Advances in Remote Sensing, 2023, 12, 123-144
https://www.scirp.org/journal/ars
ISSN Online: 2169-2688
ISSN Print: 2169-267X

Land Use Land Cover Dynamics of Oba Hills Forest Reserve, Nigeria, Employing Multispectral Imagery and GIS

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How to cite this paper: Bukoye, J.A., Oluwajuwon, T.V., Alo, A.A., Offiah, C., Israel, R. and Ogunmodede, M.E. (2023) Land Use Land Cover Dynamics of Oba Hills Forest Reserve, Nigeria, Employing Multispectral Imagery and GIS. *Advances in Remote Sensing*, **12**, 123-144.
https://doi.org/10.4236/ars.2023.124007

Received: November 2, 2023
Accepted: December 26, 2023
Published: December 29, 2023

Abstract

Land use Land cover (LULC) has undergone progressive changes worldwide over the years. However, there is limited information available about these changes in Oba Hills Forest Reserve, Nigeria. The existing spatial analysis of the forest excluded important land use classes like settlements. Therefore, this study aimed at assessing the dynamics of LULC in Oba Hills Forest Reserve between 1987 and 2019. Images from Landsat 5, Landsat 7, and Landsat 8 for the years 1987, 2001, 2013, and 2019 were obtained and subjected to preprocessing and classification using the maximum likelihood algorithm, change detection, and Normalized Differential Vegetation Index (NDVI). The coordinates of specific benchmark locations and other points were acquired for ground-truthing and developing Digital Elevation Model (DEM). Three distinct LULC classes were identified: forest, bare land (including open spaces, agriculture, rocks, and grasslands), and built-up areas. The forest cover in the reserve gradually decreased from 56% in 1987 to 47% in 2019, resulting in a total area loss of 455.4 hectares. Correspondingly, the other LULC classes experienced exponential expansion. Bare land increased from 44% in 1987 to 52% in 2019, while the built-up area expanded by 57.28 hectares. These changes are attributed to prevalent anthropogenic activities such as agriculture, grazing, logging, firewood collection, and population growth within the catchment area. The declining NDVI values in the forest reserve, from 0.52 to 0.44 within the years of assessment, further substantiated the substantial loss of forest cover. The DEM and topographical map highlighted notable steep slopes and elevations of up to over 550 m above sea level (asl) within the reserve, which have implications for forest growth and dynamics. In conclusion, this study reveals extensive rates of forest cover changes into bare land, primarily for agriculture, and settlements, and offers further recommendations to reverse the trend.

Keywords

Landsat, Normalized Differential Vegetation Index, Change Detection, Deforestation, Digital Elevation Model

1. Introduction

Forests provide varieties of ecosystem services spanning from local livelihoods and socioeconomic benefits such as food, wood, fuel, and water to global ecological services, including biodiversity conservation, provision of wildlife habitats, nutrient cycling, soil and water regulation, carbon dynamics, and climate change mitigation [1]. However, the unabatedly increasing global rate of deforestation and forest degradation has resulted in a significant reduction in forest cover, thereby limiting the capacity of the forests to sustain the provision of these valuable ecosystem goods and services, more prominently in the tropical developing nations [2]. Human activities often referred to as land use, such as mining, logging, urbanization, tourism, overgrazing and agricultural expansion have proximately engendered continual yet considerable loss of forests and their resources through deforestation and forest degradation [3] [4]. These activities are principally associated with the processes of exploiting and converting forest (land) to meet human needs, while exacerbating the reduction of global forest area and their socio-ecological and carbon storage potential [5] [6].

Land use mainly describes a series of ways in which land has been put to use, while the land cover is the physical characteristics of the earth's surface distributed in the form of vegetation, water, soil and other physical features of the land which are created by human activities [7]. Land Use/Land Cover (LULC) is a prominent general term that indicates the modification of the earth's terrestrial surface and the classification of human activities and natural elements on such landscapes. It is a crucial driver of global change [8]. In the past two centuries, the impact of human activities on the land has grown enormously, altering entire landscapes, and ultimately impacting the earth's nutrient and hydrological cycles as well as the climate [9]. The sustainable management of the forest landscapes and their resources and planning for future development requires timely and accurate forest cover change detection and monitoring techniques [10]. In recent decades, Geographic Information System (GIS) and remote sensing have proven crucial, credible and effective in providing precise spatiotemporal information for forest cover dynamics assessment [11]. Most important layers of biophysical, land use/land cover, and socioeconomic information in a GIS database are derived from an analysis of remotely sensed data [12]. Satellite remote sensing significantly facilitates the monitoring, detection, quantification, and mapping of forest cover patterns and changes, because of its repetitive data acquisition, a digital format appropriate for computer processing, and accurate geo-referencing approaches [13] [14].

