Journal of Agroforestry and Environment

Volume 17, Issue 2, 2024

Journal DOI: https://doi.org/10.55706/jae

Journal homepage: www.jagroforenviron.com

Assessment of Land Use and Land Cover Changes in Afi River Forest Reserve Cross River State, Nigeria

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Received: 11/10/2024

Accepted: 28/12/2024

Available online: 31/12/2024

Abstract: Forest conversion remains a pressing concern for the global environmental community. This study evaluated the impact of land use and land cover (LULC) changes on selected ecosystem components in the Afi River Forest Reserve, Cross River State, Nigeria. Spatial and temporal changes over a 30-year period (1992 to 2022) were evaluated using Landsat-4 Thematic Mapper (TM) for the 1992 images and Landsat-7 Enhanced Thematic Mapper (ETM) images for 2002 and 2022. A supervised classification method was employed to classify and map LULC types and future changes up to 2052 predicted. Six distinct land use types-dense vegetation, farmland/sparse vegetation, built-up area, bare land, rock, and water bodies were identified. A significant decline in dense vegetation from 312.14 km² in 1992 to 271.28 km² in 2022 was observed while farmland, built-up areas, and bare land increased. The decline in dense vegetation highlights the pressures from agricultural expansion, urbanization, and other anthropogenic activities. A further decline in dense vegetation to 220.32 km² by 2052 and further expansions in the areas covered by farmland, water bodies, built-up areas, and bare land, were predicted. The observed trends highlight the urgent need for immediate action to combat environmental degradation in the Afi River Forest Reserve. Prioritizing sustainable land use practices, such as agroforestry and sustainable agriculture, is essential to alleviate agricultural pressures. Strengthening community-based forest management programs to foster local participation and commitment to conservation efforts. Furthermore, continuous monitoring of LULC changes is vital for informing adaptive management strategies and implementing effective policy interventions.

Keywords: Sustainable land use: Forest conservation: Remote sensing: Forest reserve.

INTRODUCTION

Natural resources are under serious pressure due to changes in land use and land cover (LULC). These LULC changes have greatly impacted the extent and condition of forests in Southern Nigeria, leading to a reduction in forest cover and disrupting the habitats of numerous rare, endangered, threatened, and endemic species (Mburu, 2019).

Forests provide essential livelihoods for millions of individuals and play a significant role in the economic development of many nations. They not only provide habitat for a wide range of species but also act as crucial carbon sinks, influence climate regulation, facilitate soil formation and conservation, regulate water systems, and conserve biodiversity. Global forest areas have been steadily declining due to the increasing human population and the subsequent expansion of land use for various purposes (Potapov et al., 2022; Wrinkler et al., 2021). This trend is evident across numerous countries worldwide.

Land use refers to the ways in which land is employed for different purposes. It involves human activities and practices that take place on a particular area of land, encompassing various purposes such as residential, commercial, industrial, agricultural, recreational, or conservation activities. Land cover on the other hand refers to the physical attributes and characteristics of the Earth's surface, encompassing natural and artificial features such as forests, grasslands, water bodies, urban areas, residential buildings, agricultural fields, and barren land (Mondal &

Zhang, 2018). It describes the type, distribution, and spatial arrangement of various surface cover types, providing information about the land's surface properties and features. On the other hand, land use and land cover change (LULCC) refers to the alteration of the Earth's terrestrial surface driven by human activities. Chima et al. (2009) identify human poverty, a decreasing amount of agricultural land per person, and the rising demand for fuelwood, timber, pasture, shelter, and food crops as key drivers behind the indiscriminate exploitation, degradation, and conversion of natural land covers, especially tropical forests. While humans have been altering land for food and essential resources for millennia, the extent of land use and land cover change (LULCC) has escalated significantly since the early 20th century (Mondal & Zhang, 2018). These alterations have been extensive, resulting in an increase of agricultural land, human population, economic production, energy consumption, and an increase in carbon dioxide emissions (Olorunfemi et al., 2020). LULCC has recently garnered significant attention in the global research community due to its profound impacts on climate change, biogeochemical cycles, ecosystem services (ESS), and biodiversity (Hasan, et al., 2020; Newbold et al., 2020; Olorunfemi, et al., 2020). According to Näschen et al. (2019), many regions in sub-Saharan Africa (SSA), including Nigeria, are susceptible to LULCC. Often, natural ecosystems are converted into agricultural land to accommodate the expanding population. This transformation exerts pressure on the seemingly limited land resources in urban areas, turning land into a critical resource. In order to assess these changes, remote sensing stands out as a tool for detecting alterations in LULCC by offering invaluable resources for tracking and examining shifts in the Earth's surface across various spatial and temporal extents. Utilizing high-resolution satellite imagery from Landsat and Sentinel missions enables the identification and cartography of diverse land cover categories. These images can be analyzed using various classification techniques, including supervised and unsupervised classification algorithms, to distinguish different land cover classes and detect changes over time (Chaves et al., 2020; Navin & Agilandeeswari, 2020). Also, change detection which involves comparing multi-temporal satellite images to detect and quantify changes in land cover classes stands out as a valuable remote sensing tool to address these alterations (Chughtai et al., 2021; Tewabe & Fentahun, 2020).

