

CLIMATE VARIABILITY AND THE CHANGING LANDSCAPE OF OLD OYO NATIONAL PARK, NIGERIA: IMPLICATIONS FOR EFFECTIVE CONSERVATION

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Funding Acknowledgement

This work was funded by the German Academic Exchange Service (DAAD) through the Climate and Environment Centre 'Future African Savannas,' from funds of the German Federal Foreign Office.

Statements and Declarations

The authors have no competing interests to declare that are relevant to the content of this article.

Climate Variability and the Changing Landscape of Old Oyo National Park, Nigeria: Implications for Effective Conservation

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DOI: <https://doi.org/10.5281/zenodo.18274434>

Abstract

Protected landscapes, though protected, face increasing ecological threats due to climate variability and change, human interference, encroachment from invasive species, habitat fragmentation, and poaching, which result in habitat degradation and biodiversity loss. In the savanna ecosystem of Old Oyo National Park (OONP), Nigeria, there is limited understanding of climate variability and landscape dynamics, which is crucial in informing effective conservation efforts. This study bridges this gap by investigating climate variability trends and changes in the land/vegetal cover and presents an argument for climate-resilient conservation. Rainfall and temperature estimates (1990 – 2024) from the TerraClimate datasets were used to investigate climatic patterns, and Landsat images (1999 – 2020) were used to analyse landscape changes, using supervised image classification. Our findings reveal very high rainfall variability, particularly in dry months, and a significant upward trend in temperature (+0.38°C/decade). Meanwhile, landscape dynamics show that the mixed open savanna dominated the park; a ~69.7% decrease in bare land, ~18.6% loss in water bodies, and ~59.8% growth in forests, implying an overall positive vegetation stability. Nevertheless, the observed climate variability versus overall positive vegetation growth showed an irony that questions the drivers of forest encroachment, preservation of native species, and the overall integrity of the savanna ecosystem, underscoring the urgent need for adaptive approaches that account for climatic and ecological complexities. Moreover, since the satellite images only detected broad land cover classes, the study recommends further research into the species diversity, ecological composition, and functions of the ecosystem to validate on-the-ground conditions, providing insights to guide targeted interventions that enhance a climate-resilient savanna ecosystem.

Keywords: Climate Variability, Climate Change, Land Use Land Cover, Savanna Ecosystem, Old Oyo National Park

INTRODUCTION

Climate variability and change have led to widespread impacts on ecosystems, causing severe damage and irreversible losses (IPCC, 2022). These may include the disappearance and extinction of species and landscapes, as well as changes in the vegetation cover of various ecosystems (He et al., 2019). Globally, climate variability is characterised by natural or anthropogenic fluctuations in temperature, precipitation, and extreme weather events over varying temporal and spatial scales. Though these natural fluctuations, such as the ENSO cycles, prolonged droughts, and heat waves, have always influenced ecological processes (Ummenhofer & Meehl, 2017; Maxwell et al., 2019), anthropogenic climate change exacerbates these variations, leading to more frequent and severe disruptions (IPCC, 2023). This, therefore, affects ecosystem stability, agricultural productivity, and water availability, thus worsening socioeconomic vulnerabilities in climate-sensitive regions.

The last decade (2011–2020) was the warmest on record, with accelerated warming in the Arctic and high-mountain regions (WMO, 2022), and global rainfall patterns showing asymmetrical shifts, wet regions such as the tropics are getting wetter while arid zones face more intense droughts (Allan et al., 2020). Meanwhile, heatwaves, heavy precipitation, and hurricanes have increased in frequency/severity (IPCC, 2021), with climate-related disasters having tripled since the 1980s (UNDRR, 2020). These have led to shifts in species distributions and phenology (e.g., flowering, migration). For instance, coral bleaching, forest dieback, and wetland drying are linked to climate extremes (Rani et al., 2019). Hence, climate variability and change will more likely continue to drive major changes in the distribution of vegetation in various ecosystems and biomes across the globe (Malhi et al., 2020).

Moreover, human activities such as deforestation, urbanisation, and agricultural expansion have also transformed over 75% of Earth's land surface, affecting biodiversity and

ecosystem services (Newbold et al., 2015). For instance, habitat destruction is the primary cause of species declines, with deforestation threatening 80% of terrestrial biodiversity (Maxwell et al., 2016). Similarly, groundwater depletion, soil erosion, and water pollution are tied to agricultural intensification and urban sprawl, establishing various trends in landscape changes globally. Studies show that the world's tree cover declined by 10% since 2000, primarily in the tropics (Hansen et al., 2013); built-up areas significantly expanded by 80% between 1992–2015, often at the expense of fertile land (Seto et al., 2012); and croplands now cover ~12% of global land, with unsustainable practices degrading 33% of soils (FAO, 2022). Notably, some of these landscape changes have also been linked with climate change, revealing significant relationships between climatic variations and vegetation cover globally (Afuye et al., 2021).

Hence, the interplay between shifting climate patterns and landscape modifications amplifies land degradation. For instance, deforestation reduces evapotranspiration, leading to decreased rainfall and increased regional warming, while urbanisation intensifies heat island effects, further stressing ecosystems and human health. Changing precipitation and temperature regimes lead to cropland abandonment or expansion into natural habitats (Zabel et al., 2014). Extreme events such as floods and droughts can further trigger abrupt LULC changes, such as land degradation. Moreover, large-scale deforestation reduces carbon sinks (Baccini et al., 2017), while urbanisation increases surface temperatures and alters local wind patterns (Zhou et al., 2015). We also see that biome shifts such as the savannization of tropical forests are increasingly reported under combined climate and land-use pressures (Staver et al., 2011). These interactions threaten ecosystems by fragmenting habitats, reducing biodiversity, and degrading soil and water resources (Newbold et al., 2015).

Across Africa, the interconnectedness between climate variability and vegetation cover change and distribution has been widely studied (Wu et al., 2016; Idris et al., 2022). Being particularly

vulnerable to climate change, higher temperature rises than the global average, and increased occurrences of droughts and floods have been projected (Wiston, 2020). Meanwhile, a decrease in vegetation vigour and rainfall, and a significant increase in temperature have been observed across the region (Nzabarinda et al., 2021), threatening various plant species, including tree cover and shrubland. Generally, the vegetation index is proportional to rainfall but inversely proportional to temperature (Ghebregabher et al., 2020); hence, it is impacted by rising temperatures and erratic rainfall. In the Horn of Africa, for instance, grassland, savanna and shrubland are more sensitive to these climatic changes (Ghebregabher et al., 2020; Measho et al., 2021), while in the savannas of West Africa, Boone et al. (2018) project large declines.