Globally, there has been a wide range of remote sensing applications as an information resource to support sustainable forest management, based on its potential to acquire synoptic and repetitive biophysical vegetation data for large geographic areas over long periods [15]. The possibility of harnessing remotely sensed data in detecting, assessing, modeling, predicting, and monitoring (past and future) changes in the spatial patterns of forest cover/use across varying temporal scales enhances forest monitoring against degradation [16]. Furthermore, the knowledge of land use/land cover changes allows the comparison of the different ecosystems within and across different countries [17].

Several studies have classified and analyzed LULC changes in different forest ecosystems and landscapes using different multispectral and hyperspectral remote sensing techniques, ranging from the tropics [18] [19] to the temperate [20]. Nigeria's forest landscapes are also not an exemption. Studies have examined LULC dynamics of diverse forest reserves (FRs) across the country, reporting an exasperatingly high rate of continuous forest cover reduction and changes. Examples include Shasha FR [21], Okomu and Gilli-Gilli FRs [22], Ogbese FR [23], Akure FR [24], Osho FR [25], Ago-Owu FR [26], Falgore Game Reserve [27] and Onigambari FR [28]. Overall, Nigeria's forest ecosystems are experiencing massive spatiotemporal changes over the last decades [10] [27], with a 5% net annual forest loss between 2010 and 2015, which is predominantly driven by agricultural expansion, uncontrolled logging, urban expansion, fuelwood and charcoal production [23] [29] [30]. Meanwhile, projections have indicated a likelihood of further intensified forest cover decrease if the needed management practices are not established to forestall the negative trends and degradation.

Oba Hills Forest Reserve uniquely serves as a habitat for biodiversity and a vital source of local subsistence and livelihoods [31]. However, increased population and rural migration have been identified as the major biotic activity and a significant factor of forest overexploitation and conversion in Osun state where Oba Hills Forest Reserve is located [31] [32]. In addition, [33] reported high participation of women in wood extraction in the reserve, spurred by the absolute dependence on fuelwood as the primary energy source for residents in and around the forest. Despite these reports and observations, there was a dearth of precise, up-to-date spatial information about the resultant impact of the degrading forest land uses and the status of the protected reserve. Recently, [34] assessed and reported tremendous changes in the forest land. However, land use classes like built-up areas were not identified and considered in their classification and change detection analysis, despite the claim and observation of increased population and settlement expansion around the forest area. An uncontrolled surge in rural settlements poses significant, critical impact on the deforestation and loss in forest cover and resources [35]. Therefore, this study aimed at evaluating the LULC changes in Oba Hills Forest Reserve over 22 years, using a multispectral remote sensing approach, bearing in mind the imperativeness of settlement and rural development in forest cover dynamics, amongst other anthropogenic factors.

2. Methodology

2.1. Study Area

The study was carried out in Oba Hills Forest Reserve, Ola-Oluwa Local Government Area of Osun state, South-western Nigeria. Oba Hills Forest Reserve is a small enclave that covers an area of about 52 km^2, encompassing and surrounded by five hills with a wide valley running between. It lies roughly between latitudes 7˚68' and 7˚83'N, and longitudes 4˚06' and 4˚14'E with an elevation of 253 meters above sea level (asl) [31] (**Figure 1**). The reserve is bounded by Ejigbo Local Government Area in the Northern part and Iwo Local Government Area in the Southern part. The vegetation of Oba Hills Forest Reserve encompasses a mixed rainforest of high trees and shrubs, including teak plantations, woodland habitats and fragments of degraded riparian forests. The climate is tropical humid, characterized by distinct wet and dry seasons. The wet season is typically from April to October while the dry season spans November till March [31]. The average annual temperature and rainfall are 27˚C and 1325 mm, respectively [36].

