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Spatiotemporal Dynamics of Forest Cover in the West Coast of Mount Cameroon National Park

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Abstract

Tropical forest ecosystems play a critical role in regulating global carbon cycles, supporting biodiversity, and sustaining ecosystem services. However, increasing anthropogenic and environmental pressures are driving significant forest cover changes, particularly within protected areas. This study assesses forest cover dynamics and their implications for ecosystem functioning in the West Coast Cluster of Mount Cameroon National Park, Cameroon. A geospatial approach integrating multi-temporal Landsat imagery (1985, 2005, and 2025) and Geographic Information Systems (GIS) was employed to quantify land use/land cover (LULC) changes. Supervised classification using Support Vector Machine (SVM) algorithms enabled the mapping of key land cover classes, while post-classification comparison techniques were used to detect temporal transitions. Results reveal a substantial decline in dense forest cover from 83.22% in 1985 to 53.02% in 2025, representing a loss of approximately 5560 ha. Concurrently, fragmented/secondary forest increased markedly from 1.81% to 29.42%, while bare soils/rocks expanded from 0.81% to 13.73%, indicating intensified degradation. These changes reflect a transition from intact forest systems to a more fragmented and heterogeneous landscape. The observed dynamics are driven by agricultural expansion, logging, settlement encroachment, and natural disturbances such as volcanic activity. The decline in dense forests suggests reduced carbon storage capacity and weakened ecosystem functions, despite partial compensation through secondary forest regrowth. Overall, the findings highlight a progressive loss of ecosystem integrity within the park. Strengthening conservation strategies, enhancing restoration efforts, and integrating forest landscapes into carbon market mechanisms are essential to sustain ecosystem functions and support climate change mitigation.

Keywords

Land Use/Land Cover, Change Detection, GIS, Remote Sensing, Agricultural Expansion, Logging, Encroachment, Mount Cameroon National Park

1. Introduction

Forests are vital components of the Earth's biosphere, providing essential ecological functions that sustain global environmental stability (Duarte et al., 2023). They regulate the carbon cycle, maintain hydrological processes, preserve biodiversity and support numerous ecosystem services crucial for human well-being. Tropical forests alone harbor over half of the world's terrestrial biodiversity and act as significant carbon sinks that help mitigate climate change (Li et al., 2025; Psistaki et al., 2024). Forest cover dynamics involve not only forest loss but also recovery and the development of secondary forests (Faye, 2015). Secondary forests often arise after disturbances or land abandonment, playing a critical role in restoring ecological functions and biodiversity (Qasha et al., 2024).

Factors influencing forest cover dynamics include local agricultural expansion, shifting cultivation and fuelwood extraction, which drive forest degradation (Maghah & Fokeng, 2021). On a broader scale, global market demands for commodities like timber, palm oil and cocoa have accelerated land conversion in many tropical regions (Mohamed, 2021). Forests play a crucial role in carbon storage, biomass productivity, soil formation, water regulation and biodiversity maintenance (Correia & Lopes, 2023). Research indicates that converting natural forests into agricultural landscapes or plantations diminishes aboveground biomass, tree diversity and structural complexity (Gakaev, 2023). Such changes adversely affect ecosystem processes like carbon cycling, soil fertility and hydrological regulation (Sovann et al., 2025).

Changes in forest cover have significant implications for ecosystem functioning and global environmental sustainability (Hallaj et al., 2024). Fragmented forests store lower carbon stocks compared to areas dominated by dense vegetation (Ahmad et al., 2023). Tropical ecosystems, rich in carbon, account for over 40% of global biodiversity (de Groot et al., 2012). In recent decades, forest cover dynamics—spatial and temporal changes in forest extent, structure and composition—have become a major environmental concern (Küçüker & Sari, 2021; Rodrigues et al., 2020). Forest ecosystems are closely linked to biodiversity, which drives ecosystem functioning (Rees et al., 2012). Diverse forest communities tend to exhibit greater ecological resilience and productivity, with studies indicating that species diversity significantly contributes to ecosystem stability and functional performance (Seifert et al., 2022). Fragmented forests often face edge effects, altered species composition and reduced habitat quality for wildlife (Ajonina et al., 2014).

Across the tropics, deforestation and forest degradation have intensified due to agricultural expansion, logging, infrastructure development and population pressures (Ustainable et al., 2007; Akoh et al., 2021; Ryan et al., 2014).

Protected areas are crucial for mitigating forest loss and conserving biodiversity (Zeng et al., 2020), yet they face pressures from surrounding communities and illegal resource extraction (Belote & Wilson, 2020). These designated areas protect ecosystems from disturbances like deforestation and land conversion, enabling long-term carbon sequestration (Gakaev, 2023). Beyond species conservation, protected areas sustain essential ecosystem functions, including carbon storage, watershed protection and landscape resilience (Adi et al., 2025; Condro et al., 2022). Landscapes with high biomass density are vital assets in climate mitigation strategies (Berisha et al., 2020; Zeng et al., 2022).

Using high-resolution satellite observations, global studies have revealed extensive changes in forest landscapes (Pettorelli et al., 2018; Zhang et al., 2020b). A landmark global analysis based on Landsat imagery estimated that approximately 2.3 million km^2 of forest cover was lost worldwide between 2000 and 2012, while only 0.8 million km^2 experienced regrowth, highlighting the increasing pressure on global forest ecosystems. Notably, the tropics recorded the most significant increases in forest loss during this period (Myroniuk et al., 2020; Psistaki et al., 2024; Wade et al., 2020).

Remote sensing technologies have enhanced the monitoring of forest cover changes across various spatial and temporal scales. Satellite imagery from platforms like Landsat, Sentinel and MODIS provides crucial data for mapping land use changes (Myroniuk et al., 2020). Researchers use classification algorithms and image processing techniques to identify forest types, detect deforestation and quantify landscape transformations (Ramachandra et al., 2023). These methods are especially valuable in areas with limited field data. The integration of machine learning and advanced classification techniques allows for more accurate detection of deforestation and land cover changes in tropical forests, supporting environmental monitoring and informing policies aimed at reducing forest loss and promoting sustainable land management (Nesha et al., 2021).