In Nigeria, the trends in climate variability have been observed, with resulting impacts on land use and land cover changes (Areola & Fasona, 2018). There has been a steady vegetation cover loss in the dryland ecosystems, including in the wet and dry seasons (Jibrillah et al., 2019). Nigeria's guinea savanna zones also show very high sensitivity to annual rainfall variations (Areola & Fasona, 2018). Between 2001 to 2017, there was a significant decline in vegetation cover within the humid and dry tropical regions of the country (Adepoju et al., 2019). While land surface temperature increased, precipitation reduced, suggesting that under projected climatic conditions, vegetation vigour will continue to decrease, especially in drier places. While this highlights a climate-driven decline, other drivers include deforestation and soil degradation (Iwuchukwu et al., 2023). The observed decline in Nigeria's derived savanna and a further predicted 46% reduction in the forest cover between 2002 and 2050 will continue to drive desertification in the region (Akintuyi et al., 2021). Overall, these changes contribute to declining ecosystem services and reduced access to social services.

Furthermore, protected areas in Nigeria, though protected, have also experienced significant

landscape changes, particularly a general decrease in vegetation cover, with climate change as a major driver (Tang & Adesina, 2022). In Kamuku National Park, for instance, climate indices explained 47% of the changes in vegetation cover (Baba et al., 2022). Within the Old Oyo National Park (OONP), changes in the landscape and vegetation structure have been linked with the severity of bush fires, distance to host communities, distance to rivers, distance to highways, elevation, and average monthly rainfall (Olaniyi & Omowale, 2022). These challenges are worsened by the existing threats of grazing, deforestation, human-wildlife conflict, ungoverned land-use policy, insufficient biodiversity distribution data, inadequate allocation of funds and manpower, among others (Oladeji et al., 2012; Osunsina et al., 2019); all undermining the integrity of critical ecosystems and the biodiversity they support.

Given the foregoing, the protected savanna ecosystem of OONP faces the imminent threat of climate variability and ecological changes, with existing projections of future climate scenarios further compromising overall conservation efforts. However, previous studies within the region have primarily focused on the observable challenges without providing insights about the local climate variability and quantifiable landscape changes. As a protected area, the landscape must be sustainably managed to support plant and wildlife biodiversity, hence the need for climate and landscape monitoring to inform effective conservation. Hence, this study explores climate variability and landscape/vegetation dynamics within OONP to provide valuable insights to inform more holistic and effective conservation strategies tailored to the unique eco-climatic conditions of the National Park. The study provides a scientific background to further strengthen conservation research, practices, and decision-making in OONP and other protected areas.

MATERIALS AND METHODS

The Study Area

The Old Oyo National Park (OONP) is a protected area and one of the seven National Parks in Nigeria, designed to safeguard, conserve, and manage exemplary samples of local flora and fauna of the country. It stretches from Oyo state to Kwara state and lies within the latitudes 8°10' N and 9°05' N and longitudes 3°30' E and 4°20' E, with an estimated total landmass of 2,512 km². OONP comprises six ranges, namely: *Tessi*, *Tede*, *Marguba*, *Sepeteri*, *Oyo-Ile*

and *Yemoso*, and is surrounded by several towns and villages, including *Baani*, *Ogundiran*, *Sooro*, *Igbeti*, *Igboho*, *Alaguntan*, *Abaja*, *Okedudu*, among others (Fig. 1). It is characterised by two major seasons: the wet and dry, receiving rainfall almost all year round, with the most significant amount received between April and October, and minimal rainfall occurring between November and March (Ogunjinmi & Braimoh, 2018). The rainy season usually begins in March and lasts till November.

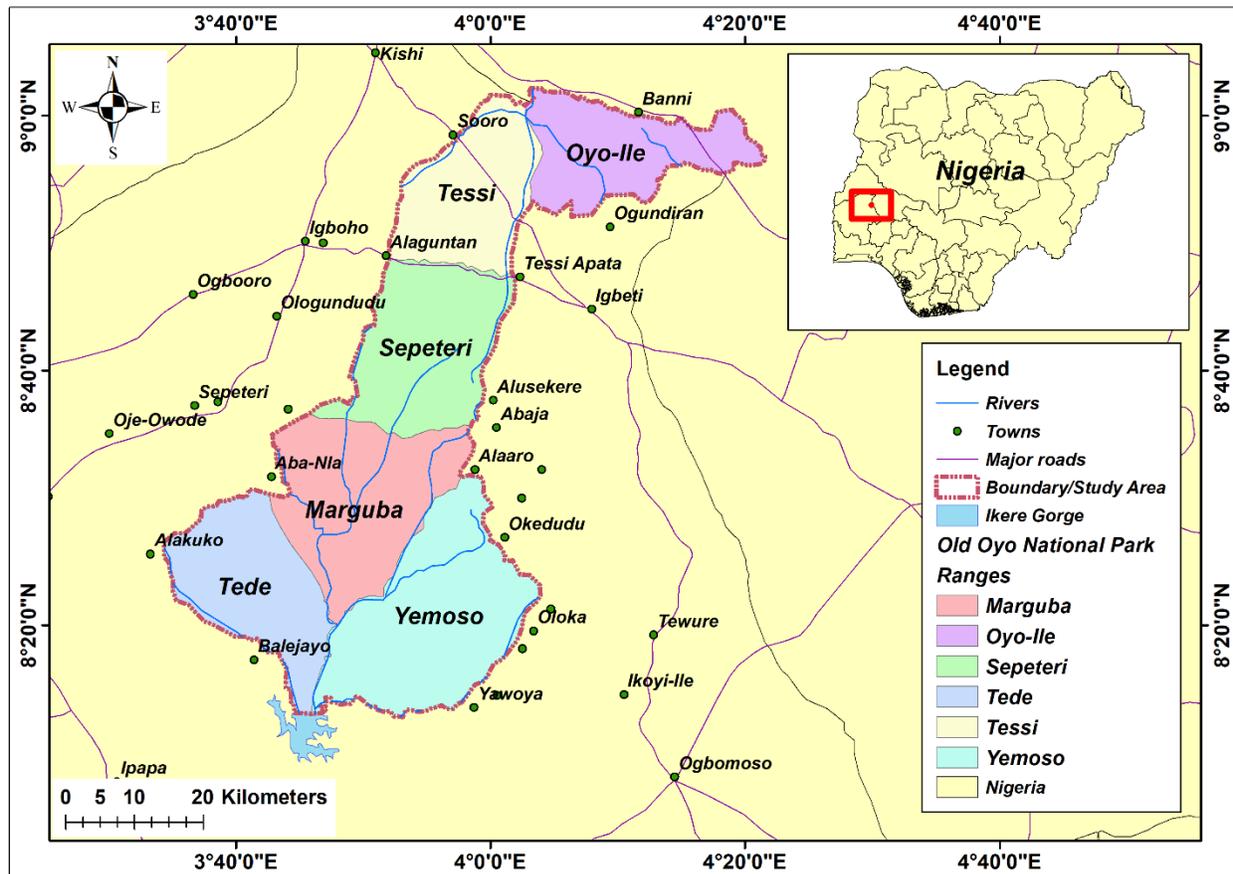


Figure 1: Old Oyo National Park and Surrounding Towns

Source: State's Ministry of Planning

OONP is characterised by the southern guinea savannah, with a mosaic of moist semi-deciduous forest, wooded savanna, and a continuous but lower layer of evergreen grasses. The terrain ranges from a lowland plain to a mild climb along the valleys of the Ogun River between 330 and 508 meters above sea level, with outcrops of granite rocks, some isolated

hills and ridges, and caves and rock shelters (Adetuga et al., 2021) and is drained by the Rivers *Ogun*, *Owu*, *Owe* and *Tessi* as well as their tributaries in the central and southern parts of the park. The Park is home to unique and native flora and fauna, including wildlife such as *Alcelaphus buselaphus*, *Hippotragus equinus*, *Panthera leo*, etc., and plant species like *Acacia* species, *Khaya*

senegalensis, *Azelia africana*, *Adansonia digitata*, etc. OONP has, however, been faced with human-wildlife conflicts, poaching, illegal logging, hunting, grazing, mining, other human activities, and climate change.

