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Spatio-temporal analysis of forest cover change in selected forest reserves in central Adamawa State, Nigeria

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Abstract

Forest reserves in Central Adamawa State, Nigeria, are increasingly threatened by anthropogenic pressures, including agricultural expansion, illegal logging, fuelwood extraction, and uncontrolled grazing. These activities have led to significant vegetation degradation, reducing biodiversity and impairing the delivery of critical ecosystem services, including food security, income generation, and carbon sequestration. This study assessed forest cover change over 40 years (1984–2024) in three forest reserves, Girei, Gurin, and Zangula, using Landsat TM, ETM+, and OLI satellite imagery. The images were processed to produce the Normalized Difference Vegetation Index (NDVI) to quantify vegetation dynamics. Results revealed a substantial increase in deforested and grassland areas (from 4.95% to 28.55% and 19.65% to 30.17%, respectively), alongside a marked decline in low, medium, and high-density forest cover (from 33.16% to 18.69%, 31.55% to 13.91%, and 10.69% to 8.68%, respectively). Statistical analysis confirmed significant changes in vegetation cover types (P = 0.006). These findings highlight the urgent need for targeted conservation strategies and policy interventions to restore and sustainably manage forest ecosystems in the region.

Keywords: Forest Degradation; NDVI; Landsat; Adamawa State; Ecosystem Services; Land Cover Change

1. Introduction

Forest cover change (FCC) is considered one of the drivers of soil degradation and climate change, and thus varies globally. Forests were reported to cover over 25% of the earth's land surface and contained about 75% of terrestrial carbon [1; 2]. These forests provide ecosystem services and support 60% of the population in developing countries with nutritional and health requirements [3]. Forest reserve is an important component of earth's ecosystems that preserve soil biomass, soil moisture, soil structure, control climate, carbon storage, soil fixation, and support for various forms of life. It also serves as a habitat for other organisms that contribute to the proliferation and protect their niche within the forest ecosystem [4]. The alteration of forest reserves due to anthropogenic factors has been affecting the global forest ecosystems and the effects have caused a lot of degradation and loss of biodiversity. Recent reports indicate that forest cover change (FCC) affects the earth's surface and serves as the second-largest source of atmospheric emission [5]. In addition, deforestation and degradation processes contribute immensely to forest cover loss [6]. Nevertheless, ninety percent of FCC in sub-Saharan Africa is altered due to increase in human population, expansion of agricultural activities, and consistent change of land use especially in Nigeria [7; 8].

Tropical forest contributes 5 to 15 percent of anthropogenic carbon emissions to the atmosphere at the global, regional, and local scales [9]. In Africa, the net annual forest cover loss was around 4 million hectares for the period of 2000–2005; and this accounted for over 55% of the total forest cover loss, globally (FAO, 2010). Nigeria used to have a large forest estate, but recently, the country has held the record for majority of forest loss in West Africa [10]. Hence, Nigeria has one of the highest rates of deforestation in Africa, approximately 3.5% or 350,000–400,000 hectares per year [11;

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12]. The Food and Agricultural Organization's Global Forest Resources Assessment 2020 put the annual rate of net forest loss in 2010-2020 in Nigeria and other African countries at 3.9 million hectares- the largest amount in the world [13].

In the dry lands of Northern Nigeria, plant genetic diversity is lost along the forests of savannah vegetation [14], especially where it houses several forest reserves. Forest reserves are portions of state lands where commercial harvesting of wood products is excluded to capture elements of biodiversity. These forest reserves are important sources of natural products such as fruits, foods, and resources for medicine [15]. Unfortunately, the continued increase in the rate of industrialization, agricultural production, illegal logging for fuelwood and charcoal making, urbanization, uncontrol animal grazing due to increase in human population have resulted in the destruction of forest ecosystems with negative consequences on global surface temperatures [16; 17].

Forest reserves in Central Adamawa State Nigeria are under serious anthropogenic pressure resulting in their degradation due to conversion to agricultural lands and urban settlements [18; 19]. Thus, a need to analyze the spatial distribution and the level of forest cover change of some of the forest reserves within selected time over space. However, several studies have been carried out using different approaches. The most common is the use of a vegetation indicator or the Normalized Difference Vegetation Index (NDVI), which is an index for describing the phenology, greenness, and productivity of vegetation. NDVI is an index of green biomass [3], and gives a measure of the volume and dynamism of vegetation on the surface area [5].