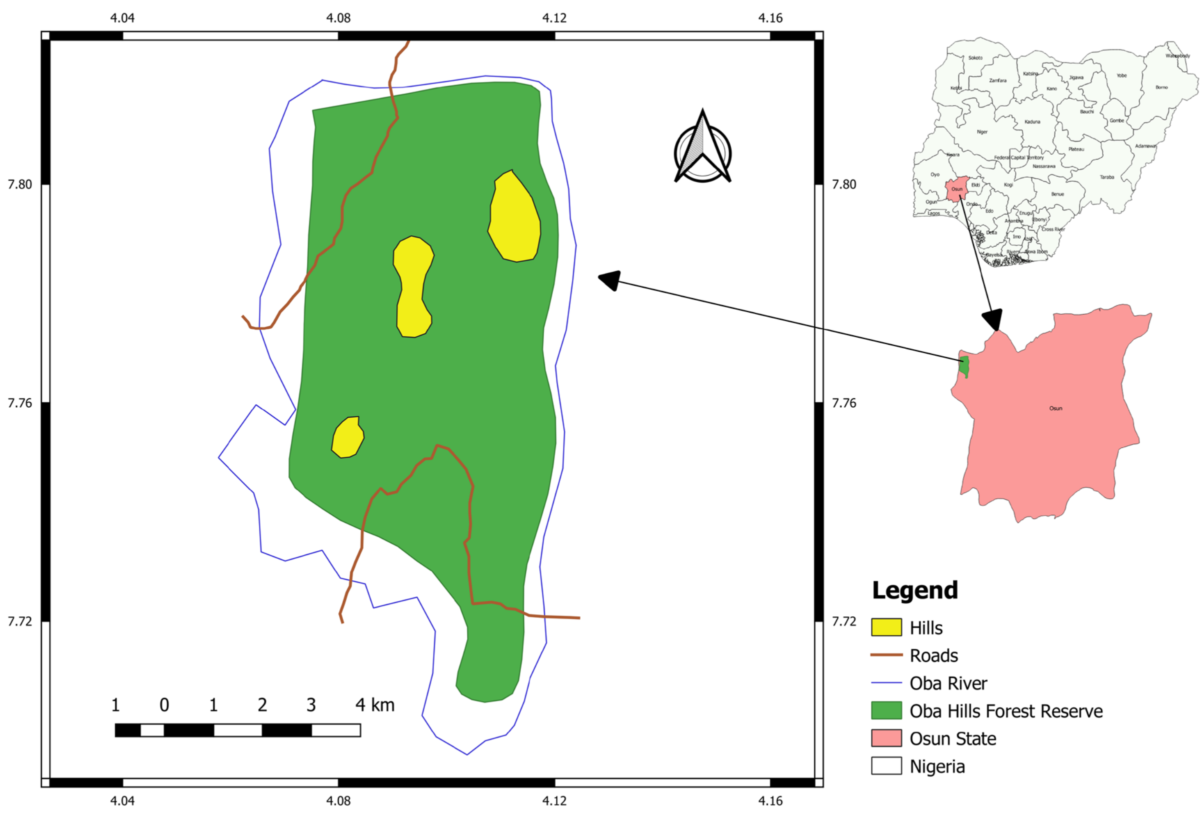


Figure 1. Map of Oba hills forest reserve.

2.2. Image Selection and Ground Truthing

The satellite imagery used for the study was obtained from the official website of USGS (United States Geological Survey) Earth Explorer. The Landsat images employed were of path and row 191/55, covering some parts of Osun and Oyo state, where the study area lies. These images included Landsat TM (Thematic Mapper) for 1987 and 2001, ETM+ (Enhanced Thematic Mapper Plus) for 2013 and Operational Land Imager/Thermal Infrared Sensor (OLI/TIRS) for 2019. The selection of these four satellite images was influenced by the importance of assessing the land use land cover dynamics over a wide temporal range as well as the accessibility of images with negligible cloud effects. It was ensured that the images had little or no cloud cover. **Table 1** summarizes some attributes of the images. The confirmation of the observations made on the satellite images was further done through ground truthing. This was actualized with the data collected on the vegetation cover, land use land cover types and the topography of the study area from several locations by GPS (Global Positioning System). Such a process resulted in a more accurate sample training and validation of the predetermined, distinguishable land cover classes in the forest reserve, as described in **Table 2**. It was also supported by Google Earth Pro's high-resolution real-time satellite images. The forest reserve's cover lacks a distinct waterbody within the area, but it is surrounded by a river located outside of its boundary (**Figure 1**). In addition, about 3350 point coordinates were obtained from the study area for the purpose of developing the Digital Elevation Model (DEM).

Table 1. Characteristics of the Landsat satellite images acquired.

