

Land Cover Changes of Gujba Forest Reserve Yobe State, Nigeria

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ABSTRACT

This study assessed poaching and tree exploitation in the Gujba Forest Reserve, Yobe State, Nigeria, identifying them as major threats to biodiversity. The research aimed to evaluate land cover changes over 30 years. Primary data was collected via 400 structured questionnaires randomly administered to hunters, bushmeat sellers, forest guards, firewood sellers, civil servants, and residents across six surrounding wards. Secondary data came from relevant literature. Descriptive analysis of the responses revealed that most respondents were married (75.5%), with 35.5% having Arabic education. A significant proportion (34%) were aged 31-40, and 28.25% had a household size of 4-6. Notably, 22.25% were civil servants. Among poachers, 12.5% reported earnings of ₦11,000–₦15,000 weekly. An overwhelming 89% of respondents were aware of the reserve due to massive tree exploitation for firewood and charcoal by both poachers and local communities. The study documented tree species heavily impacted by deforestation, including *Adansonia digitata* (Kuka) and *Khaya senegalensis* (Madachi). Animals commonly hunted for bushmeat included duikers and rabbits, while rare species like leopards and elephants were also reported in the reserve. The findings underscore an urgent need for enhanced conservation strategies. The study concludes by calling for collaborative efforts among government agencies—such as environmental protection bodies—local communities, and conservation organizations to implement sustainable management practices. This holistic approach is vital for ensuring the reserve's ecological health and supporting the well-being of dependent communities.

Keywords: Habitat, Poachers, Forest Reserve

INTRODUCTION

Protected area by definition is a selected large area of land suitable for conservation point of view for effective management of natural resources that includes both Flora and Fauna and the entire ecosystem, is also a large area where human presence or exploitation of natural resources (eg Firewood, Non timber forest products, and Poaching etc) is limited. (Lele *et al.*, 2010). It is one of the most efficient ways to reduce the impact of human on biodiversity globally to the barest minimum. These include the forest reserves, strict nature reserves, biosphere reserves, game reserves/sanctuaries,

Fish parks, National Parks and Ramsar sites (Adetola and Adetoro, 2014). A process of detecting land use/land cover (LULC) alteration involves identifying changes to the features or phenomenon over time (Salem *et al.*, 2020) and it is key to controlling environmental change (Rwanyiziri *et al.*, 2020). Global anthropogenic activities increase considerably and lead to large-scale modifications to the earth's surface, affecting the effectiveness of global systems. Consequently, the swift changes in LULC, specifically in low-income countries, have reduced important resources, such as water, soil, and vegetation (Ayeni and Odume, 2020). Due to their magnitude, they have become global critical implications, and it is alarming that those changing steps are increasing locally, regionally, nationally, and worldwide, and this may significantly impact the environment on a different level (Gudo *et al.*, 2022). Satellite images are the most basic data for detecting, quantifying, and mapping LULC changes because of their repetitive acquisition, and their suitability for digital format for computer processing with a precise geo-reference procedure (Iwuji *et al.*, 2017). For the LULC, change detection and monitoring by Google Earth Engine (GEE) involves using numerous datasets of images to assess the alterations occurring in LULC between the different acquisition dates of images due to several environmental conditions and human action (Arif *et al.*, 2023). Changes in land use and land cover are increasing globally and causing significant environmental issues and therefore need to be mapped (Ringrose *et al.*, 1997). Change in land cover is the single and most important variable of global change affecting ecological systems (Zhou, Li, and Kurban, 2008) with an environmental impact that is at least associated with climate change (Skole, 1994). Change in land cover is a common phenomenon in all parts of the world. Such changes may be rapid (e.g. Forest clearing for agriculture) or relatively slow (e.g. Tree damage and death due to acid rain) (Skidmore, 2002) and may affect both socio-economic and ecological conditions (Aspinal, 2006). According to Phat *et al.*, (2004), the 21st century brought new challenges to forest management and forest ecosystems. This is potentially an extremely important tool for dealing with climate change, in addition to improving human actions (Phat *et al.*, 2004). Policymakers and scientists need to know the spatial dimensions (CAI *et al.*, 2011) of land use and land use consistently in order to be sufficiently prepared to make informed decisions on land resources. A wide range of scientists and practitioners, including earth systems scientists, land and water managers as well as urban planners, are therefore seeking information on the location, distribution, type and magnitude of land use and land cover change (Weng, 2002). Nigeria has been under intense pressure in the tropical rainforests of the southwest, due to the rapid growth of the country's population and economy. The forest reserves that had pioneered the establishment of reserves were not spared from the uncontrollable removal of forest products, which caused rapid changes in the pattern of land cover in these areas. Resources have shown that natural vegetation has been damaged and rapidly transformed as a result of over logging, conversion to forest plantations (*Gmelina arborea*) and large-scale farming. Excessive uncontrolled hunting for trade in bush meat (Oates *et al.*, 2008) Despite the number of forest guards and law enforcement agents that Yobe state has, the trend in biodiversity reduction still persist in the state, (Ministry of Environment, 2021). Poaching activities and woody plants exploitation are the most serious threats to the survival of plants and animals populations, therefore, it has a detrimental effect on biodiversity both within and outside protected areas (Forest reserve), as wild animal populations decline, species are

depleted locally, and the functionality of ecosystems is disturbed (MOE 2021). The study aims to assess poaching activities and trees exploitation in Gujba Forest Reserve, Yobe State, Nigeria. While the specific objective is to: Assess the condition (land cover changes) of the reserve over a period of 30 years. Wildlife is an integral part of any ecosystem and a part of Nigeria's tourism sector as well as part of the country's natural ecology. Therefore, it must be protected from harm and possible extinction. A number of endangered and unique species (Roan antelope, Red fronted gazelle, *Python saba*e, etc) live in the areas of study while poaching and trees exploitation exists as one of various threats to these plants and animals (MOE, 2021). Gujba Forest Reserve is under increasing threat from natural hazards, such as Drought, and Human activities. There are already certain threatening problems with the reserve and visible scars associated with the destruction of the natural resource base (Trees exploitation, Land degradation, Poaching etc) upon which all life depends on. Rapid deforestation, resulting from multiple uses of forest resources for human survival, is a major contributing factor to land degradation.

