

Monitoring of Pandam National Park, Nigeria

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Abstract: The high demand for certain wood species in China and other regions, including Nigeria, has exerted pressure on protected areas worldwide. Pandam National Park is among the forests affected by this demand, driven by illegal loggers operating locally in collusion with foreign wood merchants. This study assessed the status of vegetation cover in the protected area before the peak of devastation, at the peak, and after it. The objective is to quantify the spatial and temporal changes in forest cover using remote sensing and GIS techniques. The Google Earth Engine (GEE) cloud-based platform was used to analyze Sentinel-2 images from 2019, 2021, and 2023, focusing on land-cover changes during those periods. The results indicated that the Normalized Difference Vegetation Index (NDVI) was higher in 2019 (0.7436) than in 2021 (0.73), with a subsequent improvement in 2023 (0.80), based on the maximum and minimum NDVI values. The cumulative forest cover change to the 2019-2021 period indicated that 208.55 sq km of forest was changed to bare surface, more than the same change in 2021-2023, which had 195.62 sq km, a reduction in forest cover destruction of 12.93 sq km. The Federal Government of Nigeria (FGN) needs to strengthen the enforcement of forest protection laws and invest in regular monitoring using advanced geospatial technologies. Integrating communities in forest surveillance alongside forest guards and adopting sustainable resource-use practices can help prevent further forest degradation. The government should reafforest the park and make it a hub for tourism, rather than just upgrading it to a National Park.

Keywords: *Illegal Logging, Forest Cover Change, Protected Areas, Sentinel-2, Google Earth Engine (GEE).*

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I. INTRODUCTION

During the past three (3) centuries, forest resources have been severely impacted and 1.5 billion hectares of forest have been lost globally. Approximately half of Germany, or 19 million hectares, was cleared every ten years between 1700 and 1850. An area nearly the size of India was cleared of trees throughout the 1990s and the first ten years of the 2000s. This still amounted to an area about twice the size of Spain, despite the "improved" rates in the 2010s. Ten million hectares of forest are lost to deforestation worldwide each year, with the tropics accounting for 95% of this loss¹.

Selective logging has affected about 400 million ha in the tropics and 1 billion ha worldwide². Africa's tropical forests have become major hotspots for illegal logging due to their dense vegetation and high international demand for timber. This exploitation is largely driven by the Chinese market, which relies on small-scale loggers to supply high-value rosewood. China's extensive rosewood industry, supported by state-backed financing and estimated to

comprise 3,000 rosewood factories across 25 regions, is valued at USA75 million and has intensified illegal extraction, making rosewood the most heavily smuggled wildlife product globally^{3,4}.

Logging is degrading tropical forests at rates higher than deforestation, driving extensive rosewood exploitation in Nigeria's Sudan and Guinea Savannah regions. Unsustainable legal and illegal logging, alongside unregulated resource extraction, have depleted protected forests, while market-driven selective logging often leads to broader forest clearing and damage to younger trees^{5,6,7,8}.

The area under Protected Areas (PAs) has grown significantly since the 1990s, as a result of international commitments, such as the Convention on Biological Diversity, which aimed to designate 17% of land areas by 2020. There were over 230,000 protected areas on land by 2018, covering 14.9% of terrestrial and inland water areas. However, these areas still cover a relatively small portion of the world's tree cover^{9,10}.

Global environmental governance policies consistently refer to the key role of protected areas in biodiversity conservation and sustainable development. Policies like the Convention on Biological Diversity and the 2030 Agenda for Sustainable Development, especially Sustainable Development Goals (SDGs) 14 and 15, recognize protected areas as key instruments for ecosystem conservation. Yet, despite these developments in protected area policy, many protected areas are experiencing environmental degradation. The loss of biodiversity is a growing problem as time moves towards 2030. Research from the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services' (2019) global assessment shows the SDGs cannot be met without significant and transformative actions to stop the loss of biodiversity¹¹.

➤ *Review of Empirical Studies*

Studies in tropical Nigeria highlight the threats to forest regions posed by illegal timber exploitation. According to¹², the unlawful export of timber, often aided by tax and royalty relief, increases personal income for syndicates at the expense of national development, emphasizing the need for stricter laws and regulations.

In Southeast Nigeria, higher logging intensities correlate with greater damage to unlogged trees, reducing their population and increasing stand destruction, demonstrating that logging intensity is a key factor in collateral forest damage¹³.

In southwestern Nigeria, studies of timber harvesting show significant levels of harvesting in protected and unprotected forest areas. Research has shown that 60 tree species were extracted in unprotected landscapes, and 57 species in forest reserves. Overall, the logging activities removed 111,377 tree stems, and the estimated volume of wood products produced was 295,089.67 m³. In particular, Osun State's forest reserves like Shasha, Ago-Owu and Ikeji-Ipetu have faced considerable logging threats. The occurrence of illegal logging and timber processing activities in these reserves pose a threat to the conservation and management of forests¹⁴.

Remote sensing forest monitoring has been found to be useful for vegetation monitoring. The Normalized Difference Vegetation Index (NDVI) and the Green Normalized Difference Vegetation Index (GNDVI) have been found to be reliable indices for assessing and monitoring forest change. These indices have strong statistical relationships with vegetation and have demonstrated high accuracy in validation studies, and are invaluable tools for monitoring and informing environmental management and policy¹⁵. Similarly, at Pandam National Park in Nigeria, African Rosewood (*Pterocarpus erinaceus*) and other valuable tree species were heavily logged, highlighting the selective pressure on economically important trees¹⁶. Socio-economic assessments around Pandam National Park further revealed that wood businessmen account for 73% of tree cutting. In comparison, 93% of respondents attributed timber extraction to perceived

government approval, highlighting the strong human and policy drivers of forest degradation¹⁷.

Monitoring forest change using widely available remote sensing data has become essential for understanding forest degradation and associated environmental risks. Accurate and reliable information is critical for this process, and geospatial technologies provide effective tools for forest assessment. In this regard, Google Earth Engine offers a robust platform for efficient monitoring of forests and protected areas¹⁸.

This study aims to assess the extent of illegal logging and to inform improved policy enforcement and resource management.

➤ *Problem Statement*

Logging activities in the Pandam National Park have led to forest cover loss and degradation, unauthorized deforestation, and illegal logging. As a result, truly undisturbed forest ecosystems are gradually disappearing, and young plants have been destroyed through indiscriminate felling of trees, thereby exposing a large expanse of bare surface in the study area^{19' 20'21'22'23'24'25}.

II. MATERIALS AND METHODS

➤ *The Study Area*

Pandam National Park falls under Qua'anpan Local Government Area of Plateau State, Nigeria. It is located between latitude 8°35' N and 8°55' N and longitude 8°00' E and 10°00' E and covers an area of about 224 square kilometers. It is located to the east of Namu (Jepjan) and Kayarda towns, to the west and north of the Do;op River. Aningo and Pandam towns are to the south (Figure 1). The park is a valuable conservation zone due to its location and ecology. Originally owned and managed by the Plateau State Government through the Plateau State Tourism Corporation, it was formally converted to a National Park when Governor Caleb Mutfwang handed it over to the Federal Government, placing it under the Nigeria National Park Service^{26,27,24}. The upgrade to a National Park was initiated by former Governor Simon Bako Lalong in 2021, but the park's formal handover was officially completed by his successor, Governor Caleb Mutfwang, on September 16, 2025.

