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Impact of Socio-Economic and Environmental Factors on Deforestation in Rwanda: A Case of Gicumbi District

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Abstract

This study examines the impact of socio-economic and environmental factors on deforestation in Gicumbi District, Rwanda, from 2004 to 2024. The objectives are to analyze spatial and temporal forest cover change, identify key socio-economic and environmental drivers, assess the effectiveness of restoration programs such as the "Green Gicumbi" initiative, and propose strategies for sustainable forest management. A mixed-methods approach was used, combining satellite imagery, remote sensing, and GIS mapping to detect forest loss hotspots, with field surveys, questionnaires, and policy reviews to capture socio-economic conditions and community perceptions. Results show significant forest decline over the past two decades, largely due to agricultural encroachment, charcoal production, and rapid population growth. Remote sensing confirmed continuous forest cover loss, while qualitative findings revealed low community awareness and limited participation in conservation. Restoration initiatives have had modest impact, hindered by weak enforcement, inadequate funding, and poor alignment between national goals and local needs. The study recommends participatory approaches that strengthen institutional capacity, expand agroforestry, promote sustainable agriculture, enhance awareness campaigns, and invest in community-led reforestation.

Keywords: *Socio-Economic, Environmental Factors, Deforestation, Gicumbi District, Rwanda*

1. Introduction

Deforestation poses a significant environmental challenge in Rwanda, particularly in rural districts like Gicumbi, where forest degradation has profound effects on local ecosystems, agricultural productivity, and water quality. Despite national initiatives aimed at mitigating deforestation, the rate of forest loss remains alarmingly high in Gicumbi. This persistent issue contributes to soil erosion, diminished water quality, and declining biodiversity, all of which threaten the livelihoods of local communities according to Bikorimana et al., (2023) and Ntabakirabose et al., (2024). While national studies have examined deforestation, there is a notable gap in research focusing specifically on Gicumbi District, especially in terms of detailed, geospatially-driven analysis over a significant period of time. The lack of comprehensive, district-level studies utilizing modern

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geospatial tools such as remote sensing and Geographic Information Systems (GIS) has hindered an accurate understanding of deforestation trends in the district. Existing studies are often limited by outdated data, insufficient spatial coverage, or a lack of temporal depth, making it difficult to assess the long-term dynamics of forest cover change. Additionally, there is limited analysis of the socio-economic and environmental drivers of deforestation at the local level, complicating the design of effective, targeted conservation strategies. This research aims to address these gaps by using satellite imagery and GIS to map deforestation trends in Gicumbi district from 2004 to 2024, while also evaluating the effectiveness of national forest restoration programs By providing a data-driven analysis, the study seeks to inform tailored policy interventions for improving forest conservation and sustainable land management practices in the district (FONERWA, 2019).

1.2 Objectives of the Research

1.3 General Objective

The main objective of this study is to investigate and quantify the trends of deforestation in Gicumbi District between 2004 and 2024 through the application of geospatial technologies, including remote sensing and GIS. This study aims to identify the key drivers of deforestation, assess the effectiveness of national forest restoration initiatives, and provide actionable recommendations for improving forest conservation practices and sustainable land management in the district

1.4 Specific objectives

i. To analyze deforestation trends in Gicumbi District from 2004 to 2024
ii. To assess the socio-economic and environmental drivers of deforestation in Gicumbi District.
iii. To evaluate the effectiveness of forest restoration programs in Gicumbi District.