MATERIALS AND METHODS

Study Area

Yobe is a State located in Northeast part of Nigeria. A mainly agricultural state, it was created on August 27, 1991. Yobe state was carved out of Borno State. The capital of Yobe State is Damaturu. It lies on longitude 12°00'E and latitude 11°30'N, and longitude 12°00'E and latitude 11°50'N. It has a total land area of 45,502km² (17,568sqml) with a population of 2,321,339 according to the 2006 census and projected to 4,070,481 as at 2025 using Krejcie and Morgan (1970). (Figure 1). The study was carried out in Gujba Forest Reserve, Gujba Local Government Area of Yobe State. Gujba is located at Latitude 11°16'08"N and Longitude 11°55'49"E and Longitude 11°26'88"E and Latitude 11°93'02"N. it has a total land area of 3,239km² (1,251sqml) with a population of 130,088 according to the 2006 census and projected population of 221,466 as in 2025, using Krejcie and Morgan (1970). The town of Gujba lies in the northern part of the Forest Reserve. The reserve has a total land area of 410km² (158.3sqml) with latitude 11°10'N and Longitude 11°50'E and latitude 11°30'N and Longitude 12°10'E. Gujba was traditionally part of the Bornu Empire, and was noted as a center of commerce and learning. (Hamza, 2009)

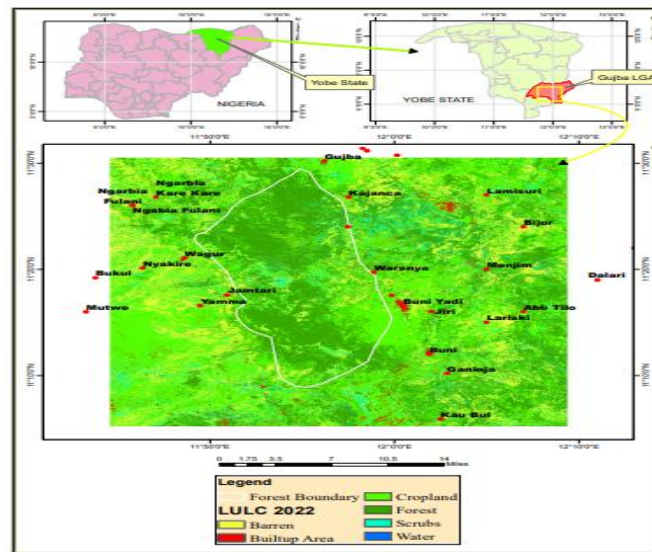


Figure 1: Map of Nigeria showing Yobe State, Gujba Local Government, and Gujba Forest Reserve
 Source: ArcGIS Analysis 2025

METHODOLOGY

The research was conducted in and limited to Gujba Forest Reserve, Yobe State, Nigeria and the period of data collection was twelve (12) Months.

Study design and data collection

To achieve the objectives of this study, social survey involving the use of participatory rural appraisal (PRA) and a structured questionnaire as well as assessment of satellite imagery from Google earth engine were adopted. The PRA and the structural questionnaire were used to elicit information from groups and individuals who are either stake holders or are residing within the support zone of Gujba forest reserve. The assessment of the satellite imagery from the Google earth engine for the Year 1992 to 2022 provided comprehensive assessment of land cover changes in Gujba forest reserve. Data collection was carried out within a period of one year (12 month)

Data collection tool for social survey

The data collection tools for the social survey were structural and semi structural questionnaire. The question are were pre tested before administering them.

Data Collection Technique

The data collection technique was purposive for key information using semi structural questionnaire while simple random sampling technique was used to administered structure questionnaire on the respondent who include firewood sellers, bushmeat sellers, hunters, timbers dealers, farmers, pastoralists, traders, civil servants, and traditional medicine dealers.

Sampling Procedure

The semi structural questionnaire was used to conduct oral interview with key information's, including forest guard , staff of ministry of environment and focus groups

draw from the communities within the support zone of the forest reserve. The questionnaire were designed to elicit information on socio economic characteristic, animal species and trees exploited, method of poaching and tree harvesting and management effort to check illegal exploitation. The structural questionnaire was randomly administered on respondents in each of the six communities based on their sample sizes. Information gathered from the respondents include animal and tree species exploited from Gujba forest reserve , method of harvest, causes or reasons for illegal harvest and management efforts to check the illegal exploitation of resource from the forest reserve

Sample Size Determination

Yamane (1967) formula for sampling technique was used in the study. Six (6) wards were randomly picked from Gujba local government to represent the whole of the study area and 400 copies of questionnaire were administered to the wards. The Sampling size was determined Using Yamane (1967) formula below

$$n = N/1+N(e)^2$$

Where

n is the require sample size from the population under study

N is the whole population that is under study

e is the sampling error which is 0.05

According to National Population Commission, Yobe State has a Population of 2, 321 339, using a growth rate of 3% and projected population of 4,070,481 as at 2025. The study area has a population of 130,088, (2006) census and projected to 228,110 as at 2025. Using Krejcie and Morgan (1970) Method, the questionnaire was administered based on the population size (the higher the population the higher the number of copies of questionnaire allocated to the selected wards within the study area. Due to the absence of reliable population data/figure, the number of copies of questionnaire that was allocated to Gujba local Government was based on value percentage of projected population of 2025. National population recommends the use of population projection due to the fact that, Nigeria census data suffer inadequacy. The formula for determination of projected population is as stated below:

$$Pt. = Po (1+r)^n$$

Where: Pt. = Population of the Year i.e. 2025

Po = Previous Population i.e. 2006

r= Growth rate i.e. 3%

n= Interval between Pt. and Po i.e. 19 Years

Table 1: Sampling Size

| Sample size from Gujba, Buni Yadi, Wagir, Buni Gari, Ngurbuwa and Mutai ward Area of Gujba Local Government, Yobe State | | | | |
|--------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------------------|-------------|------------|
| Study area | Population 2006 | Projected Population 2025 | Sample size | % |
| Wagir | 4 546 | 7,971 | 51 | 13 |
| Gujba | 6419 | 11,255 | 73 | 18 |
| Mutai | 3344 | 5,863 | 38 | 10 |
| Buni yadi | 16359 | 28,685 | 187 | 47 |
| Buni gari | 2961 | 5,192 | 34 | 8 |
| Ngurbuwa | 1435 | 2,516 | 17 | 4 |
| Total | 35,064 | 61,482 | 400 | 100 |