In Central Africa, forest cover change is increasingly monitored using geospatial technologies such as remote sensing and Geographic Information Systems (GIS) (Anh et al., 2021; Demichelis et al., 2020; Hansen et al., 2008). These tools allow researchers to analyze multi-temporal satellite imagery to detect patterns of deforestation, forest fragmentation and regeneration over time (Pettorelli et al., 2018). Such approaches have proven essential for understanding long-term landscape transformations and for guiding conservation planning (Kazadi Mukaku et al., 2024). Studies suggest that distance-driven urban climate effects associated with nearby urban centers have an effect on protected areas (Mcdonald et al., 2009). Within Africa, the Congo Basin does not just represent the second largest contiguous tropical rainforest system after the Amazon, but it also plays a crucial role in maintaining global carbon balance, regional climate stability and biodiversity conservation (Blake et al., 2010; Soudan-Nonault, 2021).

In many rural communities across Cameroon, forest resources remain essential for livelihoods and cultural identity (Kettunen & Brink, 2013; Sebastian et al., 2023). Surveys conducted in forest regions of Cameroon have shown that local populations strongly value provisioning services, particularly food and fuel resources derived from forests (Ndikebeng et al., 2023). In Cameroon, protected areas constitute an essential component of national strategies for biodiversity conservation and climate change mitigation (MINEPDED, 2022). Despite its ecological importance, Mount Cameroon National Park in general and the west coast cluster has experienced increasing environmental disturbances driven by both climatic and human-induced factors. Climate change is influencing vegetation dynamics through alterations in rainfall patterns, increasing temperatures and the occurrence of extreme weather events (Qi et al., 2025).

This research aims to assess forest cover dynamics in the West Coast Cluster of Mount Cameroon National Park and their impact on key ecosystem functions, particularly carbon stock dynamics and ecosystem integrity, by integrating remote sensing analysis with ecological interpretation to inform conservation strategies and climate change mitigation efforts.

2. Materials and Methods

This study adopts a geospatial approach that integrates remote sensing and Geographic Information Systems (GIS) to assess forest-cover dynamics and their implications for ecosystem functioning within the West Coast Cluster of Mount Cameroon National Park. The methodology focuses on detecting land-cover changes over time and linking these changes to ecosystem functions, particularly forest carbon stock.

Study Area

The West Coast Cluster of Mount Cameroon National Park (MCNP) is one of the compartments of Mount Cameroon national park, located in the South-West Region of Cameroon along the Gulf of Guinea in Central Africa. Mount Cameroon National Park constitutes one of the most ecologically significant protected landscapes within the Cameroon Volcanic Line, encompassing diverse altitudinal gradients, complex volcanic geomorphology, and highly productive tropical forest ecosystems. This study focuses specifically on the western coastal section of the park, an ecologically dynamic interface between montane forest systems and lowland coastal environments.

Geographically, the west Coast Cluster of Mount Cameroon National Park lies approximately between 4˚00'N and 4˚20'N latitude and 8˚55'E and 9˚20'E longitude, locating it on the southwestern flanks of Mount Cameroon, the highest peak in West and Central Africa (4095 m above sea level). The location map **Figure 1** illustrates the spatial extent of the West Coast Cluster extending from near-coastal settlements toward inland forested slopes, forming an important ecological corridor connecting marine-influenced ecosystems with submontane and montane forest zones. This geographic positioning places the study area within a region strongly influenced by both Atlantic maritime climatic systems and orographic processes generated by Mount Cameroon's massive volcanic structure (Joseph et al., 2023).

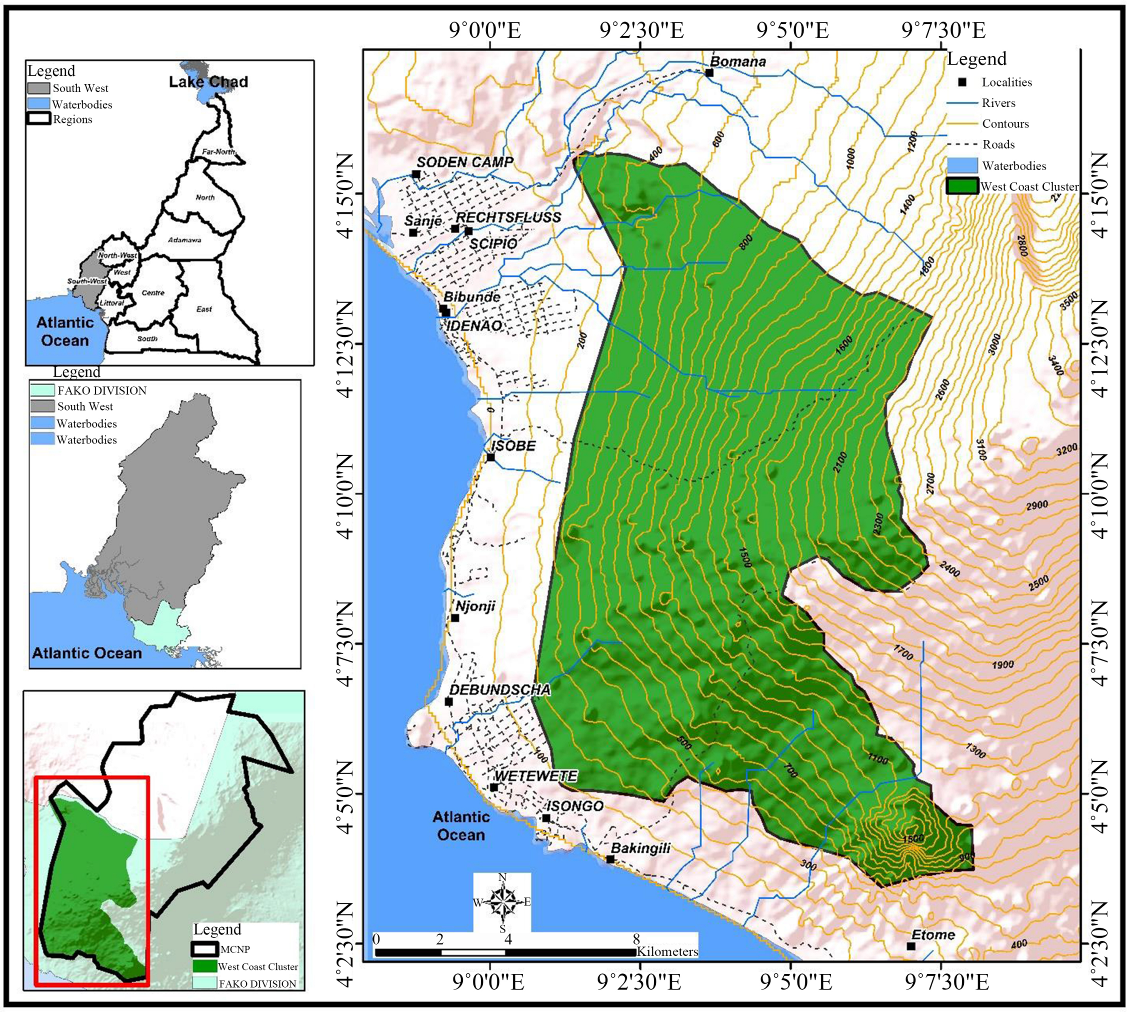

Figure 1. Location map of west coast cluster of Mount Cameroon national park (MCNP).