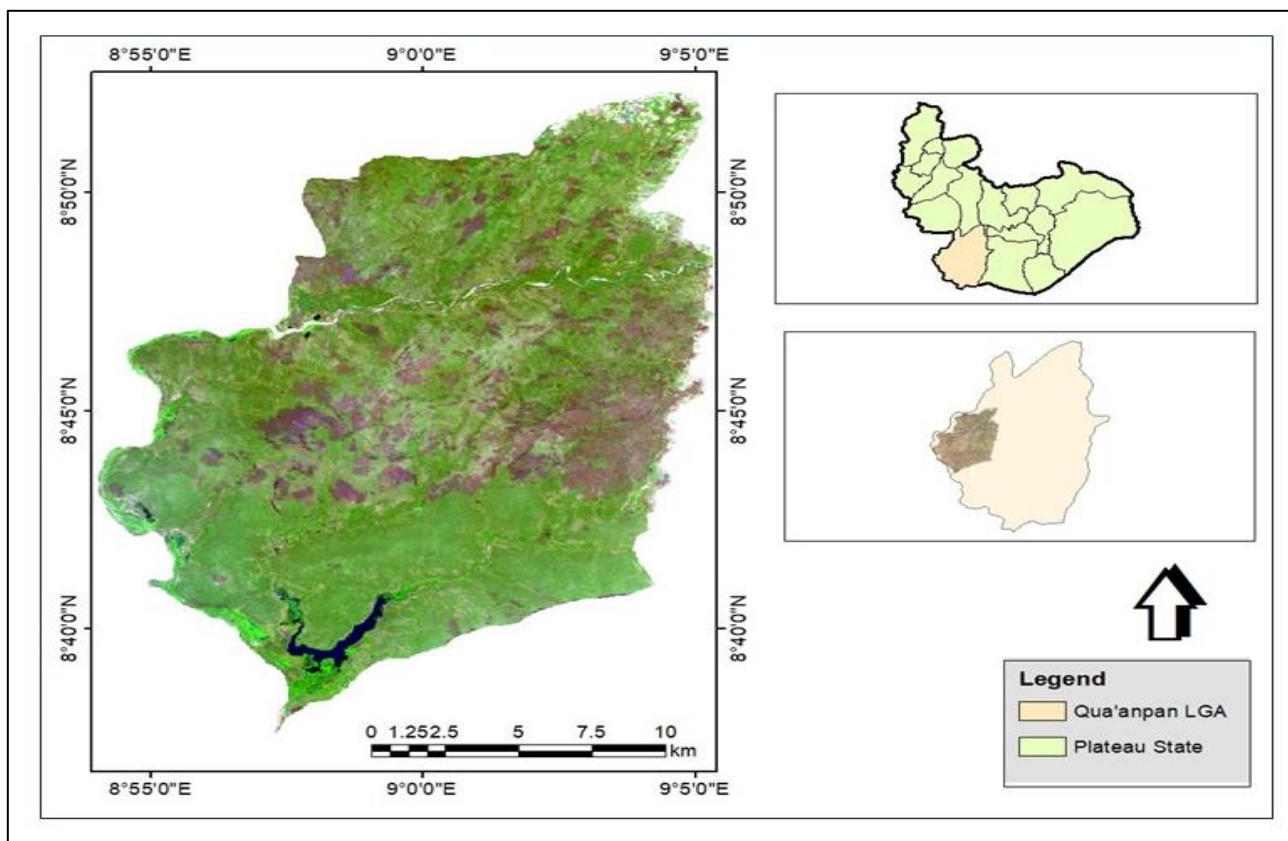


Fig 1 Plateau State Showing the Study Area

Pandam National Park was gazetted in 1972 and officially began operations on October 25, 1975, under Joseph Gomwalk, the then Military Governor of Benue–Plateau State. Parts of the game reserve were later converted into a park to protect its savanna wetlands and forests. Due to persistent conservation and security challenges, the Federal Government of Nigeria designated it as one of 10 new National Parks in 2020 to conserve biodiversity and reduce criminality in protected areas.

During the transition between the handover of the reserve and its full takeover by the Nigerian National Park Service, the area experienced widespread illegal logging and effectively became a no-man’s forest. Local resistance to the destruction was deflected to the Federal Government, while the reserve turned into a hotspot for illegal fishing, grazing, hunting, armed robbery, and kidnapping, resulting in damages to biodiversity and serious environmental consequences^{28,29}.

• *Climate*

The region's climate is marked by a wet and a dry season. The months of April to November are generally considered the wet season and the period December to March the dry season. Rainfall is highly variable, ranging from 0.0 mm during the dry season to 243.5 mm during the wet season, with an annual rainfall of 1,000 mm - 1,500 mm. The region has a fairly high temperature regime, with an annual average temperature around 32 °C. The monthly average temperature varies from 25.8 °C (August) to 35.7 °C (March)^{26, 27, 30, 31}.

• *Relief and Drainage*

Pandam National Park ranges in altitude from 175 to 315 m above sea level, sloping gradually southwards to form a basin that includes Pandam Lake, a 2 km² wetland complex. The Park is well drained, with the southern part fed by the Kurmi, Zurzurfa, and Dogon Ruwa streams flowing into Pandam Lake, while the northern and western areas are drained by the Do’op and Li rivers and their tributaries^{26,27}.

• *Vegetation*

Pandam National Park covers approximately 224 sq km of pristine savanna, wetlands, and forest, though it has been affected by various anthropogenic activities^{26,30,31}.

➤ *Datasets*

• *Remote Sensing Data*

Sentinel-2 images from 2019, 2021, and 2023 were used for supervised classification at biennial intervals to assess land-cover changes in Pandam National Park. The years were selected to represent pre-peak timber exploitation (2019), peak timber exploitation (2021), and post-peak timber exploitation (2023). The targeted year 2019 marks when logging was progressively mild, but 2021 represents the most disastrous year within the window period of handover of the Park to the FGN, while 2023 marked when the Park was abandoned because the targeted trees were exhausted. Images were obtained via Google Earth Engine (GEE), which facilitated cloud-based processing and

avoided challenges with data storage, network issues, and satellite downloads.

- *Secondary Data*

Administrative spatial data for Nigeria and Plateau State were obtained from GRID.3 to delineate the study area, with boundaries clearly defined using Google Satellite Hybrid imagery. The dataset, projected to WGS 1984, Zone 32N, was essential for accurate statistics following land-cover classification in the research area.

- *Validation*

Classified maps of land cover were compared with high-resolution imagery in Google Earth Pro. This was necessary as a cheaper means of complementing ground truthing due to the insecurity in the park. The features validated were those classified among which are water bodies, vegetation, and bare surfaces. This was done to see if classified features matched visible reality.

III. DATA ANALYSIS

- *Image Preprocessing*

Satellite images for 2019, 2021, and 2023 were selected with less than 10% cloud cover, mostly during the dry season, to ensure clear visibility of forest features and relevant variables for analysis before preprocessing. The GEE was used to query and filter the Landsat images for the research region using `ee.ImageCollection()`, with a 10% cloud cover threshold and a date range specified. The NDVI images ($NDVI = (NIR - Red) / (NIR + Red)$) were derived by using the `normalizedDifference()` function on the NIR and Red bands of the images.

The Google Earth Pro high-resolution imagery was used to check the landcover classes in Pandam National Park, to ensure spatial and temporal match with the Sentinel-2 data. The verified reference data were split into training and testing data sets used to train the Random Forest classifier in GEE, to enhance and verify the results of forest cover change.

