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LANDUSE CHANGES AND VEGETATION HEALTH ASSESSMENT OF NGEL NYAKI FOREST RESERVE, TARABA STATE, NIGERIA

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ABSTRACT

The preservation of forest ecosystems is of paramount importance in the face of global environmental challenges. In Nigeria, the Ngel Nyaki forest reserve (NNFR) represents a critical area of biodiversity and plays a significant role in climate regulation and water resource management. This study comprehensively assessed the extent of landuse and vegetation changes in the forest reserve over the past 30 years by utilising Remote Sensing (RS) technology and Geographic Information System (GIS) analysis. Landsat 4-5 and Landsat 8 images were obtained to classify the landuse and land cover for both the catchment area and the forest using the maximum likelihood algorithm. The vegetation health indicated by the Normalised Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI) and Green Chlorophyll Index (GCI) from 1993 to 2023 were determined. The results revealed that there was a decrease of 10,626.03 hectares (6.24%) in the dense forest and the open land increased to 22,067.73 hectares (4.49%) of the total land area of the catchment area from 1993 to 2023. Same trend was observed in the NNFR whereby the dense forest decreased to 126.54 hectares (80.01%). From 1993 to 2023, the mean NDVI and GCI slightly decreased to 0.28 and 1.86 respectively while NDWI and EVI maintained their statuses. SLAVI increased from 0.73 in 1993 to 0.84 in 2023. These findings underscore the pressing need for effective conservation measures to mitigate the adverse impacts of deforestation on biodiversity and ecosystem services of this forest reserve.

Keywords: Deforestation, Degradation, NDVI, Reserved Forest, Vegetation Indices

INTRODUCTION

Human beings, since the earliest stage of settlement, are dependent on land for their food production and various sorts of economic development which have been constantly modifying the global landscape. The relentless pressure to meet the needs of increasing population and demand-driven development activities have amplified the stress on earth's land (Foley *et al.,* 2011; Weinzettel Hertwich, Peters, Steen-Olsen, & Galli, 2013). In this context, human-caused activity and its associated landuse/land cover (LULC) changes have become an inevitable issue for the present time and stressing the risks of environmental degradation around the globe (Paiboonvorachat, 2008). The continuous monitoring of the Earth's surface through remote sensing technologies is an essential source of spatiotemporal data for deriving useful LULC information (Phiri & Morgenroth, 2017).

Landuse and land cover classification is an important means for monitoring environmental variations. Thematic maps, which are outputs from LULC classification are key for the formulation of effective land management, planning and urban policies (Hlatywayo & Masvosve, 2015; Rimal Zhang, Keshtkar, Wang, & Lin 2017). Land degradation and LULC, require monitoring of earth resources, and benefit greatly from remotely sensed products that have the capability to collect huge amounts of data cheaply and regularly for vast areas compared to field methods (Van Lynden and Mantel, 2001). These tools are essential to investigate the effects of human activities, whereby land use plays a critical role by influencing the surface-energy budgets as well as the carbon-cycle effects (Pielke Sr. *et al*., 2002). Changes in LULC driven by the need for more energy, food, and other resources to support a growing population, result in changing the physical properties of the land surface (Foley *et al*., 2005).

Nigeria is home to several protected forests, which are critical for preserving biodiversity, supporting ecosystems, and providing essential ecological services. Some of the notable protected forests in Nigeria include the Cross River National Park, Ngel Nyaki Forest Reserve, Gashaka Gumti National Park, Okomu National Park, Afi River Forest Reserve and Yankari Game Reserve, among others. Nigerian protected forests face numerous threats that endanger their ecological integrity and sustainability (Borokini et al., 2012; Imarhiagbe, Onyeukwu, Egboduku, Mukah, & Ogwu, 2022). The Ngel Nyaki Forest Reserve, recognized for its ecological significance and rich biodiversity, is facing mounting pressures from human activities, leading to land use and vegetation changes (Ali, Ashraf, Gulzar, Akmal, & Ahmad, 2020). The extent and patterns of these changes remain largely unexplored, raising concerns about the potential adverse impacts on the environment, wildlife, and the livelihoods of local communities.

The absence of comprehensive studies evaluating the extent and drivers of land use and vegetation changes in the Ngel Nyaki forest reserve hinders the development of effective conservation and sustainable land management strategies (Abdulrahaman et al., 2024). Therefore, this study aimed at evaluating the changes in LULC of the Ngel Nyaki forest reserve in the last 30 years in Nigeria using remote sensing techniques. The following key questions were addressed: i. How has the LULC changed in the catchment area of Ngel Nyaki forest reserve over the past 30 years? ii. How has the LULC changed in the Ngel Nyaki forest reserve over the past 30 years? iii. What are the trends and patterns of vegetation dynamics in the forest reserve during the same period?