Topographically, the landscape is characterized by steep volcanic slopes, dissected valleys, and lava-derived landforms resulting from historical eruptions of Mount Cameroon. Elevation increases rapidly from near sea level along the coast to high-altitude forest zones inland, creating pronounced ecological gradients over relatively short horizontal distances. These gradients strongly influence vegetation distribution, soil formation, hydrological processes, and ecosystem productivity (Innocent & Dieudonné, 2012). The underlying geology is dominated by basaltic lava flows and pyroclastic deposits, producing fertile but erosion-prone Andosols that support dense forest growth while remaining sensitive to disturbance (Ewane et al., 2021).

Climatically, the West Coast Cluster experiences a humid tropical climate controlled by moist southwesterly winds from the Atlantic Ocean. Orographic uplift along the mountain slopes generates extremely high rainfall, often exceeding 3000 - 5000 mm annually, making the Mount Cameroon region one of the wettest environments in Africa (Mekuate Kamga et al., 2023). Persistent cloud cover, high atmospheric humidity, and relatively stable temperatures create favourable conditions for evergreen tropical forests and high biomass accumulation, which are critical for carbon storage and ecosystem functioning.

Vegetation within the West Coast Cluster of Mount Cameroon National Park comprises a mosaic of lowland rainforest, submontane forest, secondary forest regrowth, and localised disturbed patches, reflecting both natural ecological processes and anthropogenic pressures, including smallholder agriculture, fuelwood collection, and settlement expansion along park boundaries (Nebasifu & Atong, 2019). These forests provide essential ecosystem services, including biodiversity conservation, watershed protection, climate regulation, and soil stabilization. The West Coast Cluster is particularly important as a biodiversity refuge supporting endemic plant species, primates, birds, and other wildlife associated with the Mount Cameroon ecosystem, such as the African Forest Elephants.

Multi-temporal satellite imagery was used to evaluate land-cover dynamics within the study area (West Coast Cluster of Mount Cameroon National Park). Satellite image data from the Landsat Program were obtained for selected years representing long-term land-cover changes. Specifically, Landsat 5 TM, Landsat 7 ETM+, and Landsat 9 OLI images with a spatial resolution of 30 meters were acquired from the United States Geological Survey Earth Explorer platform. These datasets provide consistent historical coverage suitable for detecting forest cover change over several decades. To improve classification accuracy and reduce atmospheric disturbances, images with minimal cloud cover during the dry and transitional seasons were selected, as seen in **Table 1**.

Table 1. Image classification characteristics from Landsat TM 1985 (Landsat thematic mapper), enhanced thematic mapper plus 2005 (ETM+) and OLI 2 operational land imager 2, 2025.

Years	Satellite Sensor	Satellite Mission	Date Acquired	Path/Row	Cloud Cover (%)	Spatial Resolution	Spectral Bands Used for Analysis
1985	TM	Landsat Program (Landsat 5)	26-Oct-85	187/057	>30	30 m	Bands 3, 2, 1 (R,G,B) - True Color Composite
2005	ETM+	Landsat Program (Landsat 7)	9-Nov-05	187/057	>50	30 m	Bands 3, 2, 1 (R,G,B) - True Color Composite; Bands 4,3,2
2025	OLI-2	Landsat Program (Landsat 9)	15-Nov-25	187/057	>40	30 m	Bands 4,3,2 (R,G,B) - True Color Composite; Bands 5,4,3

Prior to analysis, satellite images were subjected to standard pre-processing procedures to ensure data consistency and accuracy (Vittek et al., 2014). These steps included radiometric correction, atmospheric correction, and geometric correction to align all images within the same coordinate reference system. Cloud masking and image clipping were performed to extract the spatial extent corresponding to the West Coast Cluster of Mount Cameroon National Park. Pre-processing procedures were carried out using ENVI software 4.5 (Li et al., 2019; Politi et al., 2016). The Panchromatic band (Band 8) was utilised to improve the image resolution prior to classification, particularly for 2005 and 2025, which was available given the Landsat Mission.

The Land use and land cover (LULC) classification was conducted using a supervised classification approach (Sun et al., 2022). Training samples representing major land-cover classes such as dense forest, Fragmented Forest/secondary forest, Grassland, Baresoils/Bare Rocks were selected based on spectral signatures derived from the satellite imagery. This landuse and Landcover classes as were classified based on specific descriptions that align with their state (**Table 2**). A supervised classification approach was adopted to categorize the satellite imagery into distinct land use and land cover classes, such as Dense Forest, Secondary Forest/Agricultural Land and Settlements/Bare soils. The ENVI 4.5 software (Harris Geospatial, 2023) was used to perform the image classification.

Table 2. Landuse/landcover classification.

Land Use Type	Description
Bare Soils/Rocks	Areas with little or no vegetation cover, exposing soil surfaces or rock outcrops. These zones may result from natural processes (erosion, landslides) or human activities such as deforestation and Urbanization.
Dense Forest	Regions dominated by continuous, closed-canopy vegetation with high tree density and minimal disturbance.
Fragmented Forest/Secondary Forest	Forest areas that have been disturbed, broken into patches, or are in stages of regrowth following human or natural disturbances (e.g., logging, agriculture, fire).
Grassland	These landscapes may be natural (savannas) or anthropogenic (resulting from deforestation or grazing).