There is paucity of information on forest cover in Central Adamawa State, especially as forest reserves are being de-reserved and converted to grazing zones and agricultural farms. The evaluation of the forest cover changes over the years will help provide requisite information necessary for the management of this vital natural resources. This study assessed the rate and pattern of forest cover change in Central Adamawa State Forest reserves with the view to recommending appropriate strategies for conservation of the forest resources.

2. Materials and Methods

2.1. Study area description

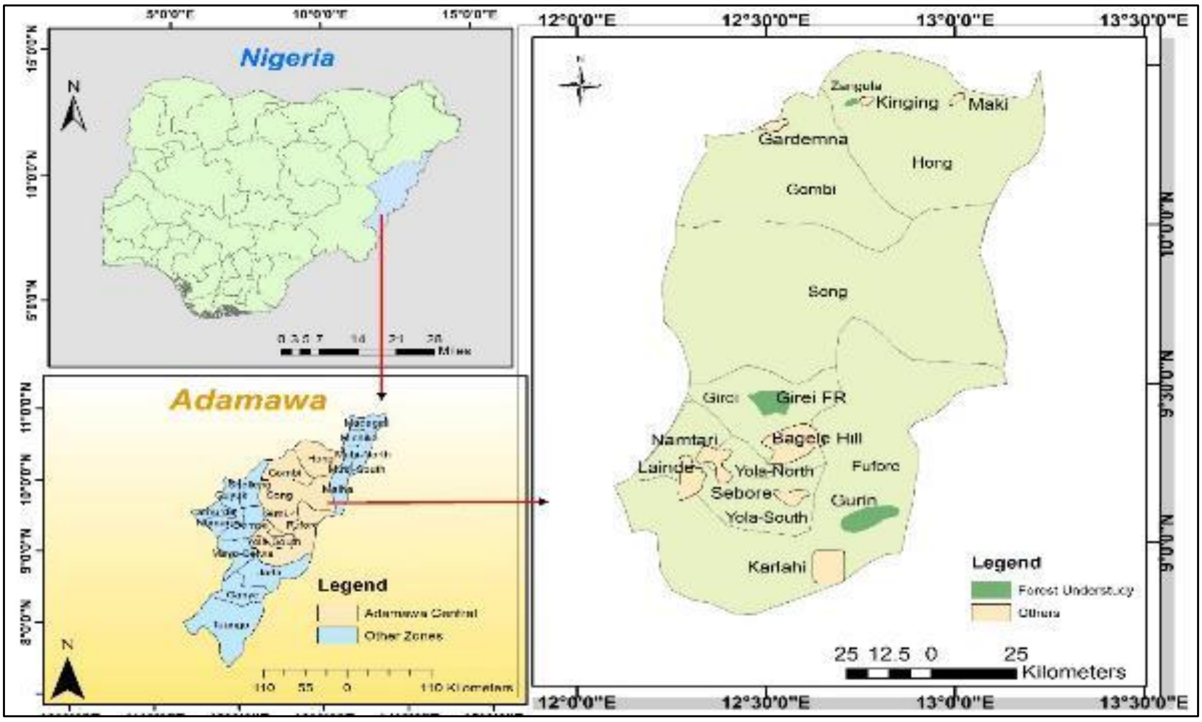

Figure 1 The study area

Central Adamawa is situated within the Upper Benue region, spanning latitudes 08°87′ to 10°68′ North and longitudes 12°38′ to 13°48′ East (Figure 1). It encompasses a total land area of approximately 16,183.57 square kilometers [20] and includes seven local government areas: Fufore, Yola South, Yola North, Girei, Song, Gombi, and Hong. The forest reserves selected for this study are located within the Northern Guinea Savanna and Sudan Savanna ecological zones of Nigeria. Collectively, these reserves cover a gazetted area of 182.94 square kilometers [21].

Geographically, the region is bordered by Mubi South, Mubi North, and Maiha local government areas to the east; Borno State to the north; Shelleng and Demsa to the west; Jada and Mayo-Belwa to the south; and the Republic of Cameroon to the southeast [20].