This study focuses on the Afi River Forest Reserve (ARFR) located in Cross River State, Nigeria, a region known for its rich biodiversity and significant ecological value. The ARFR, part of the Cross-River Rainforest, is one of the most important conservation areas in Nigeria, harboring a variety of flora and fauna, including endangered species such as the Cross River gorilla. Over the past few decades, the ARFR has experienced considerable land use and land cover changes due to anthropogenic activities, prompting the need for a detailed analysis of these changes and their implications for future conservation efforts. The study aimed to analyze the spatial and temporal changes in land use and land cover in the Afi River Forest Reserve over a 30-year period from 1992 to 2022 using satellite remote sensing in order to provide insights into the drivers and extent of deforestation and land conversion in the forest reserve. Additionally, the study aims to predict future land cover changes for the next 30 years using remote sensing applications.

Understanding the intricate interplay among factors influencing land use and land cover change, along with their impacts on land and natural resources, is crucial for implementing suitable measures in the sustainable management of land resources. This understanding can inform future projections of land use and land cover changes and facilitate the implementation of appropriate policy interventions aimed at achieving effective land use management.

MATERIALS AND METHODS

Study Area

The Afi River Forest Reserve, located in the south-south region of Nigeria, spans Cross River State, directly west of the Cross River National Park's Okwangwo division. The reserve is situated roughly between latitudes 6008' and 6026'N and longitudes 8050' and 9005'E, covering an area of 383.32 square kilometers, including the region known as Afi Mountain (Aigbe & Ekpa, 2015; Bassey et al., 2022). The Afi River Forest Reserve is one of the largest remaining forest blocks in Cross River State, second only to the Cross River National Park. Positioned between the Afi Mountain Wildlife Sanctuary and the Mbe Mountains Community Forest, the reserve serves as a crucial corridor for the Cross-River gorillas inhabiting both areas. The terrain is mountainous and extensively dissected by rivers and streams, creating spectacular scenery. The highest elevation is Afi Mountain, located in the center-north of the reserve. The vegetation predominantly consists of Guinea–Congo lowland rainforest. The region receives an average annual rainfall of 2,000 to 2,500 mm, with the dry season occurring from November to February (BirdLife, 2022). The mean annual temperatures in the area are 22.2°C on Afi Mountain and 27.4°C in the lowland areas. Additionally, the mean annual relative humidity is 78% at 7.00 Hr (Aigbe & Ekpa, 2015). The topography of the study area is highly intricate, featuring numerous interconnected ridge systems, isolated peaks, and outcrops, with elevations ranging from 200 to 1200 meters above sea level. Rapidly flowing, high-gradient streams drain the Afi River Forest Reserve, forming a significant watershed (Aigbe & Ekpa, 2015).

DOI: https://doi.org/10.55706/jae1738

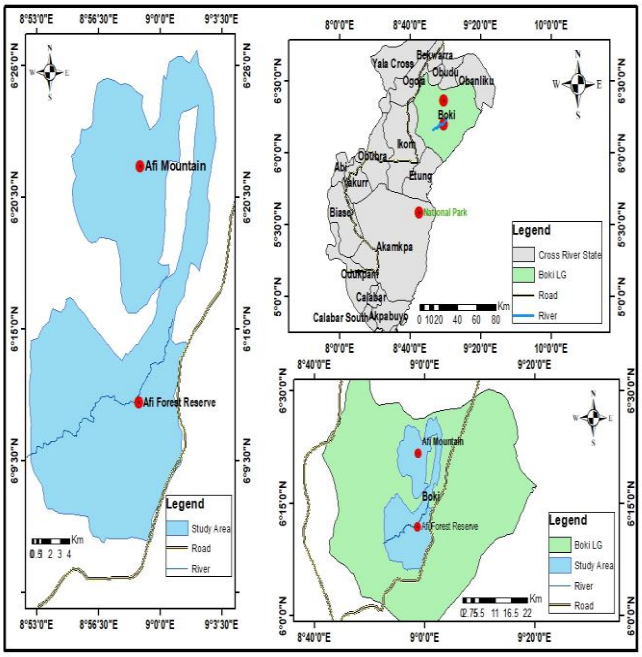

Figure 1: Study Area Map

Data Collection

The study utilized Satellite Landsat Imageries acquired from the United States Geological Survey- Global Visualization Viewer (USGS-GLOVIS) in time series, 1992-Thematic Mapper (Tm), 2002, 2012 and 2022 - Enhanced Thematic Mapper (ETM). The features of the Landsat images used are presented in Table 1.

