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Abstract

Purpose: The purpose of this article is to analyze the spatiotemporal dynamics of land use and land cover (LULC) changes in the Ebo Forest Reserve, a biodiversity hotspot in West Africa, over a 30-year period from 1994 to 2024.

Materials and Methods: This study employed high-resolution satellite imagery from the Landsat sensor and a supervised classification approach to delineate LULC classes, including Dense Forest, Secondary Forest/Agricultural Land, and Settlements/Bare Soils. An accuracy assessment was conducted to validate the LULC maps, revealing overall accuracies of 99.08% in 1994, 99.89% in 2009, and 100% in 2024.

Findings: The results demonstrated a significant decline in Dense Forest cover from 98.0% in 1994 to 82.0% in 2024, alongside an increase in Secondary Forest/Agricultural Land (from 1.8% to 8.3%) and Settlements/Bare Soils (from 0.2% to 9.7%). These changes reflect the evolving needs of rural communities, driven by population growth, agricultural expansion, and infrastructure development. Climate change was identified as a critical driver affecting ecosystem productivity and resilience.

Implications to Theory, Practice and Policy: The findings underscore the need for a balanced approach to managing LULC changes and climate impacts, ensuring sustainable resource management while supporting community development. Policymakers should prioritize frameworks that facilitate sustainable practices to preserve the ecological integrity of the Ebo Forest Reserve.

Keywords: *Land Use/Land Cover, Change Detection, GIS, Remote Sensing, Ebo Forest Reserve*

(JEL Codes; Q15: Land Ownership and Tenure, Q24: Land Use and Land Cover, Q51: Valuation of Environmental Effects, C63: Computational Techniques; Simulation Modeling)

1.0 INTRODUCTION

Land use and land cover change (LULCC) is a global phenomenon that has been extensively studied and documented in recent years. The modification of the Earth's terrestrial surface by human activities is the primary driver of these changes (Foley *et al.*, 2005; Lambin *et al.*, 2001). While the alteration of land to obtain livelihoods and other essential resources has occurred for thousands of years, the current extent, intensity, and rate of LULCC are far greater than in the past (Lambin and Meyfroidt, 2011; Meyfroidt *et al.*, 2018).

Historically, humans have modified land for thousands of years to obtain livelihoods and other necessities. However, the current scale, intensity, and speed of these changes are significantly greater than ever before. These alterations are major drivers of unprecedented changes in ecosystems and environmental processes at local, regional, and global levels. Consequently, LULCC plays a vital role in the contemporary study and analysis of global environmental changes, providing essential data for ecological management and future environmental planning (Hassan *et al.*, 2016). Research in various fields highlights the importance of LULCC in applications such as agriculture, environmental management, ecology, forestry, geology, and hydrology. These applications address critical issues like cropland loss, soil degradation, urban expansion, and changes in water quality. In recent decades, significant international initiatives have focused on studying land use changes to understand the driving forces behind these transformations. These efforts have encouraged researchers to develop and utilize various techniques to detect and model environmental dynamics at different scales (Hassan *et al.*, 2016).

These rapid and widespread LULCC are the driving forces behind unprecedented local, regional, and global-level changes in ecosystems and environmental processes (Foley *et al.*, 2005; Millennium Ecosystem Assessment, 2005). The conversion of natural landscapes to agricultural lands, urban areas, and other human-dominated land uses can have significant impacts on biodiversity, ecosystem services, and the overall environmental health of a region (Newbold *et al.*, 2015; Seto *et al.*, 2012). Consequently, understanding and monitoring LULCC has become crucial for ecological management, environmental planning, and decision-making (Foley *et al.*, 2005; Lambin and Meyfroidt, 2011).

Africa is a continent facing significant land use and land cover changes (LULCC) driven by rapid population growth, urbanization, and economic development (Brink and Eva, 2009; Alo and Pontius, 2008). These changes have profound implications for the continent's biodiversity, ecosystem services, and sustainable development (Lambin *et al.*, 2003; Teferi *et al.*, 2013). Cameroon, located in Central Africa, is no exception, with its diverse landscapes undergoing substantial transformations (Ordway *et al.*, 2017; Megevand, 2013).

The Littoral region of Cameroon, where the Ebo Forest Reserve is situated, is a biodiversity hotspot that has been subjected to increasing anthropogenic pressures in recent decades (Nkembi *et al.*, 2019; Nkembi and Maisels, 2020). The Ebo Forest Reserve is home to a diverse array of flora and fauna, including several endangered and endemic species (Gonwouo *et al.*, 2006; Maisels *et al.*, 2018). However, the reserve faces threats from deforestation, agricultural expansion, and the development of infrastructure, which have the potential to significantly alter the landscape and disrupt the delicate ecological balance (Nkembi *et al.*, 2019; Nkembi and Maisels, 2020).

Satellite remote sensing and geographic information systems (GIS) have become essential tools for quantifying, mapping, and detecting LULCC patterns in Africa and Cameroon (Brink and Eva, 2009; Ordway *et al.*, 2017). Digital change detection techniques, such as post-classification comparison (PCC), have been widely employed to identify and describe the prevalent changes in land cover and land use (Gao and Liu, 2010; Mondal *et al.*, 2016). The PCC method, which compares independently classified images from different dates, offers the advantage of directly representing the nature of the changes occurring (Yuan *et al.*, 2005; Mondal *et al.*, 2016).

LULCC studies have been conducted in various environments, including agriculturally productive, arid, and semi-arid regions (Rembold *et al.*, 2000; Shalaby and Tateishi, 2007; Gao and Liu, 2010). LULCC studies in Africa have been conducted in various environments, including tropical forests, savannas, and urban areas (Brink and Eva, 2009; Teferi *et al.*, 2013; Ordway *et al.*, 2017). However, the impacts of LULCC are particularly acute in developing countries, where rapid urbanization and population growth often lead to the encroachment of valuable natural habitats and agricultural lands (Lambin *et al.*, 2003; Megevand, 2013).

To address the need for a comprehensive understanding of the spatiotemporal dynamics of LULCC in the Ebo Forest Reserve, this study aims to (1) identify and delineate different land use and land cover categories and patterns of change from 1994 to 2024, (2) integrate supervised classification and visual interpretation using GIS to examine the potential of integrating GIS with remote sensing in studying the spatial distribution of different LULCC, and (3) identify the major driving forces and their extent of contribution to LULCC in the Ebo Forest Reserve.

