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Assessing Anthropogenic Impacts on Stubb's Creek Forest Reserve, Nigeria: A Remote Sensing and GIS Approach

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Land use-land cover (LULC) changes, particularly in tropical regions like the Niger Delta of Nigeria, are critical drivers of global environmental shifts. This study focuses on the spatial assessment of forest depletion in the Stubb's Creek Forest Reserve (SCFR) in Akwa Ibom State, amidst rapid infrastructural and industrial developments. The data used includes Landsat 5 of 30m TM, Landsat 7 of 30m TM, and Landsat 8 of 30m ETM for 1986, 2003, and 2018 respectively. Using remote sensing and GIS techniques, the research analyzes LULC dynamics between 1986 and 2018 and projects future trends to 2028. Results reveal a significant depletion of forest covers, particularly the Dense Forest, due to anthropogenic activities like oil and gas exploration and infrastructure

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development. Over the study period, the Dense Forest cover decreased from 12,296 hectares (41.9% of the total area) in 1986 to 9,149 hectares (31.2%) in 2018. Conversely, built-up areas increased from 1,385 hectares (4.7%) to 3,358 hectares (11.4%) during the same period. The study forecasts a continued decline in forest cover, with a projected Dense Forest cover of 7,474 hectares (25.45%) in 2028. These findings underscore the urgent need for sustainable land management policies to mitigate biodiversity loss and environmental degradation. Remote sensing and GIS tools prove instrumental in monitoring and understanding LULC changes, offering valuable insights for informed decision-making in environmental conservation and land use planning.

Keywords: Land use-land cover (LULC); remote sensing; GIS; deforestation; biodiversity loss; environmental degradation.

1. INTRODUCTION

One key driver of global climate change is the variation of land use - land cover (LULC) change [1,2,3,4] and this can have significant implications for global policy issues [4,5,6,7], and environmental issues including emission of greenhouse gases, loss of biodiversity and decrease in the capacity of lands and habitats to support human enterprises [3, 8,9,10,11,12]. In tropical regions, LULC changes are a huge concern due to the rapid changes in the distribution and characteristics of tropical forests and the ecosystem services derivable from them [3,8,9,10,11,13,14,15]. Land cover changes are based on the anthropogenic use of the land. Geospatial assessments have revealed that deforestation is one of the significant causes of changing land cover in different parts of the world. Studies have established that the highest rates of forest alteration and conversion have occurred in areas with heavy dependence on forest land for infrastructural development, industrial development, and subsistence agriculture [8,9,13,16]. In the oil-rich Niger Delta region of Nigeria, intense oil and gas exploration, development projects and agricultural activities have been implicated in land vegetative cover depletion [8,9,14,16]. To understand how LULC change affects and interacts with global earth systems, information is needed on what changes occur, where and when they occur, as well as the rate at which they occur. Remote sensing application in LULC assessment has revealed actual changes in land use land cover on regional and global scales. The rapid expansion of infrastructural and industrial developments in Akwa Ibom State, Southern Nigeria, including multinationals and indigenous oil and gas exploration, has led to substantial depletion of forest covers in sensitive areas like the Stubb's Creek Forest Reserve (SCFR) in Akwa Ibom State [8,9,13,14,16]. This has un-arguably led to encroachment on the hitherto reserved forest areas. Despite ongoing research efforts on LULC patterns, there remains a need for the development of basic quantitative statistics on spatial land use-land cover of Nigeria. There is relatively less virgin vegetation/forest in many states of Nigeria. In Akwa Ibom State, the rate of forest loss is accelerating due to unregulated anthropogenic exploitation [8,16,17,18]. This research focuses on the spatial assessment of forest depletion in the World Database of Protected Areas (WDPA) 37027 in Stubb's Creek Forest Reserve (SCFR) in Akwa Ibom State [19] and other development features that have occurred in the reserved area resulting in loss of forest cover.

1.1 Statement of Problem

In recent years, SCFR has witnessed noteworthy infrastructural and industrial developments in Akwa Ibom State, including increased oil and gas exploration activities and the establishment of residential estates and roads [8,9,17]. These activities have resulted in habitat conversion and deforestation, particularly within the SCFR, the only gazetted forest reserve in the state [8,9,17]. Recently, additional upstream exploration and downstream organizations have increased activities to establish their bases within the immediate vicinity of the only gazetted and biodiversity-rich forest reserve in the State. Despite existing laws and regulations, weak enforcement mechanisms have exacerbated the issue, leading to continuous fragmentation of the reserve and loss of vegetative cover [8,9,14]. This presents the difficult situation of continuous fragmentation of the reserved area leading to land conversion, depletion of vegetative cover, and ultimately, biodiversity loss.

These have continued without visible attempts by the government to evaluate the status of changes in the reserve due to constant exploitation to implement a Net-Positive Impact on the indigenous biodiversity and ecosystem services of the SCFR [8,9].

1.2 Aim and Objectives

This study aims to assess the rate of depletion of forest cover in the SCFR and generate a comprehensive understanding of land use and land cover changes over a three-decade period. The specific objectives are as follows:

i. Develop a land use-land cover using supervised classification scheme.
ii. Determine the trends, rate, and spatial distribution of LULC change between 1986 and 2018.
iii. Predict future changes in land use-land cover by 2028.

1.3 Justification

The urgency of this study lies in the critical need to address the escalating rates of forest depletion and habitat loss in the SCFR. By employing remote sensing and GIS techniques, this research seeks to provide valuable insights into the extent and drivers of LULC changes, facilitating informed decision-making for sustainable land management and biodiversity conservation efforts.