- *Land Cover Classification in Google Earth Engine*

Land cover classification was mainly carried out using the GEE. It was used to classify specific land cover classes, such as vegetation, water and bare land. The mean pixel values were calculated for each year to create mean composite images for each period to enable consistent temporal comparisons of land cover changes.

- *Random Forest Classification Algorithm*

Random Forest classification was used due to its high performance across diverse datasets, robustness to noise, and superior classification accuracy compared to other algorithms. Classification was done using training data and spectral indices (including NDVI) as input features. The Random Forest algorithm (`ee.Classifier.randomForest()`) was used to classify the land cover in the image collection.

- *Change Detection*

The study conducted change detection analysis on Pandam National Park by classifying Sentinel images from 2019, 2021, and 2023 and vectorizing the thematic maps. The vectors were intersected to identify transitions between feature classes over time, and the changes were visualized using bar graphs in MS Excel. The analysis revealed sizable forest cover change and highlighted the environmental impacts associated with land-use changes.

IV. RESULTS

- *Forest Cover Sensitivity Using Spectral Index*

The Normalized Difference Vegetation Index (NDVI) analysis for 2019, 2021, and 2023 shows variations in vegetation health and density over time, which were used to assess forest cover change. NDVI values range from +1 to -1, where values closer to +1 indicate dense, healthy vegetation, and values closer to -1 represent areas with little or no vegetation (such as bare land, degraded forest, and water bodies). By comparing the NDVI maps across the three years, areas showing a consistent reduction in NDVI values can be interpreted as zones experiencing progressive deforestation or forest disturbance, whereas stable or increasing NDVI values suggest vegetation recovery or regeneration.

The NDVI results show notable temporal changes in forest condition between 2019 and 2023. In 2019 (Fig. 2), the dominant high NDVI value (0.7436) indicates extensive healthy vegetation before major disturbance. By 2021 (Fig. 3), generally lower NDVI values across the forest reflect widespread vegetation loss and forest devastation, marking the peak period of degradation. In 2023 (Fig. 4), the increase in the highest NDVI value to 0.80 indicates partial vegetation recovery, particularly at lower levels. Overall, the results suggest a transition from healthy forest cover to degradation, with 2021 representing the height of vegetation loss, followed by signs of gradual recovery after the takeover by the National Park Service.