The classification process applied machine-learning algorithms, particularly the Support Vector Machine (SVM)classifier, due to its robustness and high accuracy in forest landscape mapping (Jangid et al., 2023; Zhang et al., 2020a). Using the Envi software, the training samples were selected using the pixel identification reflection in relation to the Ground Control Points that were imported into the Envi Software. Image classification was performed in ENVI using the Radial Basis Function (RBF) kernel, which is widely recognized for its ability to model complex non-linear relationships in multispectral remote sensing data. The classifier parameters (penalty parameter C and kernel parameter γ) were optimised iteratively through repeated testing to maximise classification accuracy while minimising misclassification among spectrally similar land-cover classes. Training samples representing all land-use/land-cover (LULC) classes were used to train the classifier, and classification performance was evaluated using independent validation samples.

SVM was selected because it performs exceptionally well with high-dimensional remote sensing datasets, effectively handles limited training samples, and minimises overfitting through structural risk minimisation. The RBF kernel was particularly suitable for this heterogeneous mountainous landscape because it can capture complex spectral separability among vegetation.

Cloud-contaminated areas were corrected through image substitution using temporally comparable Landsat scenes with minimal cloud cover, ensuring complete spatial coverage of the study area. For Landsat 7 ETM+ imagery affected by the Scan Line Corrector (SLC)-off failure, data gaps were corrected using the GapFill algorithm implemented in QGIS prior to image import and classification in ENVI. All imagery was subsequently processed using a common study-area mask and standardized to the same spatial resolution to ensure temporal consistency and comparability across all assessment years. These procedures as shown in Figure 2 minimized potential biases associated with sensor-specific artifacts and missing data.

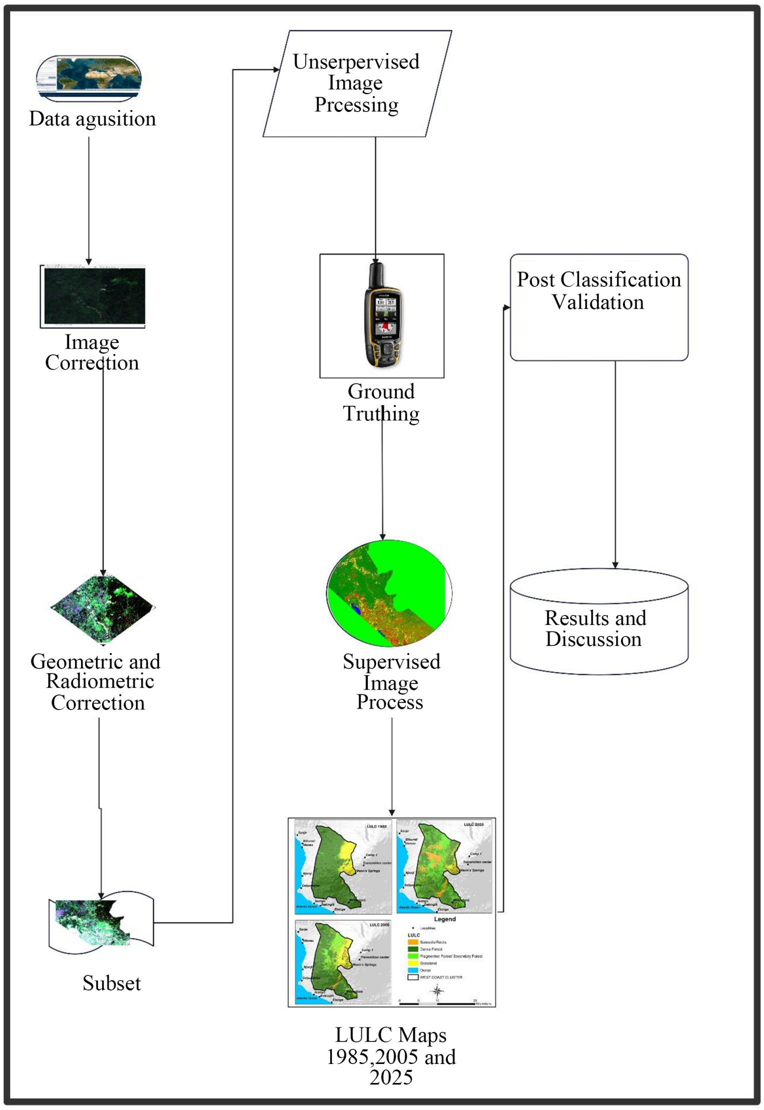

Figure 2. Image classification methodology scheme.

The classification procedure generated thematic land-cover maps for each selected year, allowing for the detection of spatial changes in forest distribution across the study area. Below demonstrates the Geospatial image classification work frame used for the analysis.

To evaluate the reliability of the classification results, an accuracy assessment was performed using ground reference data collected in the field using a Hand Garmin 65 GPS (Global Positioning system) and high-resolution imagery from Google Earth (Hsiao & Cheng, 2013; Rwanga & Ndambuki, 2017). Only classification outputs achieving acceptable accuracy thresholds (generally above 85%) were considered suitable for further analysis. Our Kappa accuracy was as follow 94.57% (0.9), 96.31% (0.94) and 94.57% (0.92) for 1985, 2005 and 2025 respectively. Post-classification comparison techniques were applied to detect changes in forest cover between different time periods (Wang et al., 2025). This approach involved comparing classified land-cover maps to quantify transitions between forest and non-forest classes (Xie et al., 2022).

To link land-cover changes with ecosystem functioning, forest cover classes were interpreted as indicators of ecosystem services, particularly carbon storage potential integrity (Bajracharya et al., 2012). Areas classified as dense forest were considered to represent high carbon storage capacity, whereas converted landscapes such as Fragmented areas and Bare soils/rock land were associated with reduced ecosystem functionality. By integrating spatial change detection results with ecological interpretation, the study provides insights into how forest cover dynamics influence ecosystem functions and conservation outcomes in Mount Cameroon National Park.

3. Results

3.1. Land Use Landcover

Table 3. LULC statistics of Landsat TM 1985 (Landsat thematic mapper), enhanced thematic mapper plus 2005 (ETM+), and OLI 2 operational land imager 2, 2025.