Research gaps in the study of land use and land cover changes (LULCC) include a lack of longitudinal studies on ecosystem responses, insufficient understanding of socioeconomic impacts on local communities, unclear interactions between climate change and LULCC, limited data on the effectiveness of conservation strategies, and inadequate insight into community perceptions and engagement. Addressing these gaps could lead to hypotheses such as the decline in ecosystem resilience with increased land cover change, the negative socioeconomic effects of LULCC on local livelihoods, and the potential for enhanced conservation outcomes through community involvement. Research questions could focus on how these dynamics interact and influence both ecological and human systems. This study will contribute to the growing body of literature on LULCC in tropical forest ecosystems, particularly in the Littoral region of Cameroon, and provide critical information for the development of effective conservation and management strategies for the Ebo Forest Reserve.

Study Area

The Ebo Forest is situated in the Littoral Region of Cameroon, and lies to the north of the Sanaga River, bridging the Nkam and Sanaga Maritime Divisions, and includes several subdivisions such as Yingui, Yabassi, Edea 2, Ngambe, and Massock-Songloulou (Ayamba *et al.*, 2024). This forest represents more than half of the key biodiversity area in Yabassi and is a significant component of the Yabassi landscape (Morgan *et al.*, 2011). The Ebo Forest Reserve (EFR) and its adjoining forests are within the Littoral Region, stretching across the Nkam and Sanaga Maritime Divisions. Geographically, it is located between latitudes 4°5'3.54" and 4°31'11.19", and longitudes 10°5'38.92" and 10°38'28.11", covering a total area of 2,067.78 km² (Fuashi *et al.*, 2019: WWF, 2003) (Fig.1).

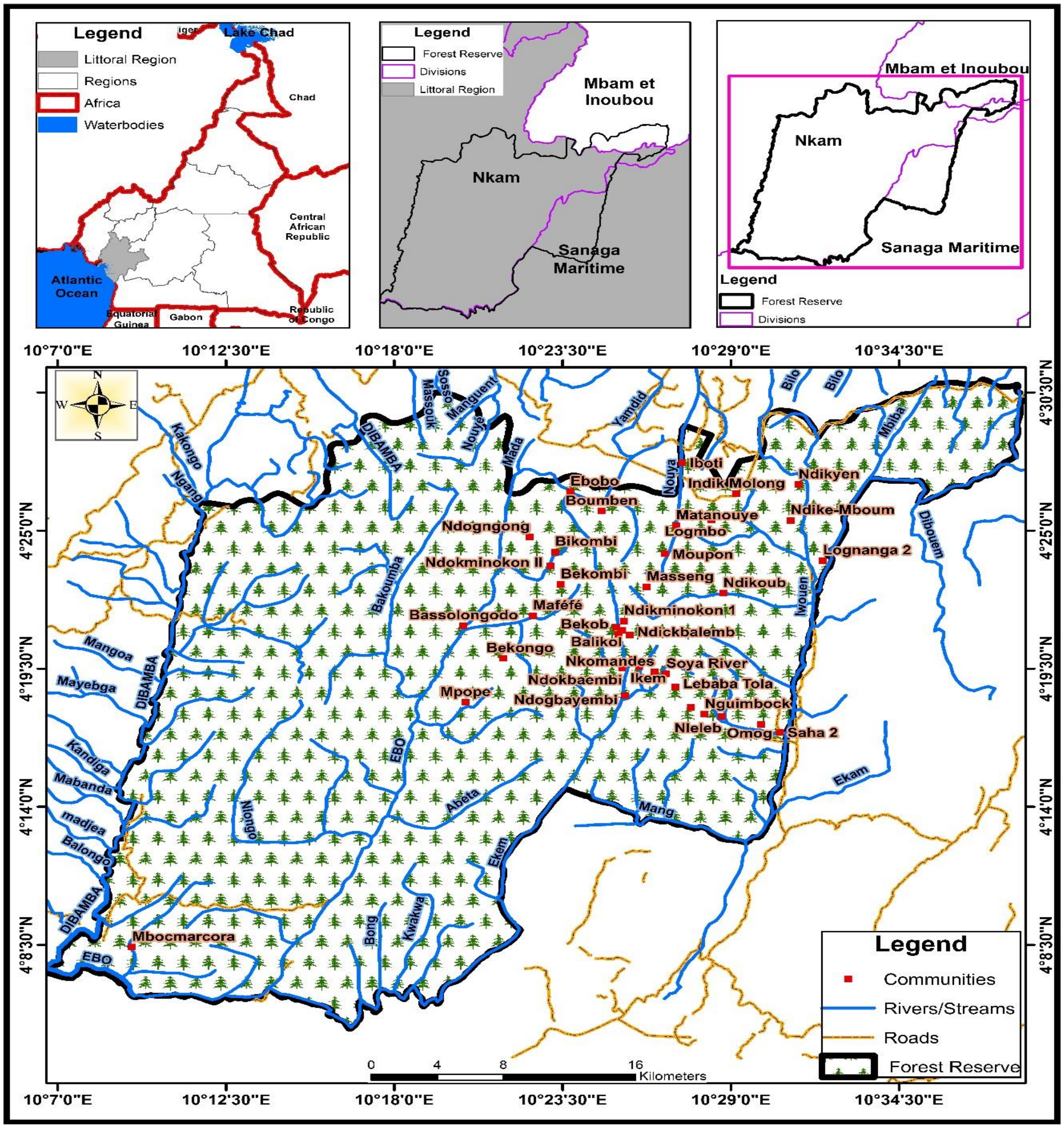

Figure 1: Location Map of the Study Area

Relevant theory that provides a framework for understanding land use and land cover changes (LULCC) is the Land Change Science framework, which integrates various disciplines, including ecology, geography, and environmental science, to examine how human activities and natural processes interact to shape land use patterns (Turner *et al.,* 2015). This theory emphasizes the complex interplay between socio-economic drivers, environmental factors, and land management practices.

Human Nature Interactions: Land Change Science posits that human activities, such as agriculture, urbanization, and infrastructure development, significantly influence land cover changes. In the context of the Ebo Forest Reserve, the study highlights how population growth and agricultural expansion have driven changes in land use patterns (Lambin *et al.,* 2001; Turner *et al.,* 2015).

Spatiotemporal Dynamics: This framework emphasizes the importance of understanding the temporal and spatial dimensions of land use changes. The study's analysis of LULC changes over a 30-year period provides insights into these dynamics, showcasing how land cover has evolved in response to socio-economic pressures and environmental factors (Foley *et al.,* 2005; Geist and Lambin, 2002).

Drivers of Change: Land Change Science identifies various drivers of LULCC, including demographic, economic, technological, and institutional factors. For example, the study identifies climate change as a critical driver affecting ecosystem productivity and resilience, aligning with the broader literature on land change (Newbold *et al.,* 2015; Seto *et al.,* 2012). Implications for Biodiversity and Ecosystem Services: The theory highlights the ecological consequences of land use changes, particularly concerning biodiversity loss and the degradation of ecosystem services. The findings of this study underscore the potential impacts of LULCC on the ecological integrity of the Ebo Forest Reserve (Hassan *et al.,* 2016; Lambin and Meyfroidt, 2011).

