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GEOSPATIAL PROJECTION OF FOREST COVER DYNAMICS IN CENTRAL ADAMAWA STATE, NIGERIA

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ABSTRACT
Forests play a central role in sustaining biodiversity and regulating climate, yet they continue to face intense anthropogenic pressures across Nigeria. This study assessed past and future changes in forest trees within Adamawa State's central zone using geospatial techniques. Landsat 4 and 5 Thematic Mapper (TM) and Landsat 8 Operational Land Imager (OLI) data for 1990, 2000, 2013, and 2021 were sourced from the United States Geological Survey repository. The Normalized Difference Vegetation Index (NDVI) was employed to evaluate forest cover changes and to project scenarios through 2050 using a linear trend model. Results revealed a substantial increase in high-density forest cover (high NDVI) between 1990 and 2000 of 230.2 km² (5.07%), but declines between 2000 and 2013 of 183.9 km² (-15.05%) and between 2013 and 2021 of 420.7 km² (-48.38%). Predictions indicate temporary regeneration by 2030 (197.99 km²), followed by severe reduction to 67.30 km² in 2040 and further loss by 2050 (-63.39 km²). Conversely, medium NDVI values (shrubs and grassland) showed steady increases, while low NDVI areas fluctuated with an overall trend of expansion. The findings suggest that unless effective conservation and sustainable land management practices are adopted, the study area will continue to experience drastic forest depletion driven by agricultural expansion, overgrazing, urbanization, and climate change. This poses serious implications for biodiversity, carbon sequestration, and ecosystem services.

Keywords: Geospatial Projection, deforestation, land use/landcover, Remote Sensing.

INTRODUCTION
Human activities have significantly affected forests and vegetation cover in Nigeria, despite persistent efforts by the government, NGOs, and local communities to mitigate deforestation. Key drivers include urbanization, infrastructure development, agricultural expansion, nomadic farming, and population growth, which have collectively exerted significant pressure on forest ecosystems (FAO, 2022). Between 1991 and 2003, approximately 25% of Nigeria's forest cover was lost, while from 2000 to 2005 the country experienced a 55.7% decline in its primary forest, accompanied by a 31.2% increase in the annual rate of forest change (FAO, 2022; Tajudeen, 2024). The alteration of ecosystems by anthropogenic activities has affected the environment, leading to significant degradation from wind and water erosion (Adamu et al., 2025).

Deforestation contributes to biodiversity loss and ecosystem degradation through human and natural factors, including logging, wildfires, drought, climate change, and overpopulation (Bodo, Gimah, & Seomoni, 2021; Singh, 2021). These activities degrade habitats, reduce soil fertility, and threaten water resources, with significant implications for both local livelihoods and global climate regulation. Increasing human demand for ecosystem services has also intensified land-use/land-cover (LULC) changes, including agriculture, settlements, and logging, prompting research into their environmental impacts (Pielke et al., 2021).

Recent LULC studies in Nigeria highlight this trend. Aliyu *et al*. (2020) projected significant urban expansion in Akure using Landsat data and a Cellular Automata/Markov model, forecasting built-up areas to rise from 5.04% in 2014 to over 26% by 2042, with a corresponding decline in vegetation. Similarly, Bello, Ojo, and Gbadegesin (2018) analyzed land cover dynamics in the Eleyele Wetland and projected a further reduction in lake area due to urban encroachment, highlighting biodiversity risks. At Gambari Forest Reserve, Mephors *et al.* (2023) found ongoing deforestation of both indigenous and plantation forests, driven by logging, farming, and settlements, and predicted further losses by 2044 without stakeholder intervention.

In the dry lands of Northern Nigeria, plant diversity is lost in the savannah forests (Green et al., 2013), especially in areas that host several forest reserves. Forest reserves are portions of state lands where commercial harvesting of wood products is excluded to capture elements of biodiversity (Abdulhakim et al., 2017). These forest reserves are important sources of natural products, including fruits, food, and medicinal resources (Langat et al., 2016). The Food and Agriculture 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 (FAO, 2020). There is a need to analyze the distribution and extent of degradation in selected forest reserves over time and space. However, several studies have been carried out using different approaches. The most common is the use of a vegetation indicator, the Normalized Difference Vegetation Index (NDVI), which describes vegetation phenology, greenness, and productivity. NDVI provides a measure of the extent and dynamics of vegetation across the surface area (Usman et al., 2012).