LULC	Area 1985	% Cover 1985	Area 2005	% Cover 2005	Area 2025	% Cover 2025
Baresoils/Rocks	149.00	0.81	634.55	3.45	2526.32	13.73
Dense Forest	15320.66	83.22	12369.80	67.20	9759.74	53.02
Fragmented Forest/Secondary Forest	333.20	1.81	2612.01	14.19	5414.88	29.42
Grassland	2607.58	14.16	2792.14	15.17	705.23	3.83
TOTAL	**18410.43**	**100**	**18408.49**	**100**	**18406.17**	**100**

Understanding long-term land-use and land-cover (LULC) dynamics is essential for assessing ecosystem structure, function and resilience, particularly in protected tropical forest areas like Mount Cameroon National Park. The analysis of LULC from 1985 to 2025 reveals significant changes impacting biodiversity preservation, forest health, water regulation and overall ecosystem stability. The findings quantify spatial and temporal changes in key LULC classes with dense forest decreasing from 15320.66 ha (83.22%) in 1985 to 9759.74 ha (53.02%) in 2025, highlighting an alarming loss of 5560.91 ha, or 30.19%, over the 40-year period (Table 3).

3.2. Land Use Landcover 1985

In 1985, the land use and land cover structure of the West Coast Cluster was predominantly characterized by dense forest, which occupied 15320.66 ha, representing 83.22% of the total area. This significant coverage illustrates the critical role of intact forests in maintaining biodiversity and carbon storage. Grassland constituted the second-largest class at 2607.58 ha (14.16%), while fragmented/secondary forest was minimal at just 333.20 ha (1.81%). The dominance of dense forest in this period indicates a landscape primarily reliant on continuous, closed-canopy forest, essential for conservation efforts aimed at preserving ecological integrity.

Landsat image classified revealed that in 1985, the land use and land cover structure of the West Coast Cluster of Mount Cameroon National Park was strongly dominated by dense forest, with relatively minor representation from other classes of the LULC. The statistical distribution seen in Table 2 reflects a highly forested landscape with limited exposure of non-forest surfaces. Dense forest constituted the overwhelmingly dominant land cover class in 1985, occupying 15320.66 ha, which represented 83.22% of the total study area. This proportion indicates that more than 4/5 of the landscape was under continuous, closed-canopy forest. The magnitude of this coverage far exceeded all other land cover categories, with a spatial extent nearly six times greater than the next largest class (grassland) (Figure 3).

Moreso, results revealed that grassland was the second most prominent land cover class, covering 2607.58 ha and accounting for 14.16% of the total area. Although significantly smaller than dense forest, grassland still represented a notable portion of the landscape, constituting over one-seventh of the total coverage. The difference between grassland and dense forest coverage was substantial, with grassland occupying approximately 12,700 ha less than dense forest. Satellite image results show that fragmented/secondary forest occupied 333.20 ha, corresponding to 1.81% of the total area in 1985. This class represented a very small fraction of the landscape compared to both dense forest and grassland. In relative terms, its coverage was less than 2%, indicating that disturbed forested areas were minimal at this time. The spatial extent of this class was nearly eight times smaller than that of grassland and more than 45 times smaller than dense forest.

Bare soils and rock surfaces formed the least represented land cover class, covering 149.00 ha, which accounted for only 0.81% of the total study area. This indicates that exposed, non-vegetated surfaces were extremely limited in spatial extent. Statistically, this class occupied less than 1% of the landscape, making it the smallest LULC category in 1985, with an area more than two times smaller than fragmented forest and over 100 times smaller than dense forest (Figure 3).

3.3. Land Use Landcover 2005

By 2005, the land use and land cover composition reflected a shift towards greater diversification, with dense forest still dominant at 12369.80 ha (67.20%), although this marked a decline of 2950.86 ha (16.02%) since 1985. The increase in fragmented/secondary forest to 2612.01 ha (14.19%) represents a notable rise of 2278.81 ha (12.38%), suggesting a transition driven by anthropogenic pressures such as agricultural expansion and illegal logging. This change underscores the urgent need for conservation strategies that address fragmentation and enhance the recovery of disturbed areas to maintain ecosystem functions (**Figure 3**).

Classified satellite images of Landsat 7 ETM+ revealed that in 2005, the land use and land cover composition of the West Coast Cluster of Mount Cameroon National Park reflects a more diversified distribution compared to earlier observations, with noticeable shifts in the relative proportions of the different land cover classes. The statistical structure shows a reduction in dominance by a single class and a more pronounced presence of transitional land cover types.

Based on the results obtained from the satellite image classification, it revealed that dense Forest remained the dominant land cover class in 2005, covering 12369.80 ha and accounting for 67.20% of the total study area. Although it still occupied more than two-thirds of the landscape, its proportional dominance was notably lower compared to earlier conditions in 1985. In terms of spatial extent, dense forest exceeded all other classes individually, maintaining an area more than four times larger than the second-largest class, fragmented forest (**Figure 3**).

Also, Fragmented/secondary forest represented a significant portion of the landscape in 2005, covering 2612.01 ha, which corresponded to 14.19% of the total area. This positioned it as the second most extensive land cover class during this period. Statistically, its coverage was nearly equivalent to that of grassland, with only a marginal difference of about 0.98%. In absolute terms, the fragmented forest occupied slightly less area than the grassland but remained within a comparable range. Grassland covered 2792.14 ha in 2005, accounting for 15.17% of the study area. This made it the second-largest land cover class, slightly surpassing fragmented forest in both area and percentage share. The difference between grassland and fragmented forest was relatively small (approximately 180 ha), indicating a close distribution between these two classes. Despite this, grassland remained substantially smaller than dense forest, occupying less than one-quarter of its area. Bare soils and rock surfaces occupied 634.55 ha, representing 3.45% of the total study area in 2005. While still the least extensive class, its spatial coverage was notably larger than in other categories, such as fragmented forest in earlier periods. Statistically, this class remained below 5% of the total area, but its extent was more than double that of the fragmented forest in 1985 and approximately one-quarter of the grassland coverage in 2005 (**Figure 3**).

3.4. Land Use Landcover 2025

In 2025, the LULC composition showed a further decline in dense forest to

9759.74 ha (53.02%), indicating a continued loss of forest cover with a decrease of 2610.06 ha (14.17%) from 2005. Fragmented/secondary forest expanded significantly to 5414.88 ha (29.42%), reflecting a gain of 2802.87 ha (15.23%). This increase emphasizes the importance of managing fragmentation to sustain ecosystem health and resilience. The notable rise in bare soils and rocks to 2526.32 ha (13.73%) also indicates a shift towards more degraded land cover, highlighting the need for targeted conservation actions to restore ecological integrity (Figure 3).