2.0 MATERIALS AND METHODS

Data Acquisition/ Satellite Imagery

This study utilized high-resolution satellite imagery from Landsat sensors to analyze the spatiotemporal dynamics of land use and land cover change in the Ebo Forest Reserve. Specifically, Landsat 5 Thematic Mapper (TM) imagery for 1994, Landsat 7 Enhanced Thematic Mapper (ETM+) imagery for 2009, and Landsat 9 imagery for 2024 were acquired from the United States Geological Survey (USGS). The selection of these specific years was made to ensure the analysis captured changes over a 30-year period, with a 15-year interval between each time frame. To minimize the effects of seasonal variations in vegetation patterns, the images were selected from the same annual season from the USGS website. In addition to the satellite imagery, ground control points (GCPs) were collected through direct field observations using a global positioning system (GPS) and Google Earth (Google, 2024). These GCPs were used for image classification and accuracy assessment purposes. Specifications of the satellite data acquired for change analysis are given in Table 1. To validate the satellite imagery interpretation, field surveys were conducted (from December 2023 to April 2024) to collect ground-based data for 2024 image analysis as ancillary data from other documents which were obtain within communities for validation of historic datasets, including GPS coordinates and land cover types. These ground control points (GCPs) were used for the image classification and accuracy assessment processes. The use of ground-truthing data is essential to ensure the reliability and accuracy of the land use and land cover classification (Foody, 2002).

Table 1: Landsat Specifications

Data	Year of acquisition	Bands/color	Resolution (m)	Band composition	Path/Row
Landsat 9	2024	Multi-spectral	15m	8,5,4	061/ 187
Landsat 7 ETM+	2009	Multi-spectral	30m	5,4,3	061/ 187
Landsat 5 TM imagery	1994	Multi-spectral	30m	5,4,3	061/ 187

Accuracy Assessment

To assess the accuracy of the land use and land cover classification, the classified results were compared with the ground control points collected during the field surveys. The accuracy assessment was performed using the ENVI 4.5 software, and standard accuracy metrics, such as overall accuracy and kappa coefficient, were calculated (Harris Geospatial, 2023). The results of the accuracy assessment revealed kappa values of 0.92, 0.99, and 1.00 for the 1994, 2009, and 2024 classifications respectively, indicating a high level of accuracy in the classification process. In addition to the satellite imagery and ground-based data, the study also gathered ancillary data such as socioeconomic, demographic, and policy information that may have influenced the land use and land cover changes in the Ebo Forest Reserve. This data was obtained from various government agencies, research institutions, and published literature. Incorporating ancillary data can provide valuable insights into the underlying drivers of land use and land cover changes (Lambin *et al.*, 2001).

Image Processing and Analysis

Prior to the image classification, several pre-processing steps were performed to ensure the quality and consistency of the satellite imageries. These steps included image pan-sharpening, where a higher-resolution panchromatic image (Band 8) was used to fuse with the lower-resolution multispectral dataset, enhancing the spatial resolution of the images (ESRI, 2023). Additionally, atmospheric and geometric corrections were applied to the images using the ArcGIS Pro 2.2 software (ESRI, 2023). The preprocessed satellite images were then classified using a support vector machine (SVM) classification model in the ENVI 4.5 software (Harris Geospatial, 2023). SVM is a supervised machine learning algorithm that has been widely used for land use and land cover classification due to its ability to handle complex and non-linear relationships in the data (Vapnik, 1995). It also included atmospheric correction, geometric correction, and cloud masking using the ArcGIS Pro 2.2 software (ESRI, 2023). Proper image pre-processing is crucial to minimize the effects of atmospheric conditions, sensor distortions, and cloud cover, which can otherwise introduce errors in the subsequent analysis (Lillesand *et al.*, 2015).

Land Use and Land Cover Classification

The classified land use and land cover maps for the three time periods (1994, 2009, and 2024) were then used to perform change detection analysis. This analysis was perform using the ArcGIS 10.8 software (ESRI, 2023) and the ENVI 4.5 software (Harris Geospatial, 2023). The changes in the area extent and spatial distribution of the different land use and land cover classes were quantified and analyzed to understand the spatiotemporal dynamics of land use and land cover change in the Ebo Forest Reserve. The delineated classes were Dense Forest, Secondary Forest/Agricultural Land and Settlements/Bare soils (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. The choice of classification algorithm can significantly impact the accuracy of the land use and land cover mapping (Foody and Mathur, 2004).

Table 2: Classes Delineated on the Basis of Supervised Classification

LULC classes	Description
Dense forest	Rainforest
Secondary forest/agricultural land	Cropland, plantations and agroforestry
Settlements/bare soils	Logging sites, roads, buildups, farms

The accuracy of the land use and land cover classification was assessed by comparing the classified results with the ground control points collected during the field surveys. Standard accuracy metrics, such as overall accuracy and kappa coefficient, which were calculated using the ENVI 4.5 software (Harris Geospatial, 2023). Accuracy assessment is essential to quantify the reliability of the classification results and identify potential sources of error (Congalton and Green, 2009).

Spatiotemporal Analysis

Land Use and Land Cover Change Detection

Change detection analysis was performed to identify and quantify the changes in land use and land cover over the selected time periods. This analysis was carried out using the ArcGIS 10.8 software (ESRI, 2023) and the ENVI 4.5 software (Harris Geospatial, 2023). Change detection techniques can reveal the magnitude, direction, and spatial patterns of land use and land cover changes (Singh, 1989). Landscape-level metrics, such as patch size, shape, and connectivity, were calculated to analyze the spatial patterns and fragmentation of the land cover types. Landscape metrics provide insights into the structural and functional characteristics of the landscape, which can be linked to ecological processes and biodiversity (McGarigal *et al.*, 2012).

The temporal trends and rates of change in the land use and land cover classes were examined over the study period. Trend analysis can help identify the trajectories and dynamics of land use and land cover changes, which is essential for understanding the long-term implications and informing land management decisions (Pontius *et al.*, 2004). Potential driving factors, such as population growth, economic development, policy changes, and environmental factors, that have influenced the observed land use and land cover changes in the Ebo Forest Reserve were identified and analyzed. Understanding the underlying drivers of land use and land cover changes is crucial for developing effective land management strategies (Geist and Lambin, 2002).

The results of the spatiotemporal analysis and driving factors analysis were presented in the form of maps, graphs, tables, and narratives. Effective visualization and communication of the findings are essential for disseminating the research outcomes and informing decision-makers (Slocum *et al.*, 2009). The implications of the land use and land cover changes on the ecological, social, and economic aspects of the Ebo Forest Reserve were discussed. Recommendations for sustainable land management and conservation strategies were provided based on the findings. Linking the research findings to practical implications and management recommendations can help guide the development of informed policies and interventions (Lambin *et al.*, 2003).