Remote sensing and GIS help with decision-making, especially in modelling and vegetation studies (Kessy et al., 2016). The integration of remote sensing and GIS makes it a powerful tool for studying vegetation dynamics globally, especially forest change detection (Oyebanji et al., 2017). The NDVI analysis of Doma forest greenness shows a substantial decrease from 1999 to 2015, attributable to human activities such as agriculture, grazing, and illegal logging (Moussa, 2015). While several studies have been conducted in the area on vegetation, like tree composition, density and diversity (Suleiman et al., 2017; Zakariya & Mohammed, 2018; Suleiman et al., 2018), dynamics and change detection (Badamasi & Yelwa, 2010; Usman et al., 2012; Idris et al., 2018), land use diversity changes (Ba et al, 2024; Adamu et al., 2025). The majority of these studies focused on changes in overall vegetation cover without projecting future scenarios. This shows the need to use a linear trend model to analyze the temporal patterns of forest change in the Guinea Savanna Forest of Adamawa State. Such models, alongside NDVI analysis, enable projections of forest cover and biomass under varying scenarios (Ahmed et a., 2022). Therefore, the main objective of this study is to assess and predict forest cover dynamics in Nigeria's Adamawa Central Zone between 2030 and 2050.

STUDY AREA

Adamawa Central lies on the upper Benue between Latitude 08 ° 87'N" and Latitude 10 ° 68'N and Longitude 12° 38E" and Longitude 13 ° 48'E (Figure 1). It covers a total land area of 16183.57 square kilometers (Zemba & Tukur, 2020). The area shares boundaries with Mubi_South, Mubi_North and Maiha local government areas in the East. Borno State to the North, Shelleng and Demsa local Government Areas in the West, Jada and Mayo-Belwa local government areas in the southern part, and the Cameroon Republic to the Southeastern part (Zemba & Tukur, 2020). The geology of the area encompasses parts of an ancient craton that was tectonically active in the geologic past. The geology of the area consists of two stratigraphic units: the quaternary river coarse alluvium and feldspar sandstone. The alluvial deposits occur mainly along the banks of the River Benue and its tributaries, comprising sand, clay, silt, silt-clay, and pebble sand. The feldspar sandstone is generally fine- to medium-grained in texture, crystalline, indurate, compact, and well-cemented when fresh (Opeloye & Dio, 2020).