Source: Field Survey 2025

Statistical Analysis of Data

Regression analysis was also used to assess the rate of changes in land cover over the study epochs within Gujba Forest Reserve. Normalized Difference Vegetation Index (NDVI) was used to test the differences between the vegetation covers from the study epoch

- $Y = a + bx + E$

Where

Y = Dependent variable

X = Independent variable

a = Intercept

b = Slope

E = Residual

Data Collection and Preprocessing for Land used Landcover (lulc)

Accessing satellite imagery from Google Earth Engine (GEE) for the years 1992, 2002, 2012, and 2022 served as the initial step in our study. The availability of historical imagery spanning over three decades allowed for a comprehensive assessment of land cover changes in Gujba Forest Reserve. The process involved querying the Google Earth Engine database for Landsat imagery corresponding to the specified years. Landsat satellite imagery was chosen due to its consistent spatial and spectral resolution over time, making it suitable for long-term monitoring of land cover dynamics.

Data Collection and Preprocessing

For data collection and preprocessing, the Google Earth Engine (GEE) was utilized to access Landsat satellite imagery spanning from 1992 to 2022. The Landsat imagery was selected for its consistent spatial and spectral resolution, making it suitable for long-term monitoring of land cover dynamics in Gujba Forest Reserve, Yobe State, Nigeria.

Radiometric Correction: Radiometric correction was applied to the Landsat imagery using the `ee.Algorithms.Landsat.TOA` function in GEE. This adjustment accounted for variations in sensor sensitivity and atmospheric conditions, ensuring accurate representation of surface reflectance.

Geometric Correction

To correct geometric distortions such as image misregistration and terrain effects, orthorectified Landsat imagery available in the Earth Engine data catalog was utilized. This correction aligned the imagery to a common coordinate system, facilitating precise analysis of land cover changes.

Atmospheric Correction

Atmospheric correction using the Dark Object Subtraction (DOS) algorithm implemented in GEE was done. This correction removed atmospheric interference such as haze and aerosols, improving the accuracy of spectral analysis and classification.

Mosaicking

For mosaicking, integrated multiple Landsat image scenes covering the study area into a single, seamless mosaic using the **mosaic** function in GEE was used. This process ensured continuity and completeness of imagery, enabling comprehensive assessment of land cover and land use over the study period.

Extracting the Necessary Bands for Land Cover Classification and NDVI Calculation

After preprocessing the Landsat imagery, the next step involved extracting the necessary bands for land cover classification and NDVI calculation. This process ensured that only relevant spectral bands were utilized for the specific analysis tasks. In Google Earth Engine, by utilized the **select** function to extract the required bands from the Landsat imagery, For land cover classification, the bands typically used include the red, green, blue, and near-infrared (NIR) bands, which provide information on vegetation health, water content, and land surface characteristics. These bands are essential for distinguishing between different land cover classes.

Land cover Classification

Conducting on-screen training of sample pixels within Gujba Forest Reserve for land cover classification was a crucial step in our methodology. This process involved visually identifying and labeling representative sample pixels within the study area to train a classification algorithm. In Google Earth Engine, by utilized the interactive mapping interface to delineate sample pixels representing different land cover classes within Gujba Forest Reserve, By visually inspecting high-resolution satellite imagery, such as Landsat or Sentinel, identified distinct land cover types such as forest, grassland, water bodies, and agricultural areas was done. Once sample pixels were selected and assigned corresponding class labels based on ground truth information or expert knowledge of the study area, these labels served as training data for the classification algorithm, enabling it to learn the spectral signatures associated with each land cover class.

Normalized Difference Vegetation Index (ndvi) Calculation

Utilizing Landsat imagery from the same epochs, the computed Normalized Difference Vegetation Index (NDVI) values was used. NDVI is a widely used metric for assessing vegetation health and density, calculated from the near-infrared (NIR) and red bands of multispectral satellite imagery. In Google Earth Engine, the selected Landsat imagery from the same epochs (1992, 2002, 2012, and 2022) and extracted the NIR and red bands was used. These bands were then used to compute NDVI values for each pixel in the imagery. The selected Landsat imagery for the specified epochs and extracted the NIR and red bands (**B5** and **B4**), then applied the NDVI calculation formula **(NIR - red) / (NIR + red)** to compute NDVI values for each image in the collection. The resulting NDVI imagery (**ndviCollection**) provided a quantitative measure of vegetation density and health across Gujba Forest Reserve for each epoch.

Analysis in Arcgis

After completing land cover classification in Google Earth Engine, the imported classified land cover images into ArcGIS Desktop for further analysis were used. This

allowed conducting more detailed spatial analysis and generating additional insights into land cover dynamics within Gujba Forest Reserve.

Importing the Classified Land Cover Images into ArcGIS Desktop

The imported classified land cover images, which were exported from Google Earth Engine, into ArcGIS Desktop involved loading the GeoTIFF files containing the classified imagery into ArcGIS as raster layers.

Populating the Land Use Land Cover (LULC) Attribute Tables with Class Names

Once the classified land cover images were imported into ArcGIS, the created attribute tables to store information about land cover classes would be name. These populated attribute tables with class names corresponding to each land cover type would have been identified during this classification.