3.0 FINDINGS

The accuracy assessment of the land use/cover classification for the years 1994, 2009, and 2024 was conducted using error/confusion matrices and Kappa statistics. This is the commonly employed approach for evaluating per-pixel classification (Lu and Weng, 2007). For the 1994 classification, the overall map accuracy was 99.0810%, with a Kappa coefficient of 0.9204. The 2009 classification had an overall accuracy of 99.8851% and a Kappa coefficient of 0.9965. The 2024 classification had a perfect overall accuracy of 100% and a Kappa coefficient of 1.0000. The high overall accuracy and Kappa coefficients for all three classification years indicate that the land use/cover maps generated are reliable and can be used for further analysis and change detection. This was reasonably good overall accuracy and accepted for the subsequent analysis and change detection (Lea and Curtis, 2010). The detailed accuracy assessment provides confidence in the reliability of the land use/cover maps and supports the subsequent analysis and interpretation of the land use/cover changes over the study period (Hassan *et al.*, 2016). The cover maps of 1994, 2009, and 2024 are shown in Figures 2, 3 and 4 respectively.

In 1994, the study area was dominated by Dense Forest, which covered a substantial 98.0% of the total land area, equivalent to 138,888.8 hectares. This indicates that the landscape was largely undisturbed, with the majority of the land covered by dense, mature vegetation. The Secondary Forest/Agricultural Land class accounted for a much smaller portion of the area, covering 1.8% or 2,521.7 hectares. This suggests that there was limited agricultural activity or secondary forest regrowth in the region at this time. The Settlements/Bare Soils class made up the smallest portion, occupying only 0.2% of the total land area, or 274.3 hectares, indicating a very low level of human settlement and infrastructure development. The total land area for the study region in 1994 was 141,684.8 hectares.

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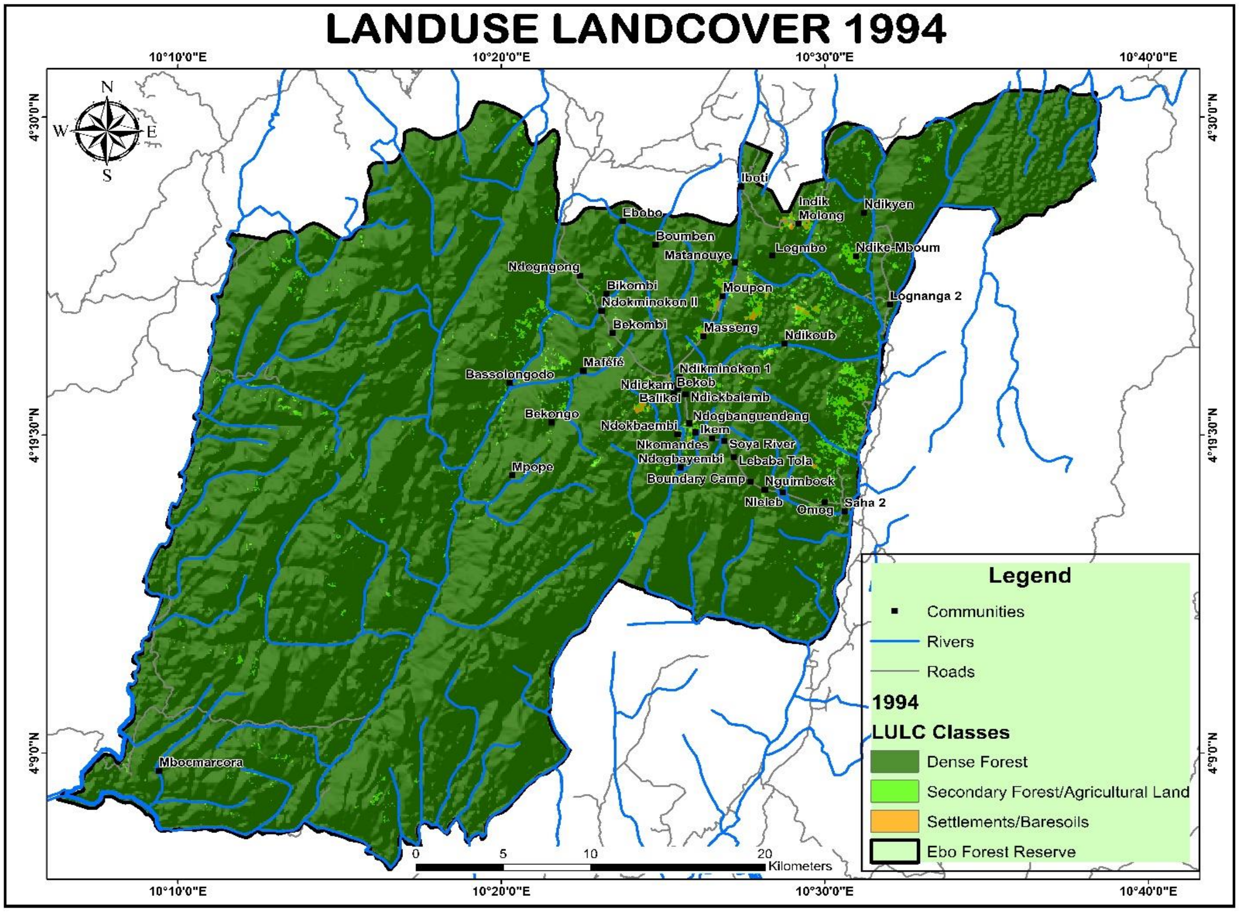

Figure 2: Classified Land Cover Map of in 1994

The predominance of Dense Forest in 1994, covering 98.0% of the total land area, suggests that the landscape was largely undisturbed and provided a vital resource base for the rural communities. These forested areas would have served as a source of timber, fuelwood, and non-timber forest products, supporting the local economy through logging and agroforestry practices (Siddiqui, 1991; UNEP, 2004). The small proportion of Secondary Forest/Agricultural Land (1.8%) and Settlements/Bare Soils (0.2%) indicates that the rural communities had a relatively low-impact presence on the landscape, relying on sustainable resource extraction and traditional farming methods.

By 2009, the land use/land cover pattern had shifted, but the landscape was still predominantly covered by Dense Forest, which accounted for 97.3% of the total area, or 137,832.8 hectares. This represents a slight decrease in Dense Forest cover compared to 1994, suggesting some level of deforestation or forest degradation during this period.