MATERIALS AND METHODS

Study Area Description

Ngel Nyaki Forest Reserve is situated within Taraba State in northeastern Nigeria, specifically on the Mambilla Plateau with an area of about 31000 Km^2 and elevation of 1400 – 1500 m (Figure 1) and is located in Sardauna local government area (Karkarna, Yusuf & Umar, 2020). The reserve spans an area characterized by diverse topography, including montane forests, and associated ecosystems (Abdulrahaman et al., 2024). The vegetation comprises grasslands together with forest islands. Ngel Nyaki Forest Reserve is renowned for its rich biodiversity, housing a variety of plant and animal species (Borokini et al., 2012). The reserve serves as a habitat for numerous endemic and endangered species, including primates, ungulates, carnivores, and diverse bird species. The region where the reserve is located receives an average annual rainfall of about 1800 mm, coupled with mean monthly temperatures ranging between 13–26°C in wet season and 16–23°C in dry season (Nzoiwu, Agulue, Mbah, & Igboanugo, 2017).

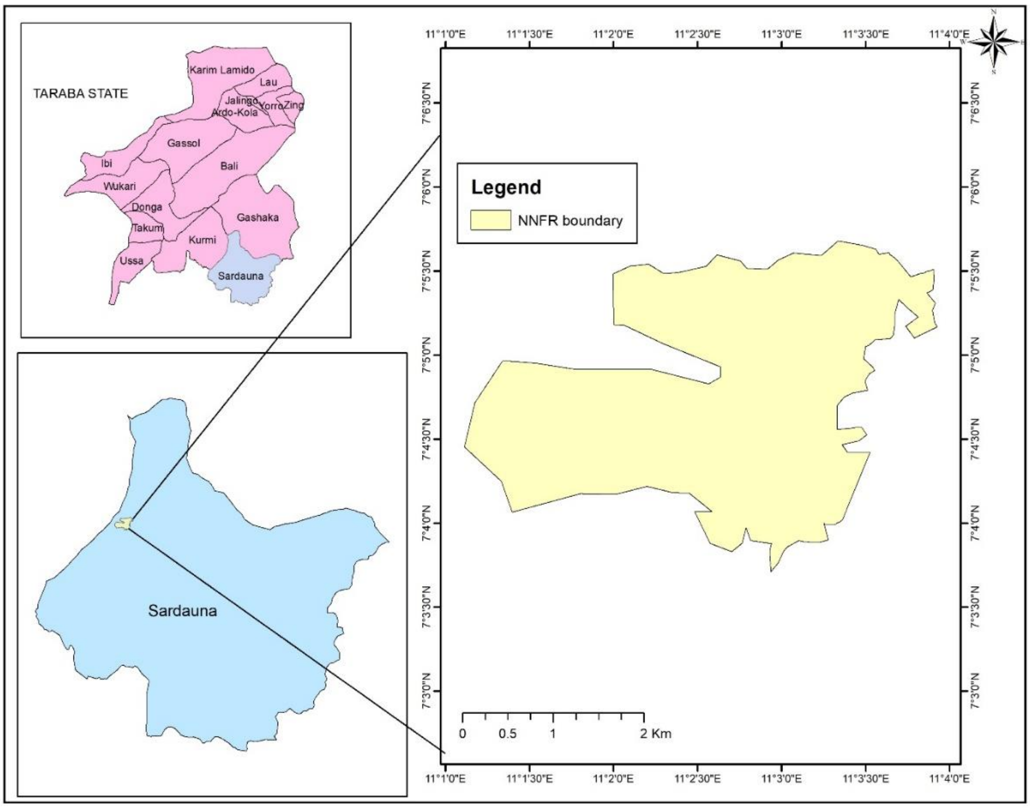

Figure 1: Study area map of Ngel Nyaki Forest Reserve, Taraba State, Nigeria

Satellite Data Collection

Landsat satellite data were used for the assessment of the changes in the land-use over the period of 1993 to 2023. Landsat satellite images were downloaded from the website of United State Geological Survey (https://earthexplorer.usgs.gov). The Landsat images include the Landsat 8 OLI / TIRS (operational land imager / thermal infrared sensor), and Landsat 4-5 TM (thematic mapper) (Table 1). For both Sardauna LGA and Ngel Nyaki Forest Reserve, the images from 1993 and 2023 were acquired along the same path/row (186/055). This geographical consistency is crucial for comparative analysis, as it ensures that the same area is being observed across different time periods. The spatial resolution of the images remains constant at 30 meters for both years. This uniformity means that each pixel in the images represents a 30 m x 30 m area on the ground. Maintaining the same spatial resolution across different time points ensures that any observed changes in the imagery are due to actual environmental changes rather than variations in image resolution.