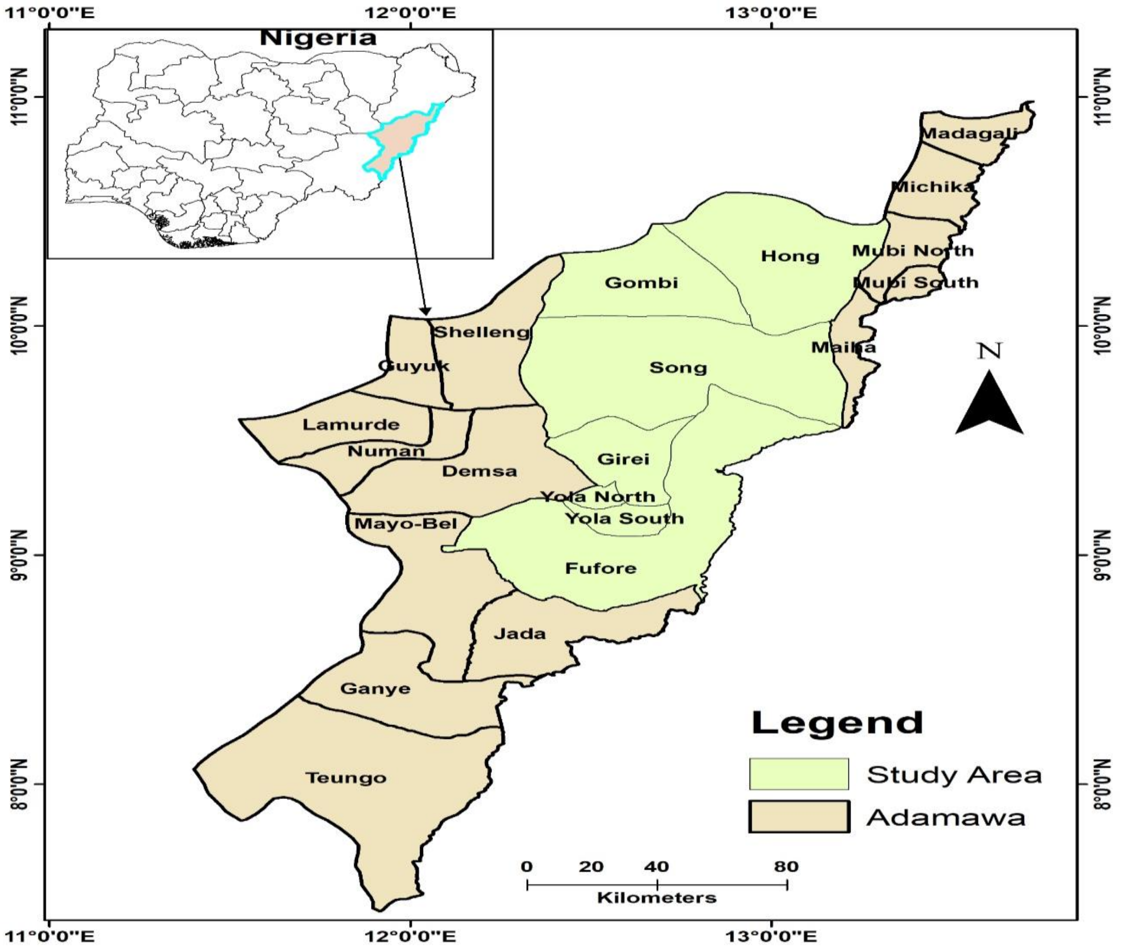

Figure 1: Study Area

The soils of Central Adamawa are derived from the Basement Complex, while in a few other places they are derived from sandstones, shales, and alluvium (Ray, 2020). The soils are generally richer in weatherable minerals and contain strongly absorptive, three-layered clay minerals with relatively large, negatively charged surface areas (Ibid). The landform type is characterized by high, low, and undulating plains with isolated, grouped hills of synclinal folds, about 600 meters in height, developed on Cretaceous sandstone and lowlands (Tukur & Mahmud, 2020). The hills are found around Sigire, Hong, Gombi, Vunoklang, and Ngurore, with rough terrain interspaced by extensive plains and isolated hills. Valleys and troughs punctuate the plains, and the lowland extends to the Benue plain.

The area experiences a tropical climate with consistently high temperatures year-round. The temperature possesses seasonal change, indicating a gradual increase from January to April, where the temperature reaches its peak as high as 44°c, and then decreases with the onset of the rainy season. (Adebayo and Zemba, 2020). The area is characterized by two well-defined seasons: rainy (wet) and dry, with an average annual rainfall of 972mm and an average of 62 rainy days. The vegetation is characterized by short grasses, tall, scattered trees, thick vegetation around hills and mountain ranges, and sparse short trees and shrubs (Akosim *et al*., 2020). The tree vegetation has over the years been modified by human activities such as farming, which involves bush burning, fuel wood exploitation, deforestation, and construction works. It is, however, necessary to note that large-scale deforestation, resulting from the indiscriminate extraction of wood for fuel and the expansion of agricultural land, has left many areas within each vegetation type with few indigenous woody plant species. The dominant woody plant species are: *Acacia Senegal, Acacia Nilotica, Adonsonia digitata, Borassus aethiopum, Ziziphus Spina-christi, Sclerocarya birrea, Terminalia avicennioides* and *Eragrostis spp* (Akosim *et al*., 2020). Adamawa Central has a population of 1,247,344, with 636,088 males and 611,256 females, and an annual growth rate of 2.5 percent (NPC, 2007). The area has a population density of 1082 persons per square kilometer. The dominant tribes in the area are Fulani, Bata, Verre, Laka, Chamba, Kilba, Marghi, Ga'anda, Hona, Bura, Lala, Ngwaba, Yungur, Mboi; however, a substantial number of Bwatiye and Tambo also dwell in the area. The major economic activities in the area are farming (rain-fed and irrigation), fishing, trading, local crafting, and livestock rearing.

MATERIALS AND METHOD

The Normalized Difference Vegetation Index (NDVI) was used to analyze forest dynamics in the study site's forested areas. NDVI values were classified into three categories: High NDVI (>0.3), representing dense forest/trees; Medium NDVI (0.14–0.3), corresponding to shrubs and grasslands; and Low NDVI (<0.14), indicating bare surfaces, rocks, and sands.
The formula for NDVI images was in equation 1.

$$NDVI = NIR - RED/NIR + RED \ldots\ldots\ldots\ldots \quad \text{equation} \quad 1$$

Where: NIR = Stands for near-infrared band
RED = Stands for red band

After the images were retrieved, a four-band dataset (Band 1, Band 2, Band 3, and Band 4) in RGB colors was created using the Layer Stack or Composite function. Using the study area boundary (6419.69 km2), images were cropped to fit the study area's boundaries. To trim the TOF research location, ArcGIS Pro 2.9 was used.