Data Collection and Analysis

The study uses Geographic Information System (GIS) techniques to analyse climate and remotely sensed land use and land cover data (Table 1). Temperature data from the TerraClimate dataset

were obtained from the Climate Engine online platform (<https://climateengine.org>) and computed into mean temperature values for each month. Monthly rainfall data were also obtained. The study used Landsat imagery from the Earth Engine Data Catalogue (<https://earthengine.google.com/>) due to its suitability, availability, and compatibility with the study's temporal scope

Table 1: Summary of datasets used in the study

Data type	Dataset	Period	Spatial resolution & relevant information
Monthly minimum temperature	TerraClimate	1990 – 2024	4-km grid ($\approx 1/24^\circ$); monthly values derived from gridded climate datasets
Monthly maximum temperature	TerraClimate	1990 – 2024	4-km grid ($\approx 1/24^\circ$); monthly values derived from gridded climate datasets
Monthly mean temperature	(Computed by authors)	1990 – 2024	4-km grid ($\approx 1/24^\circ$); calculated as mean of monthly minimum & maximum temperature
Monthly precipitation (rainfall)	TerraClimate	1990 – 2024	4-km grid ($\approx 1/24^\circ$); monthly aggregated precipitation
Land surface imagery	Landsat 5 TM, 7 ETM, and 8 OLI/TIRS	1999, 2010, 2020	30-m spatial resolution; atmospherically corrected surface reflectance products

Source: Authors' analysis, 2025

The temperature and rainfall dataset were analysed using R software (version 4.4.2). Trends and variability from 1990 to 2024 were evaluated. Descriptive statistics, including mean values, were computed, and deviations (z-scores) were calculated to identify extremes. The Mann-Kendall trend test was used to determine the direction and significance of trends. Graphs were employed to visualise trends and seasonal patterns, providing insights into the extent of climate variability and potential long-term warming signals. The Landsat data was analysed using machine learning techniques and supervised classification within the Code Editor platform of Google Earth Engine. *Water bodies, bare land, mixed open savannah and forest outliers and woodlands* were the classes used. The training samples for each class type were utilised to develop classification rules, and the algorithm was trained to recognise spectral

patterns associated with each category. ArcMap 10.5 and MS Excel were used for quantification of landscape changes, change detection, and mapping.

RESULTS

Climate Variability Within the Protected Savanna Ecosystem

The protected savanna ecosystem received a mean annual rainfall of 1,232.8 mm from 1990 to 2024, with a minimum value of 914.3 mm (1992) and a maximum of 1,435.7 mm (2008). Monthly rainfall distribution (Table 2) shows that the rainy season peaks between June and September, with July and September recording the highest monthly rainfall (Fig. 2). Meanwhile, January, December, and February are consistently the driest months. Very high rainfall variability was observed in dry months: December (CV=131.6%) and February

(CV=94.6%), meanwhile, monsoon (June–September) rains are more stable. However, interannual rainfall exhibits moderate variability

with a standard deviation of 116.1 mm and a coefficient of variation of 9.4%.

Table 2: Summary Table for Monthly Rainfall Distribution

Month	Mean Rainfall	Minimum Rainfall	Maximum Rainfall	SD	CV (%)	Trend (mm/year)	Significance
January	7.5	0.0 (1992)	26.1 (2006)	6.5	86.9	+0.01	Not significant
February	14.4	0.0 (2000)	50.6 (2011)	13.6	94.6	-0.03	Not significant
March	50.0	2.1 (1990)	82.9 (2013)	19.4	38.9	+0.85	Significant
April	94.3	53.4 (2015)	123.2 (2022)	16.6	17.6	-0.06	Not significant
May	154.2	112.8 (2009)	201.9 (1991)	23.9	15.5	-0.35	Not significant
June	202.3	138.0 (2019)	261.6 (2017)	36.2	17.9	+0.79	Not significant
July	164.9	99.0 (2021)	235.2 (2008)	33.1	20.1	+0.12	Not significant
August	156.6	68.7 (1992)	273.9 (2021)	42.9	27.4	-0.03	Not significant
September	203.6	129.6 (2002)	262.3 (2010)	32.3	15.9	+0.43	Not significant
October	151.2	78.4 (2001)	225.2 (1994)	36.4	24.1	+0.98	Not significant
November	27.2	9.3 (1996)	55.7 (2010)	10.7	39.1	+0.17	Not significant
December	6.6	0.0 (1994)	32.3 (2017)	8.7	131.6	+0.00	Not significant
Annual	1232.8	914.3 (1992)	1435.7 (2008)	116.1	9.4	+2.83	Not significant

Note: Low CV (<20%) = stable and predictable rainfall; moderate CV (20–50%) = manageable level of variability; high CV (> 50%) = Significant fluctuations; and very high CV (> 100%) = extremely variable; rainfall is unreliable.

Source: Authors' analysis, 2025

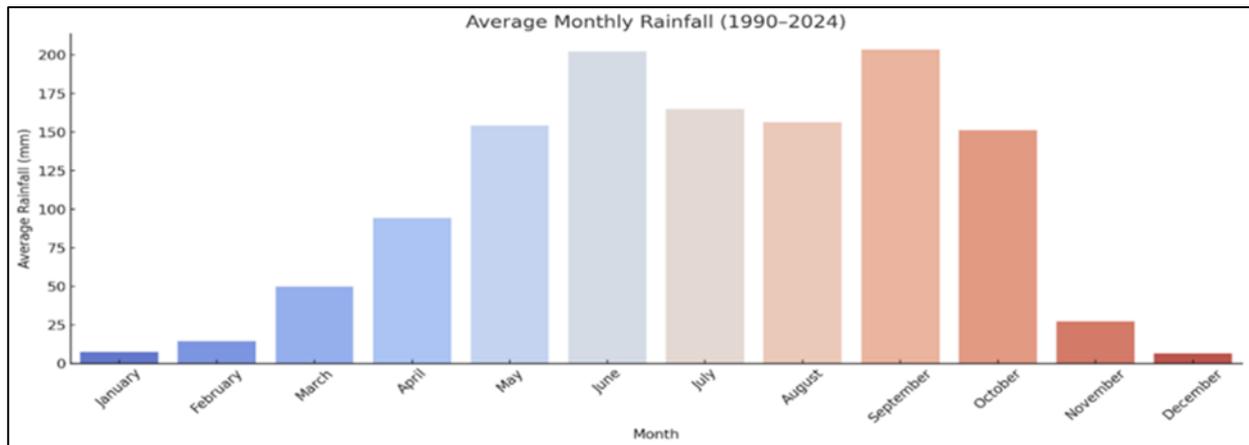


Figure 2: Average Monthly Rainfall (1990 – 2024)