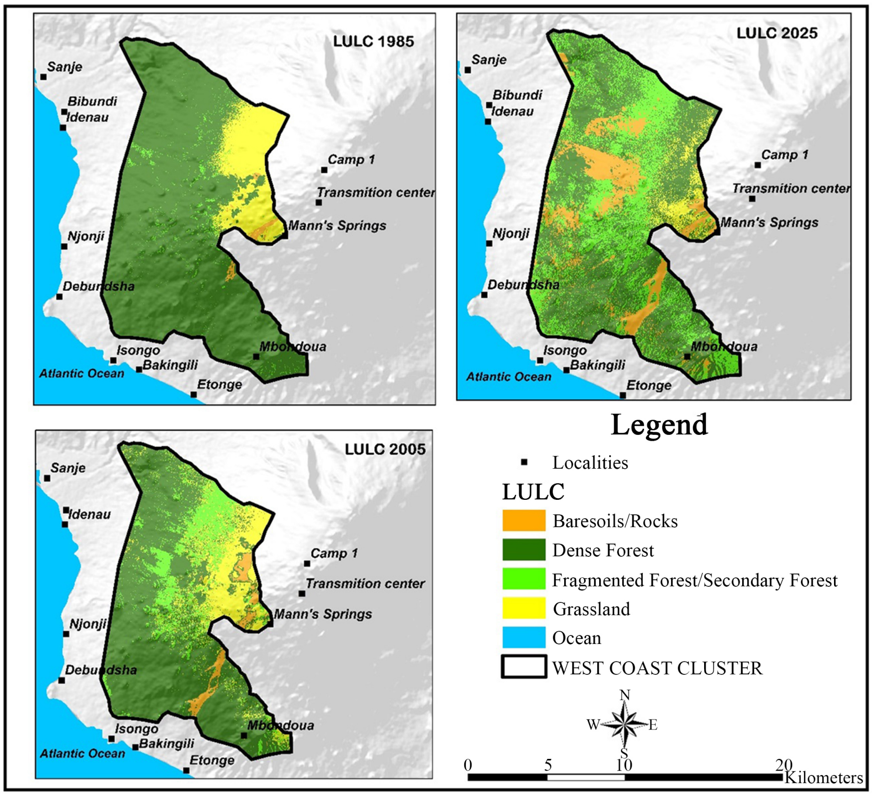

Figure 3. Land use/land cover map of west coast cluster of Mount Cameroon national park.

In 2025, the land use and land cover composition of the West Coast Cluster of Mount Cameroon National Park shows a markedly redistributed pattern among the major classes, with no single class exceeding three-quarters of the total area. The statistical structure reflects a more even spread across multiple categories, although clear differences in magnitude remain. Dense forest continued to be the largest land cover class in 2025, occupying 9759.74 hectares and accounting for 53.02% of the total study area. This indicates that just over half of the landscape was covered by dense forest. In relative terms, its share was only marginally greater than the combined proportion of all other land cover classes. Despite maintaining the highest individual coverage, its extent was less than twice that of fragmented forest, showing a reduced dominance compared to earlier distributions.

Fragmented or secondary forest covered 5414.88 hectares, representing 29.42%

of the total area in 2025. This made it the second most dominant land cover class, occupying nearly one-third of the study area. Statistically, its extent was more than half that of dense forest, with a difference of approximately 4300 hectares. The proportion of this class was substantially higher than that of grassland and bare surfaces, positioning it clearly as a major component of the landscape.

Bare soils and rock surfaces accounted for 2526.32 hectares, which corresponds to 13.73% of the total area. This placed it as the third largest land cover class in 2025. In comparative terms, its coverage was roughly half that of fragmented forest and about one-quarter of dense forest. The proportion exceeded that of grassland by a considerable margin, with a difference of nearly 10 percentage points, indicating a strong representation within the overall distribution. Grassland occupied 705.23 hectares in 2025, accounting for 3.83% of the total study area. This made it the least represented land cover class during this period. Statistically, its extent was significantly lower than all other categories, being more than three times smaller than bare surfaces and nearly eight times smaller than fragmented forest. Its proportional share remained below 5%, indicating a minimal contribution to the overall land cover distribution in the year 2025 (**Figure 3**).

1985-2005: Comparative LULC Changes

Between 1985 and 2005, in the West Coast Cluster of Mount Cameroon National Park, clear shifts occurred across all land cover classes. Dense forest decreased from 15320.66 ha (83.22%) to 12369.80 ha (67.20%), reflecting a net loss of 2950.86 ha and a decline of 16.02%. Despite remaining the dominant class, its proportional share reduced substantially over these 20 years. Fragmented/secondary forest exhibited a pronounced increase, rising from 333.20 ha (1.81%) to 2612.01 ha (14.19%). This corresponds to a gain of 2278.81 ha and an increase of 12.38%, making it one of the most rapidly expanding classes during this interval. The magnitude of this increase brought it to near parity with grassland in percentage terms. Grassland showed a modest increase from 2607.58 ha (14.16%) to 2792.14 ha (15.17%), representing a gain of 184.56 ha and a slight rise of 1.01%. Its proportional share remained relatively stable compared to other classes, with only minimal variation over the period. Bare soils and rocks increased from 149.00 ha (0.81%) to 634.55 ha (3.45%), reflecting a gain of 485.55 ha and an increase of 2.64%. Although still the smallest class in 2005, it recorded a noticeable relative expansion compared to its 1985 extent (**Table 4**).

Table 4. LULC statistics of Landsat TM 1985 (Landsat thematic mapper), enhanced thematic mapper plus 2005.