Table 1: Characteristics of the Landsat Satellite Images Used

Satellite Features	Sardauna LGA		Ngel Nyaki Forest Reserve	
	1993	2023	1993	2023
Sensors	Landsat 4-5 TM+	Landsat 8 OLI/TIRS	Landsat 4-5 TM+	Landsat 8 OLI/TIRS
Path/row	186/055	186/055	186/055	186/055
Spatial Resolution	30 m	30 m	30 m	30 m
Date of acquisition	02/02/1993	27/12/2023	02/02/1993	27/12/2023
Number of bands	7	11	7	11

Pre-processing Techniques

After loading the Landsat raster files into the GIS environment for pre-processing, they underwent various enhancements. This included checking data quality, mosaicking, and clipping. Image processing techniques were applied to improve the clarity of the image, making it easier to identify and categorize different land use types (Jande, Nsofor, & Abdulkadir 2019; Akomolafe and Rahmad, 2020). The boundaries of the catchment area were used to isolate the area of interest within the larger image mosaic using QGIS 3.32.1. The image pre-processing was done to ensure easier detection and classification of the land-use types (Jande *et al.,* 2019).

Land Use and Land Cover Classification

The land use and land cover change of the catchment area (Sardauna LGA) and the Ngel Nyaki forest reserve were classified using the land cover categories including dense forest, built up areas, open land and wetlands (Table 2). The dense forest class represents areas where the tree canopy density exceeds 70%. Moderate forests have a tree canopy density ranging between 40% and 70%. These forests are less dense compared to dense forests. Open land refers to areas with very low or no vegetation. This category includes rocky outcrops, barren lands, and abandoned agricultural fields. Built-up areas encompass urban and rural regions, including farmhouses and other structures. These areas are characterized by significant human modifications of the landscape, including residential, commercial, and industrial developments. Wetlands are regions with natural or artificial ponds and lakes. These areas are characterized by the presence of water, either permanently or seasonally. The maximum likelihood algorithm was used for this classification through the semi-automatic plugin in QGIS 3.32.1.

Accuracy Assessment

Accuracy assessment is a critical step in remote sensing analysis to evaluate the reliability and precision of classified land cover maps or vegetation indices. It involves comparing the results obtained from remote sensing data with ground truth information collected from field surveys or higher-resolution imagery. The kappa coefficient is a statistical measure of agreement between classified and reference data, correcting for the agreement that would be expected by chance alone. It considers both omission and commission error and provides a measure of classification accuracy that accounts for class imbalance.

Kappa Coefficient = (Overall Accuracy - Expected Accuracy) / (1 - Expected Accuracy).

Table 2: Description of LULC Classes of the Study Area

LULC class	Description
Dense Forest	Forest with tree canopy density above 70%
Moderate Forest	Forest with tree canopy density between 40 and70%
Open Land	Area with very low or no vegetation, rocky outcrops, barren land, abandoned land
Built Up	Urban Areas, Rural Areas, Farmhouses
Wetlands	Natural & Artificial ponds/lakes

Vegetation Change Analysis

The vegetation change analysis of the Ngel Nyaki Forest Reserve involved time-series analysis of vegetation indices, such as the Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Enhanced Vegetation Index (EVI), Soil-Adjusted Vegetation Index (SLAVI) and Green Chlorophyll Index (GCI) over the study period. The following formulas were used to calculate the vegetation indices:

NDVI = (NIR - Red) / (NIR + Red)

EVI = 2.5 x ([Band Near Infrared – Band Red]/[Band Near Infrared + 6 x Band Red + 7.5 x Band Blue + 1])

NDWI = (Band Green – Band Near Infrared)/(Band Green + Band Near Infrared)

Specific Leaf Area Vegetation Index (SLAVI) = ([Band 5])/([Band 4+ Band 6]) for Landsat 8

SLAVI = ([Band 4])/([Band 3+ Band 5]) for Landsat 4&5

Green Chlorophyll Index (GCI) = Band 5/Band 3 - 1 for Landsat 8

GCI = Band 4/Band2 – 1 for Landsat 4&5.