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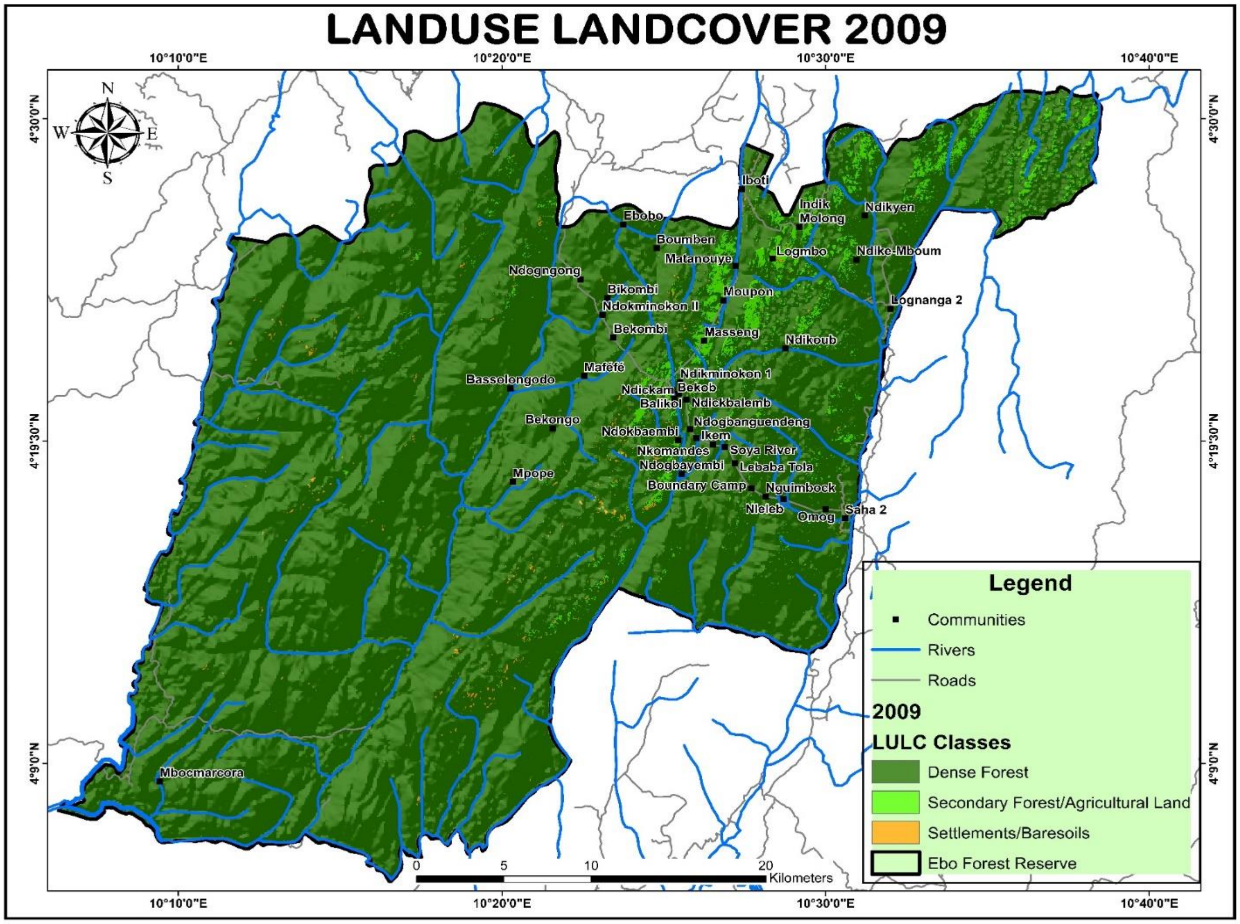

Figure 3: Classified Land Cover Map of in 2009

The Secondary Forest/Agricultural Land class increased to 2.4% of the total area, covering 3,393.1 hectares, indicating a modest expansion of agricultural activities or secondary forest regrowth. The Settlements/Bare Soils class also increased slightly, but only to 0.3% of the total area, or 454.7 hectares, suggesting a gradual increase in human settlement and infrastructure development. The total land area for the study region in 2009 was 141,680.5 hectares.

By 2009, the slight decline in Dense Forest cover (to 97.3%) and the modest increase in Secondary Forest/Agricultural Land (to 2.4%) and Settlements/Bare Soils (to 0.3%) suggest a gradual shift in the land use patterns. This could be attributed to the growing population and the need for the rural communities to expand their agricultural activities and settlements, leading to the conversion of some forested areas (Ellis *et al.*, 2004; IUCN, 2005). However, the landscape was still predominantly covered by dense, mature vegetation, indicating that the rural communities were able to maintain a relatively balanced relationship with the natural environment.

In 2024, the land use/land cover patterns underwent more significant changes. While Dense Forest remained the dominant class, its coverage decreased substantially to 82.0% of the total area, covering 116,140.6 hectares. This represents a significant decline in the extent of Dense Forest, likely due to a combination of factors such as deforestation, forest degradation, and conversion to other land uses. The Secondary Forest/Agricultural Land class experienced a more substantial increase, growing to 8.3% of the total area, covering 11,772.3 hectares.