Source: Authors' analysis, 2025

More recently (2020 – 2024), rainfall oscillated between near-normal (2022: 1,232 mm) and wetter conditions (2023: 1,371 mm). The Mann-Kendall trend test ($\tau = 0.1395$, $p = 0.2442 > 0.05$) indicates that the observed total annual rainfall trend is not statistically significant, though having an estimated average annual change of +2.83 mm/year and a range of -1.52 mm/year to 6.00 mm/year. Hence, despite year-

to-year fluctuations, there is no clear long-term trend in rainfall. Meanwhile, there were five dry years ($-1.5 \leq z < -0.5$), fifteen normal years ($-0.5 \leq z \leq 0.5$), and ten wet years ($0.5 < z \leq 1.5$), with the following extreme dry years: 1992 ($z = -2.74$), 2001 ($z = -1.92$), 2013 ($z = -1.60$), 2015 ($z = -1.61$); and an extreme wet year: 2008 ($z = 1.74$). Using the 95th percentile threshold (228.1 mm/month) for identifying extreme rainfall

events, 21 months (5%) exceeded the threshold, with 8 months exceeding 250 mm (which is the flood risk threshold in tropical monsoon regions).

The mean temperature across the region from 1990 to 2024 was 26.11°C, with 1992 being the coolest year (25.37°C) and 2024 the hottest (27.06°C). Monthly averages (Table 3) reveal that the coolest month is August (23.81°C) and the hottest is March (28.68°C). The dry season temperature peaks in March and is considered the pre-monsoon heat. The temperature values revealed a low interannual variability with a standard deviation of 0.42°C and a CV of 1.62%. The mean annual temperature trend (Fig. 2) for the study period (1990-2024) shows a statistically significant warming of +0.38°C/decade based on the Mann-

Kendall test ($\tau = 0.69$, $p = 0.00 < 0.05$), with a projected increase of 3.8°C per century if the trend continues. The 95% confidence interval for the slope ranges from 0.030 to 0.044°C per year, confirming a consistent upward trend in temperature. Within the protected savanna ecosystem, there are year-to-year fluctuations (within the range of a few degrees) in temperature with an overall upward trend. Temperature extreme was observed in 2024 (27.06°C) as extremely warm ($z = 2.25$), with two other warm years ($+1.0 < z \leq +2.0$), eight cool years ($-2.0 \leq z < -1.0$), and twenty-three normal years ($-1.0 \leq z \leq +1.0$). Notably, 7 of the 10 hottest years occurred post-2010 (2016–2024). The +0.38°C/decade warming trend matches the IPCC’s West Africa warming rate.

Table 3: Summary Table for Mean Monthly Temperature Distribution

Month	Mean	Min	Max	SD	CV (%)	Trend (°C/year)	Significance
January	26.16	24.73 (1992)	27.43 (2014)	0.70	2.69	0.02	Not significant
February	28.03	26.65 (2000)	29.19 (2024)	0.64	2.29	0.04	Significant
March	28.68	26.98 (1993)	30.57 (2024)	0.64	2.22	0.04	Significant
April	28.04	26.63 (1997)	29.59 (2024)	0.65	2.33	0.04	Significant
May	26.91	25.62 (1997)	28.37 (2024)	0.62	2.31	0.04	Significant
June	25.39	24.62 (1997)	26.56 (2024)	0.47	1.86	0.03	Significant
July	24.37	23.38 (1992)	25.77 (2023)	0.53	2.18	0.04	Significant
August	23.81	22.94 (1992)	24.88 (2023)	0.45	1.90	0.04	Significant
September	24.48	23.43 (1992)	25.51 (2023)	0.47	1.92	0.03	Significant
October	25.35	24.11 (1991)	26.54 (2023)	0.57	2.24	0.04	Significant
November	26.15	24.77 (1992)	26.98 (2023)	0.54	2.08	0.04	Significant
December	25.95	24.50 (1994)	27.00 (2016)	0.53	2.06	0.02	Significant
Annual	26.11	25.37 (1992)	27.06 (2024)	0.42	1.62	0.038	Significant

Source: Authors’ analysis, 2025

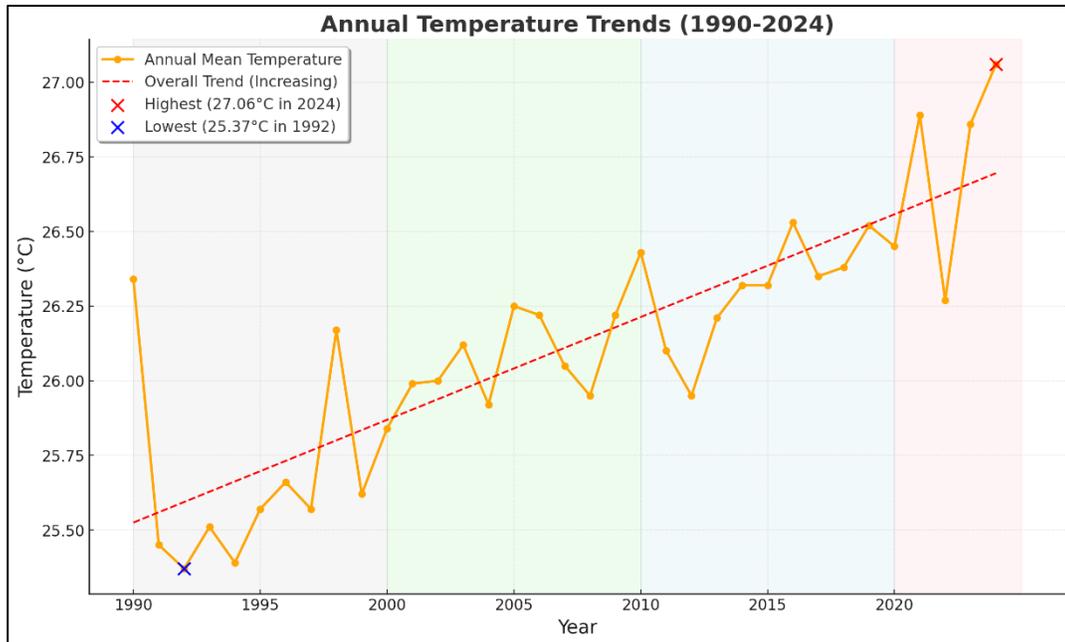


Figure 3: Annual Temperature Trends Across the Study Area (1990 – 2024)

Source: Authors' analysis, 2025

Monthly rainfall and temperature plots over the period 1990–2024 are presented in Fig. 4 and Fig. 5, respectively. Seasonal climate dynamics (Table 4) reveal that the monsoon contributes 59% to annual rainfall across the region. Meanwhile, the pre-monsoon (March–May) and post-monsoon (October–November) periods exhibit the most pronounced warming, with

temperatures increasing at approximately $+0.4^{\circ}\text{C}$ per decade, exceeding the annual average and that observed during the core monsoon and dry seasons. Overall, the significant warming trend with year-to-year and monthly rainfall variability reflects a common climate change scenario in many parts of West Africa.