The Normalized Difference Vegetation Index (NDVI) was then applied to the images for each time period using the formula in equations 2 and 3.

$$\text{Landsat 4-5: } NDVI = (\text{Band } 4 - \text{Band } 3) / (\text{Band } 4 + \text{Band } 3) \ldots\ldots\ldots \text{ equation } 2$$
$$\text{Landsat 8: } NDVI = (\text{Band } 5 - \text{Band } 4) / (\text{Band } 5 + \text{Band } 4) \ldots\ldots\ldots \text{equation } 3$$

Multi-temporal satellite images underwent change detection using the subtraction (image differencing) method, with sequential comparisons conducted for 1990–2000, 2000–2013, and 2013–2021 (see Table 1).

Table 1: Characteristic Features of Satellite Data

Time Period	Satellite Image	Path/Row	Acquisition Date	Bands Used in Analysis	Sensor/ Resolution	Source
1990	Landsat 4-5 Thematic Mapper	185/53, 185/54	17th December 1990	1,2,3,4	TM 30m	USGS
2000	Landsat 4-5 Thematic Mapper	185/53, 185/54	Ist Februar 2000	1,2,3,4	TM 30m	USGS
2013	Landsat 8 Operational Land Imager	185/53, 185/54	28th March 2013	2,3,4,5	OLI 30m	USGS
2021	Landsat 8 Operational Land Imager	185/53, 185/54	14th December 2021	2,3,4,5	OLI 30m	USGS

Source: USGS (2026)

From these analyses, land-cover change tables were generated to quantify increases and decreases in forest cover, expressed both in square kilometers and as percentage change (see Table 2). The observed NDVI changes for 1990, 2000, 2013, and 2021 formed the basis for predicting future forest cover through 2050. A Linear Trend Model (LTM) was employed to project changes in forest classes (km²) using explanatory variables such as observed, fitted, and forecast values, and accuracy measures were applied for model validation. The LTM operates on the assumption that future states of a system can be modeled from preceding observations (Maitra, 2019). Forecast results were visualized through graphs (Figures 2–4), showing projected changes in low, medium, and high NDVI categories for 2030, 2040, and 2050. The linear forecasting model was expressed as in equation 4:

$$Yt = a + bT \quad \text{equation 4}$$

Where: Yt = is the predicted value at time t,
a = is the intercept,
b = is the slope (rate of change).

Parameters were estimated through simple regression, with time (T) serving as the independent variable. This integrated approach provided both historical change detection and future projections of forests within the study area.

Because Adamawa Central Zone is located within the Nigerian Northern Guinea Savanna, its forest cover is not as dense as that of the Southwestern Nigerian rainforests. Thus, partitioning the continuous NDVI layer into distinct, discrete land-cover classes (low, medium and high) based on the local ecological baselines of the study area.

Low NDVI (-1.0 - 0.25): Represents highly disturbed or non-vegetated surfaces (settlements, sandbars along the Benue River, degraded soils).

Medium NDVI (0.26 – 0.45): Represents seasonal savanna grasses, shrubs, and subsistence agricultural plots.

High NDVI (>0.45): Represents the target Forest Class (dense tree canopies, continuous woodlands, and riverine/gallery forests).

RESULTS AND DISCUSSIONS

The results of the land-cover change analysis of percentage changes in forest tree cover in the study area are presented in Table 2. The result revealed that low-density forest cover occupied a total land area of 4,088.8 km2 in 1990 and decreased to 1,241.4 km2 in 2000, indicating a decrease of 62.61%. Also, the medium density occupied a total land area of 1,737.5 km2 in 1990 and increased to 3,198.0 km2 in 2000, indicating a 32.18% increase. The result further indicates that high-density forest occupied a total land area of 549.2 km2 in 1990, increasing to 779.4 km2 in 2000, representing an increase of about 5.07%. This means that rocks and bare surfaces give way to shrubs and grassland, with slide bursts in the forest, which might be due to increased plantation and a slower rate of logging. A similar trend in slide variations also occurred in tree density between 2000 and 2013, with low density occupying a total land area of 1,241.4 km2 in 2000 and increasing to 1,603.0 km2 in 2013, indicating an increase of 29.59%. Similarly, medium density in the year 2000 occupied a total land area of 3198km2, increased to 3,874.4km2 in 2013, indicating an increase of 55.36%. While high density in the year 2000 occupied a total land area of 779.4 km2, it decreased to 595.5 km2 in 2013, representing a 15.05% decline.