RESULTS AND DISCUSSION

Land Use and Land Cover (LULC) Classification

Sardauna LG Catchment Area LULC

Results presented in Table 3 and Figure 2 show the LULC change data for the years 1993 and 2023, along with the change detection over the period of 1993 to 2023. In 1993, the area covered by dense forest was 170,410.32 hectares, accounting for 34.66% of the total land area. By 2023, the area of dense forest decreased to 159,784.29 hectares, representing 32.50% of the total land area. There was a decrease of 10,626.03 hectares in the dense forest, which corresponds to a decrease of 6.24% relative to the 1993 area. The built-up area comprised 306,596.25 hectares in 1993, constituting 62.36% of the total land area. By 2023, the built-up area slightly decreased to 302,330.07 hectares, accounting for 61.49% of the total land area. The change in the built-up area from 1993 to 2023 shows a decrease of 4,266.18 hectares, equivalent to a decrease of 1.39%. Over the period from 1993 to 2023. In 1993, the open land area was 14,596.92 hectares, representing 2.97% of the total land area. By 2023, the area of open land increased significantly to 22,067.73 hectares, accounting for 4.49% of the total land area. The change in open land area over the period shows a substantial increase of 7470.81 hectares, which corresponds to a considerable percentage increase of 51.18%. The wetlands area was minimal in 1993, covering only 12.87 hectares, which was virtually negligible in terms of percentage. However, by 2023, the wetlands area expanded significantly to 7,434.27 hectares, representing 1.51% of the total land area. The change in wetlands area from 1993 to 2023 is substantial, with an increase of 7,421.4 hectares, corresponding to a remarkable percentage increase of 57.664%.

Table 3: Areas of Land Occupied by Each LULC Class in Sardauna LGA

LULC Class	1993		2023		1993	2023
	Area (ha)	Area (%)	Area (ha)	Area (%)	Change in area (ha)	Change in area (%)
Dense Forest	170410.32	34.66	159784.29	32.50	-10626.03	-6.24
Built Up	306596.25	62.36	302330.07	61.49	-4266.18	-1.39
Open Land	14596.92	2.97	22067.73	4.49	7470.81	51.18
Wetlands	12.87	0.003	7434.27	1.51	7421.4	57664
Total area (ha)	491616.40	100	491616.40	100		

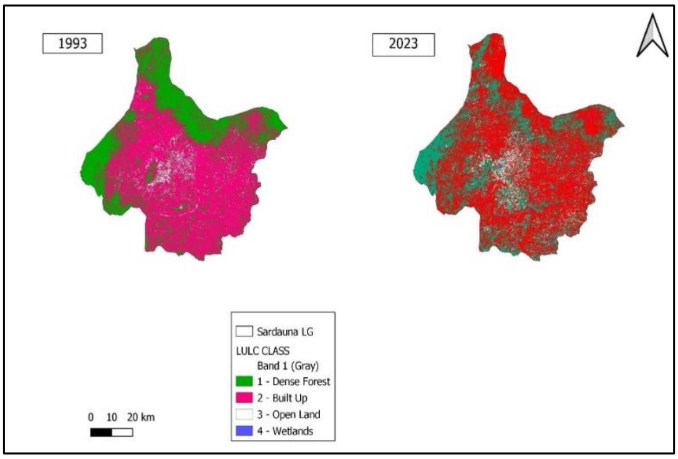

Figure 2: Land Use and Land cover map of Sardauna LG catchment area (1993 and 2023)

Ngel Nyaki Forest Reserve LULC

The LULC change analysis for the Ngel Nyaki forest reserve between 1993 and 2023 presented in Table 4 and Figure 3. In 1993, the Ngel Nyaki forest reserve had 632.88 hectares of dense forest, constituting 63.40% of the total area. By 2023, the area of dense forest decreased to 126.54 hectares, representing only 12.68% of the total area. The change in dense forest area over the period from 1993 to 2023 shows a substantial decrease of -506.34 hectares, equivalent to a percentage decrease of -80.01%. This indicates a severe loss of dense forest cover within the reserve. The area classified as moderate forest in 1993 was 244.26 hectares, accounting for 24.47% of the total area. Over the 30-year period, the moderate forest area increased dramatically to 725.13 hectares, constituting 72.64% of the total area. The change in moderate forest area from 1993 to 2023 shows an increase of 480.87 hectares, representing a substantial percentage increase of 196.87%. This indicates a considerable expansion of moderate forest cover within the reserve, likely due to regrowth or afforestation efforts.

In 1993, there were 121.05 hectares of open land within the Ngel Nyaki forest reserve, accounting for 12.13% of the total area. By 2023, the area of open land slightly increased to 146.52 hectares, representing 14.68% of the total area. The change in open land area over the period shows a modest increase of 25.47 hectares, equivalent to a percentage increase of 21.04%. This indicates a minor expansion of open land within the reserve, possibly due to deforestation or land use changes. Overall, the analysis of LULC change in the Ngel Nyaki forest reserve reveals significant transformations in forest cover types over the 30-year period. There has been a substantial loss of dense forest cover, accompanied by a considerable increase in moderate forest cover. These changes likely reflect human activities such as logging, deforestation, and reforestation efforts within the reserve.