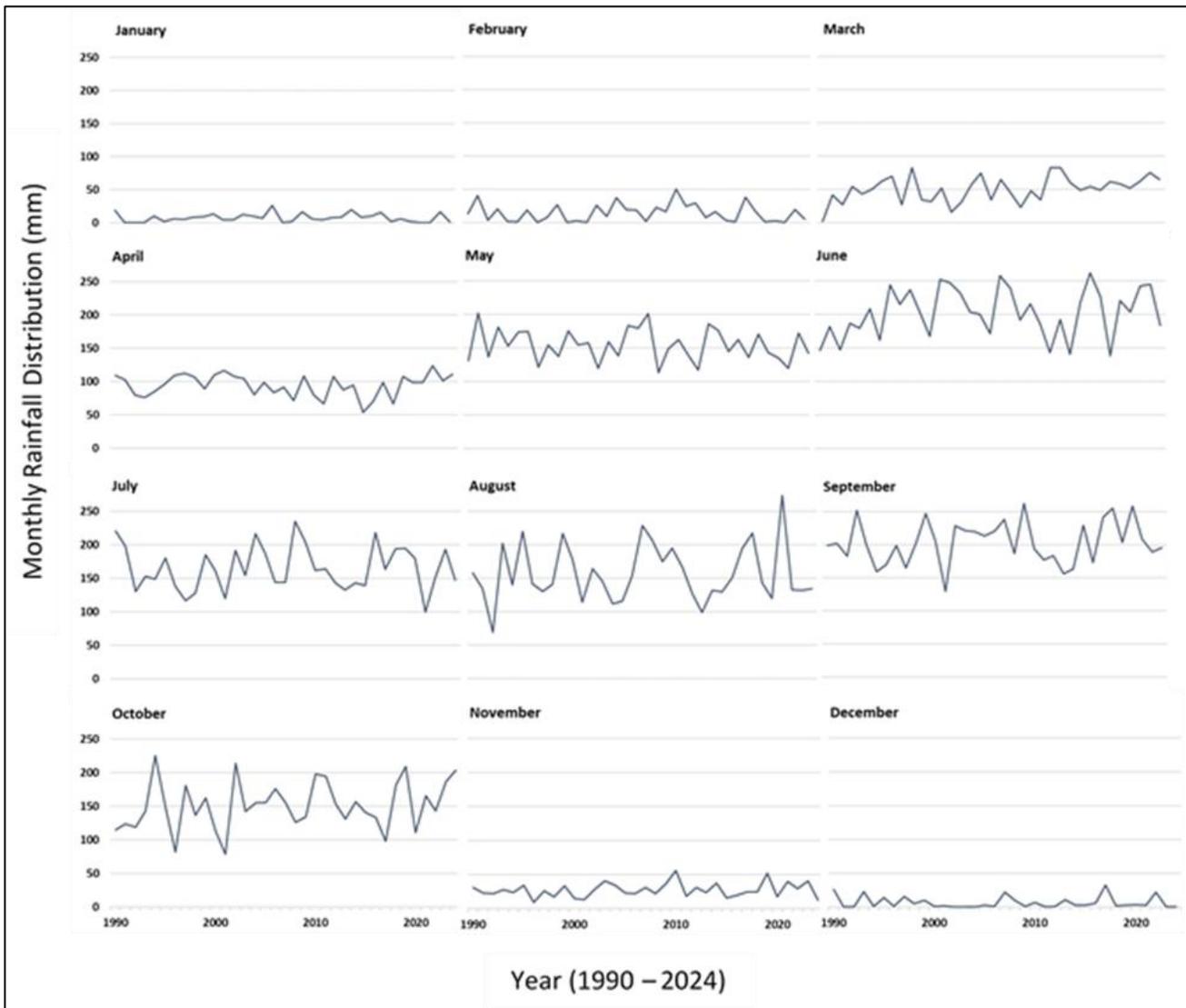


Figure 4: Monthly rainfall trends from January to December for the period 1990–2024
Source: Authors' analysis, 2025