Table 2: Landcover Change of Trees inside Forests in percentages between 1990 and 2021

Landcover Change of Trees Inside Forests					
NDVI Class/Year	**1990 AreaKm² (a)**	**2000 AreaKm² (b)**	**Changes between 1990 and 2000 Area km² (b-a)**	**% Change (km²)**	**Remark**
Low (< 0.14)	4088.8	1241.4	-2847.4	-62.61	Decreased
Medium(0.14-0.3)	1737.5	3198.0	1460.5	32.18	Increased
High(> 0.3)	549.2	779.4	230.2	5.07	Increased
Total	6375.5	5218.8	4538.1	100	
NDVI Class/Year	**2000 AreaKm² (a)**	**2013 AreaKm² (b)**	**Changes between 2000 and 2013 Area km² (b-a)**	**% Change (km²)**	**Remark**
Low (< 0.14)	1241.4	1603.0	361.6	29.59	Increased
Medium (0.14-0.3)	3198.0	3874.4	676.4	55.36	Increased
High(> 0.3)	779.4	595.5	-183.9	-15.05	Decreased
Total	5218.8	6072.9	1221.9	100	
NDVI Class/Year	**2013 AreaKm² (a)**	**2021 AreaKm² (b)**	**Changes between 2013 and 2021 Area km² (b-a)**	**% Change (km²)**	**Remark**
Low (< 0.14)	1603.0	1755.1	152.1	17.49	Increased
Medium (0.14-0.3)	3874.4	4171.2	296.8	34.13	Increased
High(>0.3)	595.5	174.8	- 420.7	- 48.38	Decreased
Total	6072.9	6101.1	869.6	100	

Low = rocks, sands, bare surface. Medium = shrubs and grassland. High-density forest/trees
Source: Laboratory Analysis, 2026

The scenario continued; however, between 2013 and 2021, it showed similar transitions across the three NDVI classes, with the low-density area increasing from 1,603.0 km2 to 1,755.1 km2, indicating a 17.49% increase. The medium density in 2013 occupied a land area of 3,874.4 km2, increasing to 4,171.2 km2, a 34.13% increase, while the high density in 2013 occupied a total land area of 595.5 km2, then decreased to 174.8 km2, a 48.38% decrease that year. This means that the forest was heavily depleted in the area as a result of population growth, coupled with a high influx of immigrants due to insurgency activity, agriculture, firewood collection, overgrazing, and construction. The result is in line with that of Ba et al. (2024) and Adamu et al. (2025), who observed that immigrant farmers, herdsmen and internally displaced persons IDP's influenced the loss of vegetation in the State.

The results of trend analysis of NDVI-predicted changes in tree abundance within the forest are presented in Figures 2, 3, and 4. The prediction is from 2030 to 2050 for low (Figure 2), medium (Figure 3), and high (Figure 4) NDVI values for trees within forests in the area, using a linear trend model; accuracy measures were produced. The prediction for low NDVI, representing rocks, sands, and bare surfaces, in 2030 will occupy a total area of 512.219 km2; in 2040, it will drop to 151.734 km2, and by 2050, it will further reduce to 815.687 km2. The prediction analysis also revealed that the medium NDVI value, representing shrubs and grassland, would occupy a total area of 5,239.65 km2 in 2030. In 2040, it increased to 6,037.39 km2, then increased further in 2050 to about 6,835.13 km2. The prediction for high NDVI values representing dense forests/trees is also in 2030 expected to be about 197.994 km2 of the total land area, then reduced to 67.302km2 of the area in 2040, and then expected to drop to -63.391 km2 in 2050, as displayed in Figures 2, 3 and 4, respectively.