2. Materials and methods

2.1 Profile of the study area

Gicumbi District, located in northern Rwanda about 58 km northeast of Kigali, lies in the eastern part of the Northern Province. It is bordered by Burera District to the north, Nyagatare, Rwamagana, and Gatsibo to the east, Rwamagana and Gasabo to the south, and Gasabo, Burera, and Rulindo to the west. Covering 828.9 km² and divided into 21 sectors, Gicumbi features both highland and lowland landscapes. The district has a temperate climate with average annual temperatures of 15–16°C and abundant but irregular rainfall ranging from 1,200 to 1,500 mm. Soils, primarily kaolisols on schist and quartz, are generally acidic. Elevations range from 1,500 to 2,500 m, with steep slopes, narrow valleys, and rugged mountains. The climate includes two rainy seasons (September–December and March–May) and two dry seasons (January–February and June–August). Situated in the Buberuka highlands, Gicumbi is predominantly agricultural. Most residents farm maize, beans, potatoes, and vegetables for both subsistence and markets, while livestock rearing cattle, goats, and poultryalso supports livelihoods. Agricultural expansion, particularly the conversion of forest to cropland and pasture, is a significant driver of deforestation in the district.

Gicumbi's hydrographic network comprises numerous rivers and streams, including Mwange, Mulindi, Mutulirwa, Walufu, Muyanza, and Gaseke, which form wetlands in the plains. The district shares the Rugezi wetlands and Lake Muhazi with neighboring districts. It falls within the Muvumba and Nyabarongo catchments, with 60% of its land in the degraded Muvumba watershed,

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part of the Kagera sub-basin in the upper Nile Basin, ultimately draining into the Mediterranean Sea. Understanding Gicumbi's geographic, climatic, and socio-economic context is essential for addressing its deforestation challenges. Insights from deforestation trend analysis can guide policy, inform sustainable forest management, and support national and regional strategies to mitigate environmental and community impacts.