Table 1: Features of Landsat Images Used

	1992	2002	2012	2022
Scene ID	LT41870561992355XXX02	LE71870562002030EDC00	LE71870562012010ASN00	LE71870562022037SG100
Path	187	187	187	187
Row	056	056	056	056
SpaceCraft ID	Landsat 4	Landsat 7	Landsat 7	Landsat 7
Sensor ID	"TM"	"L7_ETM"	"L7_ETM"	"L7_ETM"
Spatial Resolution	30m	30m	30m	30m
Acquisition Date	1992-12-20	2002-01-30	2012-01-10	2022-02-06
Datum	"WGS84"	"WGS84"	"WGS84"	"WGS84"
UTM	32	32	32	32

Data Analysis

To analyze the spatial and temporal changes in land use and land cover (LULC) in the Afi River Forest Reserve from 1992 to 2022 at 10-year intervals, a series of methodological steps were undertaken. First, appropriate satellite imagery was acquired, ensuring cloud-free images that minimize seasonal and phenological effects, capturing data at ten-year intervals.

Image Processing and Classification

After acquiring the Landsat images, the pre-processing phase was initiated to prepare the data for analysis. This phase involved several critical steps to ensure the images were suitable for accurate classification and change detection. The first step was to perform a false color composite through band stacking, which involves combining multiple spectral bands to enhance the visibility of different land cover types. Image enhancement techniques were then applied to improve the clarity and contrast of the images, making it easier to distinguish between various land cover classes. Additionally, image mosaicking was conducted to merge images from the same year that covered different parts of the study area, creating a seamless and comprehensive view of the Afi River Forest Reserve. These steps ensured geometric compatibility and enhanced the visual interpretability of the images for subsequent analysis. Following pre-processing, supervised classification using the Maximum Likelihood Classifier (MLC) was performed on the false color composite images. The MLC algorithm is widely used for its effectiveness in categorizing pixels based on their spectral signatures. This process resulted in the creation of a base map that delineated different thematic classes within the study area. To ensure the accuracy of the classification, ground truthing was conducted. This involved validating the classified data against actual ground conditions using a confusion matrix, which compares the classified data with reference data to determine the accuracy of the classification.

Accuracy Assessment of Image Classification

The final image classification accuracy was assessed using the Kappa coefficient (Khat), a statistical measure that evaluates the agreement between the classified map and reference data, taking into account all elements of the error matrix. This step was crucial in ensuring that the classification was reliable and could be used for further analysis.

Post-classification comparison was employed to quantify LULC changes over the 30-year period from 1992 to 2022. This method involves comparing classified maps from different years to identify changes in land cover. Standard preprocessing techniques, such as spatial, spectral, and radiometric enhancements, were applied to the Landsat images to improve the quality of the data. Unsupervised classification was also used to determine the spectral signatures of various land cover classes, providing an additional layer of data for analysis.

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Prediction of Future Land Use Change

The Cellular Automata (CA) and Markov Chain algorithm (CA–Markov) were employed to predict and simulate future LULC changes in the Reserve. This predictive modeling approach combines historical LULC data with transition probabilities to forecast future land cover scenarios. By analyzing past trends and incorporating them into the CA–Markov model, the study provides insights into potential future changes, helping to inform conservation and land management strategies for the next 30 years.

RESULTS

The land use and land cover (LULC) maps for the years 1992, 2002, 2012, and 2022 are presented in Figures 2, 3, 4, and 5, respectively. These maps identify six distinct land use types: dense vegetation, farmlands, water bodies, rocky terrain, built-up areas, and bare land. The color scheme used in the maps includes dark green for forest vegetation, light green for farmland or sparse vegetation, dark brown for rock, blue for water bodies, and orange for built-up areas.