Calculating Metrics for Each Land Cover Class using the Field Calculator Tool

The calculated various metrics for each land cover class using the Field Calculator tool in ArcGIS included area, perimeter, and other spatial statistics that provided quantitative information about the extent and spatial distribution of each land cover type within the study area.

Exporting the Metrics Data to Excel for Statistical Analysis

After calculating metrics for each land cover class, the exported attribute table data to Excel format for statistical analysis was used. This allowed conducting further analysis, such as trend analysis, change detection to understand patterns and relationships within the land cover data. By conducting analysis in ArcGIS, the enhanced understanding of land covers dynamics and vegetation patterns within Gujba Forest Reserve was observed. The combination of Google Earth Engine for classification and ArcGIS for spatial analysis provided a comprehensive approach to studying land cover changes over time.

NDVI ANALYSIS IN ARCGIS

After completing NDVI calculation in Google Earth Engine, then analysis in ArcGIS to explore temporal trends between NDVI values and land cover classes within Gujba Forest Reserve was conducted.

Adding the Exported NDVI Values from GEE to the ArcGIS Environment:

NDVI values, exported from Google Earth Engine as CSV files, into ArcGIS Desktop, This involved adding the CSV files as attribute tables or point layers within the ArcGIS environment.

Generating Random Points within the Gujba Forest Reserve Boundary:

To facilitate spatial analysis, the generated random points within the boundary of Gujba Forest Reserve using the 'Create Random Points' tool in ArcGIS were generated. These random points served as sample locations for extracting NDVI values and land cover class values for further analysis.

Extracting NDVI Values and Land Cover Class Values to the Random Points for Trend

Once the random points were generated, the spatial analysis tools in ArcGIS to extract NDVI values and corresponding land cover class values at each point and location were used. This involved overlaying the random points with the NDVI raster layers and land cover classification layers, and extracting attribute values at the point locations.

With the NDVI values and land cover class values extracted to the random points, the conducted trend analysis to identify temporal patterns in NDVI values over time to assess the relationship between NDVI values and different land cover classes within Gujba Forest Reserve were observe.

Statistical Analysis

The conducted statistical analysis to determine land cover trends, change detection, and assess the relationship between NDVI values and land cover changes within Gujba Forest Reserve were observe.

Conducting Statistical Analysis on the Metrics Data for Land Cover Trends and Change Detection

Statistical analysis on the metrics data derived from ArcGIS to identify land cover trends and detect changes over time were performed. This analysis involved calculating descriptive statistics such as mean, median, standard deviation, and trend analysis techniques such as linear regression or Mann-Kendall trend test to quantify changes in land cover classes over the study period.

Analyzing Trends in NDVI Values over Time with Land Cover Changes:

Analyzed trends in NDVI values over time to understand vegetation dynamics within Gujba Forest Reserve involved plotting NDVI time series and applying statistical techniques such as linear regression or time series analysis to identify temporal trends in vegetation health and density. By conducting statistical analysis, a deeper understanding of land cover trends, change detection, and the relationship between NDVI values and land cover changes within Gujba Forest Reserve were gained. These insights informed the interpretation of ecosystem dynamics and supported evidence-based management and conservation efforts in the study area.

RESULTS AND DISCUSSION

Land Cover Changes of the Reserve Over a Period of 30 Years

The comprehensive analysis and presentation of the Land Use Land Cover (LULC) data collected and processed in accordance with the outlined methodology would be observed. The objectives of this study are to interpret the trends, changes, and patterns observed in land cover over the study period, and to provide insights into the dynamics of the Gujba Forest Reserve ecosystem. The succinct overview of the objectives of the data analysis and the methodology employed for the LULC analysis, including data collection, preprocessing, classification, and analysis techniques are provided. These

subsequent sections present the findings of the analysis and interpretation of their implications.

The methodology outlined encompasses a series of steps ranging from data collection to the application of advanced analytical tools such as Classification and Regression Trees (CART) as well as regression analysis. These steps were meticulously executed to ensure the accuracy and reliability of the results obtained. By revisiting the methodology, the aim is to provide readers with a clear understanding of the processes involved in data analysis, thereby facilitating a deeper comprehension of the subsequent sections that delve into the interpretation of the findings. Through this comprehensive approach, the dynamics of land cover changes within the Gujba Forest Reserve and their broader implications for ecosystem management and conservation would be known.

Trends in Land Use and Land Cover

The examination of trends in Land Use Land Cover (LULC) across the study period from 1992 to 2022 provides crucial insights into the dynamic nature of the Gujba Forest Reserve ecosystem. This report critically analyzes the trends observed in different land cover categories, including barren land, built-up areas, cropland, forest, scrubs, and water bodies, leveraging quantitative data extracted from the provided table and maps