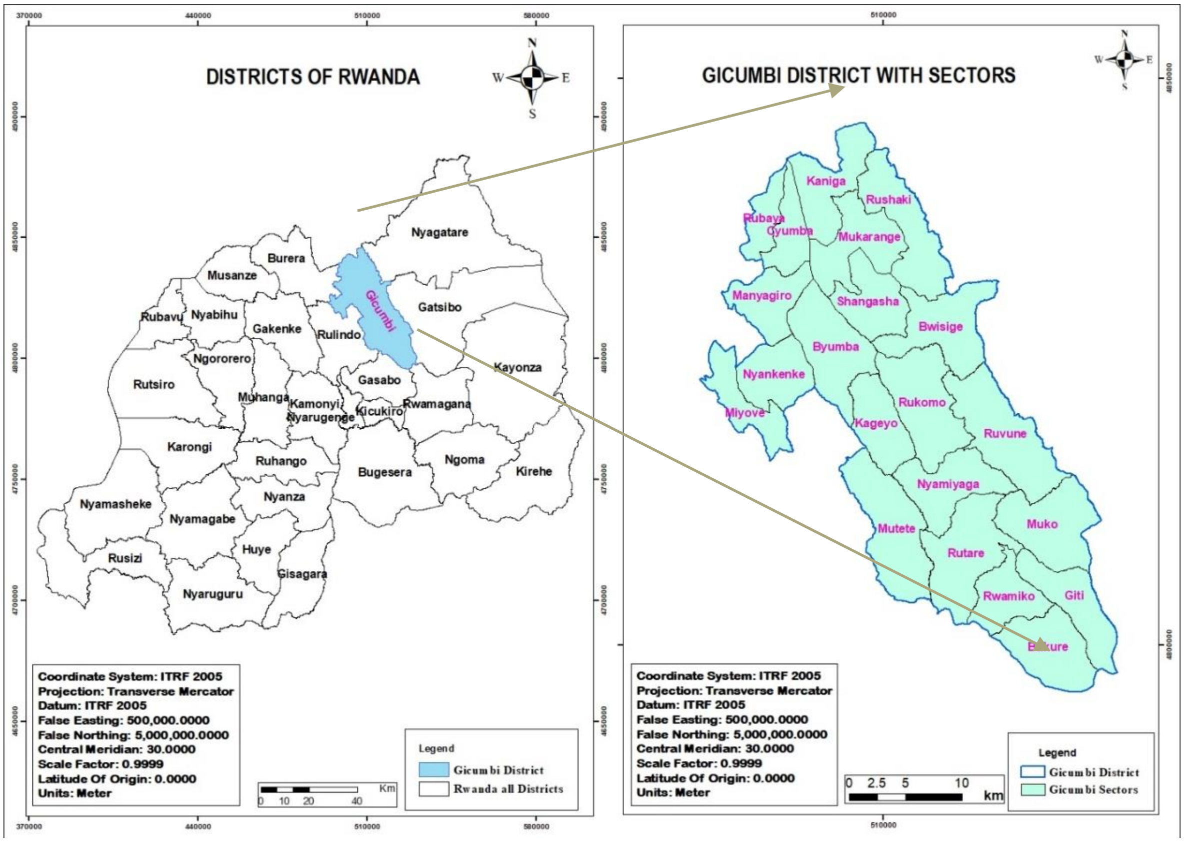

Figure 3. 1 Study area (Source: Rwanda geoportal)

2.2 Research design and data collection methods

This study employs a descriptive survey design with explanatory elements to analyze deforestation trends in Gicumbi District, Rwanda, from 2004–2024. The approach combines quantitative methods satellite imagery, remote sensing, and GIS mapping to document spatial patterns of forest loss, with qualitative methods with surveys, interviews, and field observations to explore socio-economic drivers such as agricultural expansion, charcoal production, and population growth.

Primary data will be collected through questionnaires targeting farmers, government officials, and other stakeholders, as well as direct field observations supported by photographic documentation. Secondary data will come from published literature, government reports, and statistical datasets from institutions such as REMA, RWB, RFA, and NISR. The target population is the 109,373 households of Gicumbi District (2022 census). Using Cochran's formula at a 95% confidence level and 5% margin of error, the adjusted sample size is 384 households, proportionally allocated across 21 sectors (18 households per sector).

2.4 Data analysis

The Satellite imagery for 2004, 2014, and 2024 from USGS Earth Explorer will be pre-processed through georeferencing, radiometric calibration, and cloud masking. Supervised classification in ERDAS Imagine will identify land cover types, with accuracy assessed against ground truth data. Change detection analysis will quantify forest loss and produce GIS-based maps showing deforestation patterns.

Questionnaire data will be cleaned and analyzed in Excel or SPSS. Quantitative data will undergo descriptive, bivariate, and multivariate analysis, while qualitative responses will be thematically analyzed to identify socio-economic drivers. Integrating geospatial and socio-economic results will reveal correlations between deforestation and factors such as agricultural expansion, charcoal production, and population growth, informing recommendations for sustainable forest management in Gicumbi District.

3. Results

Understanding the demographic and socio-economic characteristics of respondents is essential for contextualizing the findings. The study considered various factors such as gender, occupation, and education level of individuals affected by deforestation in Gicumbi district.

Table 4.1: Background of respondents

Characteristics of the respondents	Frequency	Percentage
1. Sex		
Male	225	58.4%
Female	160	41.6%
Total	**384**	**100.0%**
2. Marital status		
Single	140	36.4%
Married	200	51.9%
Divorced	25	6.5%
Separated	20	6.2%
Total	**384**	**100.0%**
3. Age		
18 to 25 years	70	18.2%
25 to 35 years	80	20.8%
35 to 45 years	90	23.4%
45 to 55 years	65	16.9%
55 to 65 years	50	13.0%

65 years and above	29	7.8%
Total	**384**	**100.0%**
4. Education Level		
No formal education	30	7.8%
Primary education	80	20.8%
Secondary education	160	41.6%
University/College	115	29.8%
Total	**384**	**100.0%**
5. Occupation		
Farmers	180	46.8%
Businesspersons	90	23.4%
Government Employees	50	13.0%
NGO/Environmental Workers	35	9.1%
Informal workers	30	7.8%
Total	**384**	**100.0%**

Source: Primary data (2025)

4.2 Analysis of Key Drivers of Deforestation in Gicumbi District

The study identified six primary drivers of deforestation in Gicumbi District based on respondents' perspectives. These factors contribute to the continued loss of forest cover, each with varying degrees of influence as of view from the respondant.