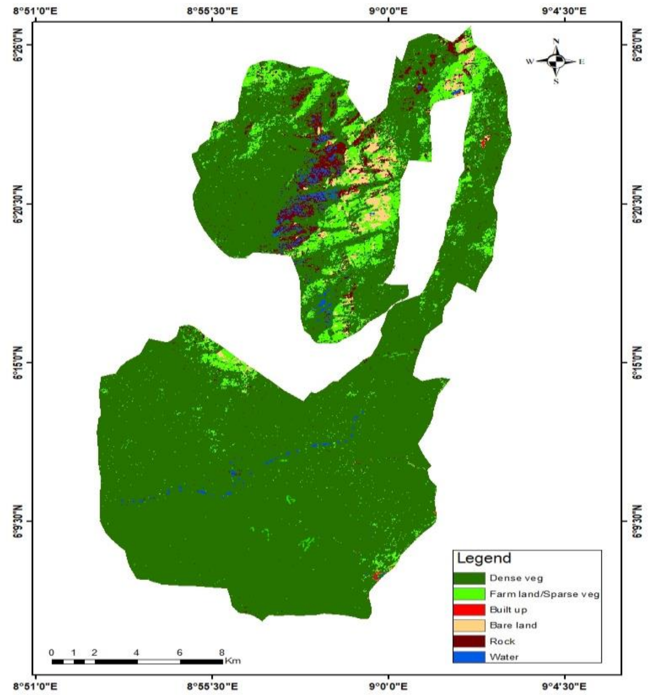

Figure 2: 1992 Land use & Land cover of Afi River Forest Reserve

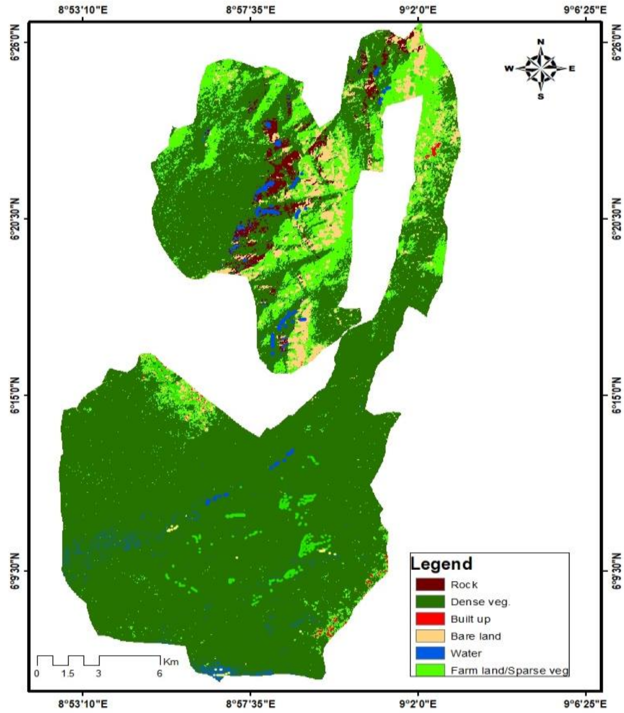

Figure 3: 2002 Land use & Land cover of Afi River Forest Reserve

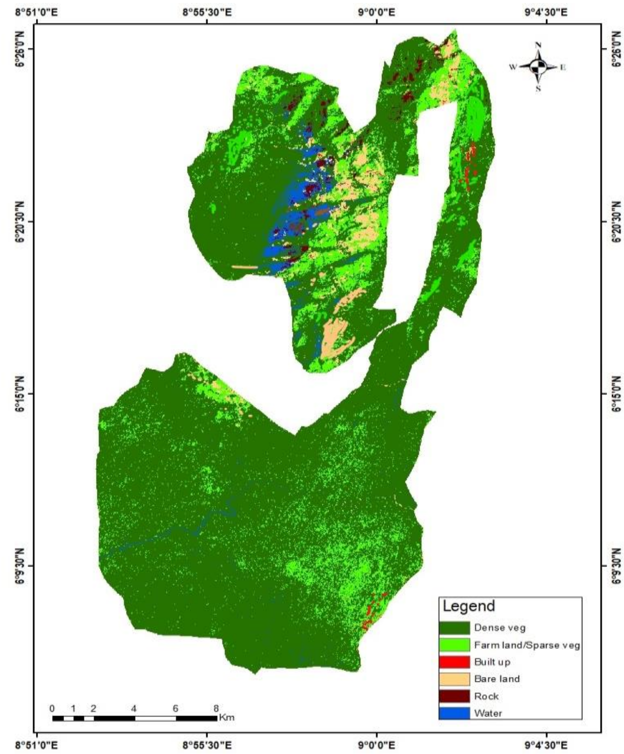

Figure 4: 2012 Land use & Land cover of Afi River Forest Reserve

DOI: https://doi.org/10.55706/jae1738

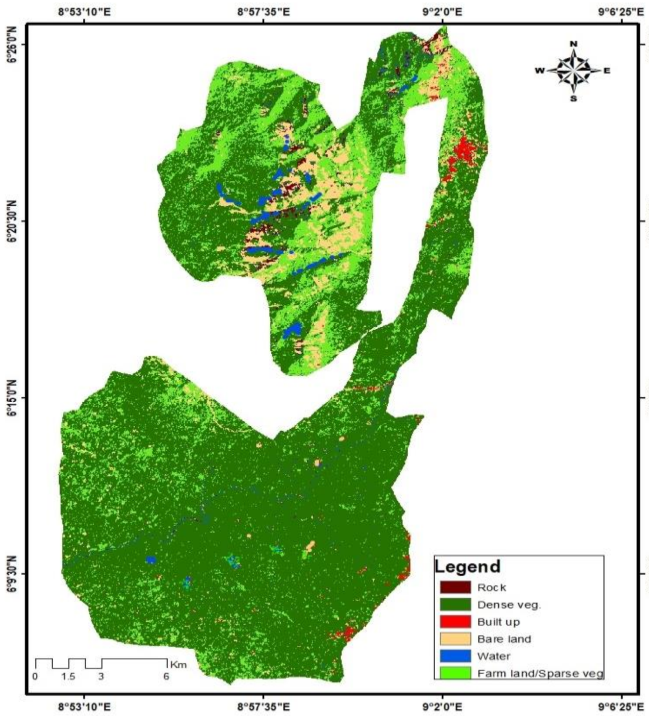

Figure 5: 2022 Land use & Land cover of Afi River Forest Reserve

The spatial distribution of these land use/cover types for the period between 1992 and 2022 is shown in Table 2, while Table 10 projects the LULC distribution for 2052. The accuracy of the LULC classifications is shown in Tables 3 to 6. The overall accuracies for the years 1992, 2002, 2012, and 2022 were 0.92, 0.90, 0.94, and 0.96, respectively. Correspondingly, the Kappa coefficient values were 90%, 87%, 92%, and 95% for the years, respectively, indicating a high level of agreement and demonstrating the reliable performance of the LULC classifications.
The study delineated various land use types, including dense vegetation (forested regions), sparse vegetation (farmlands), water bodies, rocky terrain, built-up areas (residential and other structures), and bare land. Throughout the study period, dense vegetation consistently had the highest coverage in the reserve, although it showed a continuous decline over the years as shown in Figure 6.

In 1992, dense vegetation covered 312.14 km², farmland 48.01 km², water bodies 5.22 km², rocky terrain 5.62 km², built-up areas 4.20 km², and bare land 8.12 km², with a total land area of approximately 383.32 km². By 2002, dense vegetation had decreased to 301.02 km², farmland increased to 54.08 km², water bodies slightly increased to 5.43 km², rocky terrain decreased to 5.00 km², built-up areas increased to 4.78 km², and bare land expanded to 12.29 km², indicating a conversion of natural vegetation to other land uses.