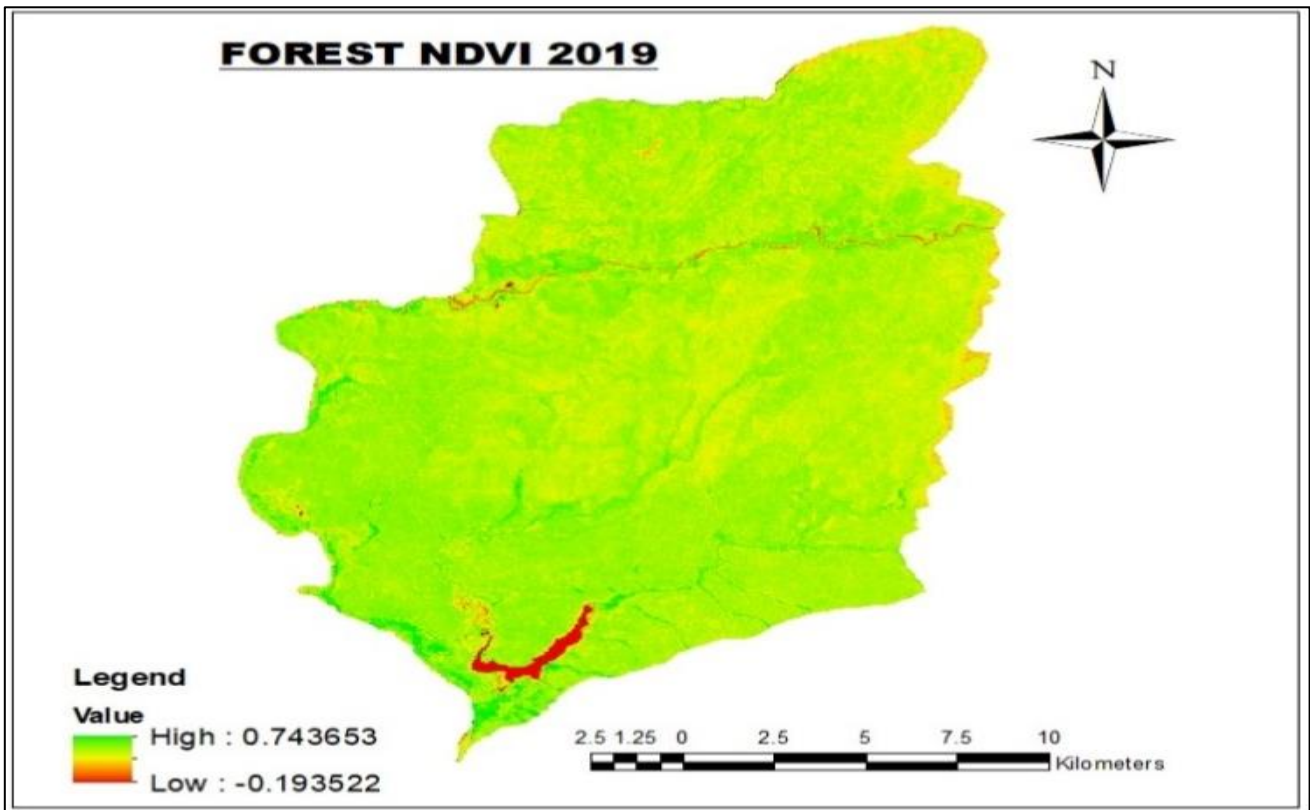


Fig 2 NDVI 2019

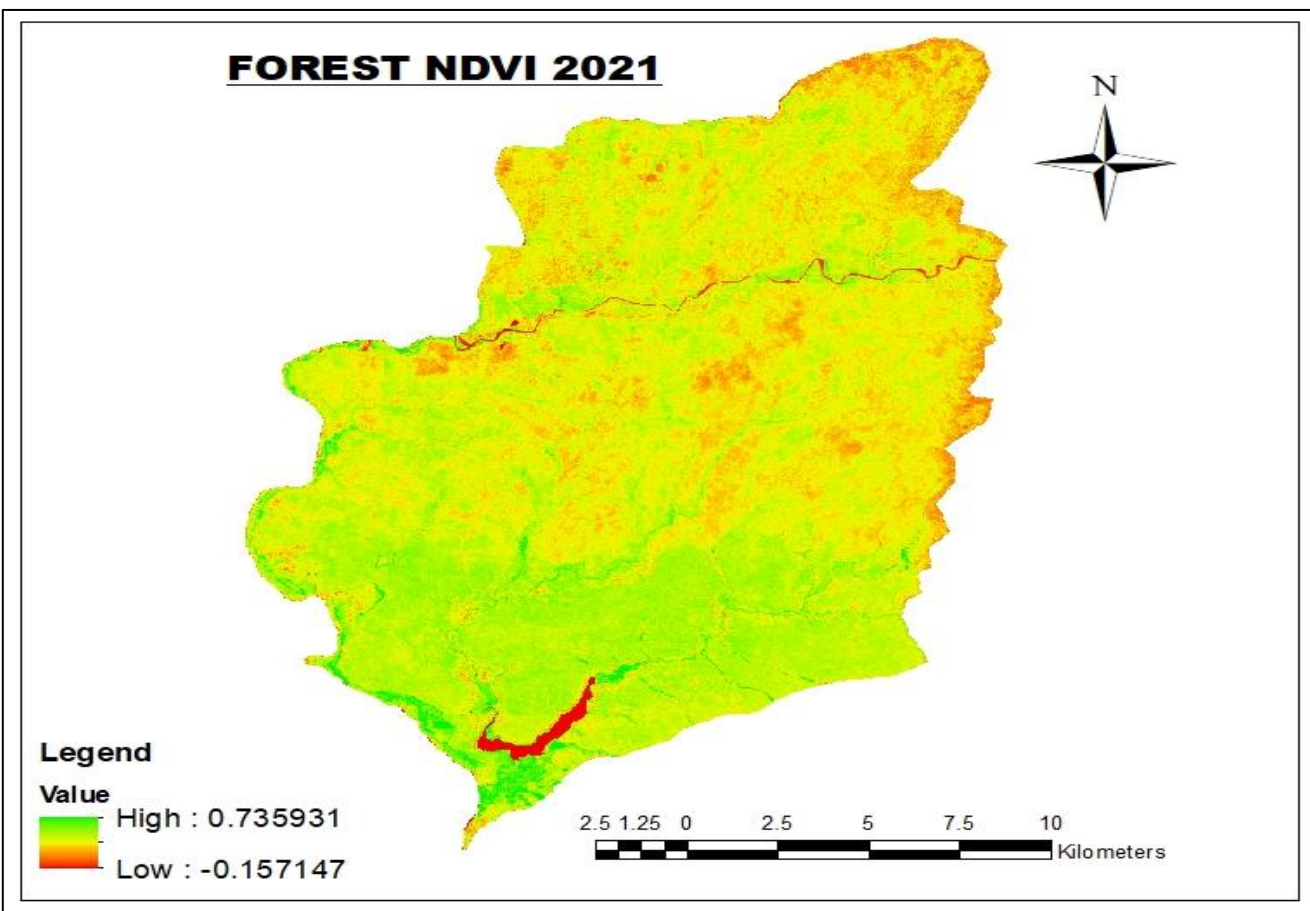


Fig 3 NDVI 2021

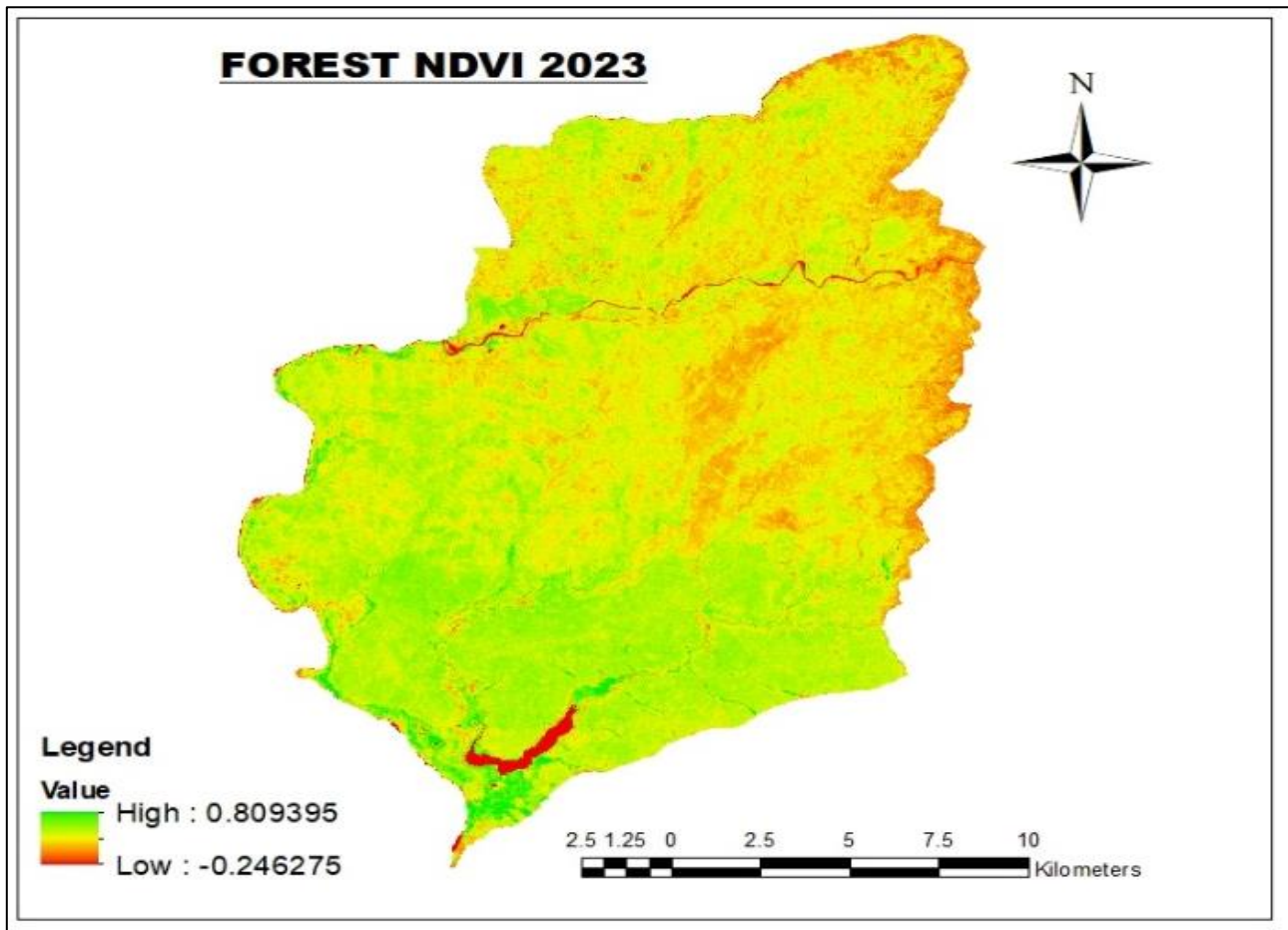


Fig 4 NDVI 2023

Land cover change follows the same pattern as NDVI: Bare ground increased markedly from 13.49% in 2019 to 23.52% in 2021, then declined to 14.47% in 2023.

Vegetation cover decreased substantially from 85.82% in 2019 to 75.91% in 2021, and increased to 81.92% in 2023 (Figures 5-8).