3.2.1 Contribution of Agricultural Expansion to deforestation

Agriculture is the leading cause of deforestation in Gicumbi, accounting for 37.7% of total responses. The demand for farmland has increased due to population growth and the need for food security. Farmers often clear forests to cultivate crops, particularly in highland areas where soil fertility is relatively better. This continuous conversion of forests into farmland accelerates environmental degradation and soil erosion.

3.2.2 Contribution of Charcoal and Firewood Production to deforestation

The second major driver is the reliance on wood fuel, which constitutes 26.0% of the responses. Many households and small industries depend on firewood and charcoal as their primary energy sources due to the high cost and limited availability of alternative fuels. This dependence has led to extensive tree cutting, significantly reducing forest cover in the district.

3.2.3 Contribution of Population Growth and Settlement Expansion to deforestation

As Gicumbi's population increases, so does the demand for land for housing and infrastructure. Representing 15.6% of respondents' views, settlement expansion is a notable factor in deforestation. The need for residential areas has led to uncontrolled urbanization, where forests are cleared to make way for new settlements, roads, and commercial developments.

3.2.4 Contribution of Illegal Logging to deforestation

Illegal logging accounts for 10.4% of the drivers of deforestation. The demand for timber, both for local use and commercial sale, has led to unregulated tree harvesting. Despite efforts to enforce conservation policies, weak monitoring systems have enabled illegal activities to persist, further threatening forest sustainability.

3.2.5 Contribution of Infrastructure Development to deforestation

Infrastructure projects, such as road construction, schools, and commercial centers, contribute to 6.5% of deforestation cases. As the district develops, more land is required for public and private projects, often at the expense of forested areas.

3.2.6 Contribution of Climate Change Effects to deforestation

Though the least reported factor at 3.9%, climate change plays a role in deforestation. Changes in weather patterns, prolonged droughts, and increased temperatures have affected tree health, making forests more vulnerable to degradation. Additionally, unpredictable rainfall has led to soil erosion, further diminishing vegetation cover.

The table below summarize the perseverance of the respondents to the deforestation drivers:

Table 3.2: Ranking the key drivers of deforestation in vew of the respondents

S/N	Deforestation Driver	Frequency (n)	Percentage (%)
1	Agricultural Expansion	145	37.7
2	Charcoal and Firewood Production	100	26.0
3	Population Growth & Settlement	60	15.6
4	Illegal Logging	40	10.4
5	Infrastructure Development	25	6.5
6	Climate Change Effects	14	3.9
Total		**384**	**100%**

Source: Primary data (2025)

Table 3.3: Views of Respondents on the Drivers of Deforestation in Gicumbi District (N=385)

Items Assessed	**SA**		**A**		**NS**		**D**		**SD**		**Mean**	**Std. Dev.**	**Comment**
	Fi	**%**	**Fi**	**%**	**Fi**	**%**	**Fi**	**%**	**Fi**	**%**			**Homogeneity/ Heterogeneity status**
Agricultural Expansion is a major cause of deforestation	145	37.7	210	54.5	10	2.6	12	3.1	8	2.1	4.19	0.395	Strong Homogeneity
Charcoal & Firewood Production contribute significantly to deforestation	100	26.0	195	50.6	20	5.2	40	10.4	30	7.8	2.28	1.168	Neutral Heterogeneity
Population Growth & Settlement expansion increases deforestation	60	15.6	170	44.2	30	7.8	80	20.8	45	11.6	2.23	0.881	Neutral Heterogeneity
Illegal Logging is a serious issue affecting forest cover	40	10.4	150	39.0	50	13.0	90	23.4	55	14.3	3.10	0.872	Moderate Variability
Infrastructure Development has contributed to forest loss	25	6.5	130	33.8	60	15.6	110	28.6	60	15.6	3.35	0.905	Moderate Variability
Climate Change Effects have worsened deforestation trends	15	3.9	90	23.4	70	18.2	140	36.4	70	18.2	2.50	1.112	Moderate Variability