Specifically, between 1992 and 2002, the area covered by dense vegetation reduced by approximately 2.9%, rocky terrain also saw a minor reduction of 0.16%, farmland, water bodies, built-up areas, and bare land expanded, with increases of 1.77%, 0.06%, 1.15%, and 1.09% respectively, as shown in Table 7.

From 2002 to 2012, dense vegetation and rocky terrain continued to decline, as did bare land, although to a lesser extent. Meanwhile, farmland, water bodies, and built-up areas continued to increase, as shown in Table 8. By 2012, dense vegetation further decreased to 293.30 km², farmland expanded to 62.31 km², water bodies increased to 5.74 km², rocky terrain slightly decreased to 4.92 km², built-up areas rose to 5.02 km², and bare land was at 12.02 km². Finally, from 2012 to 2022, a more pronounced reduction in dense vegetation to 271.28 km² and a significant increase in farmland to 75.34 km² was observed. During this period, water bodies decreased to 5.10 km², rocky terrain slightly declined to 4.88 km², built-up areas increased to 6.17 km², and bare land expanded considerably to 20.54 km². This period marked a continuation of the trends observed earlier, with substantial expansions in farmland, built-up areas, and bare land, alongside further reductions in dense vegetation, water bodies, and rocky terrain, as highlighted in Table 9.

The prediction of land use change by the year 2052, as illustrated in Figure 7, indicates a further significant decline in dense vegetation within the reserve. Between 2022 and 2052, dense vegetation is projected to decrease drastically from 271.28 km² to 220.32 km². Concurrently, there will be substantial changes in other land cover types. Farmland is expected to increase from 75.34 km² to 115.68 km², rocky terrain is predicted to decrease from 4.88 km² to 4.08 km², built-up areas are anticipated to grow significantly from 6.17 km² to 10.82 km², and bare land is projected to expand from 20.54 km² to 25.81 km², indicating further land degradation and deforestation.