2. LITERATURE REVIEW

Land use refers to the human activities and practices that occur on the Earth's surface, primarily to utilize land for various economic, social, and environmental purposes. It encompasses how people allocate and manage land resources to meet their needs, including activities such as agriculture, urban development, transportation infrastructure, forestry, mining, conservation, recreation, and industrial production [20,21,22,23,24]. This often involves the allocation of land for specific purposes, influenced by factors such as geographic location, topography, climate, soil fertility, water availability, economic demand, cultural preferences, and government policies. Different types of land use can coexist within a geographic area, and they may compete for limited land resources, leading to conflicts and trade-offs between various land uses. The authors further expressed that, sustainable land management, environmental conservation, urban planning, natural resource management, and socioeconomic development require an understanding of land use patterns and changes. They also emphasized that land use planning and zoning regulations serve as essential instruments for directing and overseeing land use practices. These measures aim to reconcile conflicting interests, mitigate adverse effects, and foster effective and fair utilization of land resources.

The physical attributes and characteristics of the Earth's surface, including natural features such as forests, grasslands, wetlands, deserts, and water bodies, as well as human-made features like urban areas, agricultural fields, roads, and infrastructure are generally referred to as land cover. It represents the observed biophysical coverage of the Earth's surface at a specific location and time, encompassing both natural and anthropogenic elements. Land cover is determined by various factors, including climate, topography, soil type, vegetation, land use practices, and human activities. It is a fundamental component of the Earth's ecosystems and plays a crucial role in regulating ecological processes, supporting biodiversity, providing habitat for species, influencing local and regional climate patterns, and contributing to ecosystem services such as water purification, carbon sequestration, and soil stabilization.

Understanding and monitoring changes in land cover over time is essential for assessing environmental trends, detecting land use changes, evaluating the impacts of human activities, informing land management decisions, and implementing conservation and sustainable development strategies. Remote sensing technologies, geographic information systems (GIS), and field surveys are commonly used tools for mapping, analyzing, and monitoring land cover dynamics at various spatial and temporal scales [25,26,27,28,29].

LULC change signifies the transformation over time in both human-induced land utilization (land use) and the physical attributes of the Earth's surface (land cover). This alteration results from diverse natural and human-influenced factors such as urbanization, expansion of agriculture, deforestation, reforestation, development of infrastructure, industrial activities, and the impacts of climate change. It can have significant implications for ecosystems, biodiversity, hydrological cycles, carbon cycling, climate patterns, and human well-being [30,31,32,33,34]. Remote sensing technologies, geographic information systems (GIS), modeling methods, and field surveys are the most common methods used to assess the levels of LULC changes at different scales and periods.

The key drivers of LULC change in the SCFR have been severally discussed including population explosion, invasive alien species, deforestation, oil and gas exploration activities, unregulated and unsustainable exploitation of natural resources, largely due to institutional weaknesses, and obsolete biodiversity/forestry laws [9,8,13,14,16,35,36]. The consequences include declining biodiversity, a degraded ecosystem, and climate change effects [8,9,14,16,17].

It was reported in the recent past that the State Government was still issuing licenses to oil and gas entities to operate within the SCFR [8]. This suggests that significant effort to preserve the relics of the already degraded and disappearing biodiversity hotspot in Akwa Ibom State is not a priority of the government. It is also not clear if there is a concrete plan to re-demarcate the boundaries of the reserve to circumvent further encroachment into the remaining forest core.

It is therefore of grave implication for the conservation of the remaining patches of the SCFR. Suffice it to say that this also has consequences for the biodiversity, ecosystems, and the services they provide. This is the core reason for carrying out this research with the key objective of predicting what the extent of the SCFR might be in 2028.

3. MATERIALS AND METHODS

3.1 Description of Study Area

The SCFR lies between latitude 4˚32'N and 4˚44'N and longitude 7˚48'E and 8˚20'E [14], mainly within three local government areas of Akwa Ibom State namely Esit-Eket, Mbo, and Ibeno as shown in Fig. 1, [8,37]. The total gazetted area as of creation in 1930 was approximately 310.78 km^2 [14,35]. The SCFR is a major biodiversity hotspot in the Gulf of Guinea [14,35] and boasts Mangrove swamp forests, Freshwater swamps, and Tropical rainforests as the key vegetation types [8,9,38]. It is also home to diverse flora and faunal species [8,9,14,37] including *Cercopithecus sclateri* (Sclater's Guenon) listed in The International Union for Conservation of Nature's (IUCN) Red List of Threatened Species [12,39, 40]. SCFR which lies within the low-lying coastal zone (elevation 16 to 22 m above sea level) with parallel beach-ridge sand deposits and intervening freshwater swamp forests is reported to be under tidal inundation [8]. The ridges are impoverished in soil nutrients and have sparse plant growth while the swamps are Densely forested and almost impenetrable in many sections [8,38]. The total annual rainfall of SCFR ranges from 1700 mm to 4700 mm and the mean monthly temperature of 25˚C to 28˚C. The soil type has been reported to be in-between well-drained loamy soil with commendable levels of organic matter, nutrients, pH, and conductivity levels as well as the poorly drained clayey soil with electrical conductivity at acceptable levels to support crop growth. This suggests why agriculture is the main occupation of the people [14,37,41].

3.2 Source of Data

The geospatial data used for the Land Use and Land Cover (LULC) analysis includes the following: 1986Landsat 5 Thematic Mapper (TM), 2003 Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and 2018 Landsat 8 ETM+. All the satellite data has the same spatial reference. The satellite data were acquired from path 188 and raw 57 of the United States Geological Survey (USGS) through the Earth Explorer website. The baseline shapefiles used for the generation of boundaries used to generate the map of the study area were acquired from the Data Management Unit, National Space Research and Development Agency. The Coordinate System of the shapefiles was projected on WGS_1984 of Universal Transverse Mercator (UTM) in Zone_32N.

3.3 Techniques for Data Analysis

The various phases of the data analysis used for this study are described below.