2.2. Methods and Data Processing

2.2.1. Reconnaissance Survey

A reconnaissance survey was carried out to gain preliminary insights into the ecological and anthropogenic conditions of the forest reserves. This field assessment informed the selection of satellite imagery and guided the interpretation of vegetation dynamics.

2.2.2. Satellite Data Acquisition

To analyze forest cover changes over a 40-year period (1984–2024), twelve multispectral satellite images were acquired from the United States Geological Survey (USGS) National Center for Earth Resources Observation and Science. The datasets included imagery from Landsat 5 Thematic Mapper (TM), Landsat 7 Enhanced Thematic Mapper Plus (ETM+), Landsat 8 Operational Land Imager (OLI), and Landsat 9 OLI sensors. Each image covered Path/Row 185/53 and 185/54, corresponding to the spatial extent of the selected forest reserves.

The acquisition dates were as follows:

- Landsat 5 TM: 6 November 1984
- Landsat 7 ETM+: 18 December 2002
- Landsat 8 OLI: 9 and 11 November 2014
- Landsat 9 OLI: 5 and 13 June 2024

All images were processed at Collection 2 Level 2 (C2L2), which includes automated radiometric, geometric, and atmospheric corrections, as well as cloud masking. The spatial resolution for all datasets was 30 meters, and the projection system used was Universal Transverse Mercator (UTM) with the WGS84 datum.

2.2.3. Image Preprocessing and NDVI Computation

Preprocessing of the Landsat imagery was performed using ArcGIS 10.8. The images were imported in GeoTIFF format and rectified to ensure spatial consistency. NDVI was computed to assess vegetation health and cover dynamics. NDVI is a dimensionless spectral index that measures the difference between near-infrared (NIR) and red reflectance, which correlates with chlorophyll content and vegetation vigor. The NDVI formulas applied were:

For Landsat 5 and 7 sensors, NDVI was computed using the formula:

$$NDVI = (Band\ 4 - Band\ 3) / (Band\ 4 + Band\ 3) \quad \text{.........equation 1}$$

For Landsat 8 and 9 sensors, the formula was adjusted to reflect the updated band configuration:

$$NDVI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4) \quad \text{.........equation 2}$$

NDVI values range from -1 to +1, with higher values indicating healthier vegetation. Specifically:

0.66 to 1.00: Very healthy vegetation

0.33 to 0.66: Moderately healthy vegetation

0.00 to 0.33: Stressed or diseased vegetation

-1.00 to 0.00: Non-vegetated surfaces or dead biomass

It is important to note that Landsat sensors use different band numbering conventions. Landsat 5 and 7 designate NIR as Band 4 and red as Band 3, while Landsat 8 and 9 assign NIR to Band 5 and red to Band 4.

2.2.4. Vegetation Classification and Change Detection

Vegetation cover was classified into five categories: deforested area, grassland, low dense forest, medium dense forest, and high dense forest. NDVI thresholds were applied to delineate these classes, and temporal comparisons were made across the four time points (1984, 2002, 2014, and 2024). Change detection analysis was performed to quantify the rate and pattern of vegetation transformation, enabling assessment of forest degradation trends.

2.3. Statistical Analysis

Descriptive statistics and change rate calculations were used to quantify annual shifts in vegetation cover. Statistical significance of vegetation changes across the study period was evaluated using appropriate inferential tests, with a threshold of $P < 0.05$ considered significant.

3. Results and Discussion

3.1. Forest Cover Change Visualization in Girei, Gurin, and Zangula Forest Reserves (1984–2024)

This paper analyzes the spatiotemporal dynamics of forest cover in three forest reserves (Girei, Gurin, and Zangul), in Central Adamawa State, Nigeria, over a 40-year period (1984–2024). The study focuses on five land cover categories: Deforested Area, Grassland, Low Dense Forest, Medium Dense Forest, and High Dense Forest. The goal is to assess the extent of vegetation change and highlight implications for conservation and ecosystem services. The data were derived from satellite imagery and expressed as percentages of total land area for each reserve. The years analyzed include 1984, 2002, 2014, and 2024.