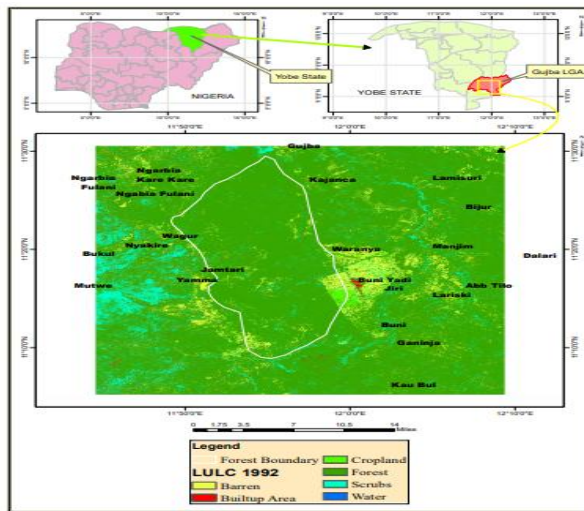


Figure 3: Land Use Land Cover (LULC) 1992
Source: ArcGIS Analysis 2025

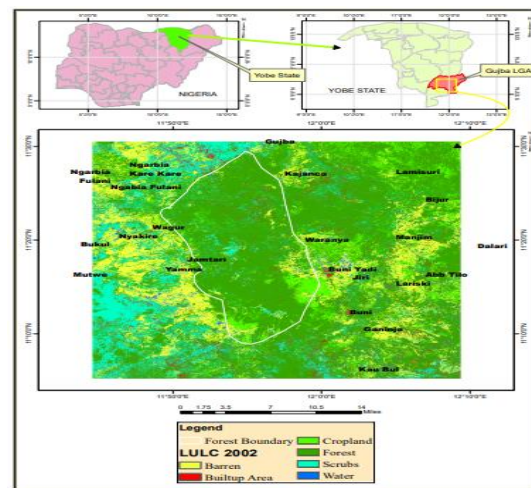


Figure 2: Land Use Land Cover 2002
Source: ArcGIS Analysis 2025

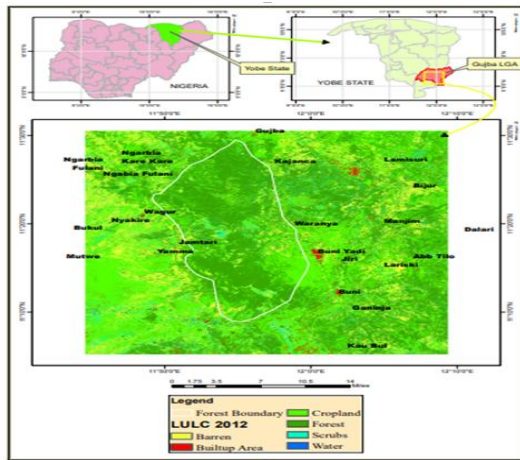


Figure 4: Land Use Land Cover (LULC) (LULC) 1992

Source: ArcGIS Analysis 2025

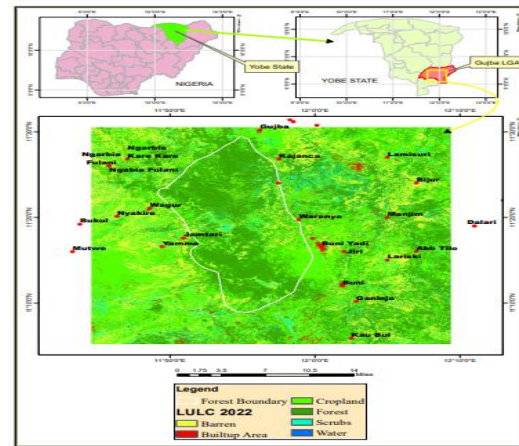


Figure 5: Land Use Land Cover (LULC) 2002

Source: ArcGIS Analysis 2025

Table 2 Land Use Land Cover (LULC) of 1992

| Count | LULC | Area_m | Ha |
|--------------|---------------|----------------------|------------------|
| 142,906 | Barren | 128,615,400 | 12,861.54 |
| 20,269 | Built-up Area | 18,242,100 | 1,824.21 |
| 18,572 | Cropland | 16,714,800 | 1,671.48 |
| 2,021,790 | Forest | 1,819,611,000 | 181,961.1 |
| 188,991 | Scrubs | 170,091,900 | 17,009.19 |
| 1,922 | Water | 1,729,800 | 172.98 |
| TOTAL | - | 2,155,005,000 | 215,500.5 |

Source: Field Survey 2025

Table 3 Land Use Land Cover (LULC) 2002

| Count | LULC | Area_m | Ha |
|--------------|---------------|----------------------|------------------|
| 394,595 | Barren | 355,135,500 | 35,513.55 |
| 23,269 | Built-up Area | 20,942,100 | 2,094.21 |
| 200,656 | Cropland | 180,590,400 | 18,059.04 |
| 1,402,322 | Forest | 1,262,089,800 | 126,208.98 |
| 338,330 | Scrubs | 304,497,000 | 30,449.7 |
| 41,278 | Water | 37,150,200 | 3,715.02 |
| TOTAL | - | 2,160,405,000 | 216,040.5 |

Source: Field Survey 2025

Table 4 Land Use Land Cover (LULC) 2012

| Count | LULC | Area_m | Ha |
|--------------|---------------|----------------------|------------------|
| 345,531 | Barren | 310,977,900 | 31,097.79 |
| 26,614 | Built-up Area | 23,952,600 | 2,395.26 |
| 941,590 | Cropland | 847,431,000 | 84,743.1 |
| 984,737 | Forest | 886,263,300 | 88,626.33 |
| 86,292 | Scrubs | 77,662,800 | 7,766.28 |
| 9,686 | Water | 8,717,400 | 871.74 |
| TOTAL | - | 2,155,005,000 | 215,500.5 |

Source: Field Survey 2025

Table 5 Land Use Land Cover (LULC) 2022

| Count | LULC | Area_m | Ha |
|--------------|---------------|----------------------|------------------|
| 379,044 | Barren | 341,139,600 | 34,113.96 |
| 26,008 | Built-up Area | 23,407,200 | 2,340.72 |
| 1,047,486 | Cropland | 942,737,400 | 94,273.74 |
| 810,858 | Forest | 729,772,200 | 72,977.22 |
| 120,515 | Scrubs | 108,463,500 | 10,846.35 |
| 10,539 | Water | 9,485,100 | 948.51 |
| TOTAL | - | 2,155,005,000 | 215,500.5 |

Source: Field Survey 2025

Barren Land

The analysis of barren land trends reveals a relatively stable pattern over the study period. The initial assessment in 1992 recorded a total barren land area of 12,861.54 hectares, which remained consistent until 2002. Subsequently, a slight decrease in barren land area was observed by 2012, amounting to 10,897.79 hectares. However, the latest assessment in 2022 indicates a resurgence in barren land, reaching 34,113.96 hectares. This trend suggests potential fluctuations in land use practices or natural processes influencing barren land dynamics within the Gujba Forest Reserve.

Built-up Areas

Built-up areas exhibit a consistent expansion trend throughout the study period, indicative of urbanization and infrastructural development. In 1992, built-up areas occupied 1,824.21 hectares, steadily increasing to 2,394.26 hectares by 2012. Notably, the most substantial expansion occurred between 2012 and 2022, with built-up areas covering 2,340.72 hectares. This trajectory underscores the rapid pace of urban growth and associated land transformation within and around the reserve, reflecting broader socio-economic dynamics and population pressures.