Table 4: Areas of Land Occupied by Each LULC Class in NNFR

LULC Class	1993		2023		1993-	2023
	Area (ha)	Area (%)	Area (ha)	Area (%)	Change in area (ha)	Change in area (%)
Dense Forest	632.88	63.40	126.54	12.68	-506.34	-80.01
Moderate Forest	244.26	24.47	725.13	72.64	480.87	196.87
Open Land	121.05	12.13	146.52	14.68	25.47	21.04
Total area (ha)	998.19	100	998.19	100		

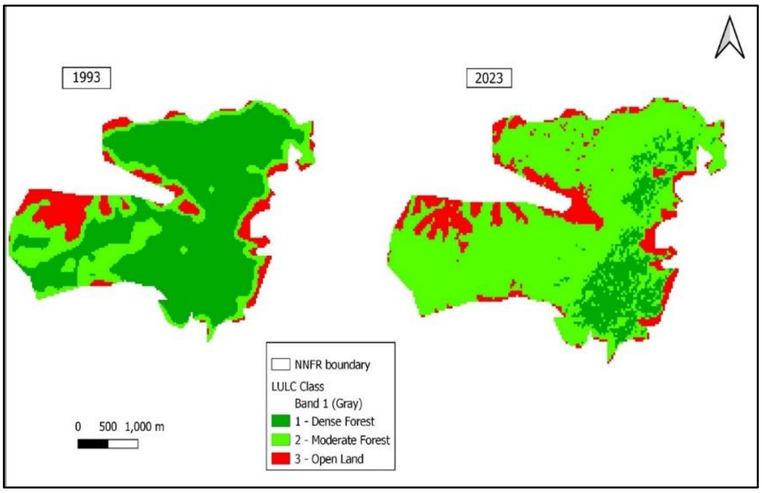

Figure 3: Land Use and Land cover map of Ngel Nyaki Forest Reserve (1993 and 2023)

Accuracy Assessment

Accuracy assessment metrics for LULC classification in the Sardauna area in 1993 and 2023 for different classes, including producer's accuracy, user's accuracy, kappa coefficient, and overall accuracy is shown in Table 5. All the Kappa coefficients for all the LULC classes in the periods under consideration were above 0.5 except for Built Up in 1993. The overall accuracies of the LULC classifications include 75.41 % for 1993 and 71.40% for 2023. Also, the accuracy assessment metrics for LULC classification in the Ngel Nyaki forest reserve for the years 1993 and 2023 is shown in Table 6. All the Kappa coefficients for all the LULC classes in the periods under consideration were above 0.5 except for Built Up in 1993. The overall accuracies of the LULC classifications include 78.41% for 1993 and 81.40% for 2023.

Table 5: Accuracy Assessment Showing the Kappa Coefficient, Producer, User, and Overall Accuracy for Sardauna LULC Classification

		1993		
LULC class	**Producer's accuracy**	**User's accuracy**	**Kappa coefficient**	**Overall accuracy (%)**
Dense Forest	54.3	99.97	0.99	75.41
Built Up	67.7	89.8	0.45	
Open Land	61.56	87.11	0.62	
Wetlands	54.6	78.90	0.56	
		2023		
Dense Forest	99.50	99.96	0.99	71.40
Built Up	60.74	72.54	0.57	
Open Land	75.34	87.54	0.66	
Wetlands	59.54	78.43	0.52	

Table 6: Accuracy Assessment Showing the Kappa Coefficient, Producer, User, and Overall Accuracy for NNFR 1993 LULC Classification

		1993		
LULC class	**Producer's accuracy**	**User's accuracy**	**Kappa coefficient**	**Overall accuracy (%)**
Dense Forest	73.80	99.76	0.99	78.41
Moderate Forest	92.66	87.10	0.68	
Open Land	74.12	100.00	1.00	
		2023		
Dense Forest	73.44	98.09	0.96	81.40
Moderate Forest	79.89	87.60	0.82	
Open Land	74.12	100.00	1.00	

Vegetation Indices Change

The data provided in Table 7 represents the mean values of various vegetation indices for the Ngel Nyaki Forest Reserve (NNFR) in the years 1993 and 2023. In 1993, the mean NDVI value for NNFR was 0.29, indicating moderate vegetation density. By 2023, the mean NDVI value slightly decreased to 0.28, suggesting a slight reduction in vegetation density over the years (Figure 4). Both in 1993 and 2023, the mean Enhanced Vegetation Index (EVI) values remained the same at 0.15 (Figure 5). This suggests consistent vegetation health and density over the 30-year period, as EVI is less sensitive to atmospheric effects compared to NDVI.