Keys: **Fi**: Frequency; Strongly agree (**SA**) was coded 5, Agree **(A)** coded 4, Not Sure **(NS)** coded 3, Disagree **(D)** coded 2, and Strongly Disagree (**SD**) coded 1. The mean classification was into 3 categories such as weak (1.00-2.00), neutral (2.01-3.00), moderate (3.01-4.00) and strong (4.01-5.00) and standard deviation was into two categories such as homogeneity (**St.dv. 0.5**). Mean: Average of perception from all 385 perceptions as coded in numbers and **St.dev**: Standard deviation which signify gap between individual perception from the general perception or mean. The comment column combines the category of mean and that of the standard deviation based on the finding

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3.3 Spatial analysis of deforestation trends

The spatial analysis of deforestation trends in Gicumbi District was conducted using geospatial techniques, including remote sensing and GIS-based mapping. This analysis provides an in-depth understanding of forest cover changes over time, highlighting areas experiencing the highest deforestation rates. By examining satellite imagery from 2004, 2014, and 2024, the study identified significant reductions in forested land, primarily due to agricultural expansion, fuelwood harvesting, and settlement growth. The findings indicate a continuous loss of forest cover, with notable deforestation hotspots emerging in central and eastern Gicumbi. This section presents a comparative assessment of deforestation patterns over the past two decades, emphasizing the role of human activities in accelerating forest depletion.

3.3.1 Forest Cover in 2004

In 2004, the total forest cover in Gicumbi District was 1,005,238 hectares. This represented a relatively dense forest cover compared to later years. During this period, forests played a crucial role in maintaining ecological balance, providing habitat for wildlife, and serving as a source of livelihood for local communities. However, early indications of deforestation were already present, primarily driven by agricultural expansion, fuelwood collection, and population growth. The use of satellite imagery and GIS techniques shows that the forest cover was more extensive in the western and northern parts of the district, with significant tree density in protected areas.