Satellite	Sensor	Path/Row	Cloud coverage (%)	Acquisition date	Spatial resolution	Source
Landsat 5	TM	191/55	0.00	08-01-1987	30 m	USGS
Landsat 7	ETM+	191/55	0.00	09-12-2001	30 m	USGS
Landsat 8	OLI/TIRS	191/55	0.00	18-12-2013	30 m	USGS
Landsat 8	OLI/TIRS	191/55	0.00	01-01-2019	30 m	USGS

Table 2. Land cover classes in Oba Hills Forest Reserve and their descriptions.

Land cover class	Description
Forested	This encompasses teak plantations, woodland habitats, and fragments of degraded riparian forest
Bare land	This includes areas used for agricultural activities, sandy areas, barely exposed rocks, open land, transitional areas and areas covered with scanty grasses
Built-up	This captures the buildings and farm sheds in the forest reserve

Adapted from [37].

2.3. Image Pre-Processing, Classification and Change Detection

The pre-processing, classification and analysis of the raster images acquired were conducted in the QGIS v.3.8 environment, with the schematic workflow presented in Figure 2. Before the classification, it was necessary to first carry out certain corrections and conversion. Since the Landsat data were obtained in DN (Digital Numbers) format, the DN values for all the considered raster bands had to be converted to Top of Atmosphere reflectance (TOA), which measures the ratio of reflected and incident energy on a surface. This was followed by a geometric correction, whereby the images were geo-referenced and registered to the appropriate coordinate reference system. Afterwards, the required raster bands of the respective images (Bands 4, 3, and 2 for Landsat TM and ETM+; and Bands 5, 4, and 3 for OLI/TIRS imagery) were selected and stacked, following [21] and [23]. This was to allow the derivation of the desired composites, for further false-colour compositing. The false colour composites were derived by reversing the arrangement of the true-colour band combination such that the vegetated area could noticeably appear as red. This process typically enhances the visualization of near-infrared wavelengths. Followed was the subsetting of the Oba Hills forest reserve from the pre-processed images. This was done by overlaying and clipping the shape file of the study area, being the area of interest, from the resultant false-colour raster composites. The clipped images were subjected to Principal Component Analysis (PCA) to enhance image interpretability, reduce information redundancy, and extract relevant information from the data.

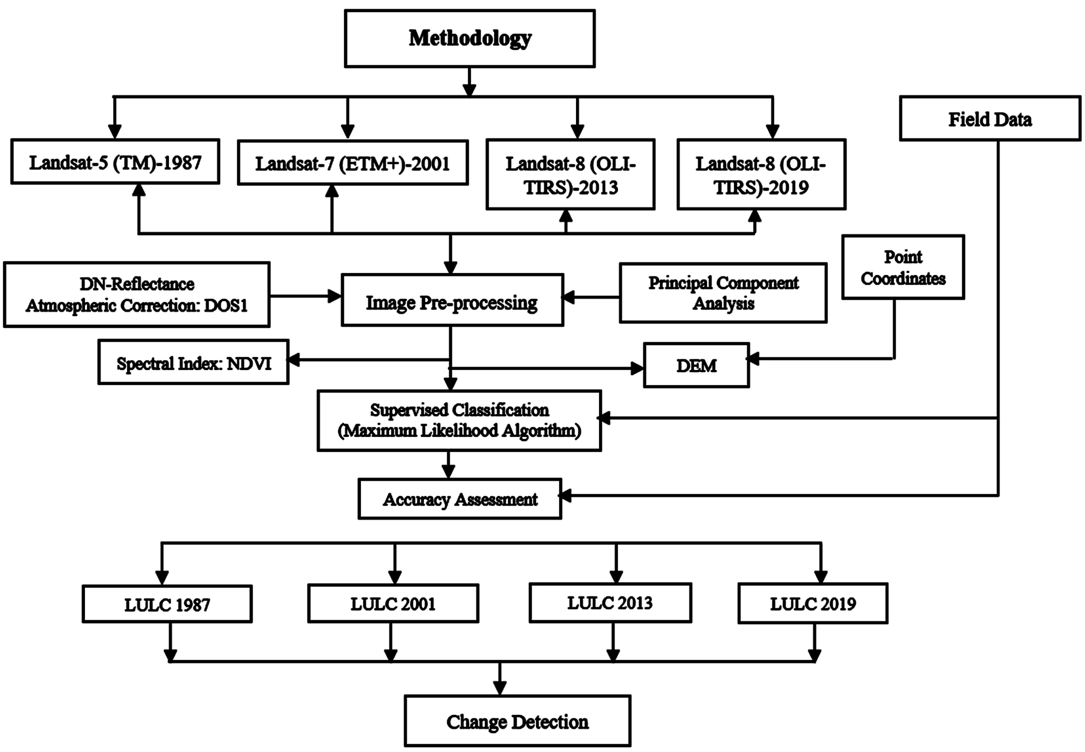


Figure 2. The schematic framework of methodology.