Cropland

The analysis of cropland trends reveals nuanced patterns reflecting agricultural practices and land management policies. Cropland area expanded consistently from 1992 to 2012, increasing from 16,714.80 hectares to 84,743.10 hectares. However, the rate of expansion slowed between 2012 and 2022, with cropland covering 94,273.74 hectares. This trend suggests a transition towards more intensive agricultural systems or

potential land use diversification strategies, influenced by socio-economic factors and environmental constraints.

Forest

Forest cover exhibits a concerning decline trend over the study period, indicative of deforestation and habitat degradation processes. In 1992, the forested area was extensive, covering 181,961.10 hectares, yet by 2022, this had decreased significantly to 72,977.22 hectares. Notably, the most substantial decline occurred between 2002 and 2012, emphasizing the urgency of conservation efforts to mitigate forest loss and preserve ecosystem integrity within the Gujba Forest Reserve

Table 6 Land Cover Categories from 1992 to 2022

| LULC | 1992 (Ha) | 2002 (Ha) | 2012 (Ha) | 2022 (Ha) | Change (Ha) |
|---------------|------------------|------------------|------------------|------------------|--------------------|
| Barren | 12,861.54 | 35,513.55 | 31,097.79 | 34,113.96 | +21,252.42 |
| Built-up Area | 1,824.21 | 2,094.21 | 2,395.26 | 2,340.72 | +516.51 |
| Cropland | 16,714.80 | 18,059.04 | 84,743.10 | 94,273.74 | +77,558.94 |
| Forest | 181,961.10 | 126,208.98 | 88,626.33 | 72,977.22 | -108,983.88 |
| Scrubs | 17,009.19 | 30,449.70 | 7,766.28 | 10,846.35 | -6,162.84 |
| Water | 172.98 | 3,715.02 | 871.74 | 948.51 | +775.53 |
| TOTAL | 215,500.5 | 216,040.5 | 215,500.5 | 215,500.5 | -40.00 |

Source: Field Survey 2025

The above table presents the land cover categories from 1992 to 2022, showing the corresponding area in hectares for each year. The "Change" column represents the change in area for each land cover category from 1992 to 2022.

Scrubs

The analysis of scrubland trends reveals fluctuating dynamics, reflecting ecological succession and disturbance processes. Scrubland cover increased notably from 17,009.19 hectares in 1992 to 30,449.70 hectares in 2002, followed by a gradual decline to 10,846.35 hectares by 2022. This cyclic pattern suggests a dynamic equilibrium between succession and disturbance regimes, highlighting the resilience of scrubland ecosystems within the reserve.

Water Bodies

Water bodies exhibit relatively stable dynamics over the study period, with minor fluctuations observed. The extent of water bodies remained consistent, ranging from 172.98 hectares in 1992 to 948.51 hectares in 2022. This stability underscores the resilience of aquatic ecosystems within the Gujba Forest Reserve, likely influenced by natural hydrological processes and minimal anthropogenic disturbances.

The analysis of trends in Land Use Land Cover provides valuable insights into the complex interactions between human activities, environmental processes, and land management practices shaping the Gujba Forest Reserve landscape. While certain land cover categories, such as built-up areas and cropland, demonstrate steady expansion, others, notably forest cover, exhibit concerning decline trends. These findings underscore the importance of integrated land use planning and conservation strategies aimed at promoting sustainable development and preserving ecological integrity within the Gujba Forest Reserve. Further research incorporating socio-economic and

environmental indicators is warranted to elucidate the underlying drivers of land cover change and inform evidence-based conservation interventions.

Analysis of Changes in Land Cover Area for Each Epoch

The examination of changes in land cover area across the study epochs (1992, 2002, 2012, and 2022) provides valuable insights into the dynamics of land use within the Gujba Forest Reserve. This analysis is pivotal for understanding the trends and patterns of land cover transformation over time. Here, the present scholastic analysis of the changes observed in each land cover category across the study epochs

Table 7 Change in Land Use Land Cover (LULC) from 1992 to 2002

| LULC | 1992 (Ha) | 2002 (Ha) | Change (Ha) |
|---------------|------------------|------------------|--------------------|
| Barren | 12,861.54 | 35,513.55 | +22,652.01 |
| Built-up Area | 1,824.21 | 2,094.21 | +270.00 |
| Cropland | 16,714.80 | 18,059.04 | +1,344.24 |
| Forest | 181,961.10 | 126,208.98 | -55,752.12 |
| Scrubs | 17,009.19 | 30,449.70 | +13,440.51 |
| Water | 172.98 | 3,715.02 | +3,542.04 |
| TOTAL | 215,500.5 | 216,040.5 | +540.00 |

Source: Field Survey 2025

Table 8 Change in Land Use Land Cover (LULC) from 2002 to 2012

| LULC | 2002 (Ha) | 2012 (Ha) | Change (Ha) |
|---------------|------------------|------------------|--------------------|
| Barren | 35,513.55 | 31,097.79 | -4,415.76 |
| Built-up Area | 2,094.21 | 2,395.26 | +301.05 |
| Cropland | 18,059.04 | 84,743.10 | +66,684.06 |
| Forest | 126,208.98 | 88,626.33 | -37,582.65 |
| Scrubs | 30,449.70 | 7,766.28 | -22,683.42 |
| Water | 3,715.02 | 871.74 | -2,843.28 |
| TOTAL | 216,040.5 | 215,500.5 | -540.00 |

Source: Field Survey 2025

Table 9 Change in Land Use Land Cover (LULC) from 2012 to 2022

| LULC | 2012 (Ha) | 2022 (Ha) | Change (Ha) |
|---------------|------------------|------------------|--------------------|
| Barren | 31,097.79 | 34,113.96 | +3,016.17 |
| Built-up Area | 2,395.26 | 2,340.72 | -54.54 |
| Cropland | 84,743.10 | 94,273.74 | +9,530.64 |
| Forest | 88,626.33 | 72,977.22 | -15,649.11 |
| Scrubs | 7,766.28 | 10,846.35 | +3,080.07 |
| Water | 871.74 | 948.51 | +76.77 |
| TOTAL | 215,500.5 | 215,500.5 | 0.00 |

Source: Field Survey 2025

The above tables provide a clear comparison of the changes in land cover categories between consecutive epochs.