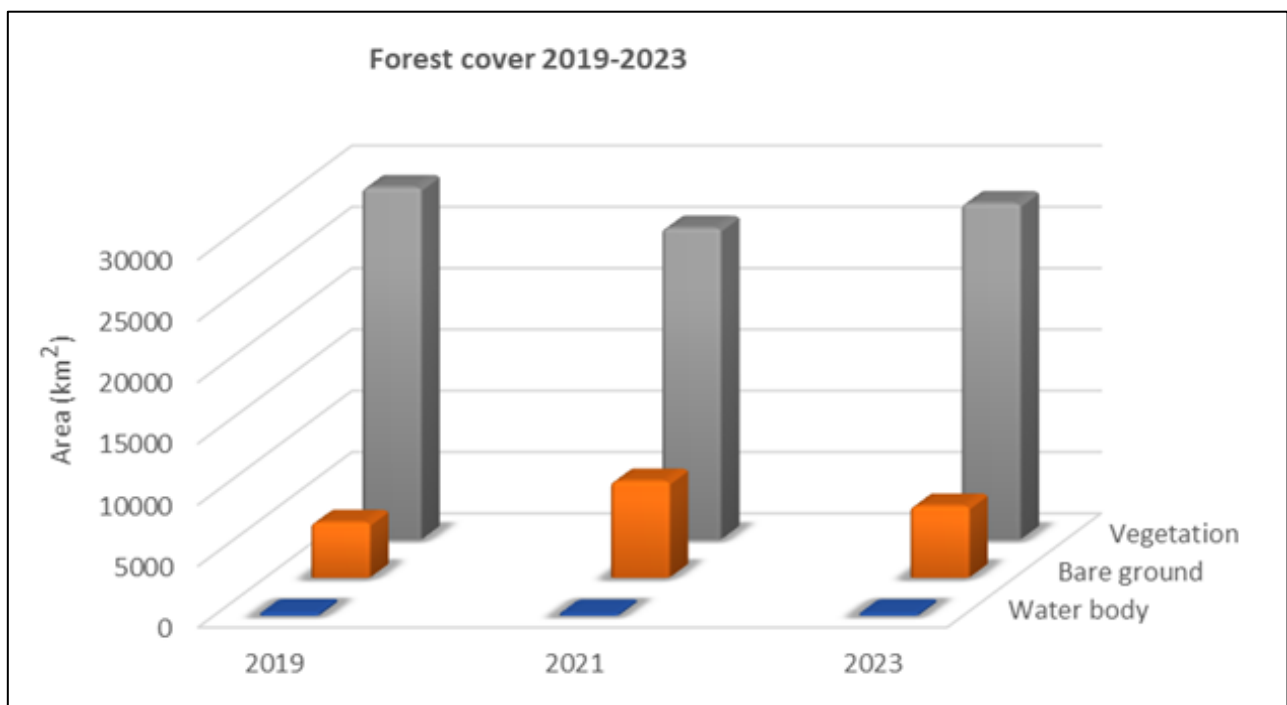


Fig 5 Forest Cover 2019-2023

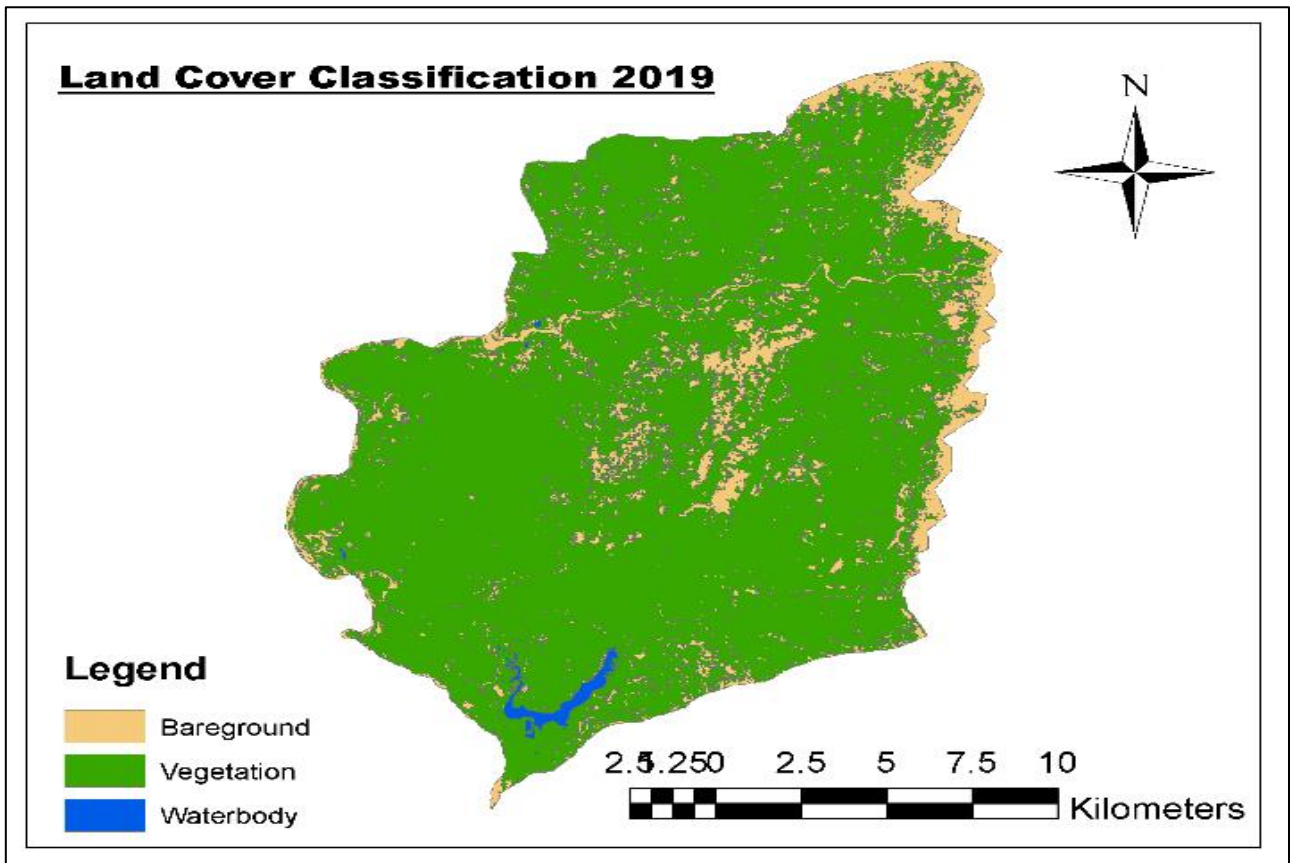


Fig 6 Forest Cover of 2019

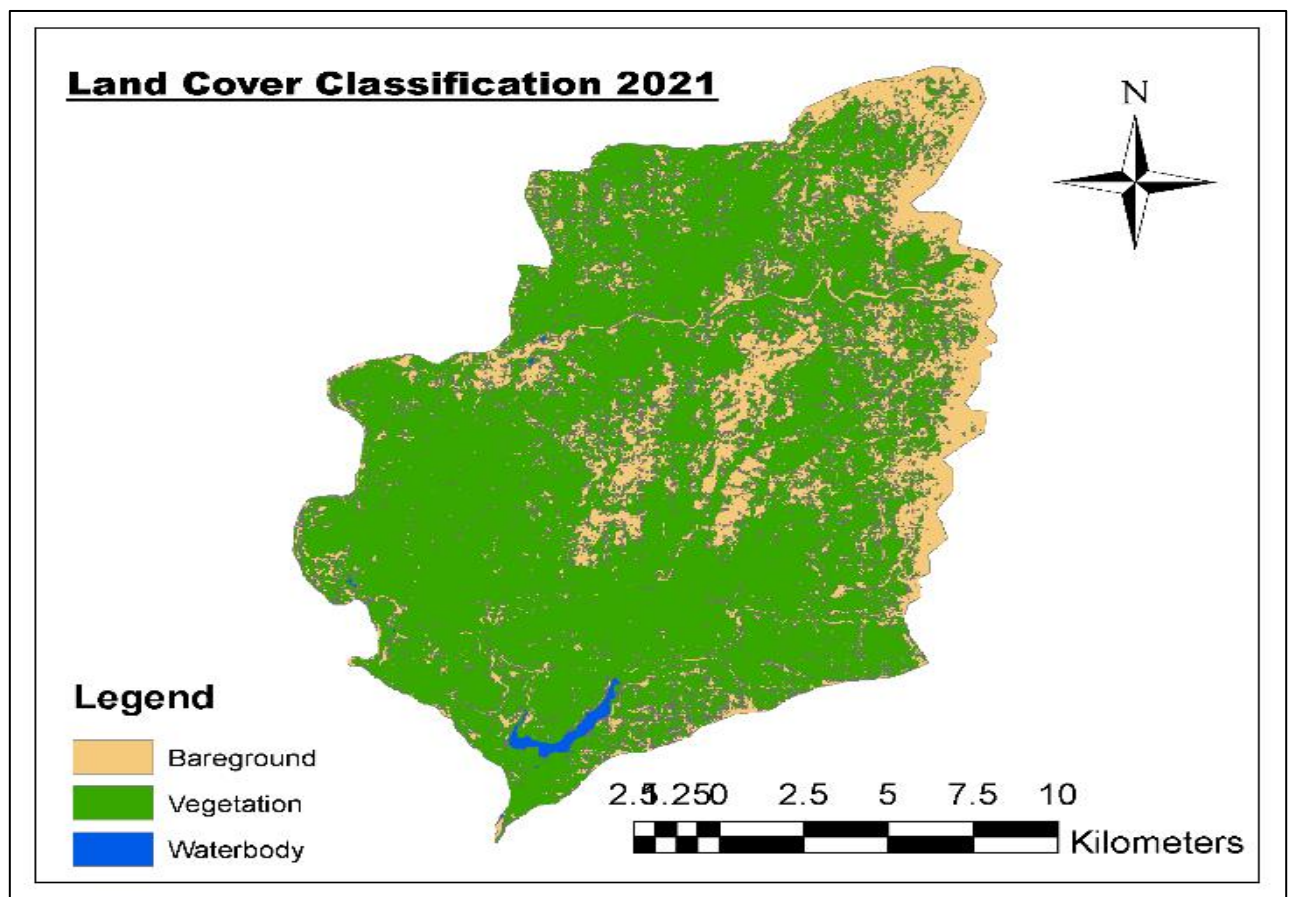


Fig 7 Forest Cover of 2021

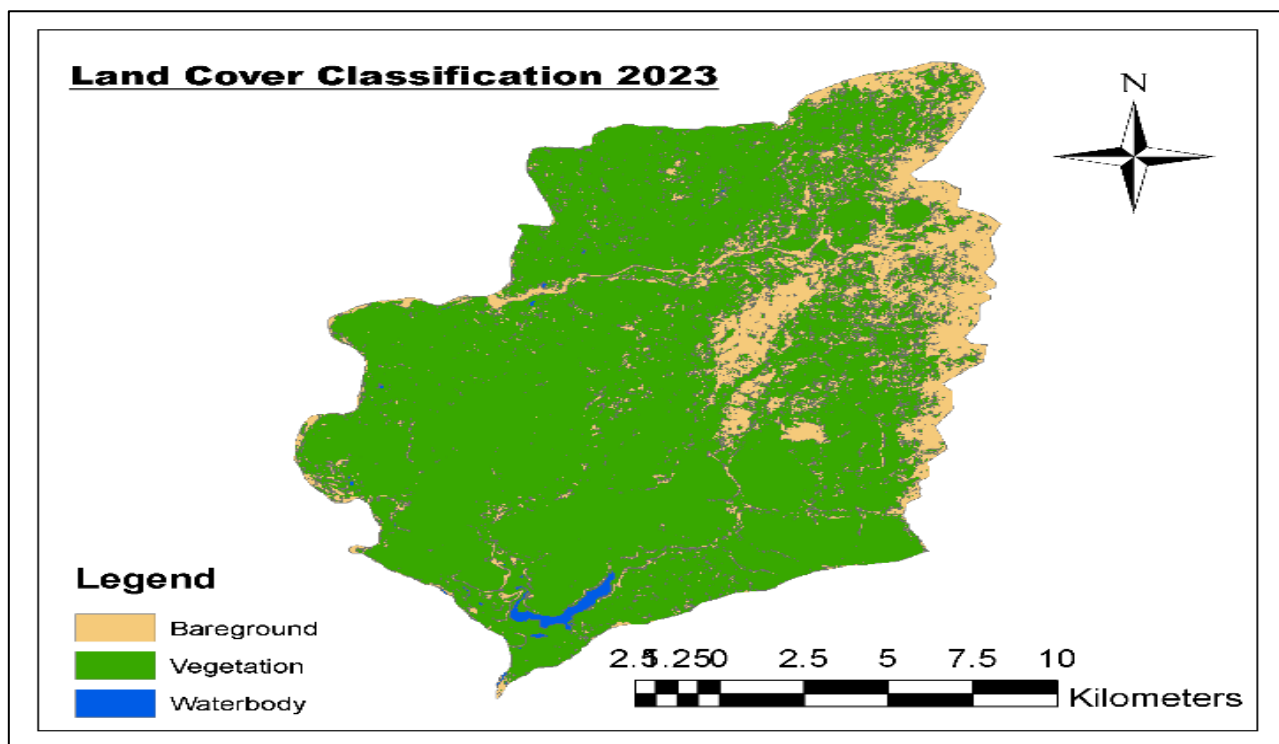


Fig 8 Forest Cover of 2023

➤ *Transformation from 2019-2021 and 2021-2023*

The biennial analysis highlights a pronounced transformation in forest condition across the study period. Between 2019 (pre-peak devastation) and 2021 (peak devastation) (Fig. 9), the forest experienced ruthless degradation, with large areas converted from vegetated cover to bare ground, marking the period of maximum forest loss. This extensive transformation reflects uncontrolled

exploitation driven by intensive logging activities involving both local actors and foreign rosewood merchants, occurring in the absence of effective regulatory or community control.

The 2021–2023 period (Fig. 10) shows a clear departure from the earlier phase of degradation, as classified imagery reveals a notable conversion of bare surfaces to vegetated areas.