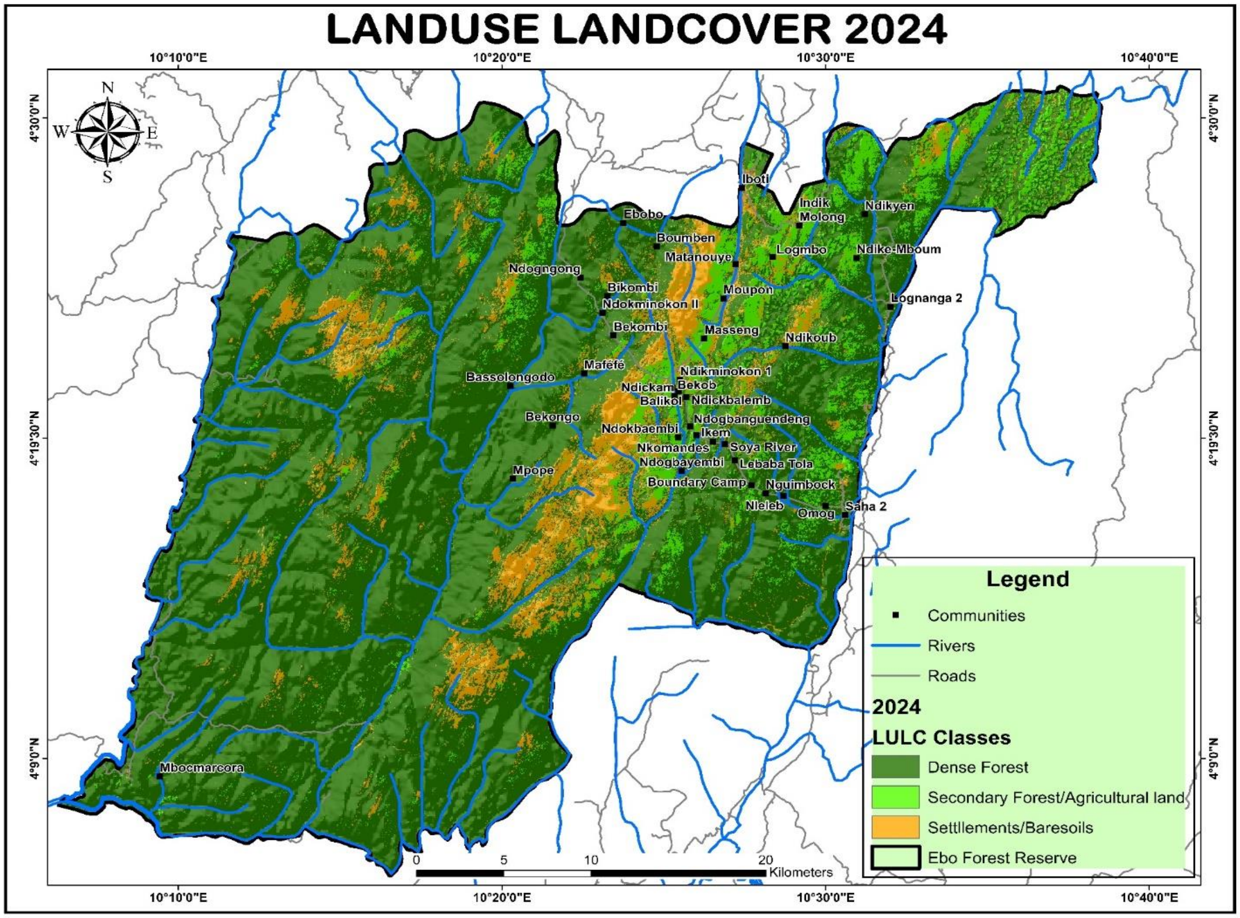

Figure 4: Classified Land Cover Map of in 2024

Table 3: Area Statistics and Percentage of the Land Use/Cover Units in 1994, 2009 and 2024

LULC	1994	%Cover 1994	2009	% Cover 2009	2024	% Cover 2024
Dense Forest	138888.8	98.0	137832.8	97.3	116140.6	82.0
Secondary Forest/Agricultural Land	2521.7	1.8	3393.1	2.4	11772.3	8.3
Settlements/Bare soils	274.3	0.2	454.7	0.3	13767.9	9.7
TOTAL	**141684.8**	**100**	**141680.5**	**100**	**141680.8**	**100**

This suggests an expansion of agricultural activities, as well as the regrowth of secondary forests in previously disturbed areas. The Settlements/Bare Soils class underwent the most dramatic change, expanding to 9.7% of the total area, or 13,767.9 hectares. This significant increase in the Settlements/Bare Soils class indicates a substantial expansion of human settlement, infrastructure, and urbanization within the study region. The total land area for the study region in 2024 was 141,680.8 hectares.

The more significant changes observed in 2024, with the substantial decline in Dense Forest cover (to 82.0%) and the substantial increase in Secondary Forest/Agricultural Land (to 8.3%) and Settlements/Bare Soils (to 9.7%), reflect a more pronounced transformation of the landscape. This could be attributed to a combination of factors, including the intensification of logging activities, the expansion of agricultural land to meet the growing food demands of the rural population, and the development of rural infrastructure and settlements to support the local communities (Butt *et al.*, 2015; Tahir *et al.*, 2013).

The decline in Dense Forest cover and the expansion of agricultural and settlement areas may have had significant impacts on the traditional livelihood activities of the rural communities. The loss of forested areas could have reduced the availability of timber, fuelwood, and non-timber forest products, potentially disrupting the local economy and forcing the communities to seek alternative sources of income (Siddiqui, 1991; Tanvir *et al.*, 2006). Additionally, the expansion of agricultural land and the development of rural infrastructure may have encroached on areas traditionally used for hunting and gathering, further impacting the subsistence activities of the local population.

These changes in land use/land cover over the three time periods (1994, 2009, and 2024) suggest a gradual but significant shift in the landscape, with a decline in Dense Forest cover, an increase in Secondary Forest/Agricultural Land, and a substantial expansion of Settlements/Bare Soils. These trends have important implications for the environmental, ecological, and socio-economic dynamics within the study area and warrant further in-depth investigation and analysis to understand the underlying drivers and consequences of these changes. These LULC changes, while reflecting the evolving needs and development patterns of the rural communities, also highlight the potential tensions between traditional land use practices and the pressures of population growth, agricultural expansion, and infrastructure development. Addressing these challenges will require a careful balance between supporting the livelihoods and well-being of the rural communities while also ensuring the sustainable management of the natural resources and the preservation of the ecological integrity of the landscape.

Table 4: Major Land Use/Cover Conversions from 1994 to 2024

LULC	Area Δ 1994-2009	% Δ 1994-2009	Area Δ 2009-2024	% Δ 2009-2024	Area Δ 1994-2024	% Δ 1994-2024
Dense Forest	-1056.0	-0.7	-21692.2	-15.3	-22748.2	-16.1
Secondary Forest/Agricultural Land	871.4	0.6	8379.3	5.9	9250.7	6.5
Settlements/ Bare soils	180.4	0.1	13313.2	9.4	13493.6	9.5
TOTAL	**-4.2**	**0.0**	**0.3**	**0.0**	**-3.9**	**0.0**

