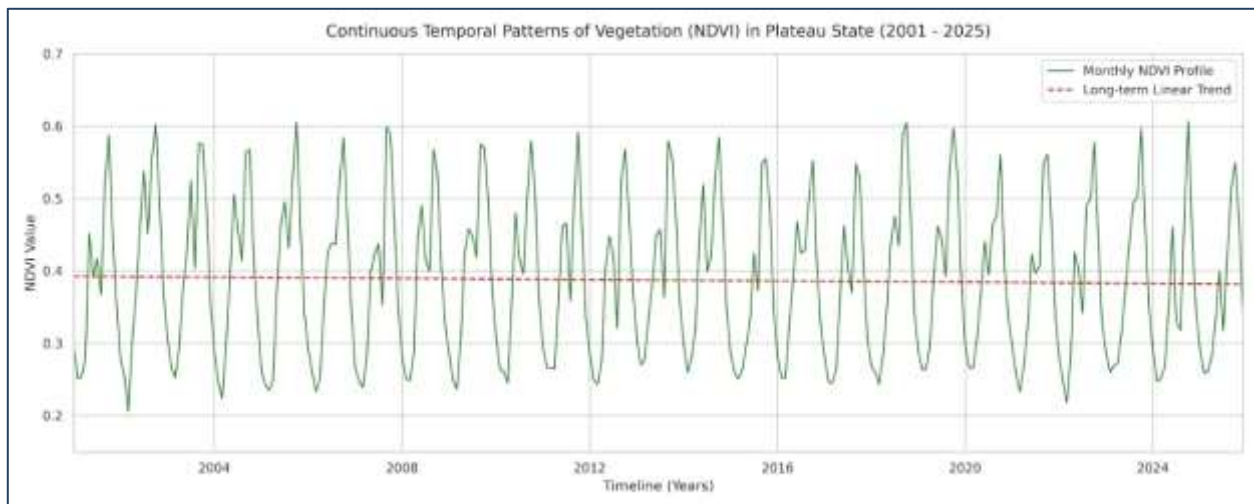


Figure 3.3: Long-term trends in annual average NDVI of Plateau State (2001 - 2025)

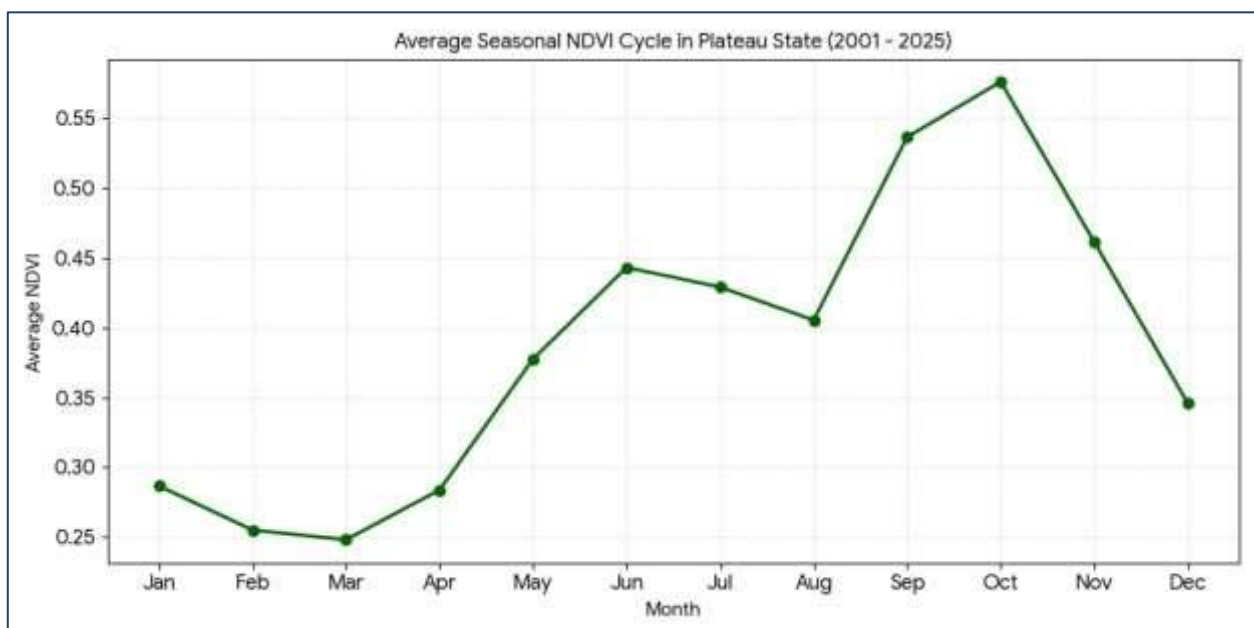


Figure 3.4: Distinct seasonal patterns of vegetation of Plateau State (2001 - 2025)