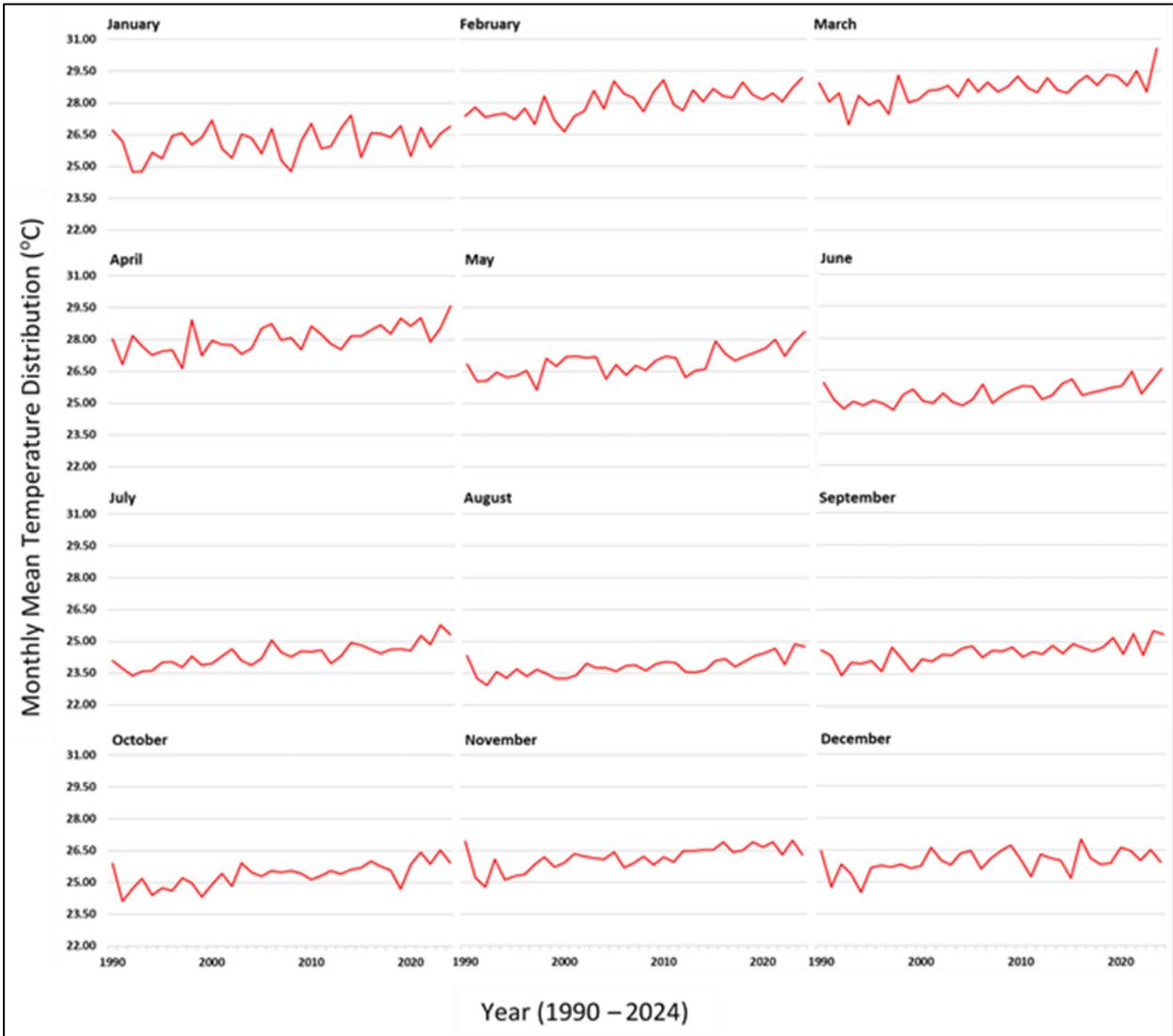


Figure 5: Monthly rainfall trends from January to December for the period 1990–2024

Source: Authors’ analysis, 2025

Table 4: Seasonal Breakdown of Climate Dynamics

Season	Months	Rainfall (mm)		Temperature (°C)	
		Mean	% Total	Mean	Trend /decade
Dry	Jan – Feb, Dec	28.5	2.3	26.71	+0.29*
Pre-Monsoon	Mar – May	298.5	24.2	27.88	+0.40*
Monsoon	Jun – Sep	727.4	59.0	24.51	+0.34*
Post-Monsoon	Oct – Nov	178.4	14.5	25.75	+0.40*

*Statistically significant trend

Source: Authors’ analysis, 2025

Land/Vegetation Cover Classification from 1990 to 2024

The Landsat images were classified into four broad classes: *water body*, *bare land*, *mixed open savannah* and *forest outliers and woodlands*. The land cover changes within the study area from 1999 to 2020 reveal significant shifts (Fig. 6). There was a reduction in water bodies (~18.6%), decreasing from 23.83 km² in 1999 to 19.40 km²

in 2020. Bare land decreased by 69.7%, declining from 176.17 km² (1999) to 53.40 km² (2020). Mixed open savanna expanded slightly by 2.7%, reaching 2,465.34 km² by 2020. Notably, forest outliers and woodlands increased (~59.8%) from 121.94 km² (1999) to 195.20 km² (2020)

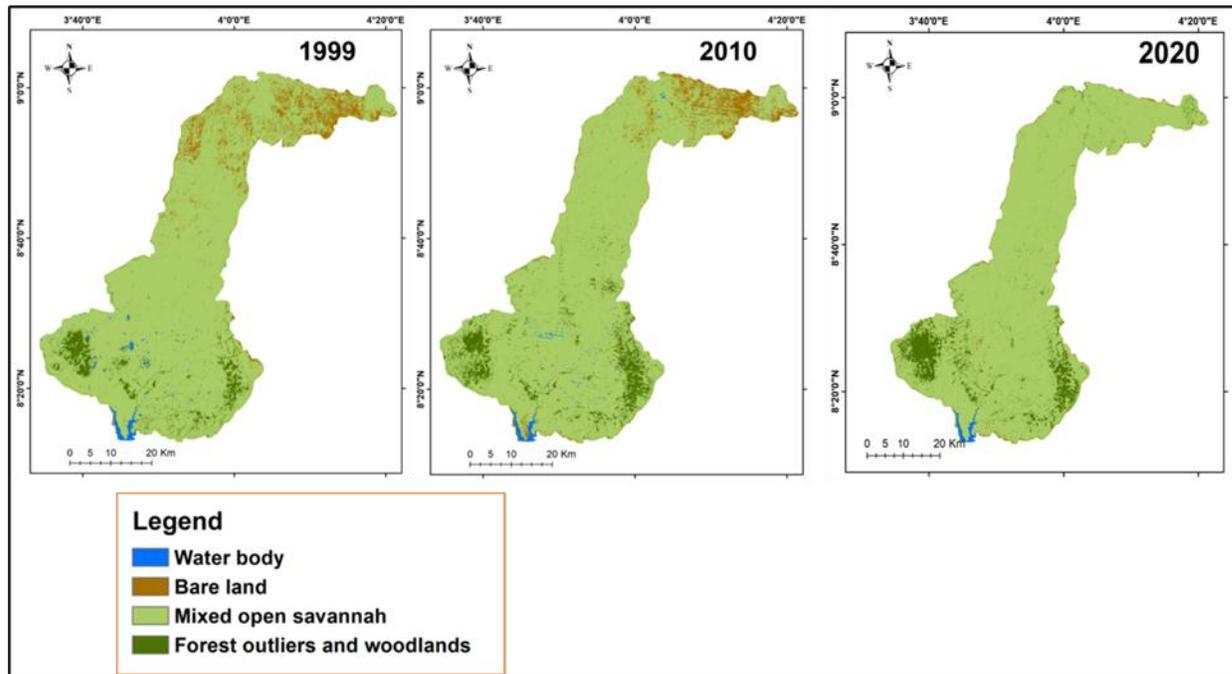


Figure 6: Distribution of land/vegetation cover classification for 1990, 2010 and 2020

Source: Authors' analysis, 2025

The total area coverage of the study area is estimated at 2733 km², with a predominant presence of mixed open savanna vegetation, an increase in forest and woodland areas, and a notable reduction in bare land (Table 5). The percentage change (net gain/loss) from change detection analysis (Table 6) reveals that there was a net loss of -18.6% in water bodies (1999 - 2020) and a substantial decrease (-69.7%) in bare land, which suggests vegetation growth. The mixed open savannah experienced a minor decrease of -0.9% (1999 - 2010), followed by a recovery of 3.2% increase (2010 - 2020),

resulting in a net change of +2.2% from 1999 to 2020. The most notable change occurred in the forest outliers and woodlands classification. From 1999 to 2010, there was a substantial increase of 52.5%, reflecting significant growth in this broad vegetation type. This trend continued from 2010 to 2020 with a 4.9% increase, resulting in an overall change of 60.1% from 1999 to 2020. The change detection analysis also revealed the magnitude of change that occurred from one classification to another (Table 7).