(i) Band combination and image processing.
(ii) Sub-mapping to extract the WDPA coverage to cover the area of interest.
(iii) Maximum Likelihood Classification
(iv) Statistical presentation of classified Land cover in hectares and accuracy assessment.
(v) Overlay analysis.
(vi) Change detection of LULC variability

3.4 Band Combination

The satellite images of 1986 and 2003 are Landsat5 and Landsat 7 respectively.

The image comes in seven (7) bands while Landsat 8 has 11 bands. For this study, Band 432 was selected because it includes the near-infrared channel (band 4) land-water boundaries are clearer and different types of vegetation are more apparent. The band 432 appeared as a false colour composite and therefore the satellite image was able to reveal the vegetation cover within the WDPA location.

3.5 Sub-Mapping

This was the technique adopted to enable the researcher to extract the area coverage of the WDPA.

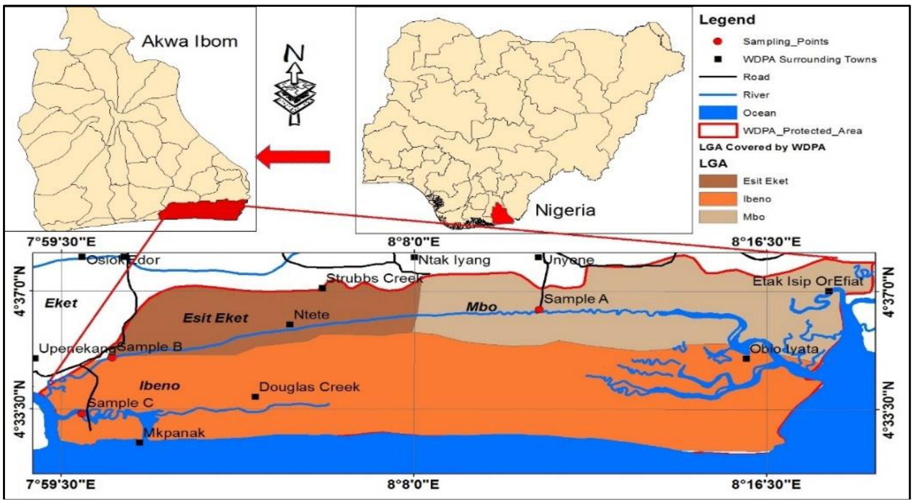


Fig. 1. Location Map of the study area [8]

Table 1. Properties of Data and Source

S/N	Type of Data	Date of data	Scale of Data	Source
1.	Landsat 8	20/12/2018	30m ETM+	USGS
2.	Landsat 7	15/01/2003	30m ETM+	USGS
3.	Landsat 5	02/12/1986	30m TM	USGS
4.	Nigeria Shapefile Data.	2013	1:15,140,906 (view scale)	NASRDA

Data was acquired during the dry season

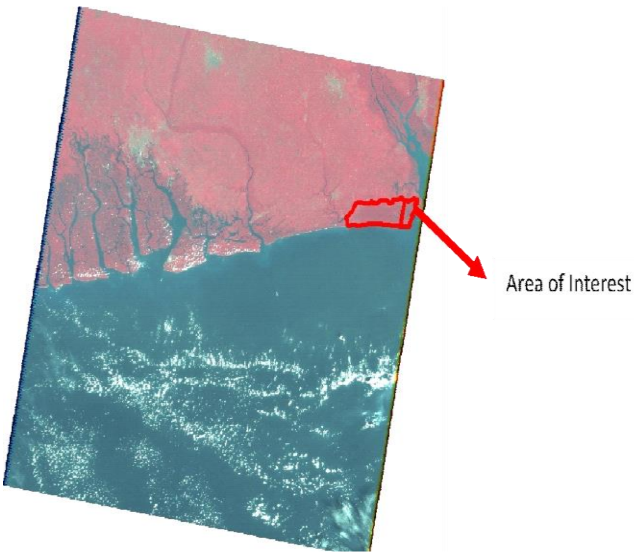


Plate 1. Landsat7 Band 432 false colour composite showing area to sub-mapped

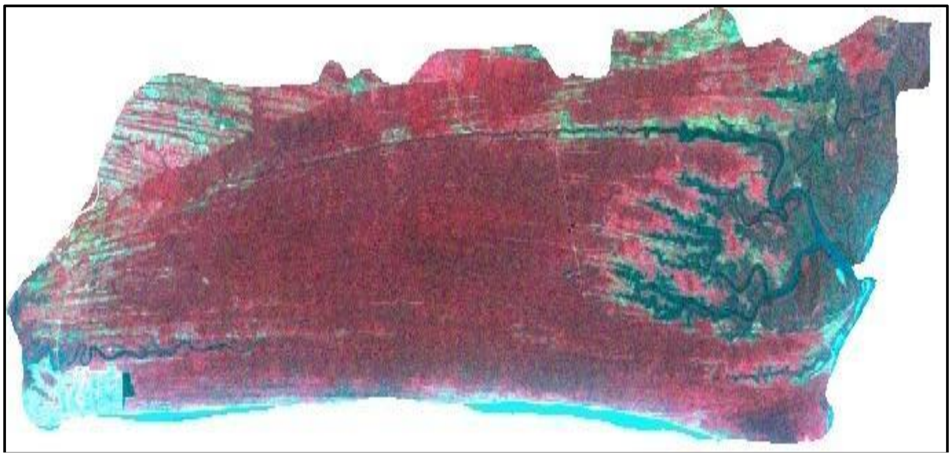
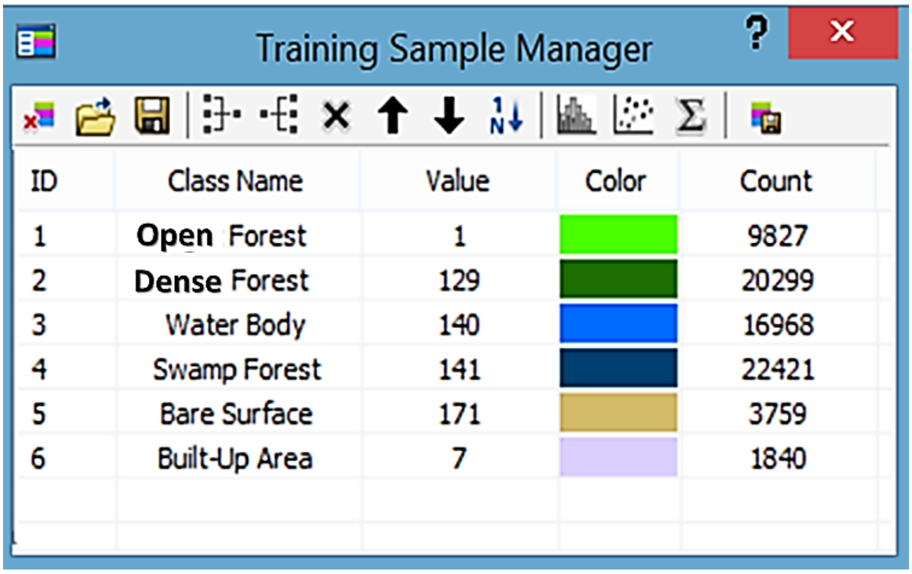