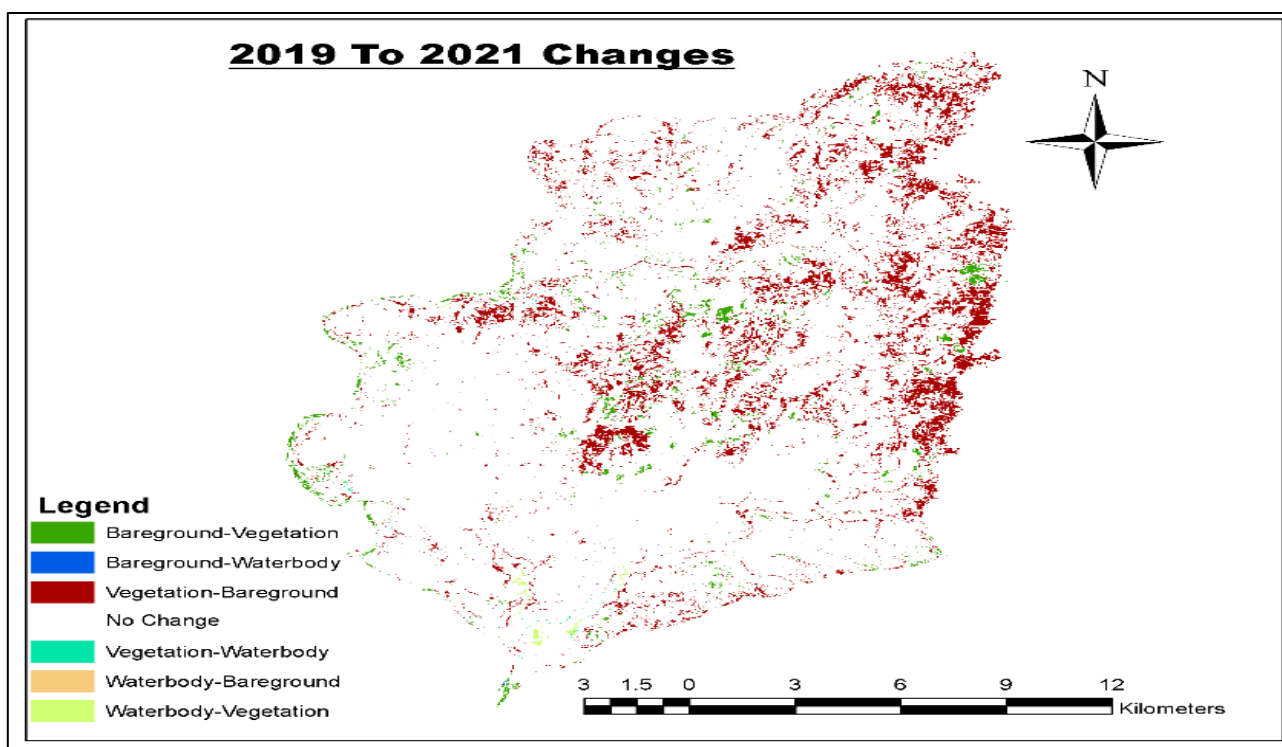


Figure 9: Forest Transformation from 2019 – 2021 (Change Detection)

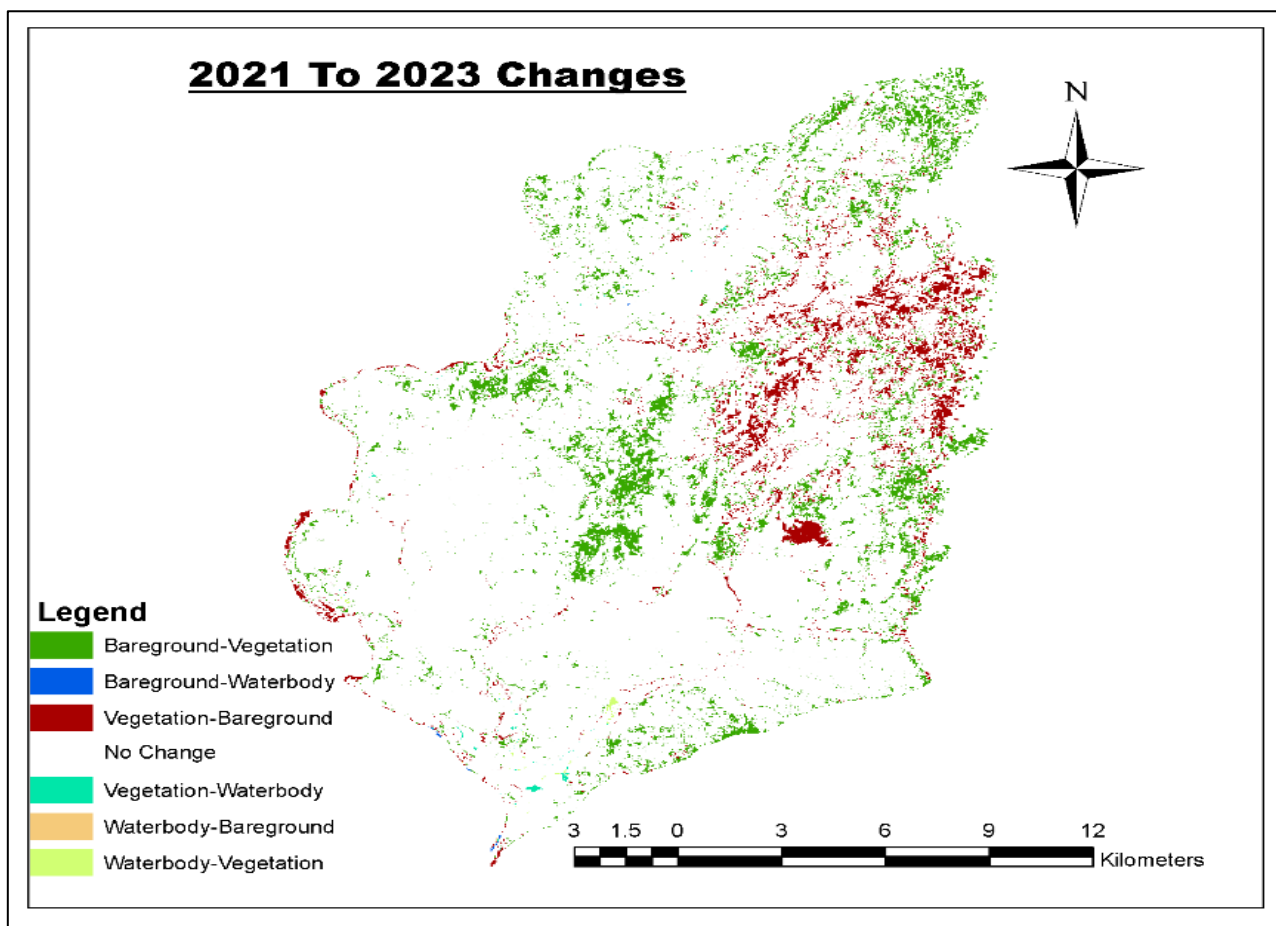


Fig 10 Forest Transformation from 2021 - 2023 (Change Detection)

The cumulative forest cover change to the 2019-2021 period of peak destruction indicated that a larger area of forest (208.55 sq km) was converted to bare surface compared to the 2021–2023 period (195.62 sq km), which had a reduction in forest cover destruction of 12.93 sq km (Figs. 11 and 12), indicating that forest destruction was more intense during the earlier period. The comparatively lower magnitude of these conversions in the latter period

suggests a decline in the rate and intensity of forest devastation after 2021, pointing to a gradual easing of destructive activities. However, despite this visible recovery, the regenerated secondary vegetation lacks the structural complexity and ecological functions of the original primary forest, indicating that full ecological restoration has not yet been achieved.