Table 5: Land cover distribution and area coverage in Km² and % of the region (1999 to 2020)

Classification	Area (km ²)		
	1999	2010	2020
Water	23.83 (0.9%)	19.17 (0.7%)	19.40 (0.7%)
Bare land	176.17 (6.5%)	136.53 (5%)	53.40 (2%)
Mixed open savanna	2411.39 (88.2)	2390.03 (87.5)	2465.34 (89.8%)
Forest outliers and woodlands	121.94 (4.5%)	186.02 (6.8%)	195.20 (7.1%)

Source: Authors' analysis, 2025

Table 6: Percentage change in area of each land cover classification

Classification	% Change		
	1999 - 2010	2010 - 2020	1999 - 2020
Water body	-19.5	+1.2	-18.6
Bare land	-22.5	-60.9	-69.7
Mixed open savannah	-0.9	+3.2	+2.2
Forest outliers and woodlands	+52.5	+4.9	+60.1

Note: Net loss (-); Net gain (+)

Source: Authors' analysis, 2025

Table 7: Land cover change matrix from 1999 to 2020 (km²). WB, water body; BL, bare land; MOS, mixed open savannah; FOW, forest outliers and woodlands.

	WB	BL	MOS	FOW
WB	12.28	0.22	10.94	0.38
BL	0.01	13.45	162.38	0.10
MOS	5.81	39.46	2261.46	104.22
FOW	1.30	0.04	30.10	90.49

Note: These land cover change matrices are interpreted as the area (in km²) of one land cover classification lost to another, while the highlighted figures represent the area (in km²) that has remained constant.

Source: Authors' analysis, 2025

While a fraction of the existing water bodies has been transformed to bare land and vegetation cover, ~12 km² remains stable. Notably, approximately 162 km² of bare land has been transformed into mixed open savannah. The mixed open savannah region also experienced significant changes, with losses to bare land and forests, but a vast area remains stable. Approximately 104 km² evolved into forest outliers and woodlands, indicating forest expansion. Conversely, about 30 km² of the forest outliers and woodland have transitioned into mixed open savannahs, indicating some

level of vegetation change within wooded areas. Overall, the satellite images show positive greening, which may imply stability in the savanna vegetation and an increase in overall vegetation cover within the region. However, there is observed forest encroachment, which has transformed a significant portion of the mixed open savanna into forests and woodlands. Spatial patterns of these land cover transitions across the study area are illustrated in Fig. 7, showing changes between 1999 – 2010, cumulatively from 1999 to 2020, and also between 2010 – 2020.

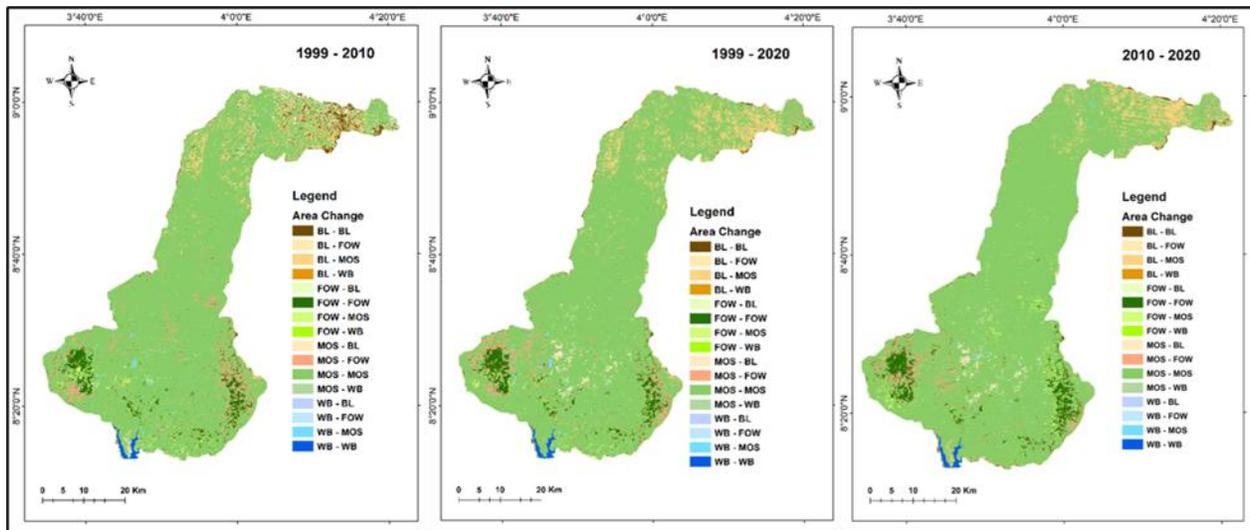


Figure 7: Change detection for the different land/vegetation cover classifications from 1999 to 2010, 2010 to 2020, and 1999 to 2020

Source: Authors' analysis, 2025

DISCUSSION

Climate Variability in OONP and Its Ecological Consequences

Climate variability and change in the tropics may be characterised by rainfall variability and warming trends (Serdeczny et al., 2017). This is seen in the observed low year-to-year variability in temperature across OONP, with an overall significant upward trend, suggesting an obvious climate change threat, as exhibited throughout Nigeria's savanna region (Muhammed et al., 2019). Annual rainfall patterns within the protected savanna ecosystem were also characterised by fluctuations and a high monthly variability, suggesting irregularity and unpredictability, especially in the dry season. The interannual variability also suggests periodic stress on the ecosystem (Synodinos et al., 2018), especially during dry years and episodes of extreme rainfall, with the recurring pattern of wet and dry years exerting intermittent pressures on vegetation, influencing growth cycles and species composition. In March, we observe a significant increase in rainfall, which reflects a pre-monsoon transitional period, during which rainfall initiation is particularly sensitive to significant warming, making early-season rainfall more responsive to climatic forcing than rainfall in other months (Nicholson, 2013).

These observed variability and trend underscore potential influences from broader climate systems such as the ENSO, as similar conditions have been observed in parts of the Guinea Savanna region (Buba et al., 2017).

All months show significantly increasing temperature trends aside from January, which is a core dry season, when temperatures are strongly influenced by the Harmattan (cooler, dry continental air masses) that can introduce variability, obscuring long-term warming signals (Nicholson, 2013). The overall pattern reflects an overarching warming trend (Robinson et al., 2021), which aligns with the IPCC's reported warming rate for West Africa, highlighting a regional coherence in climate change patterns. Rising temperatures over time, as marked by extreme temperature events (in 2021 and 2024), pose a more consistent ecological threat (Akpoterai, 2025). This continuous rise in temperature, particularly the notable acceleration during the dry season, could exacerbate evapotranspiration, reducing soil moisture availability. More so, the thermal stress during dry months tends to hinder the recovery of moisture-dependent species, favouring drought-

tolerant vegetation and potentially altering the floristic composition of the savanna (Sankaran, 2019). Furthermore, the pattern of increased frequency of hot years post-2010 accentuates the potential for heat stress. In ecosystems characterised by seasonal rainfall, the increased thermal load during the pre-monsoon heat phase (March) could reduce the physiological vigour of vegetation before the onset of rains, potentially delaying the greening period and affecting biomass accumulation.

Landscape Changes in OONP: An Adaptive or Degrading Response?