Table 7: Mean of Vegetation Indices of NNFR in 1993 and 2023

Vegetation index	1993	2023
NDVI	0.29	0.28
EVI	0.15	0.15
SLAVI	0.73	0.84
NDWI	-0.25	-0.25
GCI	2.14	1.86

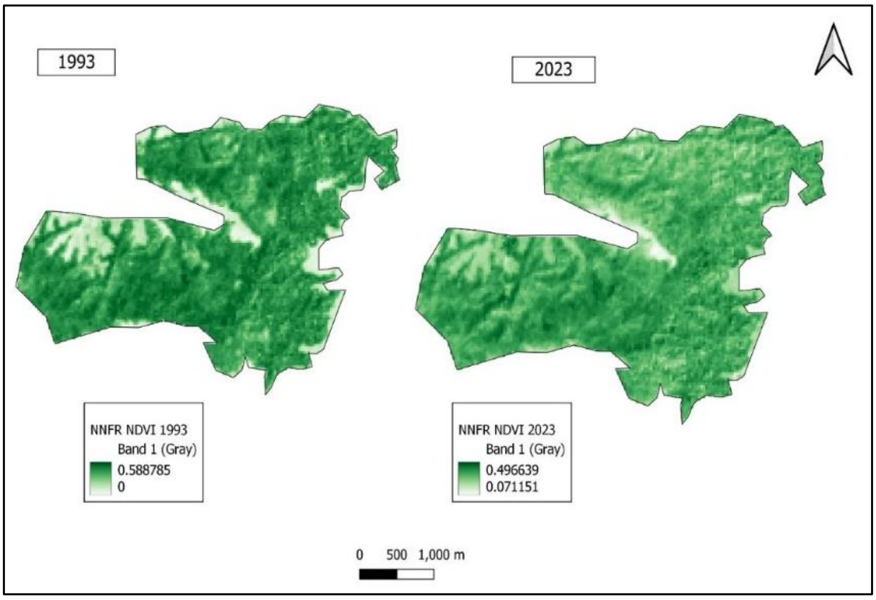

Figure 4: Normalised difference vegetation index (NDVI) of Ngel Nyaki Forest reserve (1993 and 2023)

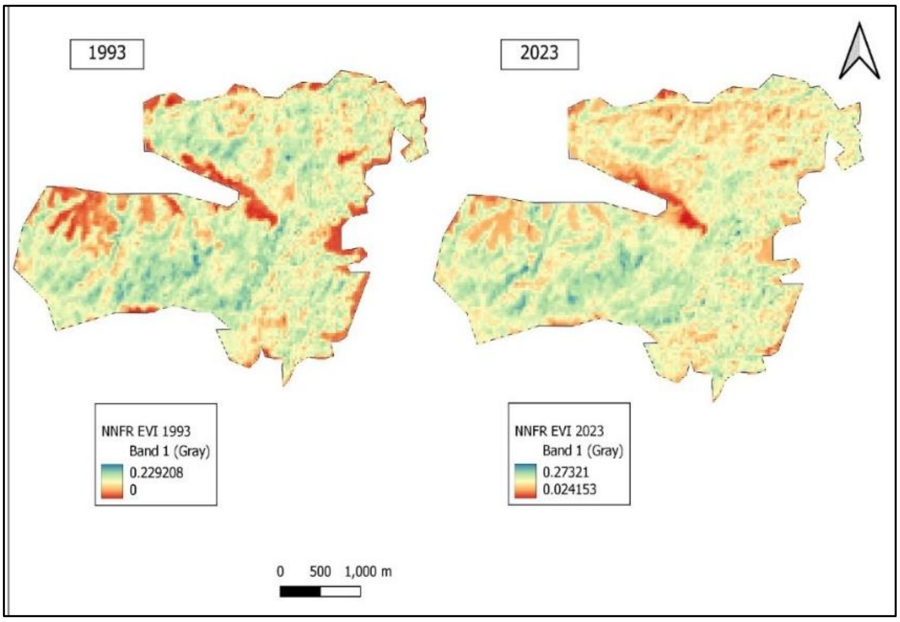

Figure 5: Enhanced vegetation index (EVI) of Ngel Nyaki Forest reserve (1993 and 2023)

The mean Soil Adjusted Vegetation Index (SLAVI) value increased from 0.73 in 1993 to 0.84 in 2023 (Figure 6). This indicates an increase in vegetation density adjusted for soil brightness, possibly due to changes in vegetation cover or soil properties over time. In 1993 and 2023, the mean Normalized Difference Water Index (NDWI) values remained the same at -0.25 (Figure 7). NDWI is an indicator of water presence, and a consistent value suggests no significant changes in water bodies within the forest over the years. The mean Green Chlorophyll Index (GCI) value decreased from 2.14 in 1993 to 1.86 in 2023 (Figure 8). A decrease in GCI may indicate a reduction in chlorophyll content or greenness of vegetation within the forest over the years.