These findings highlight the ongoing conversion of dense forest to farmland and other land uses, emphasizing the need for effective land management and conservation strategies to mitigate further loss of forest cover in the Afi River Forest Reserve.

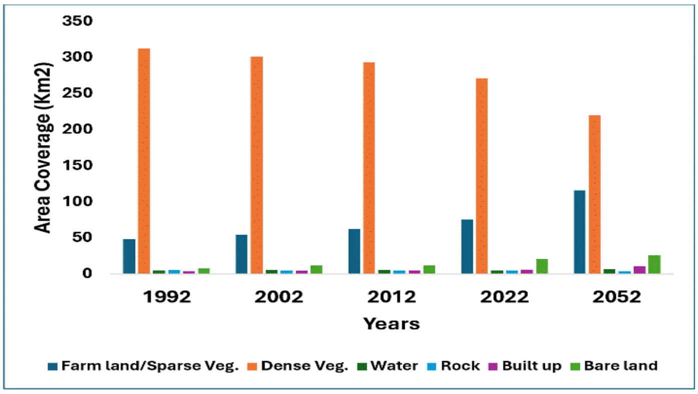

Figure 6: Average Coverage of Individual LULC Class

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Table 2: Land Use & Land Cover Classification from 1992-2022

	1992		2002		2012		2022	
LULC Type	**Area(km^2)**	**%**		**%**		**%**		**%**
Farmland/Sparse Veg.	48.01	12.53	54.80	14.30	62.31	16.26	75.34	19.66
Dense Veg.	312.14	81.43	301.02	78.53	293.30	76.52	271.28	70.77
Water	5.22	1.36	5.43	1.42	5.74	1.50	5.10	1.33
Rock	5.62	1.47	5.00	1.30	4.92	1.28	4.88	1.27
Built up	4.20	1.10	4.78	1.25	5.02	1.31	6.17	1.61
Bare land	8.12	2.12	12.29	3.21	12.02	3.14	20.54	5.36
Total Land Area	**383.32**	**100**	**383.32**	**100**	**383.32**	**100**	**383.32**	**100**

Table 3: Accuracy of 1992 LULC Classification

LU/LC Type	**Dense Veg**	**Farm/Sparse Veg**	**Water**	**Built up**	**Bare land**	**Rock**	**Ground Points**	**Comm. Error**	**User's accuracy**
Dense Veg	48	0	1	0	4	0	53	0.09	0.917
Farm/Sparse Veg	0	48	2	2	0	0	52	0.08	0.9223
Water	1	0	47	0	1	0	49	0.04	0.9673
Built up	0	0	0	49	1	1	51	0.02	0.9857
Bare land	4	1	0	0	51	1	57	0.09	0.9102
Rock	0	0	2	0	1	49	52		
Total	**53**	**49**	**52**	**51**	**58**	**51**	**263**		
Omission Error	0.09	0.02	0.06	0.04	0.10	0.02			
Producer's Accuracy	0.91	0.98	0.94	0.96	0.90	0.98			
Overall Accuracy	**0.92**								
P(r)	**0.20**								
Kappa Coefficient	**0.90**								
Kappa (%)	**90**								

Table 4: Accuracy of 2002 LULC Classification

LU/LC Type	**Dense Veg**	**Farm/Sparse Veg**	**Water**	**Built up**	**Bare land**	**Rock**	**Ground Points**	**Comm. Error**	**User's Accuracy**
Dense Veg	44	0	2	0	2	0	48	0.08	0.92
Farm/Sparse Veg	2	49	0	0	0	0	51	0.04	0.96
Water	1	1	46	1	2	1	52	0.10	0.90
Built up	1	2	0	51	0	0	54	0.06	0.94
Bare land	1	0	6	3	47	0	57	0.18	0.82
Rock	1	0	1	0	1	52	55		
Total	50	52	55	55	52	53	264		
Omission Error	0.1	0.06	0.15	0.07	0.08	0.02			
Producer's Accuracy	0.9	0.94	0.85	0.93	0.92	0.98			
Overall Accuracy	**0.90**								
P(r)	**0.20**								
Kappa Coefficient	**0.87**								
Kappa (%)	**87**								

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Table 5: Accuracy of 2012 LULC Classification