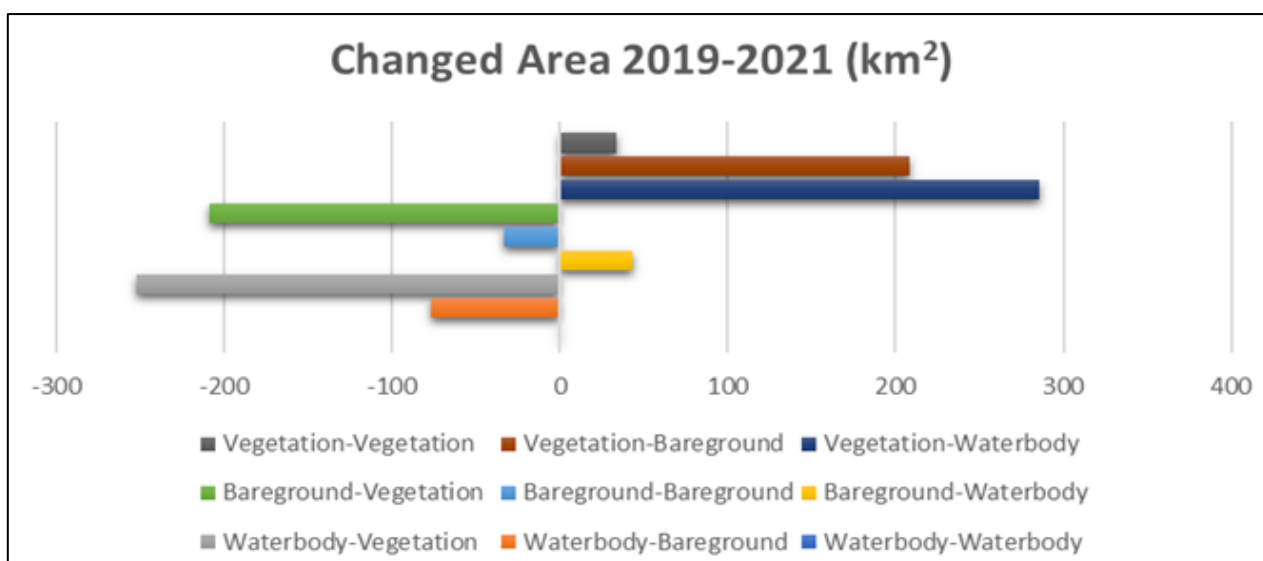


Fig 11 Changed Area from 2019-2021

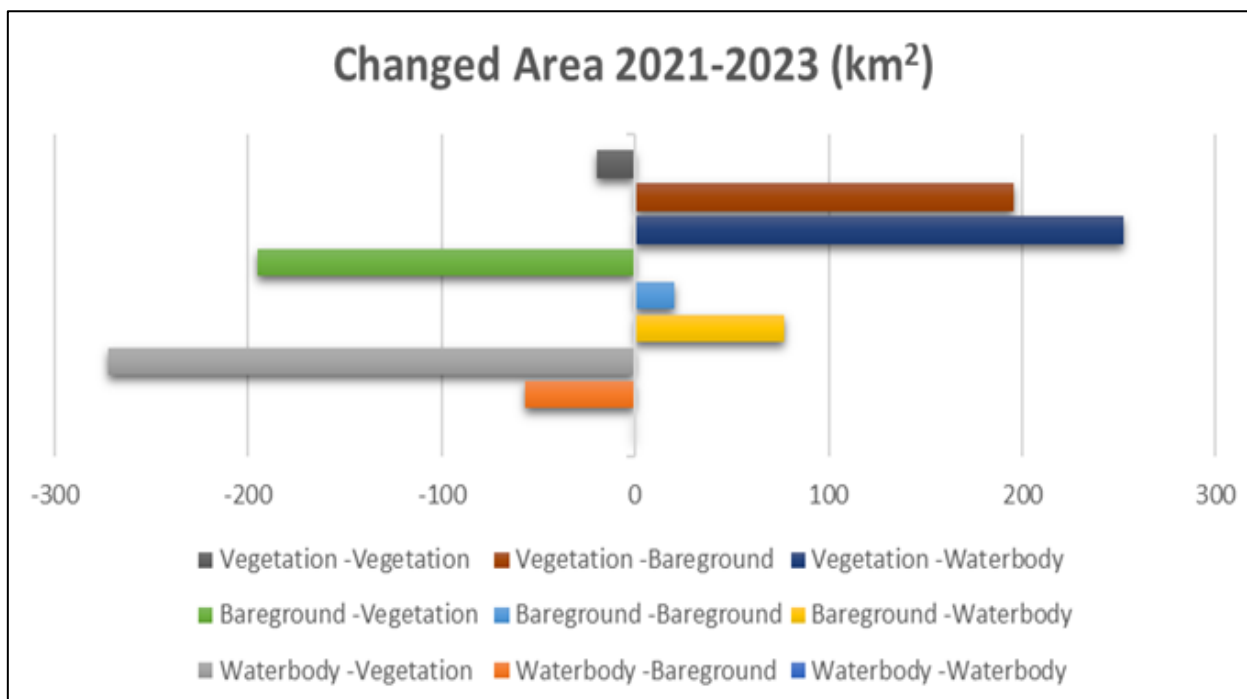


Fig 12 Changed Area from 2021-2023

➤ *Accuracy Assessment*

The Google Earth Pro imagery served as a reference dataset and was used for evaluation by comparing classified values versus observed features in the imagery. This process provided an output in the Google Earth Engine with a confusion matrix.

[[0, 0, 0, 0] = 0 samples, no predictions.
 [0, 13, 0, 0] = 13 samples, all correctly classified.
 [0, 0, 17, 0] = 17 samples, all correctly classified.
 [0, 0, 0, 17] = 17 samples, all correctly classified.
 Kappa coefficient = 1
 The overall accuracy = (13 +17+17) / (13 +17+17) = 47/47 = 1 = 100% accuracy.

V. DISCUSSION

The study used Sentinel 2 NDVI data from 2019, 2021, and 2023 to assess forest cover. The resulting spectral index trends clearly captured forest change over time, consistent with the findings of¹⁵, who used NDVI for mapping and monitoring forest cover.

The study found a shift from densely vegetated forests to sparsely forested areas primarily due to illegal timber extraction, aligning with the findings of^{16,14}. The targeting of choice species like the African rosewood, leading to the mortality of surrounding trees and the destruction of vegetation in the study area, corroborates the findings of¹³. The findings highlight that species-focused illegal logging accelerates forest sparsity and threatens future forest regeneration.

The transformation of vegetative areas to bare ground in the study area is similar to the findings of^{32,33}, who reported that forest loss was replaced by other land cover.

The major driver of forest cover change in this study agrees with a similar submission by³⁴, who noted that logging was the second major driver of vegetation loss in forest reserves, after agricultural encroachment. This prompted an investigation into the pre-devastation, peak devastation, and post-devastation periods. The illegal logging during the invasion window, which targeted the forest's transition to a park, was the study's main focus.

VI. CONCLUSION

The devastation of Pandam National Park during its transition to a National Park raises concerns and highlights the issues of federal ownership of natural resources, where illegal activities occur unchecked. The study highlights the dynamic nature of forests and the increasing pressure from anthropogenic factors. Findings demonstrate the effectiveness of remote sensing and GIS techniques in detecting spatial and temporal changes in forest cover, providing reliable data for conservation planning. Overall, consistent monitoring and collaborative governance remain essential for preserving the integrity of Pandam National Park. Proper attention to Pandam National Park in Qua'anpan LGA, Plateau State, is essential to ensure the transition enhances protection rather than enabling destruction.

RECOMMENDATION

➤ *Aerial Surveillance*

Use unmanned aerial vehicles (drones) equipped with wide thermal cameras to monitor human and machine activities at night. Conduct focused patrols to scout difficult-to-reach areas and find new logging clearings almost instantly. Monitor with historical data for patterns.

➤ *Real-Time Forest Intelligence System*

Create a central monitoring centre where forest guards and other security personnel receive and relay data from drones and satellites, and map areas of forest devastation. Create applications that will allow forest workers to geotag illicit logging in the forest in real time.

➤ *Tracking Criminals*

Most forests are homes to armed groups that abduct people and attack local populations. Where logging is connected to armed groups can be found using data from aerial surveillance, and such information can be shared with security services.

➤ *Community-Based Intelligence Gathering*

Securing forests with incentives and involving the community as part of the team can be effective ways to obtain sensitive information. Locals can use WhatsApp or SMS to report suspicious activity.

➤ *Enforce Laws and Regulations*

When humans are not punished for encroaching, natural resource degradation continues. Drone imagery can be used as evidence against violators in court. To discourage others, the government should take the initiative to make sure that criminal activity in the forests is dealt with.

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