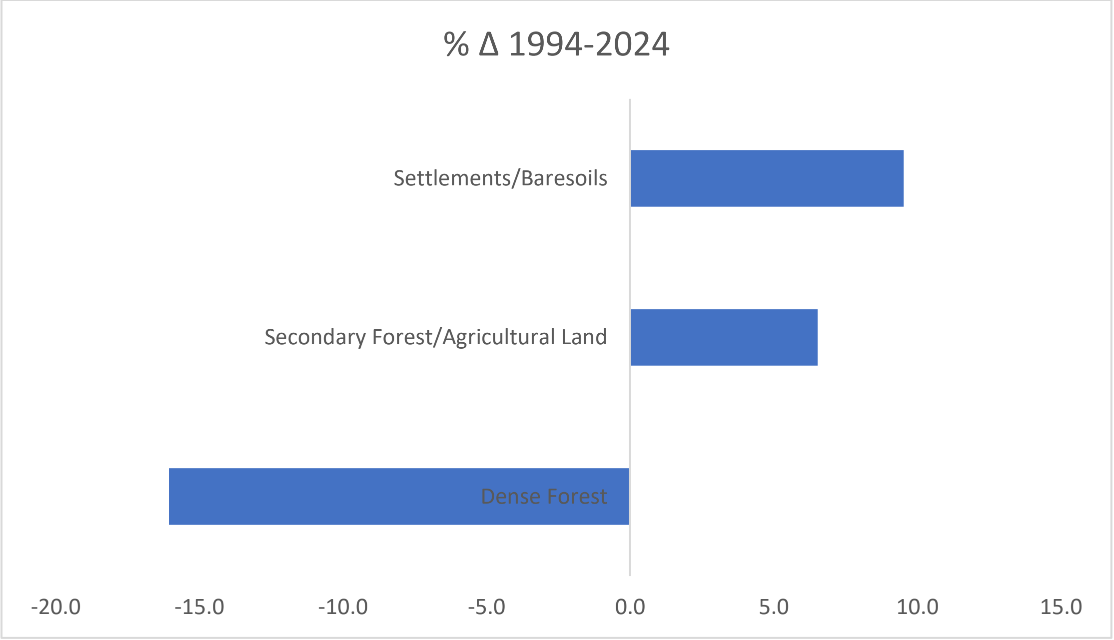

Figure 5: Major Land Use Conversion from 1994 to 2024

The data shows that between 1994 and 2009, the area under Dense Forest declined by 1,056 hectares (-0.7%). This relatively small decline during this initial period suggests that the rural communities were able to maintain a relatively balanced relationship with the forested areas, likely through sustainable logging and agroforestry practices (Siddiqui, 1991; UNEP, 2004). However, the period between 2009 and 2024 saw a much more significant decline in Dense Forest cover, with a loss of 21,692.2 hectares (-15.3%). This substantial decrease in forest cover is consistent with findings from other studies in rural areas of developing countries, which have documented the impacts of population growth, agricultural expansion, and infrastructure development on natural forests (Ellis *et al.*, 2010; Butt *et al.*, 2015).

The increase in Secondary Forest/Agricultural Land (871.4 hectares or 0.6% between 1994-2009, and 8,379.3 hectares or 5.9% between 2009-2024) and Settlements/Bare Soils (180.4 hectares or 0.1% between 1994-2009, and 13,313.2 hectares or 9.4% between 2009-2024) reflects the growing needs of the rural communities for agricultural land and living space. This is a common trend observed in many rural areas, where the expansion of agricultural activities and the development of settlements often come at the expense of forested lands (Chigbu *et al.*, 2011; Tripathi and Kumar, 2012).

Table 5: Change Detection

Classes	Dense Forest (%)	Secondary Forest /Agricultural land (%)	Settlements/Bare soils (%)	Row Total (%)	Class Total (%)
Unclassified	0	0	0	0	0
Dense Forest	40.569	13.51	52.778	100	100
Secondary Forest/Agricultural land	3.937	68.182	33.437	100	100
Settlements/Bare soils	55.494	18.308	13.786	100	100
Class Total	100	100	100	0	0
Class Changes	59.431	31.818	86.214	0	0
Image Difference	-58.894	4172.979	5508.876	0	0

Equivalent Class Pairings
Dense Forest <==> Dense Forest
Secondary Forest/Agricultural land <==> Secondary Forest/Agricultural land
Settlements/Baresoils <==> Settllements/Baresoils

The overall change in LULC between 1994 and 2024 shows a net decrease of 3.9 hectares, indicating a relatively small net change in the total land area. However, the significant shifts in the composition of the landscape, with a 16.1% decline in Dense Forest and a 6.5% increase in Secondary Forest/Agricultural Land and a 9.5% increase in Settlements/Bare Soils, suggest that the rural communities have undergone substantial transformations in their land use patterns and livelihood strategies (Reis, 2008; Tahir *et al.*, 2013).

These LULC changes highlight the complex interplay between the traditional resource-based livelihoods of the rural communities and the pressures of population growth, agricultural expansion, and infrastructure development. Addressing these challenges will require a balanced approach that supports the development needs of the rural communities while also ensuring the sustainable management of the natural resources and the preservation of the ecological integrity of the landscape (IUCN, 2005; Tanvir *et al.*, 2006). Climate change is widely recognized as a significant driver of LULC changes worldwide (IPCC, n.d.). Alterations in temperature and precipitation patterns can have far-reaching consequences on various ecological processes, including agricultural productivity, forest nutrient cycles, and the overall resilience of natural ecosystems (Johnson *et al.*, 2000; Bonan, 2008).

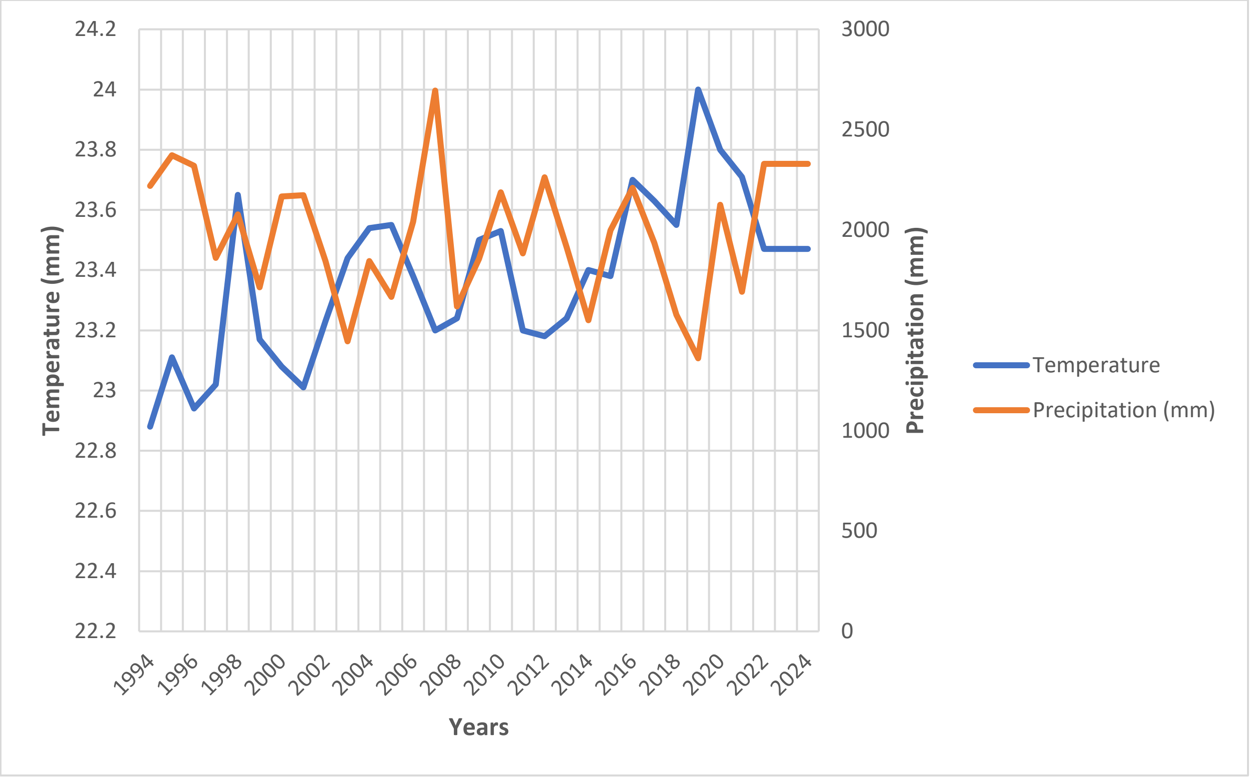

Figure 6: Change in Temperature and Precipitation from 1994 to 2024

Precipitation is a crucial factor in the continuous destruction of forests and agricultural lands. Higher rainfall can enhance growing period duration in some areas, but it can also lead to the loss of fertile soils due to intense flooding and hinder the drying and storage of crops (UNEP, 2004). Conversely, declining precipitation can contribute to the reduction of woody biomass, which is a significant issue, as the declining rate of forest area is the second highest in the world, ranging from 4-6% per year (UNEP, 2004).