Plate 2. Sub-Mapped Landsat-7 Satellite Image



Training Sample Manager

ID	Class Name	Value	Color	Count
1	Open Forest	1		9827
2	Dense Forest	129		20299
3	Water Body	140		16968
4	Swamp Forest	141		22421
5	Bare Surface	171		3759
6	Built-Up Area	7		1840

Fig. 2. Attribute of the Training Sample for the supervised classification

This involves using the pre-determined area coverage of the shapefile to extract the image by masking in ArcGIS 10.0 using the same projected coordinate system of the Landsat Imageries adopted for the previous analysis of the shapefiles. The projection was in WGS 1984 of Northern UTM.

3.6 Satellite Image Classification Scheme

In this study, we employed a supervised classification scheme, specifically drawing from Anderson, J.R., 1976 [42] basic classification framework. After conducting the supervised classification, we sub-mapped the satellite data to extract the area of interest. The resulting sub-mapped image served as the basis for developing the distinct classes outlined in Fig. 2.

Notably, we refined this classification scheme to align with the study's objectives, which centered on assessing changes in the vegetative cover of the Forest Reserve (WDPA). The concept for improving the Anderson, J.R., 1976 [42] classification scheme was based on the dominant land covers within the study area.

The development of the training sample was in line with achieving the set objectives of this study. A total of six (6) land cover classes were identified in the study, and they include Dense forest vegetation implies a high tree density, often found in rainforests or areas with abundant vegetation cover, and Moderate or Open Forest Moderate" or "open forest" suggests a lower tree density, which aligns with savannah woodlands or transitional zones and the farmland and the swamp forest, Built-up area, Bare surface area and water body.

The supervised digital signature class developed from the sample site was used to classify a set of false colour Landsat satellite imagery of band-432 RGB adopting maximum likelihood classifier and creating a classified raster as the output of the LULC map. This was the same procedure for the three study intervals of 1986, 2003 and 2018.

3.7 Accuracy Assessment

This is one of the most important final steps of image classification. Accuracy assessment aims to quantitatively assess how effectively the pixels were sampled into the correct land cover classes. Moreover, the key emphasis for accuracy assessment pixel selection was on areas that could be identified on both Landsat high-resolution images. A total of 326280 points (locations) were created in the classified image of the study area. The Accuracy Assessment Cell Array Reference column was filled according to the best guess of each reference point.

The overall classification accuracy = No. of correct points/total number of points

$$= \frac{268246}{326280} = 82.2\%$$

KAPPA analysis is a discrete multivariate technique used in accuracy assessments. KAPPA analysis yields a Khat statistic (an estimate of KAPPA) that is a measure of agreement or accuracy. For this land use land cover classification, the Kappa Coefficients of the accuracy assessment were also generated to rate the entire classification accuracy.

3.8 LULC Projection

Landsat satellite image for 1986 and 2018 was reclassified using the Quantum GIS 2.18 version software and the MOLUSCE tool in QGIS was used to analyze the variables of the initial and final classified images with reference to the spatial variables. The LULC of the study area was projected for 10 years and the result was presented in maps and tables.

4. RESULTS PRESENTATION

The land use land cover map shown in the Fig. 3 below revealed the distribution of the land cover in the study area and their dynamics. In this study, a total of 6 land cover was studied as described in the methodology, after the classification, various colours were assigned to the land covers to depict their real colour on the earth surface. Thus, the bare surface was represented with Sahara sand colour, Built-up cover was represented with Dark Umber, the Open forest was represented with Medium apple green colour, swamp forest was represented with deep forest green, the Dense forest cover was represented with fir green colour and the water body was represented with Cretean blue. All these colours were selected from the ArcGIS colour scheme to suit the classification. See the result below.