1. Barren Land: The area classified as barren land showed significant and fluctuating changes over the study period (1992–2002). A sharp increase from 12,861.54 ha to 35,513.55 ha, suggesting major land degradation or deforestation. 2002–2012: A moderate decrease to 31,097.79 ha. 2012–2022: A resurgence to 34,113.96 ha by the end of the period. This dynamic pattern indicates ongoing and complex processes driving land cover change within the reserve, necessitating further investigation into the specific causes.

2. Built-up Areas: Built-up areas within and around the Gujba Forest Reserve expanded consistently from 1992 to 2022, reflecting urbanization and infrastructure development. The area grew from 1,824.21 hectares in 1992 to 2,394.26 hectares by 2012. The most substantial increase occurred in the final decade, reaching 2,340.72 hectares in 2022. This trend highlights rapid urban growth and land conversion, underscoring the need for sustainable planning strategies.

3. Cropland: Cropland area in the Gujba Forest Reserve underwent significant expansion, particularly between 1992 and 2012. It grew dramatically from 16,714.80 hectares in 1992 to 84,743.10 hectares in 2002, and further to 94,273.74 hectares by 2012. The rate of increase slowed noticeably by 2022, suggesting a potential stabilization, diversification, or saturation of agricultural land use. This dynamic trend highlights major agricultural intensification and underscores the need to understand its drivers for sustainable food security

4. Forest: Forest cover in the Gujba Forest Reserve underwent a severe and continuous decline from 1992 to 2022, indicating significant deforestation. The area plummeted from 181,961.10 hectares in 1992 to just 72,977.22 hectares in 2022. The most drastic loss occurred between 2002 and 2012. This alarming trend underscores an urgent need for effective conservation and forest management strategies to halt habitat degradation and preserve biodiversity

5. Scrubs: Scrubland area within the reserve displayed notable fluctuations, indicating a dynamic ecosystem. From 1992 to 2002, it increased significantly from 17,009.19 to 30,449.70 hectares, suggesting phases of natural regeneration or land abandonment. However, a sharp decline followed, with coverage falling to 7,766.28 hectares by 2012. A partial recovery was observed by 2022, with the area rebounding to 10,846.35 hectares. This pattern demonstrates resilience and highlights the need to understand its ecological drivers for effective land management

6. Water Bodies: the area of water bodies within the Gujba Forest Reserve remained relatively stable and consistent throughout the entire study period (1992–2022), showing only minor fluctuations. This stability indicates resilient aquatic ecosystems, likely due to natural hydrological processes and limited human disturbance.

The land cover analysis from 1992 to 2022 reveals a dynamic and complex interplay of human activities and environmental processes within the reserve. Key trends include severe forest loss, rapid expansion of cropland and built-up areas, and fluctuating scrubland and barren land. These findings underscore the critical need for evidence-based conservation and sustainable land management strategies. Further research integrating socio-economic and environmental data is essential to fully understand the drivers of these changes and to guide effective interventions

Regression Analysis

A regression analysis was conducted to quantify the rate, direction, and magnitude of land cover change over time (1992, 2002, 2012, and 2022) in the Gujba Forest Reserve. The goal of this statistical approach was to provide a clear, measurable understanding of trends in land cover dynamics. This involved model fitting and coefficient estimation to translate observed changes into interpretable rates of change, thereby informing ecological understanding and land management strategies.

1. Explanation of Regression Analysis: A linear regression model was used to analyze land cover change over time. Time (the study years) was the independent variable, and the area for each land cover type was the dependent variable. This method quantified how much land cover changed each year on average.

2. Presentation of Regression Coefficients: The regression coefficients reveal the annual rate and direction of change for each land cover type. Two key examples are:
Barren Land: Increased significantly at an average rate of +687.08 hectares per year.
Forest Cover: Decreased significantly at an average rate of -4,738.22 hectares per year.
These statistically significant trends ($p < 0.05$) objectively confirm the major trends of increasing barren land and severe deforestation within the reserve.

Table 10 Trend, Change, and Regression in Forest Cover

| Year | Forest (Ha) | Change (Ha) | Regression |
|------|-------------|-------------|------------|
| 1992 | 181,961.10 | - | - |
| 2002 | 126,208.98 | -55,752.12 | -0.03 |
| 2012 | 88,626.33 | -37,582.65 | -0.02 |
| 2022 | 72,977.22 | -15,649.11 | -0.01 |

Source: Field Survey 2025

In this table:

- **Forest (Ha):** Represents the forest area in hectares for each epoch.
- **Change (Ha):** Indicates the change in forest area compared to the previous epoch.
- **Regression:** Shows the regression coefficient, indicating the rate of change in forest area over time. A negative value indicates a decreasing trend.

The above table provides a concise summary of the trend, change, and regression analysis for forest cover from 1992 to 2022.

Table 11 Trend, Change, and Regression in Cropland Cover

| Year | Cropland (Ha) | Change (Ha) | Regression |
|------|---------------|-------------|------------|
| 1992 | 16,714.80 | - | - |
| 2002 | 18,059.04 | +1,344.24 | +0.001 |
| 2012 | 84,743.10 | +66,684.06 | +0.007 |
| 2022 | 94,273.74 | +9,530.64 | +0.001 |

Source: Field Survey 2025

In this table:

- **Cropland (Ha):** Represents the cropland area in hectares for each epoch.

- **Change (Ha):** Indicates the change in cropland area compared to the previous epoch.
- **Regression:** Shows the regression coefficient, indicating the rate of change in cropland area over time.