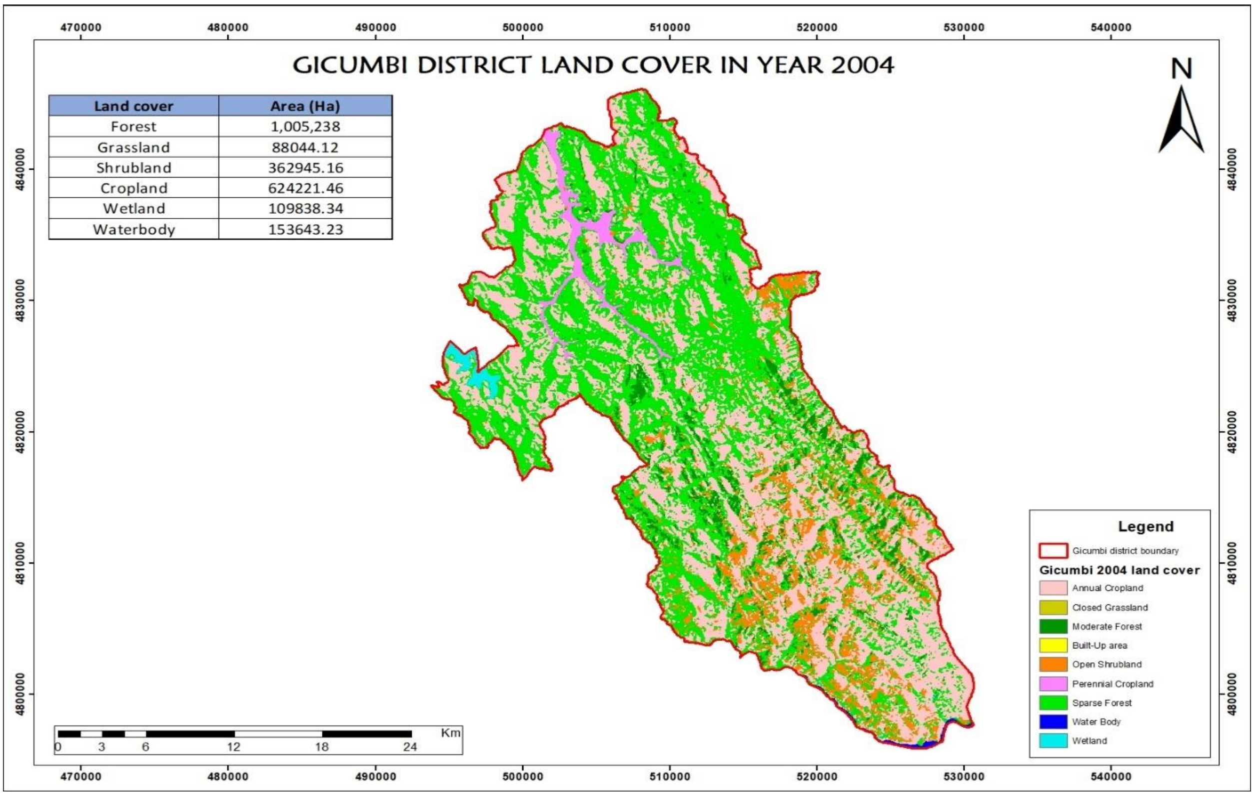

Figure 3. 1 Forest Cover in 2004 (Source: Landsat image)

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3.3.2 Forest Cover in 2014

By 2014, forest cover in Gicumbi had declined significantly to **690,550 hectares**, reflecting a loss of approximately **250,156 hectares** over the decade. The primary drivers of deforestation during this period included the conversion of forest land into agricultural fields, increased logging for construction and fuelwood, and settlement expansion. GIS-based spatial analysis revealed that deforestation was particularly severe in central and eastern Gicumbi, where high population density and economic activities accelerated tree clearance. The annual rate of forest loss between 2004 and 2014 was calculated at **25,016 hectares per year.**