Table 1 Forest Cover Classification of Selected Forest Reserves in Central Adamawa State

Category	1984 (km^2)	1984 (%)	2002 (km^2)	2002 (%)	2014 (km^2)	2014 (%)	2024 (km^2)	2024 (%)	Rate of Change
Girei Forest Reserve									
Deforested Area	4.53	5.79	10.61	13.57	6.85	8.76	22.53	28.82	3.97
Grassland	14.58	18.65	18.01	23.03	20.54	26.27	23.97	30.66	0.64
Low Dense Forest	22.27	28.49	20.88	26.71	24.82	31.75	15.46	19.78	-0.31
Medium Dense Forest	26.99	34.53	18.53	23.71	18.94	24.23	11.68	14.94	-0.57
High Dense Forest	9.81	12.54	10.15	12.98	7.03	8.99	4.54	5.80	-0.54
Total	78.18	100	78.18	100	78.18	100	78.18	100	
Gurin Forest Reserve									
Deforested Area	3.75	3.84	6.53	6.72	13.48	13.86	28.29	29.11	6.55
Grassland	19.66	20.08	33.34	34.31	33.21	34.17	29.19	30.04	0.48
Low Dense Forest	37.09	37.88	34.29	35.28	33.45	34.42	16.49	16.97	-0.56
Medium Dense Forest	28.76	29.37	17.64	18.15	16.45	16.93	12.58	12.94	-0.55
High Dense Forest	8.64	8.83	5.39	5.54	0.6	0.62	10.64	10.94	-0.23
Total	97.19	100	97.19	100	97.19	100	97.19	100	
Zangula Forest Reserve									
Deforested Area	0.81	10.71	1.06	14.01	0.78	10.31	1.18	15.58	0.45
Grassland	1.85	24.43	1.89	24.96	2.3	30.38	2.25	29.73	0.22
Low Dense Forest	1.53	20.22	2.07	27.34	2.47	32.63	2.07	27.35	-0.36

Medium Dense Forest	2.19	28.92	1.87	24.71	1.4	18.49	1.27	16.78	-0.42
High Dense Forest	1.19	15.72	0.68	8.98	0.62	8.19	0.8	10.56	-0.33
Total	7.57	100	7.57	100	7.57	100	7.57	100	

The analysis of vegetation cover dynamics across Girei, Gurin, and Zangula Forest Reserves from 1984 to 2024 reveals a consistent trend of forest degradation driven by anthropogenic activities. The annual rate of change for deforested areas was highest in Gurin (6.55%), followed by Girei (3.97%) and Zangula (0.45%), indicating varying intensities of land-use pressure across the reserves. These increases in deforested land are symptomatic of expanding agricultural frontiers, illegal logging, and fuelwood extraction activities that have been widely documented as major drivers of forest loss in Nigeria.

Grassland cover also exhibited positive growth across all sites, with annual rates of 0.64%, 0.48%, and 0.22% in Girei, Gurin, and Zangula respectively. This trend suggests a conversion of forested land into open landscapes, which may support grazing and subsistence farming but offer limited ecological services compared to dense forest ecosystems.

In contrast, medium and high dense forest categories experienced consistent declines. Girei and Gurin recorded annual reductions of -0.57% and -0.55% in medium dense forest, and -0.54% and -0.23% in high dense forest, respectively. These declines reflect a loss of mature forest structure, which is critical for biodiversity conservation, carbon storage, and microclimatic regulation. Zangula showed a slight increase in low dense forest (+0.36%), possibly due to secondary regrowth or transitional vegetation, but still suffered losses in medium (-0.42%) and high dense forest (-0.33%). These findings corroborate earlier studies by [22] who reported widespread forest degradation and de-reservation in Nigeria, particularly in the Southwest. The observed patterns also align with [5], who warned that continued anthropogenic disturbances could lead to the complete deforestation of Nigeria's forest reserves, undermining national efforts to achieve sustainable development and climate resilience. The implications of these trends are profound. The loss of dense forest cover compromises ecosystem services such as carbon sequestration, water regulation, and habitat provision. Moreover, the expansion of deforested and grassland areas may exacerbate soil erosion, reduce agricultural productivity, and increase vulnerability to climate extremes.