A supervised classification was thereafter conducted using the maximum likelihood algorithm, employing the Semi-automatic Classification Plugin (SCP) plugin in QGIS [38]. About 60 Regions of Interest (ROIs) were created in each image, which were evenly distributed to adequately capture all the land cover classes. The maximum likelihood system helps to determine the likelihood of each raster pixel belonging to any of the predetermined land cover classes and then assigns a pixel to the most probable class considering its spectral signature [39]. It is considered most preferable for LULC change detection than other options like Minimum Distance and Spectral Angle Mapping [40]. The areal extent for individual cover class in each of the assessed images (years) was finally computed from the pixel count. Furthermore, a cross-tabulation analysis, including the comparison of LULC change statistics method, was adopted to map and quantify the pixel changes from one LULC class to another within the epoch frames considered: 1987-2001, 2001-2013, and 2013-2019. The percentage change and rate of change within the given epoch frames were also computed for better comparison using the area (ha) of the LULC classes (Equations (1)-(4)), as similarly adopted in previous studies [21] [23] [41] [42].

$$\%\,\Delta = \frac{\text{OC}}{\text{SC}} * 100 \tag{1}$$

$$\%\,\Delta \text{ in year} = \frac{Y_2 - Y_1}{Y_1} * 100 \tag{2}$$

$$\text{Average Rate of } \Delta = \frac{Y_2 - Y_1}{T_2 - T_1} \tag{3}$$

$$\%\text{ Average Rate of Change} = \frac{\text{Average Rate of Change}(\text{ha/yr})}{\text{Difference in year}} * 100 \tag{4}$$

where, OC = observed change ($Y_2 - Y_1$); ASC = absolute sum of change *i.e.*, fixed year (starting year); $Y_2 - Y_1$ = observed change; Y_2 = ending year; Y_1 = starting year; $T_2 - T_1$ = periodic interval between the initial period and the final period.

2.4. Accuracy Assessment

Accuracy assessment is an important step for evaluating the results of the classification process [37] [38]. The accuracy of the classified images was therefore assessed to ensure the credibility of the output information obtained from the raster data employing stratified random sampling [39] [43]. An error matrix, developed for each investigated year, was used for this assessment. This is widely used for classification accuracy to derive a series of descriptive and analytical statistics [44]. The class-based accuracy evaluation method (including the Producer Accuracy, PA and User Accuracy, UA) and the overall accuracy of the classification images were considered. These were confirmed by the commonest measure, Kappa coefficient (K), which ranges from 0 to 1, where the highest value indicating highest accuracy [39] [45]. K was computed using Equation (5).

$$K = \frac{(\text{TP} \times \text{TCP}) - \sum(\text{Column Total} \times \text{Row Total})}{\text{TP}^2 - \sum(\text{Column Total} \times \text{Row Total})} \tag{5}$$

where, TP is total pixels, and TCP is total corrected pixels.

2.5. Normalized Differential Vegetation Index (NDVI) and Digital Elevation Model (DEM)

NDVI remains a widely used vegetation index and provides information on the amount and vigour of vegetation and forest cover considering the near-infrared (NIR) and visible red bands of the electromagnetic spectrum. In this study, we conducted the NDVI analysis for each of the images (*i.e.*, years of assessment). For TM and ETM+ images, the reflectance radiated in the NIR band 4 (0.77 - 0.90 μm) and the RED band 3 (0.63 - 0.69 μm) was considered, whereas NIR band 5 (0.85 - 0.88 μm) and RED band 4 (0.64 - 0.67 μm) were adopted for the OLI sensor. NDVI was calculated (Equation (6)) using the spectral indices tool in QGIS, consistent with [23] and [39].

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}} \tag{6}$$

where, NIR represents the near-infrared reflectance and RED represents the reflectance in the red band. The NDVI value ranges from −1 to 1. The highest value represents the forested area, while the lowest NDVI value indicates the built-up.