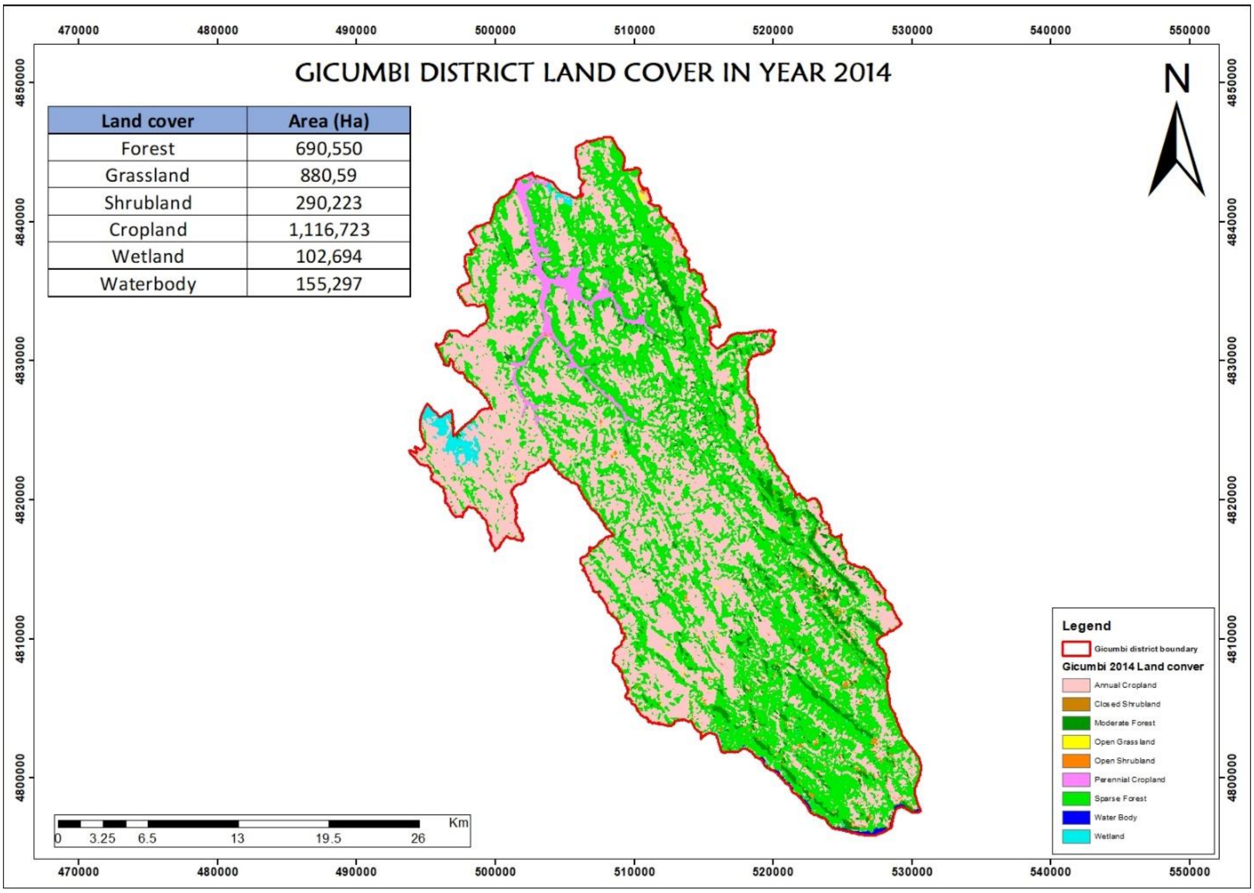

Figure 3. 2 Forest Cover in 2014 (Source: Landsat image)

3.3.3 Forest Cover in 2024

The most recent assessment, based on satellite imagery for 2024, indicates that the total forest cover in Gicumbi has further declined to **432,578 hectares**. This represents an additional loss of **322,504 hectares** between 2014 and 2024, with an **accelerated deforestation rate of 32,250 hectares per year**. The factors responsible for this continued decline include unsustainable agricultural practices, illegal logging, urbanization, and charcoal production. The loss of forested land has exacerbated soil erosion, reduced biodiversity, and increased vulnerability to climate change effects, making reforestation efforts more urgent than ever.

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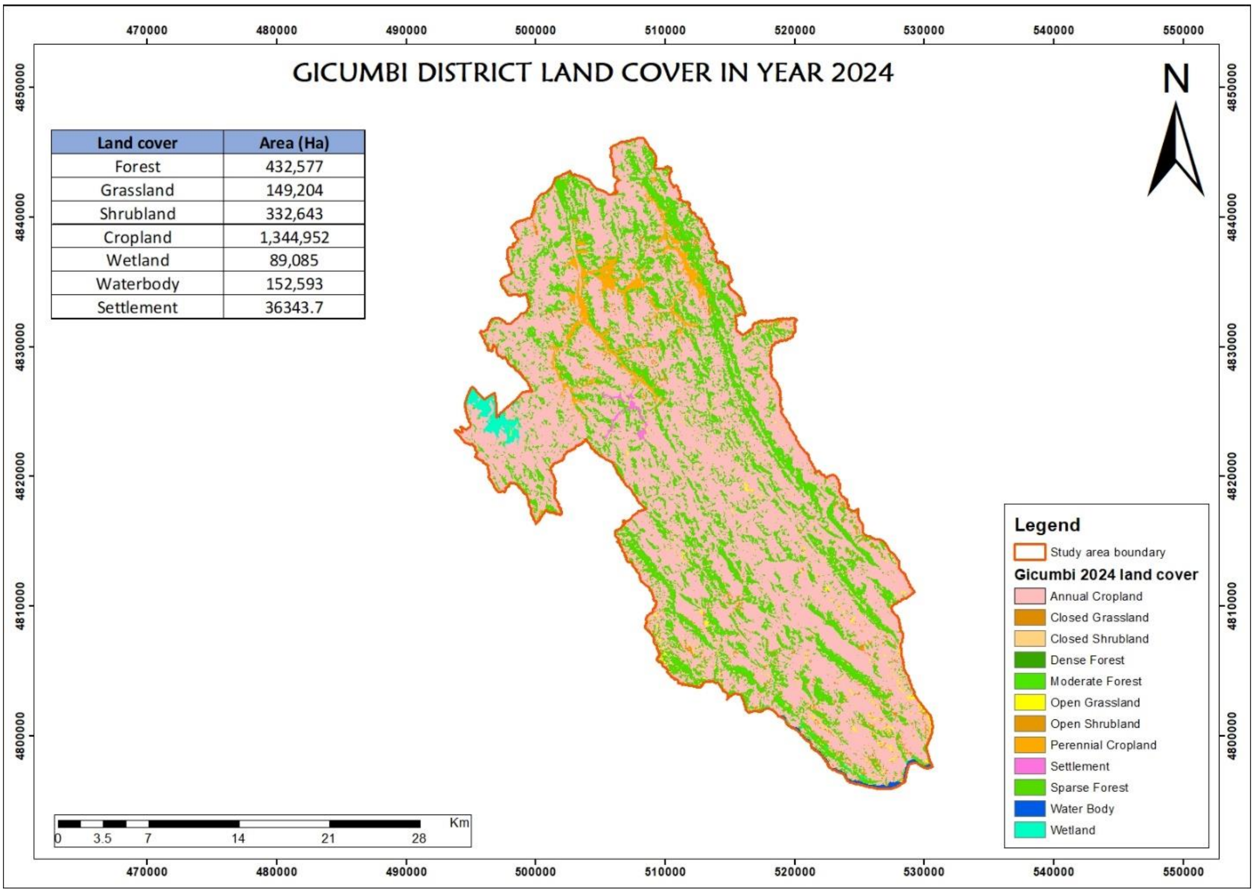