The Intergovernmental Panel on Climate Change (IPCC) has predicted that an increase in the average global temperature can lead to changes in atmospheric moisture and precipitation patterns, resulting in more intensive rainfall, floods, drying of rivers, unpredictable weather patterns, and frequent drought events (IPCC, n.d.). These climate-induced changes can have significant implications for land use and land cover, as they can affect the availability and distribution of water resources, the productivity of agricultural and forest ecosystems, and the overall resilience of these systems to environmental stressors (Hassan *et al.*, 2016).

Planners and decision-makers across various sectors will need to confront the challenges posed by a changing climate and adopt a range of adaptation practices to ensure sustainable urbanization, better conservation of water supplies, forests, and agricultural lands, and the development of alternative strategies for their management (Johnson *et al.*, 2000; Bonan, 2008). In the context of LULC, it is crucial to understand the complex interactions between climate change and the various biophysical and socioeconomic factors that drive land use and land cover changes. By incorporating the latest scientific evidence and projections on the impacts of climate change, policymakers and land-use planners can develop more informed and effective strategies to mitigate the adverse effects of climate change on LULC and promote the sustainable management of natural resources (Hassan *et al.*, 2016).

The findings from the analysis of land use and land cover changes (LULCC) in the Ebo Forest Reserve have significant implications for ecological management, policy formulation, and community development. The substantial decline in Dense Forest cover, from 98.0% in 1994 to 82.0% in 2024, highlights the urgent need for biodiversity conservation strategies. The Ebo Forest Reserve is home to numerous endemic and endangered species, and habitat loss poses a direct threat to their survival. Strengthening conservation policies to enhance the protection of critical habitats within the reserve. Implementing stricter regulations against illegal logging and land conversion can help mitigate further biodiversity loss (Bennett, 2004). Establishing long-term monitoring programs to track changes in species populations and habitat conditions. This data can inform adaptive management strategies that respond to ongoing ecological changes (Harrison *et al.*, 2014). The increase in Secondary Forest/Agricultural Land and Settlements/Bare Soils indicates a shift towards more anthropogenic land uses. This transition necessitates a focus on sustainable land management practices, including promoting agroforestry systems that integrate tree planting with agricultural activities can enhance biodiversity while providing economic benefits to local communities (Nair, 1993). Such practices can improve soil health, increase carbon sequestration, and reduce erosion. Involving local communities in land management decisions is crucial. Education and awareness programs can empower residents to adopt sustainable practices that balance development needs with ecological preservation (Pretty, 1995).

The identification of climate change as a critical driver of ecosystem change emphasizes the need for adaptive strategies. The implications include developing strategies to enhance the resilience of ecosystems to climate impacts. This can involve restoring degraded areas, maintaining ecological corridors, and preserving genetic diversity within species (Holling, 1973). With policymakers adopting integrated land use planning approaches that consider climate projections and potential impacts on land cover (Seto *et al.*, 2012). This can help anticipate changes and implement proactive measures to mitigate negative effects. The findings reveal that land use changes are closely linked to socioeconomic factors such as population growth and infrastructure development. Thus, the implications for socioeconomic development include encouraging economic diversification beyond traditional agriculture and logging can reduce pressure on forest resources. Promoting ecotourism and sustainable harvesting of non-timber forest products can provide alternative livelihoods (Boo, 1990), future infrastructure projects should be carefully assessed for their environmental impact. Strategic planning can help minimize habitat fragmentation and ensure that development aligns with conservation goals (Forman and Alexander, 1998). Implementing and enforcing laws that protect forest ecosystems is vital. Policies should be developed to regulate land use changes and promote sustainable practices (McNeely, 1993). Increased funding for research on LULCC and its impacts is essential. Supporting studies that explore innovative conservation methods and sustainable practices can enhance the effectiveness of management strategies (Sutherland *et al.*, 2004).

4.0 CONCLUSION AND RECOMMENDATIONS

The analysis of land use and land cover (LULC) changes in the study area over the period from 1994 to 2024 reveals a significant transformation of the landscape. The data shows a gradual but substantial decline in Dense Forest cover, from 98.0% in 1994 to 82.0% in 2024, accompanied by an increase in Secondary Forest/Agricultural Land and a dramatic expansion of Settlements/Bare Soils. These LULC changes reflect the evolving needs and development patterns of the rural communities within the study region. The decline in Dense Forest cover is likely attributable to a combination of factors, including the intensification of logging activities, the expansion of agricultural land to meet growing food demands, and the development of rural infrastructure and settlements to support the local population. While the initial period from 1994 to 2009 saw a relatively modest decline in forest cover, the subsequent 15 years witnessed a much more substantial decrease, highlighting the accelerating pressures on the natural environment.

The expansion of Secondary Forest/Agricultural Land and Settlements/Bare Soils underscores the growing importance of agricultural activities and human settlement development within the region. This shift in land use patterns has significant implications for the traditional livelihood strategies of the rural communities, potentially disrupting their access to timber, fuelwood, and non-timber forest products, and encroaching on areas traditionally used for hunting and gathering. These LULC changes also have wider implications for the environmental and ecological dynamics of the study area. The decline in Dense Forest cover and the expansion of human activities can lead to the loss of biodiversity, the degradation of ecosystem services, and the increased vulnerability of the landscape to the impacts of climate change. Addressing these challenges requires a balanced approach that supports the development needs of the rural communities while also ensuring the sustainable management of natural resources and the preservation of the ecological integrity of the landscape.

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Authors' Contributions

Tataw Guilen-Noel Nghokapi, Melle Ekane Maurice and Athanasius Fuashi Nkwatoh were responsible for conceptual contributions and research design. Tataw Guilen-Noel Nghokapin and Kamah Pascal Bumtu were responsible for experimental work. Tataw Guilen-Noel Nghokapin is the principal researcher and wrote the manuscript. All authors read and approved the final manuscript

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Competing Interests

The authors declare that they have no competing interests.

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