The OONP landscape has undergone substantial transformations from 1999 to 2020, underscoring a dynamic response to the interplay between climatic variability and anthropogenic factors. Nevertheless, over the years, the mixed open savannah has dominated the vegetation cover, suggesting that this vegetation type has remained relatively stable over time. This aligns with the findings of Olaniyi & Omowale (2022) and may be attributed to effective management practices, including fire management, avoided grazing, and its natural resilience (Akpoterai, 2025), which is essential for maintaining biodiversity and ecosystem functionality (Adedibu et al., 2022). The reduction in bare land and the concurrent increase in forest and woodland areas are indicative of vegetative encroachment, which reflects either natural succession and human-led restoration or conservation efforts, or both. More so, the slight increase in mixed open savannah, coupled with the substantial expansion of forest outliers and woodlands, points to a trend of gradual reforestation or woody thickening within the savanna matrix.

As observed within OONP, while the overall trend in the Nigeria Guinea Savanna region leans towards degradation, about 48% of the region appears to remain stable, and this is particularly evident in many protected areas (Adenle et al., 2020), demonstrating the vital role conservation efforts play in preserving the Nigeria Guinea Savanna's ecological health. More so, this

vegetative shift could be partially attributed to climate variability. During wetter years, the enhanced moisture availability may support the germination and establishment of woody plants (Adedibu et al., 2022), particularly in areas previously characterised by sparse vegetation or bare land. Meanwhile, the most notable change for OONP is the decrease in bare land over the two decades, underscoring a significant trend towards improved vegetation coverage, also observed in Gashaka-Gumti National Park (Kwesaba et al., 2023). This stabilisation of bare ground through increased canopy cover can mitigate soil erosion, improve microclimatic conditions, and foster biodiversity.

On the other hand, water bodies experienced a net loss over the study period, potentially linked to fluctuations in rainfall patterns and hydrological dynamics, and increased evaporation rates driven by warming temperatures. This signifies shifts in the availability of water resources within the park, and has similarly been observed in Gashaka-Gumti (Kwesaba et al., 2023) and Kainji Lake (Adeyemi & Ibrahim, 2020) national parks in Nigeria, and is associated with the growing impact of climate change on precipitation patterns across the region. In similar regions in Nigeria, these patterns of water reduction occur alongside a commonly observed net decrease in vegetation cover (Kwesaba et al., 2023). For OONP, the transition of bare land to savannah and forests suggests landscape recovery, indicating that, under suitable climatic conditions, the savanna ecosystem demonstrates a resilient trajectory towards increased vegetation density. Nevertheless, this positive trend of increasing vegetation within the protected savanna, despite significant climate variability, presents a striking ecological contradiction.

Ecological Stability Versus Emerging Vulnerabilities

Despite the apparent greening trend, the stability of the protected savanna ecosystem remains threatened due to climatic uncertainties. The

observed inconsistency in rainfall patterns and the upward temperature trajectory could disrupt the newly established vegetative structures (Zhang et al., 2019). For instance, the projected temperature rise may reduce the water use efficiency of existing plant species, necessitating shifts toward more drought-adapted flora. Furthermore, the observed transition of some forest areas back to mixed savannah also hints at ongoing ecological tension between wooded and grassy biomes. This dynamic could be influenced by fire regimes, herbivory, and microclimatic variations (Oliveras & Malhi, 2016), all of which are sensitive to temperature and moisture changes. Hence, while the overall landscape appears to be greening, the balance between grassland and woodland remains fluid, shaped by the synergistic effects of climatic variability and ecological processes.

Additionally, despite the stability in the mixed open savanna vegetation, a significant proportion has been converted to forest cover, which Olaniyi and Omowale (2022) associated with forest restoration. More broadly, this may be associated with a natural regeneration of wooded areas, poor fire management practices, and a response to the presence of invasive species, preventing savanna regeneration but leading to forest encroachment over time (Akpoterai, 2025). Studies have observed a trend of change in vegetation type from open savanna to woodland due to invasive species (Heringer et al., 2019). From the analysis of the satellite images, there is an overall improvement in vegetation cover within OONP, which presents a positive shift. However, not all vegetation cover increase signifies ecological improvement, as it is not always appropriate to interpret satellite-derived greening trends as vegetation improvement or recovery (Herrmann & Tappan, 2013). It is crucial to consider the type of vegetation growing and its impact on the ecosystem's overall health. Moreover, the expansion of forests within OONP poses an existential threat to native species of the savanna, disrupting the established ecosystem balance.

Conservation Implications

Firstly, the reduction in water bodies and the intensification of the dry season heat stress warrant proactive measures to protect water resources and manage heat-tolerant plant species. Also, the observed increase in forest cover within the protected savanna presents a complex conservation challenge. The guinea savanna is a fire-adapted, open-canopy ecosystem characterised by a balance between grasslands and scattered trees, which supports a unique mix of herbaceous and woody species. Hence, the gradual encroachment of dense woody cover can disrupt this balance, potentially displacing fire-adapted grasses and altering habitat availability for savanna-dependent species (Devine et al., 2017). Such shifts may reduce habitat heterogeneity, threaten native species, and compromise the ecological integrity of the ecosystem. Additionally, the observed greening could mask the proliferation of invasive, drought-tolerant species, which are often capable of rapidly colonising disturbed or stressed environments. In such cases, these species may form dense thickets, suppress native undergrowth, alter nutrient cycles, affect the sustenance of wildlife, and ultimately reduce overall biodiversity.

Given the significant warming trend and rainfall variability, the long-term stability of this landscape remains uncertain. Rising temperatures, particularly during the dry season, can increase evapotranspiration rates, reduce soil moisture retention, and heighten fire risk, potentially affecting vegetation health (Sankaran, 2019). Moreover, without targeted conservation efforts to protect native species and manage invasive spread, the current trajectory may lead to a homogenised landscape dominated by ecologically disruptive species, which are resilient despite climate variability. Conservation strategies should therefore prioritise the protection of native flora, the use of effective fire management strategies, and the control of invasive species to preserve the unique structure and function of the guinea savanna. This

approach will help ensure long-term resilience of the ecosystem in the face of climate change, ensuring that the ecological integrity of the protected savanna is not compromised.

CONCLUSION

Despite the absence of a clear long-term trend in rainfall, the pronounced interannual variability and significant warming trend (+0.38°C/decade) indicate an increasingly volatile climate within OONP, with potentially profound impacts on ecological dynamics. The observed expansion of woody cover and reduction in bare land suggest a greening trend that might imply ecosystem recovery. However, the observed climate variability versus a positive vegetation growth presents an irony likely masked by a more complex reality, where invasive, alien, and drought-tolerant species are potentially outcompeting native flora, transforming the landscape, and altering ecological processes. The expansion of forest outliers also raises concerns about the long-term integrity of the guinea savanna, which relies on a delicate balance between grassland and tree cover. Hence, without effective conservation strategies, including the protection of native species and effective fire management practices, this seemingly positive vegetation trend could undermine ecosystem stability. The study, therefore, recommends further research to assess the on-the-ground vegetation structure, species composition, and ecological functions, to determine whether the observed greening trend genuinely reflects ecosystem stability or merely masks underlying ecological disruptions. Overall, this research underscores the urgent need for adaptive management approaches that account for climatic uncertainties and ecological complexity.

Statements and Declarations

The authors have no competing interests to declare that are relevant to the content of this article.

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