LU/LC Type	Dense Veg	Farm/Sparse Veg	Built up	Water	Bare land	Rock	Ground Points	Commision Error	User's Accuracy
Dense Veg	49	1	1	0	1	0	52	0.06	0.94
Farm/Sparse Veg	3	51	0	2	0	1	57	0.09	0.91
Built up	0	0	47	0	2	1	50	0.04	0.96
Water	0	0	1	45	0	0	46	0.02	0.98
Bare land	0	0	0	0	50	0	50	0.00	1.00
Rock	0	1	0	4	0	47	52		
Total	52	53	49	51	53	49	258		
Omission Error	0.06	0.02	0.04	0.04	0.06	0.04			
producer's Accuracy	0.94	0.98	0.96	0.96	0.94	0.96			
Overall Accuracy	**0.94**								
p(r)	**0.20**								
Kappa Coefficient	**0.92**								
Kappa (%)	**92**								

Table 6: Accuracy of 2022 LULC Classification

LU/LC Type	Dense Veg	Farm/Sparse Veg	Built up	Water	Bare land	Rock	Ground Points	Commision Error	User's Accuracy
Dense Veg.	47	0	0	1	2	0	50	0.06	0.94
Farm/Sparse Veg	0	49	0	0	0	0	49	0.00	1.00
Built up	1	0	49	0	0	2	52	0.02	0.98
Water	0	0	0	49	0	0	49	0.00	1.00
Bare land	2	1	1	0	48	1	53	0.08	0.92
Rock	0	0	1	0	2	49	52		
Total	**50**	**50**	**51**	**50**	**52**	**52**	**253**		
Omission Error	0.06	0.02	0.02	0.02	0.04	0.04			
producer's accuracy	0.94	0.98	0.98	0.98	0.96	0.96			
Overall Accuracy	**0.96**								
p(r)	**0.20**								
Kappa Coefficient	**0.95**								
Kappa (%)	**95**								

Table 7: LULC Change Detection from 1992-2002

LULC Type	1992 (km^2)	2002 (km^2)	Observed change (km^2)	% change	Remark
Farmland/Sparse Veg.	48.01	54.80	6.79	1.77	Gain
Dense Veg.	312.14	301.02	-11.12	-2.90	Loss
Water	5.22	5.43	0.21	0.05	Gain
Rock	5.62	5.00	-0.62	-0.16	Loss
Built up	4.20	4.78	0.58	0.15	Gain

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Bare land	8.12	12.29	4.17	1.08	Gain
Total Land Area	**383.32**	**383.32**		**100**	

Table 8: LULC Change Detection from 2002-2012

LULC Type	2002(km^2)	2012(km^2)	Observed change (km^2)	% change	Remark
Farmland/Sparse Veg.	54.80	62.31	7.51	1.96	Gain
Dense Veg.	301.02	293.30	-7.72	-2.01	Loss
Water	5.43	5.74	0.31	0.08	Gain
Rock	5.00	4.92	-0.08	-0.02	Loss
Built up	4.78	5.02	0.24	0.06	Gain
Bare land	12.29	12.02	-0.27	-0.07	Loss
Total Land Area	**383.32**	**383.32**		**100**	

Table 9: LULC Change Detection from 2012-2022

LULC Type	2012(km^2)	2022(km^2)	Observed change (km^2)	% change	Remark
Farmland/Sparse Veg.	62.31	75.34	13.03	3.40	Gain
Dense Veg.	293.30	271.28	-22.02	-5.74	Loss
Water	5.74	5.10	-0.64	-0.17	Loss
Rock	4.92	4.88	-0.04	-0.01	Loss
Built up	5.02	6.17	1.15	0.30	Gain
Bare land	12.02	20.54	8.52	2.22	Gain
Total Land Area	**383.32**	**383.32**		**100**	

Table 10: Projected Area Covered by Each Land Cover Type (2052)

	2052	
LULC Type	**Area(km^2)**	**%**
Farmland/Sparse Veg.	115.68	30.18
Dense Veg.	220.32	57.48
Water	6.61	1.72
Rock	4.08	1.06
Built up	10.82	2.82
Bare land	25.81	6.73
Total Land Area	**383.32**	**100**