LULC	Area Δ 1985-2005	% Δ 1985-2005
Baresoils/Rocks	485.55	2.64
Dense Forest	−2950.86	−16.02
Fragmented Forest/Secondary Forest	2278.81	12.38
Grassland	184.56	1.00
TOTAL	**−1.94**	**0.00**

2005-2025: Comparative LULC Changes

From 2005 to 2025, the LULC distribution continued to shift significantly. Dense forest declined further from 12369.80 ha (67.20%) to 9759.74 ha (53.02%), representing a loss of 2610.06 ha and a decrease of 14.18 percentage points. This indicates a continued reduction in its overall share, although the rate of percentage decline was slightly lower than in the previous period. Fragmented or secondary forest increased markedly from 2612.01 ha (14.19%) to 5414.88 ha (29.42%). This corresponds to a gain of 2802.87 ha and an increase of 15.23 percentage points, making it the class with the largest absolute and proportional growth during this period. Its share more than doubled, reinforcing its position as a major land cover category. Grassland experienced a sharp decline, decreasing from 2792.14 ha (15.17%) to 705.23 ha (3.83%). This represents a loss of 2086.91 ha and a reduction of 11.34 percentage points. The magnitude of this decrease contrasts strongly with its relative stability in the earlier period. Bare soils and rocks showed a substantial increase from 634.55 ha (3.45%) to 2526.32 ha (13.73%), reflecting a gain of 1891.77 ha and an increase of 10.28 percentage points. This significant rise elevated it from a minor to a more prominent land cover class by 2025 (Table 5).

Table 5. LULC statistics of enhanced thematic mapper plus 2005 (ETM+), and OLI 2 operational land imager 2, 2025.

LULC	Area Cover Δ 2005-2025	% Cover Δ 2005-2025
Baresoils/Rocks	1891.77	10.28
Dense Forest	−2610.05	−14.17
Fragmented Forest/Secondary Forest	2802.87	15.23
Grassland	−2086.91	−11.34
TOTAL	−2.33	0.00

1985-2025: Long-Term Comparative LULC Changes

Over the entire 40-year period from 1985 to 2025, the cumulative changes in LULC are pronounced. Dense forest declined from 15320.66 ha (83.22%) to 9759.74 ha (53.02%), resulting in a total loss of 5560.92 ha and a decrease of 30.20%. This represents the largest absolute reduction among all classes. Fragmented/secondary forest increased from 333.20 ha (1.81%) to 5414.88 ha (29.42%), corresponding to a gain of 5081.68 ha and an increase of 27.6%. This is the most substantial overall increase, both in area and percentage, across the study period. Grassland decreased from 2607.58 ha (14.16%) to 705.23 ha (3.83%), reflecting a loss of 1902.35 ha and a decline of 10.33%. This indicates a notable contraction in its spatial extent over the long term. Bare soils and rocks increased from 149.00 ha (0.81%) to 2526.32 ha (13.73%), resulting in a gain of 2377.32 ha and an increase of 12.92%. This long-term growth represents a substantial relative expansion, moving from a minimal to a more significant share of the total landscape (Table

6).

The land use and land cover (LULC) dynamics in the West Coast Cluster of Mount Cameroon National Park are shaped by a complex interplay of anthropogenic pressures and natural environmental factors. Notably, agricultural expansion, particularly by smallholder farmers, has led to the clearing of dense forest areas, resulting in a loss of 2950.86 ha (16.02%) of dense forest between 1985 and 2005. Additionally, illegal logging has contributed to an increase in fragmented forest by 2278.81 ha (12.38%) during the same period, underscoring the need for enhanced conservation efforts. Natural processes, including volcanic activity, have also influenced LULC, with bare soils and rocks rising from 149.00 ha (0.81%) in 1985 to 2526.32 ha (13.73%) in 2025, highlighting the importance of integrating these factors into conservation strategies. Furthermore, limitations in enforcement and community engagement in conservation management have hindered effective restoration efforts, as evidenced by the total loss of 5560.91 ha of dense forest over the 40-year period, emphasizing the urgent need for comprehensive actions to restore ecological integrity and ensure long-term sustainability in the region.

Table 6. LULC statistics of Landsat TM 1985 (Landsat thematic mapper), enhanced thematic mapper plus 2005 (ETM+), and OLI 2 operational land imager, 2025.

LULC	Area Cover Δ 1985-2025	% Cover Δ 1985-2025
Baresoils/Rocks	2377.32	12.92
Dense Forest	−5560.91	−30.19
Fragmented Forest/Secondary Forest	5081.68	27.61
Grassland	−1902.35	−10.33
TOTAL	**−4.27**	**0.00**

LULC Transition Matrix

Below is a table showing the transition matrices for the time periods 1985-2005, 2005-2025, and 1985-2025.

1985-2005 (%)						
	Dense Forest	Fragmented Forest	Grassland	Baresoils	Row Total	Class Total
Dense Forest	76.568	41.931	2.671	10.85	100	100
Fragmented Forest	13.656	43.719	2.624	2.833	100	100
Grassland	8.025	12.852	10.59	14.105	100	100
Baresoils	1.752	1.498	84.115	72.212	100	100
Class Total	100	100	100	100	0	0
Class Changes	23.432	56.281	89.41	27.788	0	0
Image Difference	−19.63	559.611	−80.648	8508.077	0	0

Continued

2005-2025 (%)						
	Dense Forest	Fragmented Forest	Grassland	Baresoils	Row Total	Class Total
Unclassified	0	0	0	0	0	0
Dense Forest	56.435	30.548	20.232	1.449	100	100
Fragmented Forest	41.454	55.603	42.114	1.278	100	100
Grassland	2.004	13.744	37.547	95.57	100	100
Baresoils	0.107	0.105	0.107	1.704	100	100
Class Total	100	100	100	100	0	0
Class Changes	43.565	44.397	62.453	98.296	0	0
Image Difference	−30.716	198.963	386.957	−98.149	0	0
1985-2025 (%)						
	Dense Forest	Fragmented Forest	Grassland	Baresoils	Row Total	Class Total
Dense Forest	51.129	36.544	3.26	43.882	100	100
Fragmented Forest	45.253	57.845	5.024	31.826	100	100
Grassland	2.356	4.984	91.653	1.929	100	100
Baresoils	1.261	0.626	0.063	22.363	100	100
Class Total	100	100	100	100	0	0
Class Changes	48.871	42.155	8.347	77.637	0	0
Image Difference	−44.316	1871.994	−5.764	59.373	0	0

4. Discussion

The land use and land cover (LULC) dynamics observed in the West Coast Cluster of Mount Cameroon National Park exhibit notable parallels with the findings of Tataw et al. (2024) in the Ebo Forest Reserve, particularly regarding significant transformations driven by anthropogenic pressures such as agricultural expansion and logging. Both studies document a marked decline in dense forest cover, with the West Coast Cluster experiencing a reduction from 83.22% to 53.02%, similar to the fragmentation and degradation reported by Tataw et al., 2024. Similar to Tataw et al., 2024, the increase in bare soils and rock surfaces, rising from 0.81% to 13.73%, underscores intensified disturbances common to both regions. These multifaceted drivers of LULC changes in both studies emphasize the complex interplay between human activities and natural factors, necessitating comprehensive management approaches to mitigate degradation (Tataw et al., 2024).