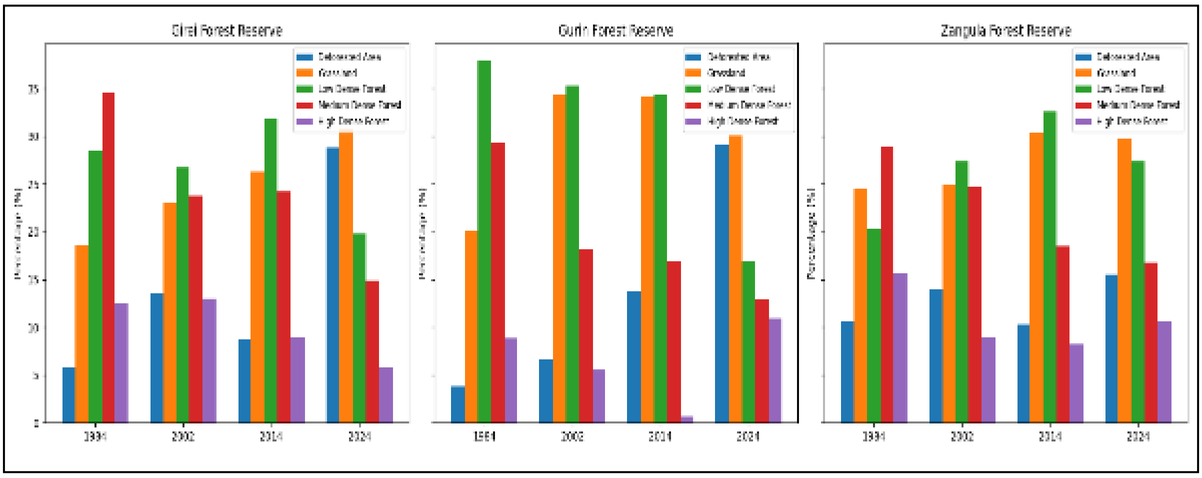

Figure 2 Forest cover percentage by category (1984-2024)

This is the grouped bar chart showing percentage changes in land cover categories across the three forest reserves. In the Girei Forest Reserve, the Deforested Area rose from 5.79% to 28.82%, indicating intense land-use pressure. Meanwhile, the Medium and Low Dense Forests declined sharply, with Medium Dense Forest dropping from 34.53% to 14.94%. In Gurin Forest Reserve, Deforested Area increased from 3.84% to 29.11%, the highest rate among the three. In contrast the High Dense Forest showed a surprising rebound in 2024, rising to 10.94% after a steep decline. In Zangula Forest Reserve, changes were more moderate, with Deforested Area increasing from 10.71% to 15.58%, while the Low Dense Forest peaked in 2014 but declined again by 2024. The data reveal a consistent trend of forest degradation across all three reserves, with significant increases in deforested and grassland areas in Figure 3.