A DEM was developed for the forest reserve using the point coordinates (>3350) obtained at different elevations within the forest. The coordinates obtained were initially saved in Keyhole Makeup Language (KML) format, after which they were loaded into TCX Converter to update and generate the respective elevation data. The interpolated natural neighbour algorithm of SAGA 2.1.2 in QGIS was adopted to generate a Digital Elevation Model following [46]. The contour lines were extracted at an interval of 10 m to generate the topographical map of the study area.

3. Results

3.1. Land Use Land Cover Patterns of Oba Hills Forest Reserve (1987-2019)

The LULC classification of Oba Hills Forest Reserve for the years 1987, 2001, 2013, and 2019 is depicted in **Figure 3**. **Table 3** further presents the area statistics of the LULC patterns for these respective years. In 1987, it was observed that the forested area covered approximately 56% of the total reserve area, spanning around 2773 hectares. This was followed by the bare land, which covered about 43.74% of the land area, occupying an expanse of 2157 hectares. Conversely, the built-up area within the forest reserve was notably smaller, comprising just 0.01% of the entire reserve and encompassing a mere 0.5 hectares. Therefore, the prominent land cover classes during this period were forest and bare land. The utilization of land for settlement within the forest estate was not significant during this year, as per the obtained results. By the year 2001, the forested area exhibited a slight reduction, constituting around 55% of the total forest reserve. However, the forest continued to remain the predominant cover category. The