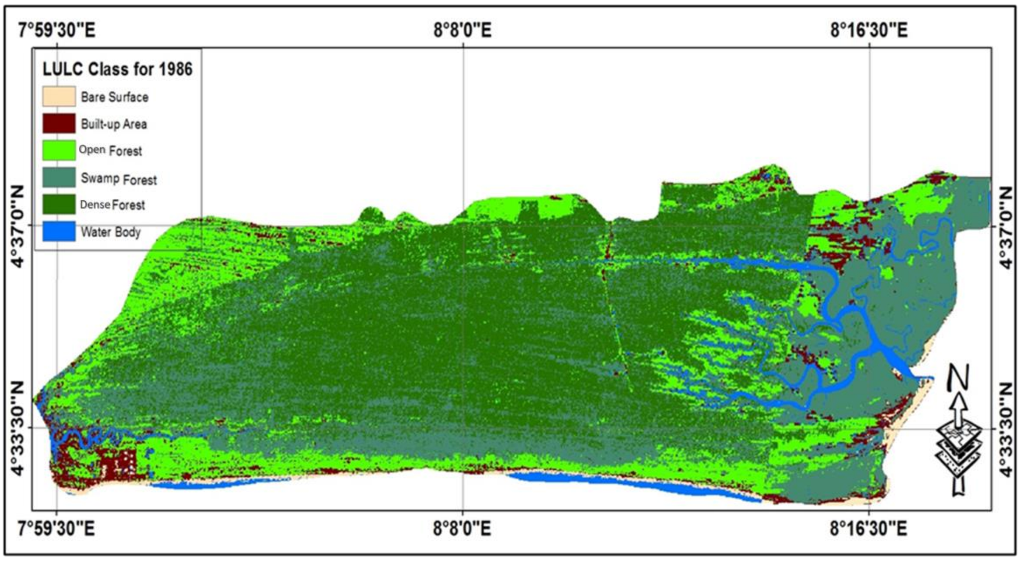


Fig. 3. LULC of WPDA in 1986

Table 2. LULC Distribution 1986 and Classification Accuracy

Name	Pixel Count	Area (M^2)	Area (Ha)	Area (%)
Bare Surface	5169	4652100	465.21	1.6
Built-up Area	15389	13850100	1385.01	4.7
Open Forest	66539	59885100	5988.51	20.4
Swamp Forest	86890	78201000	7820.1	26.6
Dense Forest	136626	122963400	12296.3	41.9
Water Body	15667	14100300	1410.03	4.8
Total	**326280**	**293652000**	**29365.2**	**100**
Accuracy Assessment	Overall Accuracy: 82.2%	Kappa Coefficient: 0.7981		

Table 3. LULC Distribution 2003 and Classification Accuracy

Name	Pixel Count	Area (M^2)	Area (Ha)	Area (%)
Bare Surface	5331	4797900	480	1.6
Built-Up Area	29235	26311500	2631	9.0
Open Forest	68581	61722900	6172	21.0
Swamp Forest	83295	74965500	7497	25.5
Dense Forest	127480	114732000	11473	39.1
Water Body	12358	11122200	1112	3.8
Total	326280	293652000	29365	100
Accuracy Assessment	Overall Accuracy: 88.23%	Kappa Coefficient: 0.8201		

Table 4. LULC Distribution 2018 and Classification Accuracy

Name	Pixel Count	Area (M^2)	Area (Ha)	Area (%)
Bare Surface	10513	9461700	946	3.2
Built-up Area	37312	33580800	3358	11.4
Open Forest	88205	79384500	7938	27.0
Swamp Forest	71087	63978300	6398	21.8
Dense Forest	101655	91489500	9149	31.2
Water Body	17508	15757200	1576	5.4
Total	**326280**	**293652000**	**29365**	**100**
Accuracy Assessment	Overall Accuracy: 86.32%	Kappa Coefficient: 0.8095		