Figure 3. 3 Forest Cover in 2024 (Source: Landsat image)

3.3.4 Overall Forest Cover Change from 2004–2024

Over the two decades between 2004 and 2024, Gicumbi District experienced a drastic reduction in forest cover from **1,005,238 hectares to 432,578 hectares**. This represents a **total forest loss of 572,660 hectares**, highlighting a **steep decline of 57%** in just 20 years. The increasing rate of deforestation, from **25,016 hectares per year (2004-2014) to 32,250 hectares per year (2014-2024),** suggests that the pressures on forest resources have intensified rather than decreased. The spatial analysis of deforestation patterns demonstrates that regions with high population growth and agricultural expansion have suffered the greatest losses. Urgent policy interventions, conservation programs, and sustainable land management strategies are required to mitigate further deforestation and promote forest restoration in Gicumbi District.

Table 3.4: Summary of forest cover change

Year	Forest cover (Ha)
2004	1,005,238
2014	690,550

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2024	432,578

3.4.1 Interpretation of deforestation rate

The annual rate of deforestation was calculated using the formula:

$$\text{Deforestation rate} = \frac{\textit{Forest cover at start} - \textit{Forest cover at end}}{\textit{Number of years}}$$

Applying this formula:

- 2004-2014: (1,005,238-690,550)/10 = 31,468Ha per year
- 2014-2024: (755,082-432,578)/10 = 25,797Ha per year

This analysis indicates that deforestation accelerated in the second decade, increasing from 31,468 hectares per year (2004-2014) to 25,797 hectares per year (2014-2024).

4. Conclusion

In conclusion, this study examined deforestation trends in Gicumbi District (2004–2024) using geospatial techniques, revealing significant forest cover loss driven by agricultural expansion, charcoal production, population growth, and infrastructure development. Hotspots were concentrated in densely populated, high-farming areas. Despite initiatives like the Green Gicumbi Project, restoration efforts lag due to weak policy enforcement, limited funding, reliance on wood-based fuels, and low community participation. Deforestation has caused soil erosion, biodiversity loss, disrupted water cycles, and reduced soil fertility, impacting agriculture and increasing climate vulnerability. The study calls for sustainable land-use practices, stronger governance, community engagement, and integration of forest conservation into national strategies to balance development with environmental protection and enhance climate resilience.

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