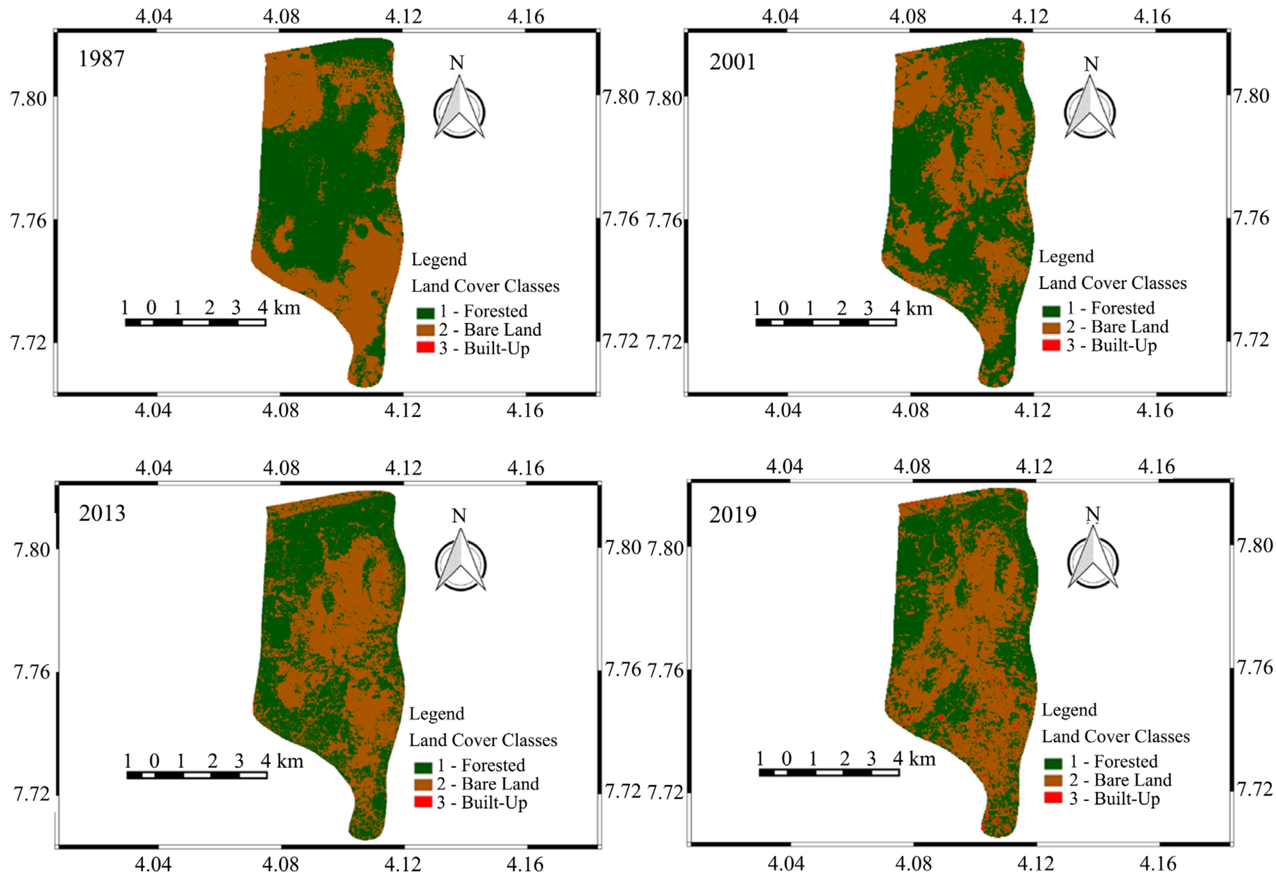


Figure 3. LULC classification of Oba hills forest reserve (1987-2019).

Table 3. Area statistics of the LULC patterns of Oba hills forest reserve (1987-2019).

Class	Land cover in 1987		Land cover in 2001		Land cover in 2013		Land cover in 2019	
	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Forested	2773.17	56.25	2748.78	55.75	2587.26	52.47	2317.77	47.01
Bare land	2156.8	43.74	2162.97	43.87	2322.59	47.11	2554.92	51.82
Built-up	0.50	0.01	18.72	0.38	20.62	0.42	57.78	1.17
Total	4930.47	100	4930.47	100	4930.47	100	4930.47	100

proportion of bare land, on the other hand, experienced a slight increase to 43.87% of the reserve. During this period, activities involving vegetation removal and the expansion of bare land had become evident, leading to the fragmentation of the previously contiguous reserve structure. The built-up area also expanded to 0.38% of the forest reserve, indicating population growth and a slight increase in land use for settlements.

By 2013, the forested area experienced a further reduction to 52.72% of the forest reserve, encompassing 2599 hectares. Conversely, the extent of bare land increased, constituting 46.86% of the reserve and spanning 2311 hectares. In the same vein, the built-up area increased slightly to 0.42% of the reserve (21 ha). As of 2019, the forest cover experienced another decrease, dwindling to 2317 hectares, which represents about 46.8% of the forest reserve. This reduction in vegetation led to a corresponding expansion for bare land, driven primarily by agricultural activities. Relative to the cover proportion observed in 2013, bare land expanded by over 4%, encompassing a total of 2555 hectares (52%) of the entire forest reserve, while the built-up area experienced a rapid surge, increasing from its previous value of 0.42% to approximately 1.2% of the total reserve. Overall, it was noticed that the forested area decreased, which was accompanied by an increase in both bare land and built-up areas.

3.2. Land Use Land Cover Change Detection of Oba Hills Forest Reserve (1987-2019)

The change detection analysis for each land cover category within the Oba Hills Forest Reserve is summarized in **Table 4**, highlighting the extent and rate of change across various epochs. From 1987 to 2001, the forested area decreased by approximately −24 ha, constituting less than −1% of the entire forest reserve, with an average annual reduction rate of −1.74 ha. During this period, the bare land expanded by 6.17 ha, showing an annual increment rate of 0.44 ha. The built-up area exhibited a substantial increase, adding over 18 ha at an increasing rate of 1.30 ha per year. Between 2001 and 2013, the forested area further declined from 55.8% to 52.5%, losing more than −149 ha at an elevated average annual rate of 12.46 ha. In contrast, bare land and built-up areas experienced notable expansion, increasing by 7.38% and 10.13%, respectively, with rates of approximately 13 ha and 0.16 ha per year.

Within the most recent epoch analyzed (2013-2019), a pronounced trend emerged, revealing a considerable forest conversion to bare lands and buildings at a rapid annual rate of −46.92 ha. The forested area underwent a significant reduction, losing over 281 ha during this period. Conversely, bare land (used for agriculture and open grassland) displayed a substantial gain of 232 ha, with an accelerated annual increase of 38.72 ha. Notably, the built-up area within the forest reserve saw a significant rise, expanding by over 37 ha, representing a percentage change of 180% and an annual rate of 6.19 ha. Throughout the entire study period (1987-2019), the forested area experienced a reduction of −16.42%, resulting in a cumulative loss of over −455 ha. The rate of forest decline averaged −14.23 ha per year, leaving a remaining forested area of 2317 ha (47%) of the

Table 4. Changes in land use land cover of Oba hills forest reserve (1987-2019).