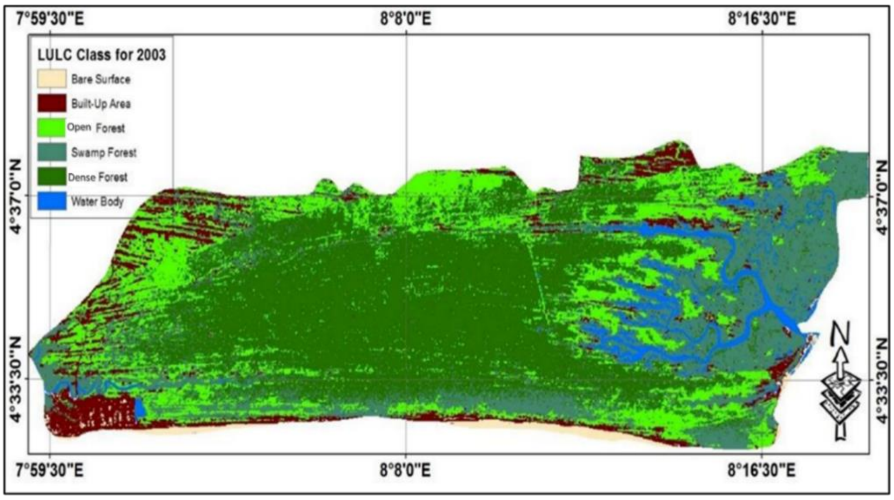


Fig. 4. LULC of WDPA area in 2003

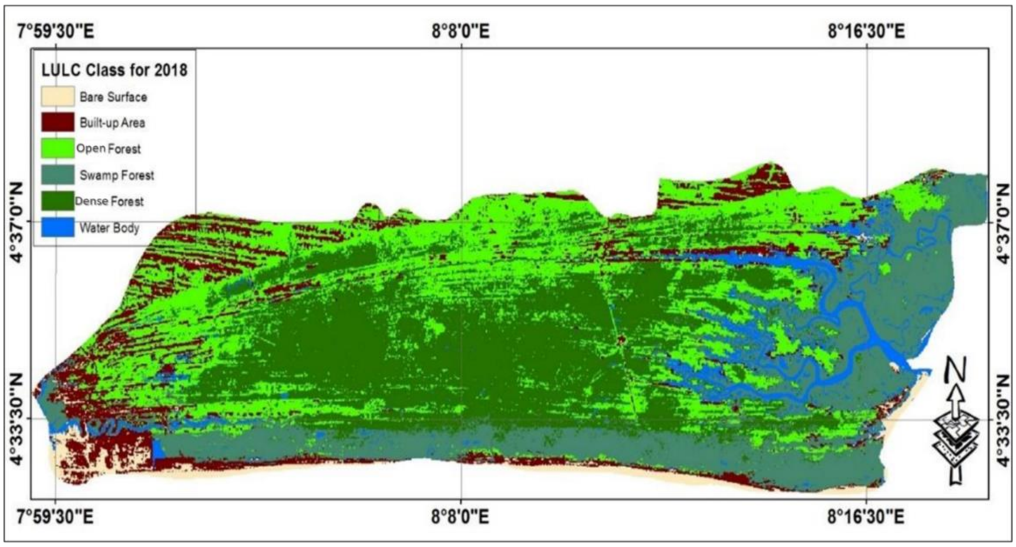


Fig. 5. LULC of WDPA area in 2018

From the land use and land cover map of 1986, it was discovered that the largest land cover was the Dense forest. It occupied about 12296.3 hectares making 41.9 percent of the entire WDPA area. This was followed by Swamp Forest cover which has about 7820.1 Hectares making up to 26.6 percent of the entire WDPA area of the study. The third-largest land cover of the area is the Open Forest cover which covers about 5988.51 hectares making up to 20.4 percent of the entire study area cover. This was followed by a water body that occupied about 1410.03 hectares, which was up to 4.8 percent of the total cover of the study area. The next cover is the built-up cover and bare surface which were amongst the least of the land covers occupying 4.7 and 1.6 percent respectively (see Table 2).

The map shows the spatial variation of the land cover classes in 2003. The land use land cover map of 2003 revealed that Dense Forest was the highest cover in that map and it occupied approximately about 11473 Hectares, which covers about 39.1 percent of the entire land cover of WDPA in 2003. The second largest of the land cover is Swamp Forest, which occupies about 7497 Hectares of the entire area making up to 25.5 percent of the area. The next to the swamp forest is Open Forest which Table 2 revealed to be about 6172 Hectares, making up to 21.0 percent of the entire WDPA area. Built-up area followed with a total land cover of about 2631 Hectares. This is about 9.0 percent of the total WDPA area. The water body and the bare surface cover are the least of the entire land use land cover assessed in the 2003 classification, they have about 3.8 and 1.6 percent of the WDPA area respectively.

From Fig. 5 above, it was revealed that the Dense Forest is still the largest land cover with a total of 9149 Hectares of the entire 29365 Hectares making up about 31.2 percent of the total WDPA area of study. The Open forest became the second-largest land cover in 2018 with about 7938 Hectares constituting about 27 percent of the total area. The third next largest land cover is a swamp forest covering about 6398 Hectares of the land cover. Swamp forests constituted about 21 percent of the entire land cover.

This is followed by the Built-up area which is about 3358 Hectares of the land cover making up to 11.4 percent of the total land cover assessed in the land use land cover map. Waterbody and the bare surface are the least among all the land cover assessed and they occupied about 5.4 and 3.2 percent respectively. See Table 4 for details.

4.1 Change Detection Analysis

Fig. 6 was generated to reveal the changes that have occurred over the years in the study area. This changes positively or negatively affected all the land cover assessed during the land use land cover classification analysis. The distribution of the changes was shown in Table 5.

This study aimed at revealing significant changes that are affiliated and contributing to the current depletion of the forest reserve in the study area. The change detection analysis revealed that from 1986 to 2003; bare surface increased with about 14.58 hectares of the total area. Built-up cover heavily increased to show there is heavy anthropogenic encroachment in the forest reserve. Thus, this caused the Dense Forest to lose about 823.14 hectares making up to 2.8 percent of the entire WDPA study area. Swamp forests were also reduced with about 323.55 hectares.

The changes between 2003 and 2018 revealed that bare surface cover continued to increase with about 466.38 making up to an addition of 1.59 percentage, this shows that there is a rapid clearing of the forest cover.

From the same result, it was discovered that Dense vegetation was the most depleted land cover in the study area, the Dense forest lost about 2324.25 hectares making up to 7.91 percent of the entire area. Also, a small component of the Swamp Forest was lost to the water body which gained about 463.50 hectares making up to 1.58 percent of the entire study area. From 2003 to 2018, it was discovered that Open forest increased, it gained about 1766.16 hectares making up to 6.01 percent of the entire area. However, the Built-up cover between 2003 to 2018 change detection analysis revealed that the Built-up area gained about 726.93 hectares making up about 2.48 percent of the entire study area.