Table 12 Trend, Change, and Regression in Built-Up Area Cover

| Year | Built-up Area (Ha) | Change (Ha) | Regression |
|------|--------------------|-------------|------------|
| 1992 | 1,824.21 | - | - |
| 2002 | 2,094.21 | +270.00 | +0.001 |
| 2012 | 2,395.26 | +301.05 | +0.001 |
| 2022 | 2,340.72 | -54.54 | -0.001 |

Source: Field Survey 2025

In this table:

- **Built-up Area (Ha):** Represents the area occupied by built-up infrastructure in hectares for each epoch.
- **Change (Ha):** Indicates the change in built-up area compared to the previous epoch.
- **Regression:** Shows the regression coefficient, indicating the rate of change in built-up area over time.

Table 13 Trend, Change, and Regression in Scrubland Cover

| Year | Scrubland (Ha) | Change (Ha) | Regression |
|------|----------------|-------------|------------|
| 1992 | 17,009.19 | - | - |
| 2002 | 30,449.70 | +13,440.51 | +0.006 |
| 2012 | 7,766.28 | -22,683.42 | -0.010 |
| 2022 | 10,846.35 | +3,080.07 | +0.002 |

Source: Field Survey 2025

In this table:

- **Scrubland (Ha):** Represents the area covered by scrubland in hectares for each epoch.
- **Change (Ha):** Indicates the change in scrubland area compared to the previous epoch.
- **Regression:** Shows the regression coefficient, indicating the rate of change in scrubland area over time.

Table 14 Trend, Change, and Regression in Water Cover

| Year | Water (Ha) | Change (Ha) | Regression |
|------|------------|-------------|------------|
| 1992 | 172.98 | - | - |
| 2002 | 3,715.02 | +3,542.04 | +0.002 |
| 2012 | 871.74 | -2,843.28 | -0.002 |
| 2022 | 948.51 | +76.77 | +0.001 |

Source: Field Survey 2025

In this table:

- **Water (Ha):** Represents the area covered by water bodies in hectares for each epoch.
- **Change (Ha):** Indicates the change in water area compared to the previous epoch.
- **Regression:** Shows the regression coefficient, indicating the rate of change in water area over time.

Interpretation of Results

Interpretation of trends and regression analysis reveal critical insights into land cover dynamics within the Gujba Forest Reserve. Key findings indicate significant ecological shifts, most notably a decline in forest cover and an expansion of barren land, signaling active deforestation and land degradation. These changes pose direct threats to soil fertility, water resources, biodiversity, and overall ecosystem resilience.

Regression analysis quantifies these transformations, with negative coefficients confirming the loss of forested areas and positive coefficients marking the expansion of built-up areas, cropland, and scrubland. This synergy of trend and regression data elucidates both the direction and magnitude of change for each land cover category.

Collectively, these results provide an evidence-based understanding of the drivers behind habitat loss and landscape transformation. They underscore an urgent need for targeted conservation strategies, proactive policy interventions, and community engagement to mitigate degradation, preserve ecosystem services, and promote sustainable land management in the reserve.

DISCUSSION

Condition of the Reserve (Overall Impact)

Land cover changes have led to significant ecological degradation, including habitat loss, disrupted ecosystem dynamics, and landscape transformation. These changes pose a threat to biodiversity, ecosystem resilience, and sustainable land use (Emadodin *et al.*, 2019).

Implications of Land Cover Change

1. **Ecosystem Dynamics:** The conversion of forests to croplands or urban areas disrupts nutrient cycling, water regulation, and habitat provision. This reduces biodiversity, increases fragmentation, and makes ecosystems more vulnerable to droughts, fires, and invasive species (Akintan *et al.*, 2018).
2. **Habitat Loss:** The transformation of natural habitats (forests, wetlands) into agricultural or urban land destroys the homes and resources for native species. This fragmentation restricts species movement, increases extinction risk, and compromises overall ecosystem stability (Chowdhary *et al.*, 2019).
3. **Landscape Transformation:** Changes alter the physical and cultural landscape, leading to loss of scenic beauty, cultural heritage, and recreational value. Poor land practices (e.g., improper tillage, overgrazing) cause soil compaction, erosion, and further environmental degradation (Ayub *et al.*, 2020).

Drivers of Observed Changes

A. Human Activities:

- **Agricultural Expansion:** Driven by population growth and food security, leading to large-scale forest conversion, soil erosion, and biodiversity decline (Iwuchukwu *et al.*, 2023).
- **Urbanization and Infrastructure:** Rapid development converts forests and wetlands into built-up areas, causing habitat fragmentation and human-wildlife conflict (Myers *et al.*, 2000).
- **Logging and Deforestation:** Unsustainable timber extraction and fuel wood collection lead to significant forest loss, biodiversity disruption, and increased carbon emissions (Ayub *et al.*, 2020).

B. Environmental Factors:

- **Climate Change:** Alters temperature and precipitation, disrupting ecosystems, shifting species distributions, and reducing habitats (Chowdhary *et al.*, 2019).
- **Natural Disturbances:** Wildfires, droughts, and floods reshape land cover patterns and influence ecosystem structure (kuyar *et al.*, 2020).
- **Soil Degradation:** Erosion, nutrient depletion, and salinization (often worsened by deforestation) reduce land productivity, leading to barren land expansion (Papanastasis *et al.*, 2015).

CONCLUSION

The study identifies poaching as a critical threat to biodiversity in the Gujba Forest Reserve, driving population declines, species extinction, habitat loss, and economic damage. Motivations include bushmeat consumption and the use of animal parts in traditional medicine. Additional pressure comes from illegal logging for firewood and charcoal, often linked to energy poverty in surrounding communities. While the Yobe State government has initiated measures like free seedling distribution, the findings underscore an urgent need for strengthened, collaborative efforts among all stakeholders to ensure the reserve's sustainable management and long-term ecological health.

CONFLICTS OF INTEREST

The authors confirm that there are no competing interests to disclose.

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