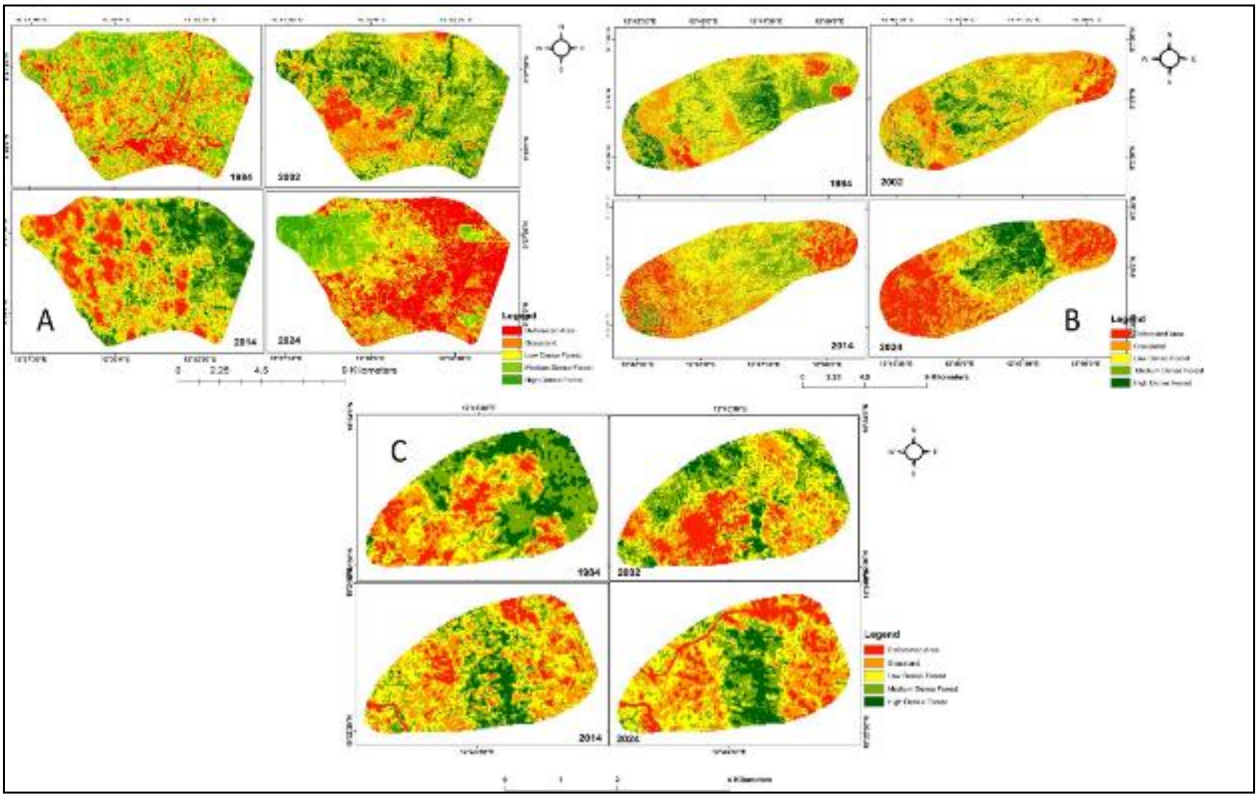

Figure 3 Visualisation of NDVI (1984-2024)

3.2. Statistical analysis and interpretation

To evaluate the significance of vegetation cover changes over the 40-year study period, NDVI values from 1984, 2002, 2014, and 2024 were analyzed using a one-way Analysis of Variance (ANOVA). This statistical approach is appropriate for comparing mean differences across multiple time points, allowing for the detection of temporal shifts in vegetation health and density.

Table 2 Analysis of Variance for NDVI Values for 1984, 2002, 2014 and 2024

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Factor	3	0.06604	0.022013	4.54	0.006*
Error	56	0.27165	0.004851		
Total	59	0.33769			
Means					
Factor	N	Mean	St Dev	95%	CI
1984	15	0.1287	0.0891	0.0926	0.1647
2002	15	0.0947	0.0409	0.0586	0.1307
2014	15	0.1833	0.0615	0.1473	0.2194
2024	15	0.1587	0.0775	0.1226	0.1947
Pooled StDev = 0.0696488					

* Significant at 0.05%

The ANOVA results yielded an F-value of 4.54, indicating that the variance between the mean NDVI values across the years is substantially greater than the variance within each year group. This suggests that the observed changes are not random fluctuations but reflect meaningful differences in vegetation conditions over time. Critically, the associated P-value of 0.006 is well below the conventional alpha threshold of 0.05, confirming statistical significance at the 99% confidence level. This robust result implies that the changes in NDVI values are unlikely to have occurred by chance and are instead attributable to underlying environmental and anthropogenic factors. The statistically significant variation in NDVI values supports the conclusion that vegetation cover in Girei, Gurin, and Zangula Forest Reserves has undergone substantial transformation. These changes are consistent with documented land-use pressures, including deforestation, agricultural expansion, grazing, and settlement encroachment. The NDVI trends reflect both degradation and, in some cases, localized regrowth, highlighting the dynamic nature of forest ecosystems under human influence. This finding reinforces the importance of continuous monitoring and targeted conservation strategies. By quantifying vegetation change with statistical rigor, the study provides evidence-based insights that can inform policy decisions, land management interventions, and ecological restoration efforts.

3.3. **Visual summary of the ANOVA results showing statistically significant changes in NDVI values across four decades.**

The chart illustrates the decline in mean NDVI values from 1984 to 2024 (Figure 4), with error bars representing standard deviation. The annotated F-value (4.54) and P-value (0.006) confirm that the differences are statistically significant at the 99% confidence level, reinforcing the conclusion that vegetation cover has undergone measurable transformation due to environmental and human pressures.