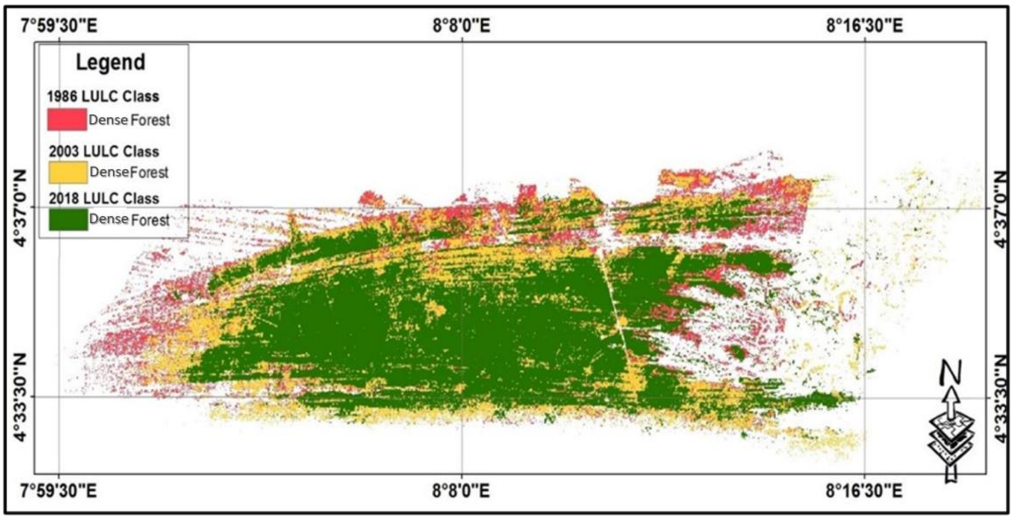


Fig. 6. Change Detection of Dense Forest cover from 1986, 2003, and 2018

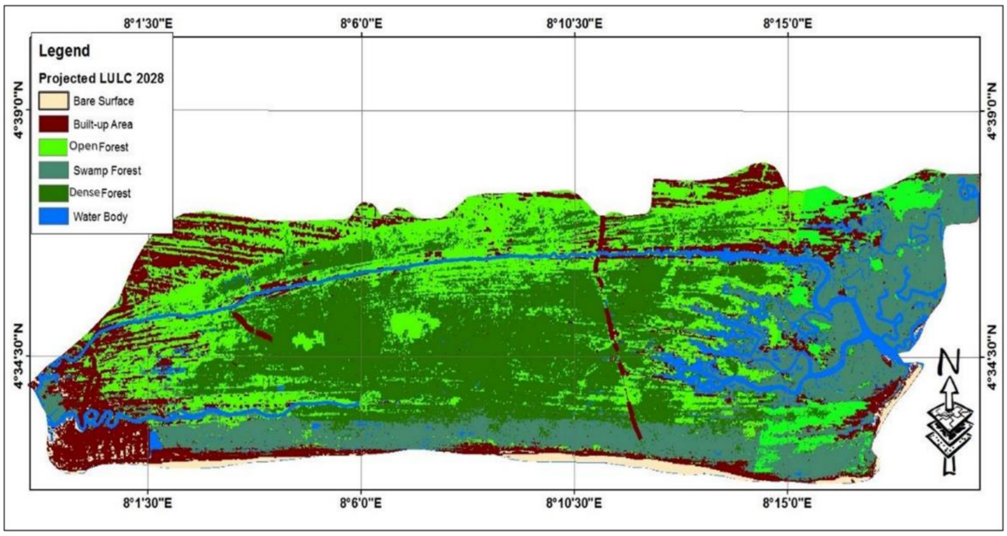


Fig. 7. Projected LULC for 2028

Table 5. distribution of change detected in 1986, 2003 and 2018

Name	Area (Ha)		Change Detection		Area (Ha)		Change Detection	
	1986	2003	(Ha)	(%)	2003	2018	(Ha)	(%)
Bare Surface	465.21	479.79	14.58	0.05	479.79	946.17	466.38	1.59
Built-up Area	1385.01	2631.15	1246.14	4.24	2631.15	3358.08	726.93	2.48
Open Forest	5988.51	6172.29	183.78	0.63	6172.29	7938.45	1766.16	6.01
Swamp Area	7820.1	7496.55	-323.55	-1.10	7496.55	6397.83	-1098.72	-3.74
Dense Forest	12296.34	11473.2	-823.14	-2.80	11473.2	9148.95	-2324.25	-7.91
Water Body	1410.03	1112.22	-297.81	-1.01	1112.22	1575.72	463.50	1.58

Table 6. Projected LULC Distribution 2028

Name	Pixel Count	Area (M^2)	Area (Ha)	Area (%)
Bare Surface	8795	7915200	792	2.70
Built-up Area	53793	48413475	4841	16.49
Open Forest	96740	87065850	8707	29.65
Swamp Forest	67105	60394275	6039	20.57
Dense Forest	83045	74740425	7474	25.45
Water Body	16803	15122775	1512	5.15
Total	**326,280.00**	**293652000**	**29365**	**100**