DOI: https://doi.org/10.55706/jae1738

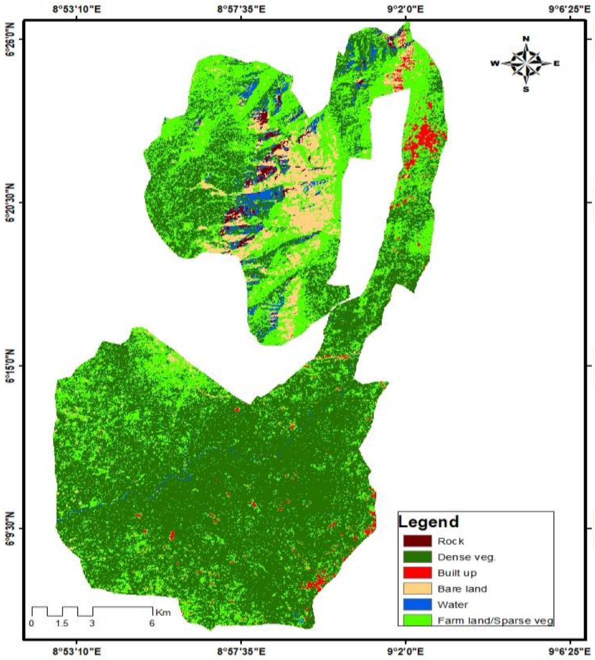

Figure 7: 2052 Predicted Land use & Land cover of Afi River Forest Reserve

DISCUSSION

The study reveals a remarkable change in the LULC of the reserve within the thirty-year period covered by the study. The expansion of farmlands, built-up areas, and bare land can be largely attributed to extensive deforestation, particularly the clearing of forests for crop cultivation and fuelwood extraction. Previous studies by Edet et al. (2016) and Krause et al. (2019) have identified constant logging, agricultural expansion, and poaching as major threats to the Afi River Forest Reserve. These activities are driven by the increasing demands of local communities surrounding the forest reserve, facilitating the expansion of the introduced land use and land cover types.

The findings of this study corroborate numerous research reports that have consistently documented the ongoing decline in forest cover across various forest reserves due to conversion to alternative land uses (Aderele et al., 2020; Appiah et al., 2021; Biaou et al., 2021; Egbuche et al., 2022). The ongoing conversion of dense forest to other land uses indicates significant anthropogenic pressure on the reserve. The decline in dense vegetation, in particular, poses a threat to the biodiversity and ecological balance of the area; as forests play a crucial role in carbon sequestration, climate regulation, and habitat provision for various species (Bakure et al., 2022; Chakravarty et al., 2019). Therefore, the reduction in forested areas could have far-reaching environmental impacts.

The projected land use changes by 2052 suggest a substantial further decline in dense vegetation within the Afi River Forest Reserve, driven by ongoing deforestation. Farmland is anticipated to expand, indicating the continued growth of agricultural activities in the area. Meanwhile, water bodies are expected to see a modest increase, potentially due to both natural hydrological changes and the effects of climate change, such as increased flooding. More intense rainfall, and rising sea levels, are also likely to contribute to the modest increase in water bodies over the next thirty years. As global temperatures rise, the frequency and severity of extreme weather events, including storms and heavy rainfall, are expected to increase, leading to more frequent and widespread flooding (Clarke et al., 2022). Flooding can create new water bodies in low-lying areas and expand existing ones. Additionally, rising sea levels may result in the inundation of coastal areas, leading to the formation of new lakes, wetlands, and other aquatic environments.

These projected changes emphasize the urgent need for effective land management and conservation strategies. The dramatic reduction in dense vegetation underscores the continuing pressure from agricultural expansion, urbanization, and potentially unsustainable land use practices. The increase in farmland and built-up areas, while reflecting socio-economic development, poses significant risks to the ecological health of the forest reserve.

CONCLUSION

This study has provided a comprehensive analysis of land use and land cover (LULC) change in the Afi River Forest Reserve in Cross River State, Nigeria, over a 30-year period from 1992 to 2022. Utilizing satellite imagery and advanced remote sensing techniques, significant trends and patterns in land cover changes were identified. The study revealed a gradual though continuous decline in dense vegetation, which is critical for maintaining the ecological balance of the reserve. During the study period (1992-2022), all the categories of land use and land cover experienced spatiotemporal changes at different rates. This decrease has been accompanied by an increase in farmland, bare land, and a slight increase in built-up areas, driven by agricultural expansion, population growth and other anthropogenic activities. Further reductions in dense vegetation by 2052, alongside increases in farmland, water bodies, built-up areas, and bare land, are most probable. These projections indicate ongoing pressures on the forest reserve, posing severe risks to its biodiversity, climate regulation functions, and overall ecological integrity.

To address the challenges facing the Afi River Forest Reserve, it is essential to implement effective conservation strategies and promote sustainable agricultural practices like agroforestry and organic farming. Strengthening land use policies through comprehensive planning and strict enforcement, engaging local communities through education, awareness, and economic incentives, is necessary. Additionally, fostering collaboration among government

DOI: https://doi.org/10.55706/jae1738

agencies, NGOs, academic institutions, and local communities can enhance conservation efforts and ensure the long-term sustainability of the Afi River Forest Reserve, and the preservation of its ecological integrity for future generations.

Conflict of Interest

There are no conflicts of interest declared by the authors.

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