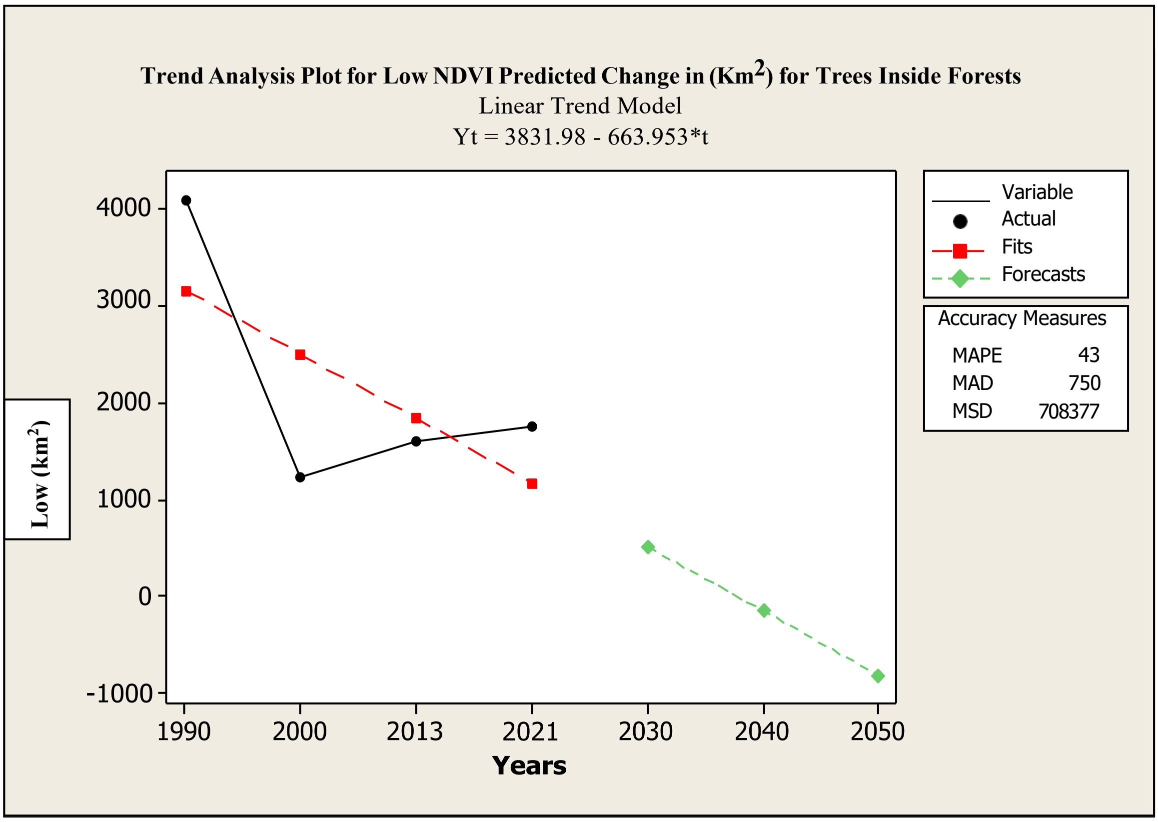

Fig. 2: Trend Analysis for Low NDVI for Trees Inside Forests
Source: Laboratory Analysis, 2026