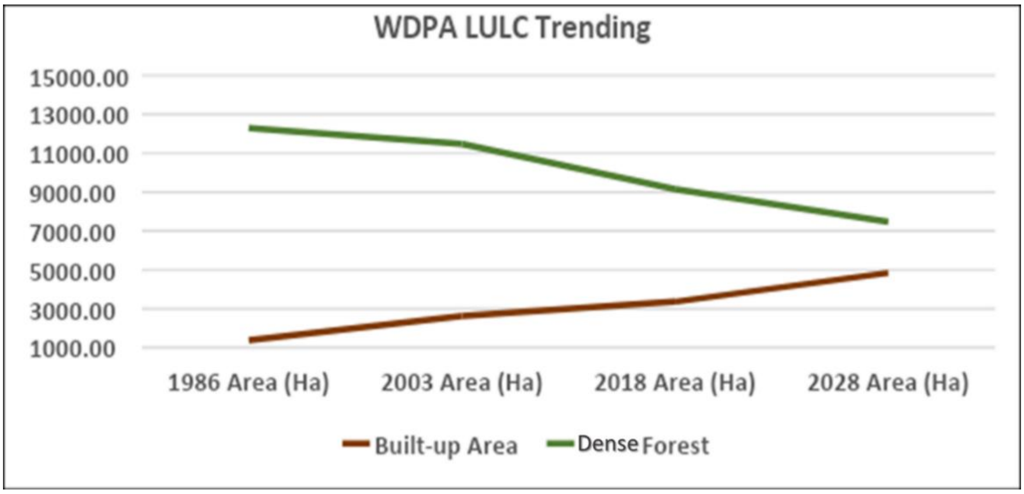


Fig. 8. LULC Trending for Built-up Area and Dense Forest Area

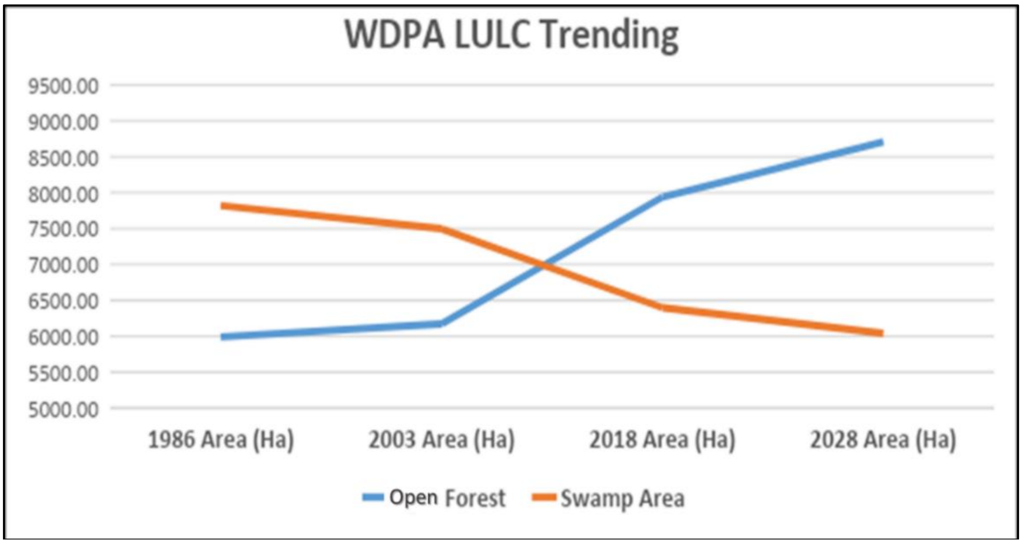


Fig. 9. LULC Trending for Built-up Area and Dense Forest Area

It revealed that Open Forest cover is highly likely to become the largest land cover in 2028 with an estimated land area of 8707 Hectares and constituting approximately about 30 percent of the total land cover of the study area. This could be based on the increasing trend of Open Forest cover over the years of analysis (see Fig. 7). The Dense Forest cover was revealed to be the second-largest land cover in the study area with a projected cover of 7474 Hectares covering approximately about 26 percent of the total study area.

Fig. 9 revealed the decreasing trend of the swamp forest cover in the study area. It appeared the third-largest cover in the 2028 projected LULC analysis displayed in Fig. 5 above. The swamp forest was estimated to cover about 6039 Hectares of the area, thereby constituting approximately about 21 percent of the entire land cover. The projected area covered by Built-up cover was projected in 2028 to be about 4841 Hectares of the entire study area cover making up to approximately 17 percent of the total land cover assessed in the projected land use land cover analysis. Waterbody and the bare surface remained the least land cover in the projected 2028 LULC analysis of the study. They occupied approximately about 5.0 and 3.0 percent respectively. See Table 5 for more details.

Fig. 8 and Fig. 9 further reiterated the changing characteristics of the studied LULC for 1986, 2003, 2018 and the projection to 2028. Land covers like Open vegetation and Built-up Area were linearly increasing while Swamp area and Dense vegetation revealed a fast-decreasing trend in their area cover in the study area. This trend is expected to continue and manifest as projected for 2028 if anthropogenic exploitation of the forest resources continues with the recorded changing trends. In summary, the study highlights the urgent need to address forest depletion and habitat loss in the Stubb's Creek Forest Reserve (SCFR), Nigeria, by implementing Specific, Measurable, Achievable, Relevant, and Time-bound (SMART) strategies. Over the past three decades, anthropogenic activities, such as oil and gas exploration and infrastructure development, have significantly altered the land use and land cover within the reserve. Notably, the Dense forest cover has decreased from 12,296 hectares (41.9%) in 1986 to 9,149 hectares (31.2%) in 2018, while built-up areas have expanded from 1,385 hectares (4.7%) to 3,358 hectares (11.4%) during the same period.

In summary, we can observe the following trends: The swamp area decreased from 2003 to 2028; Built-up areas increased over the same period; Open Forest cover increased; Dense Forest cover decreased significantly; Water bodies increased slightly, and Bare surface areas increased.

5. CONCLUSION AND RECOMMENDATION

This study showcases the capabilities of Remote Sensing and GIS in evaluating the temporal and spatial variations of land use and land cover in the study area. Efforts were made to accurately identify six land use-land cover classes and monitor their evolution over time. These classes were distinctly represented for each study year, with a particular focus on the reduction of the three forest cover classes, especially the Dense forest cover, which has been the dominant cover since the study area was declared a World Database on Protected Areas (WDPA).

It's noteworthy that the biological resources associated with each of the studied land use-land cover classes in the WDPA are expected to change (either increase or decrease) in line with the changing trends in the studied land use-land cover. The observed increase in Open vegetation by approximately 183.78 hectares over the years could be attributed to afforestation efforts.

The study results suggest anthropogenic encroachment on the WDPA study area. To address these challenges, industries, particularly those related to oil and gas, operating within or near forest reserves must adhere to standard practices as recommended by the International Petroleum Industry Environmental Conservation Association (IPIECA) and The International Association of Oil & Gas Producers (IOGP) Biodiversity and Ecosystem Services (BES) Fundamentals Guidance. This includes the implementation of eco-friendly technologies, reduction of deforestation, and support for reforestation efforts. Collaborative efforts with stakeholders, including local communities, non-governmental organizations, and government agencies, are crucial to develop and implement effective conservation strategies tailored to the needs of the SCFR. Community participation in conservation initiatives, such as sustainable land use practices and advocacy for supportive policies, is vital for long-term success and should be measurable in terms of their impact on forest recovery while addressing livelihood issues.

Moreover, policymakers should bolster legal frameworks, invest in monitoring technologies, and advocate for SMART sustainable development policies. By setting specific targets for forest recovery and reduction of built-up areas, governments can ensure that interventions are measurable and achievable within a set timeframe.

By 2028, it is projected that the Dense Forest cover could potentially decrease to approximately 7,474 hectares (25.45% of the total area), while built-up areas may stabilize or slightly decrease.

These measures would not only benefit the local environment and biodiversity but also contribute to sustainable development and resilience in the face of global environmental challenges.

The study further recommends revisiting the diverse needs for land use-land cover in the study area to implement actions that will promote the increase of vegetative cover, contrasting the current practice. This approach could potentially position the SCFR towards achieving the United Nations Net Zero Goal by 2050 within the WDPA.

COMPETING INTERESTS

Authors have declared that no competing interests exist**.**

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