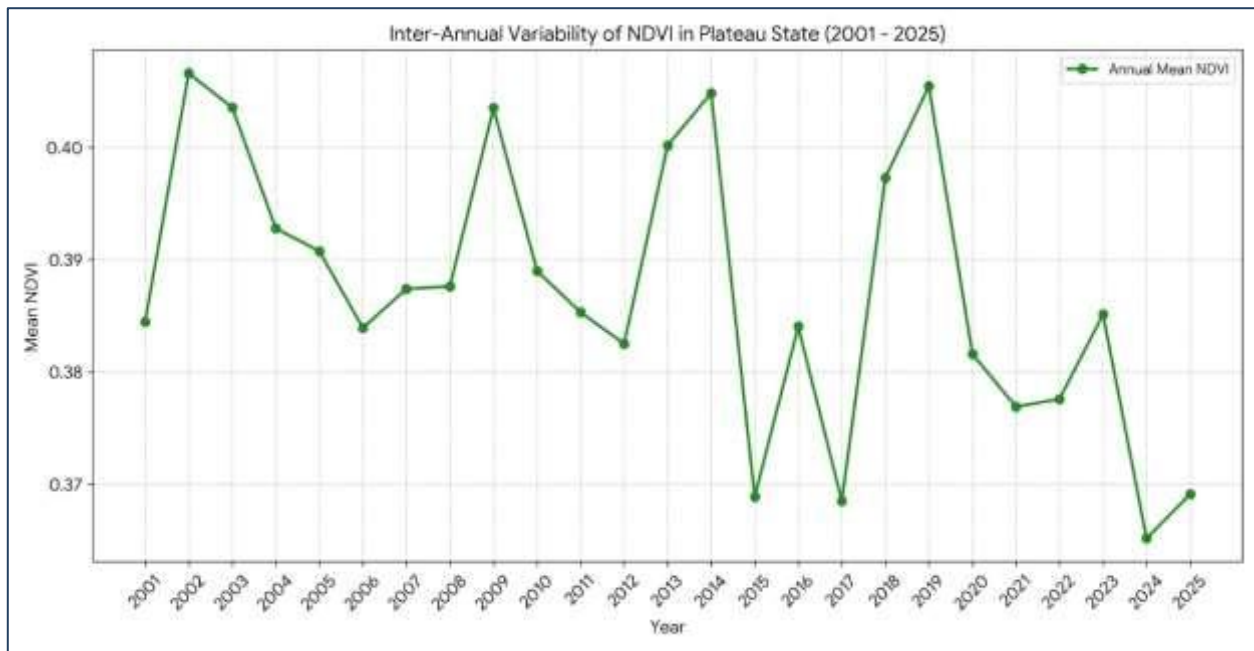


Figure 3.5: Periods of accelerated decline or stability in vegetation cover of Plateau State (2001 - 2025)

4.2 Discussion

Plateau State's vegetation shows a moderate overall cover of 0.384 (NDVI), suggesting a balanced yet vulnerable ecosystem. The narrow range of interannual variability (0.3638-0.4046) highlights the ecosystem's resilience to climatic shifts but also its sensitivity; even minor fluctuations profoundly impact agriculture and resource availability.

Crucially, the absence of a strong long-term linear trend indicates an "oscillating landscape" that's resilient to episodic stresses rather than undergoing pervasive degradation or greening. This capacity for recovery after periods of decline is a vital asset, yet it demands dynamic management strategies focused on mitigating decline and promoting regrowth.

The distinct seasonal patterns are the "heartbeat" of the region, profoundly dictating agricultural cycles, water availability, and socio-economic rhythms. The stark contrast between the lean dry season (Jan-Mar) and the lush peak season (Sep-Oct) underscores the critical dependence on timely rainfall.

The observed slight decrease of -0.015 in annual average NDVI from 2001 to 2025 is small and not significant. Qualitatively, this small magnitude is likely within the natural year-to-year variability and not statistically significant without rigorous testing. Temporal patterns confirm this, showing episodic declines interspersed with recovery, with lower NDVI values becoming more frequent in recent years.

5. Conclusion and Recommendations

5.1 Conclusion

Plateau State's vegetation is characterized by moderate cover, strong seasonality, and an oscillating long-term trend, showcasing both ecological resilience and vulnerability. Understanding these dynamic patterns is critical for developing adaptive strategies in agriculture, water conservation, and environmental management to ensure the region's long-term ecological and socio-economic well-being.

5.2 Implication

The study shows moderate and oscillating NDVI trends in Plateau State suggest an ecosystem balanced yet increasingly vulnerable. Episodic declines, particularly in later years, indicate heightened environmental stress, requiring proactive management despite overall long-term stability.

5.3 Recommendations

Based on the findings of this study, the following recommendations are proposed:

- **Advanced Monitoring:** High-resolution remote sensing with ground-based validation should be integrated for refined vegetation health assessments.
- **Adaptive Management:** Climate-smart agricultural practices and robust water resource conservation strategies should be implemented.
- **Interdisciplinary Research:** Socio-ecological studies should be conducted to identify specific drivers of vegetation change, informing targeted interventions.

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