The land use and land cover (LULC) dynamics observed in the West Coast Cluster of Mount Cameroon National Park over the 40-year period from 1985 to 2025 reveal a pronounced transformation of the landscape, consistent with findings from other studies. The substantial decline in dense forest cover, which decreased from 83.22% to 53.02%, aligns with global trends reported by Jayathilake et al. (2021) and Wade et al. (2020), indicating that agricultural expansion remains a primary driver of deforestation. This shift from a predominantly intact forest system to a more heterogeneous landscape reflects cumulative disturbances over time, corroborating the observations of van der Valk & Warner (2009) regarding the emergence of mosaic landscapes in response to both anthropogenic and natural pressures.

The notable rise in bare soils and rock surfaces, increasing from 0.81% to 13.73%, underscores intensifying disturbance processes within the study area. This trend aligns with findings from Roba et al. (2025) and Solomon et al. (2019), who document similar patterns of forest-to-savanna transitions linked to land degradation and climate variability across sub-Saharan Africa. The simultaneous decline in grassland cover further emphasizes the extent of landscape transformation, suggesting that even transitional vegetation types are being altered or replaced over time, corroborating the broader ecological implications identified in other studies.

These LULC changes have significant repercussions for carbon stock distribution and ecosystem functioning. The reduction in dense forests, which serve as primary carbon reservoirs, leads to a redistribution of carbon from stable, high-density pools to more dynamic and lower-density systems, as noted by Islam et al. (2017). While the growth in fragmented forests suggests ongoing regeneration, the overall carbon storage capacity of the landscape is likely diminished due to reduced biomass. This observation is supported by Nzabarinda et al. (2025), who link deforestation to increased atmospheric carbon concentrations, emphasizing the urgency of implementing conservation measures to mitigate these impacts.

The implications for ecosystem function are profound, as the reduction in dense forest cover disrupts key ecological processes such as nutrient cycling and hydrological regulation. This aligns with findings from Faria et al. (2023), which highlight how fragmentation modifies environmental conditions and influences species composition. The increase in degraded surfaces disrupts soil processes and water dynamics, limiting the ecosystem's capacity to sustain productivity and resilience, a concern echoed in studies conducted in Ethiopia (Sitotaw et al., 2025).

The drivers of these LULC transitions are multifaceted, involving both anthropogenic and natural factors. Agricultural expansion, logging, and settlement growth have played dominant roles in the conversion and degradation of forested areas, confirming results from Sisay et al. (2024). These pressures are often concentrated in accessible regions, leading to spatially uneven patterns of change. Meanwhile, natural processes such as volcanic activity associated with Mount Cameroon contribute to localized disturbances, echoing findings from Karátson & Thouret (2025) regarding the interaction between human activities and natural vulnerabilities that exacerbate landscape transformation.

An important aspect emerging from these findings is the apparent inadequacy of restoration efforts within the park, as highlighted by Ameja et al. (2022), who discuss successful restoration projects in Mozambique. Despite the observed degradation, limited evidence of effective restoration interventions suggests that current management strategies may not adequately address the scale or intensity of landscape change. This gap not only prolongs the persistence of degraded land cover but also hinders the recovery of ecosystem functions and carbon storage capacity, a concern reiterated by Stanturf & Mansourian (2020).

5. Conclusion

The analysis of land use and land cover (LULC) dynamics in the West Coast Cluster of Mount Cameroon National Park over the period 1985-2025 reveals a clear and sustained transformation of the landscape, characterized by a substantial decline in dense forest cover and a concurrent expansion of fragmented forests and degraded land surfaces. The progressive reduction of dense forest from a dominant 83.22% to 53.02%, alongside the marked increase in secondary vegetation and bare surfaces, underscores a transition from a largely intact forest ecosystem to a more heterogeneous and structurally altered landscape. Dense forest cover is considered representative of relatively high ecosystem integrity because it maintains greater structural complexity, biodiversity support, habitat connectivity, and ecological functionality. Similarly, dense forests are associated with the highest aboveground biomass and carbon storage potential, whereas degraded vegetation, agricultural land, bare land, and built-up areas generally exhibit progressively lower carbon stocks. Consequently, multiple related studies corroborate key findings indicating that interpretations of ecosystem integrity and carbon dynamics are based on established ecological relationships among land-cover type, vegetation structure, and biomass accumulation rather than on direct field-based carbon measurements. Drivers of these transformations are multifaceted, with local anthropogenic pressures such as agricultural expansion, logging and settlement encroachment playing a central role, compounded by natural factors, including volcanic activity and geomorphological processes associated with the Mount Cameroon landscape, as confirmed by other literature from different parts of the world. The limited evidence of successful restoration efforts emphasizes a critical gap in current conservation strategies, especially in areas requiring active ecological recovery.

Despite the application of advanced geospatial techniques and rigorous analytical procedures, this study was subject to several limitations. Persistent cloud cover, inherent differences among satellite sensors, and the complex topography of the mountainous landscape introduced uncertainties into the detection and interpretation of forest cover dynamics. Furthermore, the absence of direct field-based carbon measurements constrained the validation of remotely sensed estimates and limited the assessment of carbon stock changes associated with observed land-cover transitions. Nevertheless, integrating multiple geospatial datasets and methodological approaches provides a robust basis for understanding the spatio-temporal dynamics of forest cover within the West Coast Cluster of Mount Cameroon.

Authors Contributions

Taboko Akongenow Lucy, Longonje Simon Ngomba, Asongwe Godwill, Athanasius Fuashi Nkwatoh and Mokake Seraphine were responsible for conceptual contributions and research design. Nkemdem Agendia D., Taboko Akongenow Lucy and Guilen-Noel N. Tataw contributed to the GIS and Remote sensing and Data analyses for this study. Levenje Kinge Romoe, Echuaba Laris, Mboza Jerry Clinton, Guilen-Noel N. Tataw and Kamah Pascal Bumtu were responsible for experimental work. Taboko Akongenow Lucy is the principal researcher and wrote the manuscript. All authors read and approved the final manuscript.

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Conflicts of Interest

The authors declare that they have no competing interests.

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