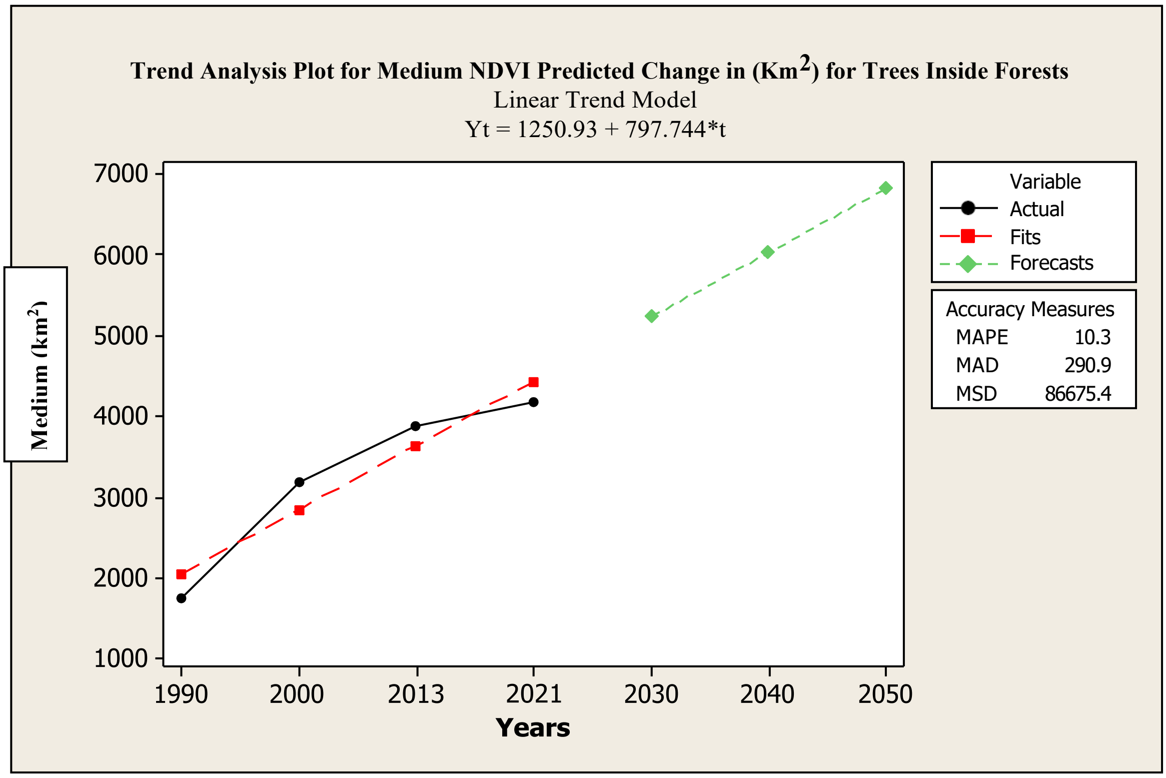

Fig. 3: Trend Analysis for Medium NDVI for Trees Inside Forests
Source: Laboratory Analysis, 2026

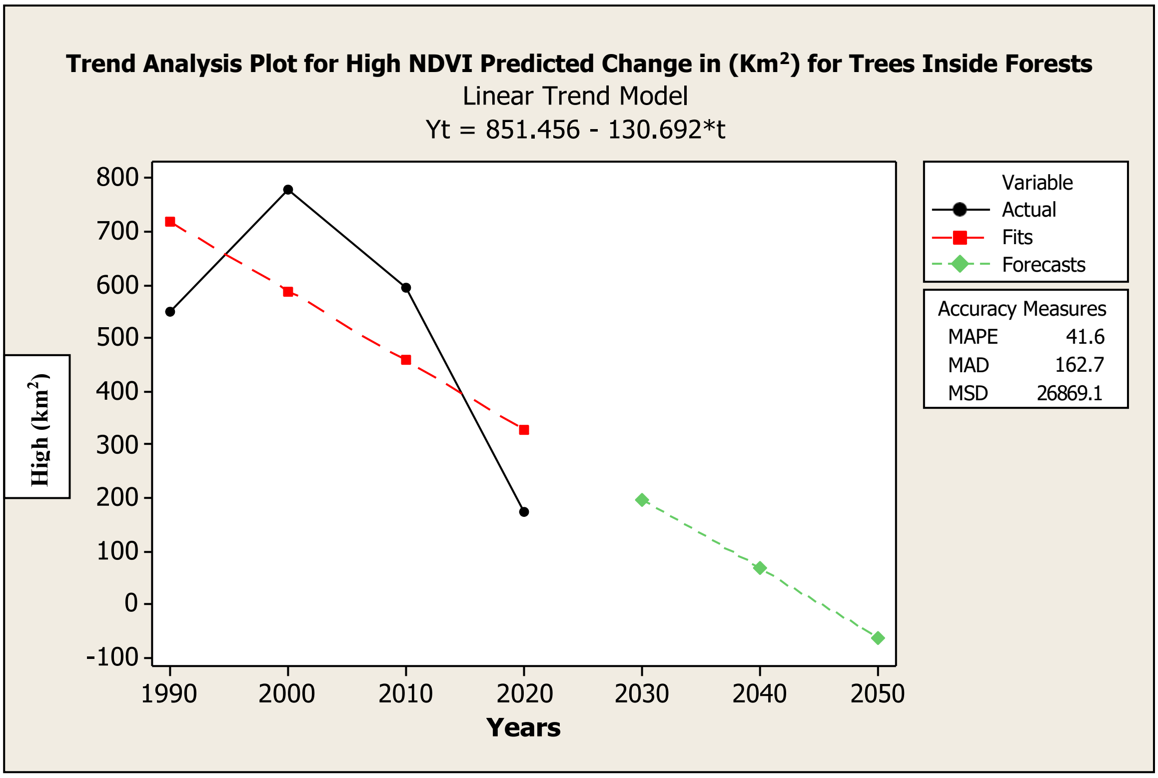

Fig. 4: Trend Analysis Plot for High NDVI for Trees Inside Forests
Source: Laboratory Analysis, 2026