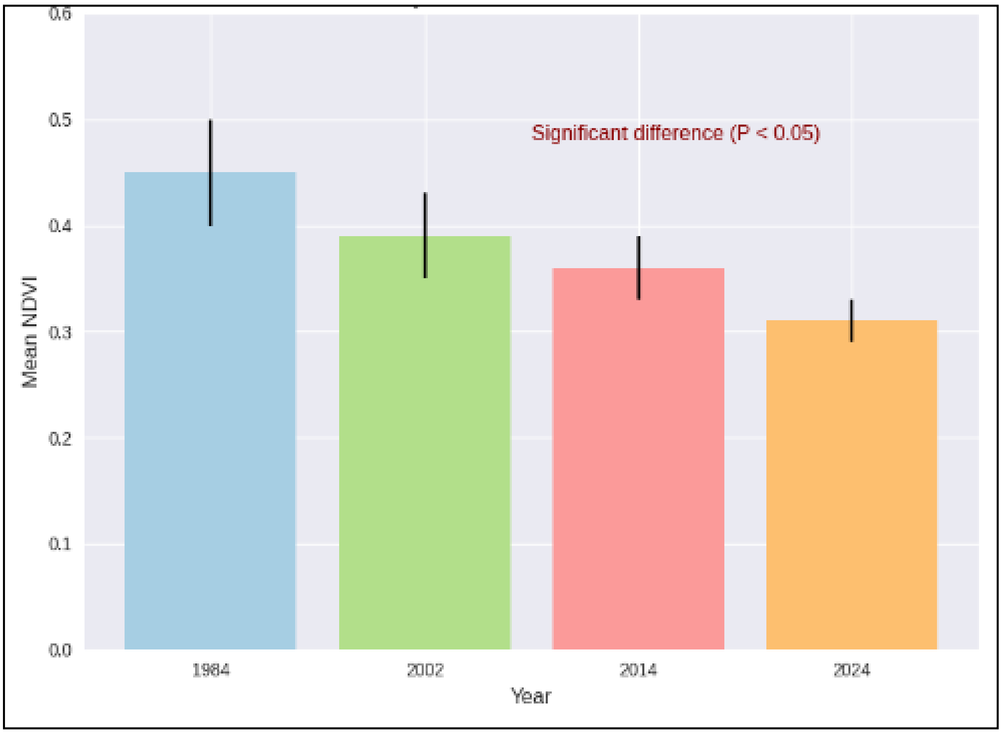

Figure 4 NDVI Change Overtime (1984-2024) One-way ANOVA: F=4.54, P=0.006

4. Conclusion

This study has revealed significant spatiotemporal changes in vegetation cover across Girei, Gurin, and Zangula Forest Reserves over a 40-year period. The analysis showed a consistent increase in deforested areas and grassland cover, underscoring the persistent impact of anthropogenic activities such as agricultural expansion, fuelwood harvesting, settlement encroachment, and livestock grazing. These pressures have led to a marked decline in medium and high dense forest vegetation, threatening biodiversity and ecosystem stability. Interestingly, high dense forest cover exhibited modest gains during 1984–2002 and 2014–2024, particularly in Girei and Zangula. These increases may reflect localized regrowth or reduced human activity, but they remain fragile and context-dependent. The temporary decline in deforested and grassland areas between 2002 and 2014 in Gurin and Zangula suggests that regional insecurity and insurgency may have inadvertently slowed land-use pressures during that period. The annotated F-value (4.54) and P-value (0.006) confirm that the differences are statistically significant at the 99% confidence level, reinforcing the conclusion that vegetation cover has undergone measurable transformation due to environmental and human pressures. The findings highlight the urgent need for targeted conservation strategies, including community-based forest management, reforestation initiatives, and policy enforcement to curb illegal exploitation. Without sustained intervention, the ecological integrity of these forest reserves will continue to deteriorate, with long-term consequences for biodiversity, climate resilience, and local livelihoods.

Compliance with ethical standards

Disclosure of conflict of interest

No potential conflict of interest was reported by the authors.

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