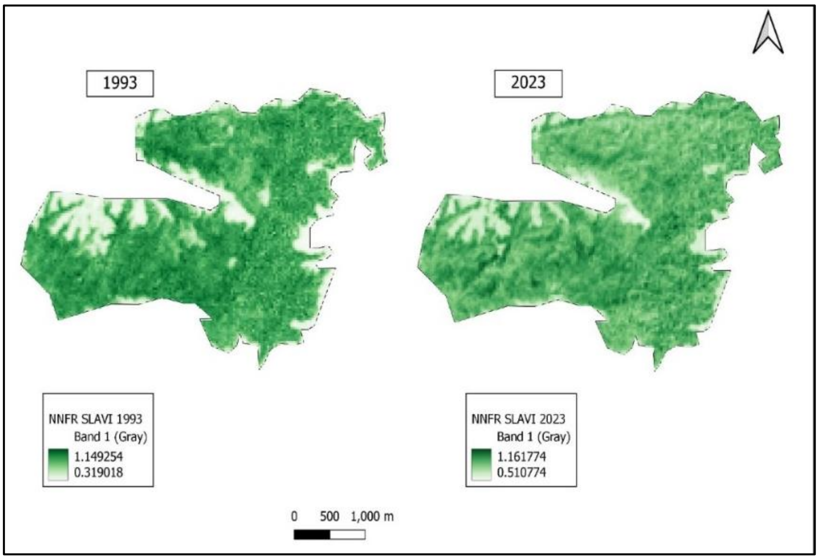

Figure 6: Soil adjusted vegetation index (SLAVI) of Ngel Nyaki Forest reserve (1993 and 2023)

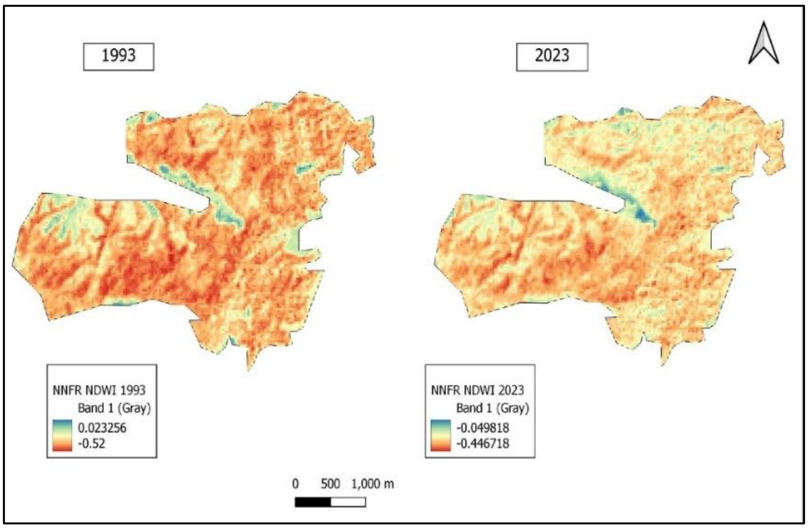

Figure 7: Normalised difference water index (NDWI) of Ngel Nyaki Forest reserve (1993 and 2023)

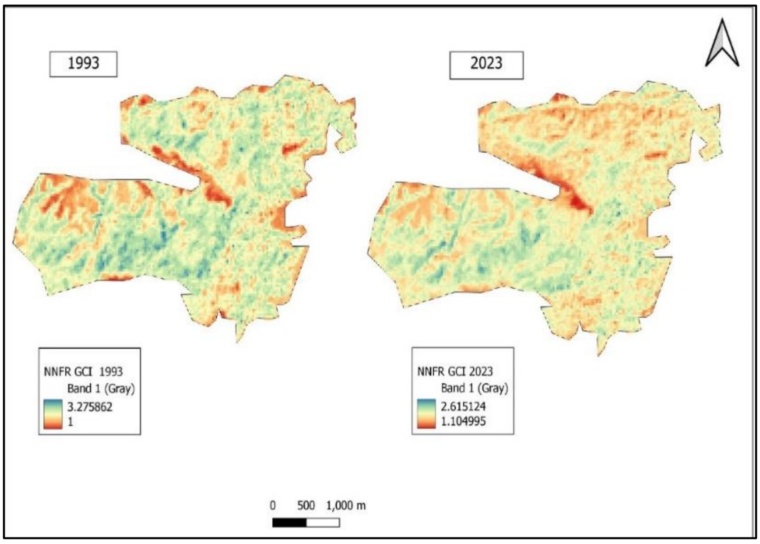

Figure 8: Green chlorophyl index (GCI) of Ngel Nyaki Forest reserve (1993 and 2023)

Discussion

The assessment of the NNFR using remote sensing techniques over a 30-year period from 1993 to 2023 has provided valuable insights into the changes in land use and vegetation. The noticeable decline in the forested areas from 1993 to 2023 in the NNFR could be due to several factors such as deforestation. This involves the conversion of forest land to agricultural or other land uses and has been a significant driver of vegetation loss. The expansion of farming activities, particularly in tropical regions, has led to extensive clearing of forest areas (Hansen et al., 2001). These activities disrupt the natural habitat and lead to fragmentation, which adversely affects biodiversity and ecosystem services (Laurance et al., 2014). From this study, the increase in the open land and wetlands of the Sardauna catchment area could have also impacted negatively on the forest reserve as there would be more demand for land for agricultural activities. It is possible that the demand for more farmland from the people in the catchment area has increased over the years. Abwage and Sale (2023) also assessed the LULC change of the same NNFR with focus on 2002 to 2022 and observed a significant reduction of the dense forest. They concluded that this could have an impact on the carbon sequestration role of the forest coupled with biodiversity loss. Interestingly, the vegetation health analysis shows some areas with improved vegetation indices, suggesting that localized conservation efforts or natural regrowth have had a positive impact (Borokini et al., 2012). These areas highlight the potential for recovery and the effectiveness of targeted conservation strategies.