According to the prediction, a positive change in trees inside forests would continue to occur, and that can occupy about 197.994 km2 by 2030, indicating that there would be some regeneration in trees inside forests within that period compared to 2021, when forests occupied 174.8 km2 in the study area. The 2040 forecast period shows a drastic decrease in forest cover to about 67.302 km2. The situation of trees in forests in the forecast year 2050 is atrocious, with a predicted dramatic decrease of -63.391 km2. This may result from rapid urbanization and population growth, which require people to clear land for the construction of houses, roads, industries, institutions, and agricultural land to sustain an ever-increasing population, as exemplified by the insurgency in the study area since 2009. This study's findings align with those of Adamu (2023), who reported consistent forest loss in Adamawa Central, with Girei Forest Reserve shrinking from 177.03 km² in 1987 to 75.98 km² in 2015, largely due to fuelwood harvesting and agricultural expansion.

Similarly, Abubakar and Idi (2023), using a 20-year MODIS dataset, observed variability in NDVI values and a negative NDVI–LST relationship across the central vegetation zone, suggesting increasing stress on vegetation cover and reduced canopy vigor, a pattern comparable to that observed in this study. Omijeh (2020) also highlighted structural and compositional changes in the Bagale Forest Reserve, attributing them to anthropogenic disturbances, particularly access-driven pressures, mirroring the degradation dynamics documented here. Furthermore, Aliyu et al. (2023) demonstrated significant land-use and land-cover transitions in Yola North LGA through machine-learning analysis, providing evidence of deforestation and agro-urban expansion. This process resonates with the declining trends in tree numbers within forests reported in the central zone of Adamawa State.

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CONCLUSION AND RECOMMENDATIONS

This study reveals a clear spatiotemporal contraction of dense tree cover within the Gazetted boundaries, with high-forested areas plummeting from over 549.2 km2 in 1990 to roughly 174.8 km2 in 2021. The study further concludes that the primary causes of land cover conversion are driven entirely by human activity, such as aggressive agricultural expansion (cultivated land) and unchecked fuelwood extraction for fuel and charcoal. If the current trend persists, the region faces significant ecological risks, including biodiversity loss, reduced carbon sequestration, and heightened vulnerability to climate change. The linear trend projection model used signals a critical trajectory: if current socio-economic pressures and policy enforcements remain unchanged, the region faces significant ecological risks, including biodiversity loss, reduced carbon sequestration, heightened vulnerability to climate change and tree density inside these forest reserves will face total ecosystem collapse by 2050, accelerating local soil erosion, reducing windbreaks, and wiping out regional carbon sinks.

The predictive validity of the methodology's robustness stems from longitudinal, multi-sensor consistency (30+ years) and standardized vegetation indexing (NDVI), rather than relying on visual interpretation alone. This is because land cover can sometimes fluctuate non-linearly due to erratic rainfall cycles; applying a long-term linear trend model provides an excellent baseline descriptor for persistent human degradation. It also effectively filters out short-term climate "noise" (like a single high-rainfall year) to expose the underlying trajectory driven by population growth and logging. This gives local environmental planners a highly dependable, data-backed projection tool to justify urgent reforestation interventions.

To halt the projected ecological collapse and reverse the multi-decade tree cover decline in Central Adamawa State's Forest reserves, the study put forward the following recommendations;

1. Demarcation and strict enforcement of forest reserve boundaries by the government through implementing regular forest ranger patrols equipped with mobile GPS tracking units to monitor and stop illegal logging and farm encroachment in real-time.

2. Community-based agroforestry and woodlot buffers should be encouraged by establishing community woodlots on the peripheries of the forest reserves, planted with fast-growing, indigenous, or adapted nitrogen-fixing tree species (e.g., *Acacia, Neem,* or *Parkia biglobosa*).

3. Government at all levels should launch target-driven reforestation campaigns focusing entirely on the degraded zones identified inside the reserves using Assisted Natural Regeneration (ANR) to protect the remaining wildlings and tree stumps from livestock grazing and fires, supplemented by active enrichment planting of native canopy trees during the rainy season.

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