Similar to the findings in NNFR, studies in other African regions have reported observed changes in vegetation density and health. Lung and Schaab (2010) assessed land cover change in Kakamega Forest using NDVI and found substantial decreases in NDVI values between 1985 and 2005. This decline was attributed to agricultural expansion and logging, mirroring the possible drivers identified in NNFR. Morton et al. (2006) assessed deforestation in the Amazon using NDVI and found significant declines in NDVI values due to logging and agricultural expansion. This is also similar to the NDVI decline in NNFR, indicating widespread deforestation issues in tropical regions. Miettinen et al. (2011) studied land cover change in Southeast Asia and observed a decrease in forested areas due to oil palm plantations and logging. The findings are consistent with NNFR, where agricultural encroachment has similarly impacted vegetation health.

The analysis of the water content in vegetation indicates a significant decrease in NDWI values from 1993 to 2023, suggesting increased water stress in the NNFR's vegetation. This trend can be attributed to several factors such as climate variability which is the changes in precipitation patterns, including prolonged drought periods. These have likely contributed to reduced water availability for vegetation. This can lead to water stress and negatively affect plant health and growth (Vicente-Serrano, Beguería, & López-Moreno, 2010). Also, over-extraction of water resources for agricultural and other uses can reduce the water available for natural vegetation, exacerbating water stress (Gerten, Schaphoff, Haberlandt, Lucht, & Sitch, 2004). The observed decrease in NDWI values at NNFR underscores the need for effective water management practices to mitigate the impacts of water stress on vegetation health. Kiage, Liu, Walker, Lam & Huh (2007) found a decline in water content of the vegetation in the Lake Nakuru Basin and correlated it with prolonged dry spells and human activities such as agriculture and urbanization. These findings align with the reduced NDWI values in NNFR, underscoring the broader impacts of climate variability on vegetation water content. Donohue, McVICAR, & Roderick (2009) studied soil water changes in Australian forests and reported a decline in water content related to extended drought periods. Similar to NNFR, the reduced soil water values in Australian forests emphasize the global influence of climatic factors on vegetation health.

The Soil-Adjusted Vegetation Index (SLAVI) provides insights into vegetation density while accounting for soil brightness. Despite the overall decline in vegetation density indicated by NDVI, SLAVI values have remained consistent, suggesting that certain areas have managed to maintain their vegetation density at the NNFR. This stability could be due to effective conservation measures. Localized conservation initiatives, such as protected areas and community-based conservation programs, may have helped maintain vegetation density in certain parts of the NNFR (Borokini et al., 2012). Green chlorophyll index is a crucial indicator of chlorophyll content and, by extension, vegetation health. The analysis reveals a decline in GCI values from 1993 to 2023, indicating reduced chlorophyll content in the NNFR's vegetation. This decline suggests decreased photosynthetic activity: lower chlorophyll content implies reduced photosynthetic activity, which can result from various stress factors, including nutrient deficiencies, pest infestations, and environmental stress (Gitelson, Viña, Ciganda, Rundquist, & Arkebauer, 2005). Abdulrahaman et al. (2024) also noted a reduction in the leaf area index (an index similar to GCI) of the same NNFR between 2015 and 2021. The observed decline in GCI values aligns with the overall trend of vegetation degradation in the NNFR, highlighting the need for comprehensive conservation efforts to address these challenges.

CONCLUSION

The assessment of land use and vegetation change in the NNFR Nigeria was done in this study. Over the study period, changes in the land cover and vegetation patterns were observed, firstly; the analysis identified pronounced deforestation within the NNFR, with substantial areas of forest cover being lost. Furthermore, the study revealed notable shifts in land use patterns, characterized by the expansion of agricultural land and wetlands. The changes pose challenges to the integrity of the reserve's ecosystems, including habitat fragmentation, soil degradation, and loss of carbon sequestration capacity.

The findings underscore the pressing need for effective conservation measures to mitigate the adverse impacts of deforestation on biodiversity, ecosystem services, and local livelihoods. Also, the result from this study is recommended to stakeholders to develop effective strategies to mitigate the adverse impacts of land use change and promote the long-term resilience of the NNFR and similar ecosystems worldwide.

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