Category	Change (1987-2001)			Change (2001-2013)			Change (2013-2019)			Change (1987-2019)		
	Area (ha)	(%)	Avg. Rate (ha/yr)	Area (ha)	(%)	Avg. Rate (ha/yr)	Area (ha)	(%)	Avg. Rate (ha/yr)	Area (ha)	(%)	Avg. Rate (ha/yr)
Forested	−24.39	−0.88	−1.74	−149.51	−5.44	−12.46	−281.50	−10.83	−46.92	−455.40	−16.42	−14.23
Bare land	6.17	0.29	0.44	159.62	7.38	13.30	232.34	10.00	38.72	398.12	18.46	12.44
Built-up	18.22	3644.0	1.30	1.90	10.13	0.16	37.16	180.25	6.19	57.28	11456.0	1.79

total forest reserve. The expansion of bare land amounted to about 398 ha, with the most significant change occurring in the latest epoch. The built-up area exhibited rapid growth, expanding from a mere 0.5 ha to 57.8 ha in 2019, indicating an annual increase of 1.79 ha. Overall, the changes in land cover in the reserve are marked by substantial reductions in forested areas and corresponding increases in bare land and built-up areas.

3.3. Accuracy of LULC Classification of Oba Hills Forest Reserve (1987-2019)

The error matrices for all the classified images of Oba Hills Forest Reserve are presented in **Table 5**, including the results of user and producer accuracies. **Table 6** summarizes the Kappa coefficient and overall accuracy for each evaluation period. The class-based user accuracy mostly fell within the range of approximately 85% - 100%. The majority of the values, accounting for 66%, were above 95%, with only one value falling below 85% recorded in the 2019 OLI/TIRS classified image, particularly in the built-up area. However, this low user accuracy value was compensated by its perfect producer accuracy. Similarly, the majority (~83%) of the producer accuracy values for the classification were impeccable or

Table 5. Accuracy assessment (error matrix) for supervised LULC classification of Oba hills forest reserve (1987-2019).

Year	Class	Forested	Bare land	Built-up	Total	User accuracy (%)	Producer accuracy (%)
1987	Forested	1736	305	0	2041	85.06	100.00
	Bare land	0	727	0	727	100.00	70.50
	Built-up	0	0	3	3	100.00	100.00
	Total	1736	1032	3	2771	285.06	270.50
2001	Forested	1371	13	0	1384	99.06	99.56
	Bare land	6	1356	7	1369	99.05	98.98
	Built-up	0	1	17	18	94.44	70.83
	Total	1377	1370	24	2771	292.55	269.37
2013	Forested	1371	13	0	1384	99.06	99.56
	Bare land	6	1356	0	1362	99.56	98.98
	Built-up	0	1	24	25	96.00	100.00
	Total	1	1370	24	2771	294.62	298.54
2019	Forested	1337	56	0	1393	95.98	93.69
	Bare land	82	1202	0	1284	93.61	94.05
	Built-up	8	20	66	94	70.83	100.00
	Total	1427	1278	66	2771	260.42	287.74

Table 6. Overall accuracy and Kappa coefficient of supervised LULC classification (1987-2019).

Year	Overall accuracy (%)	Kappa accuracy
1987	89.00	0.75
2001	99.03	0.98
2013	99.28	0.99
2019	94.01	0.89

nearly perfect, with only two values approximately around 71%, observed for bare land and built-up areas in 1987 and 2001, respectively. The forested area category consistently recorded the highest user and producer accuracies across the evaluation periods. Overall, our classification was accurate and valid, as further justified by the overall accuracy and Kappa measures. We observed excellent overall accuracy rates of 89.00%, 99.03%, 99.28%, and 94.01% for the years 1987, 2001, 2013, and 2019, respectively. Additionally, satisfactory Kappa coefficients of 0.75, 0.98, 0.99, and 0.89 were obtained for the same years. The (2001) ETM+ and (2013) OLI/TIRS images recorded the highest overall accuracy, while the oldest (1987) TM image had the lowest.

3.4. NDVI Analysis of Oba Hills Forest Reserve (1987-2019)

The maps depicting the predominant vegetation index used for vegetation mapping, namely NDVI, of the Oba Hills Forest Reserve are shown in Figure 4. These maps illustrate the greenness and corresponding NDVI values across the assessed epochs spanning from 1987 to 2019. The overall NDVI values for the forest reserve varied from 0.52 to −0.38 during the years of assessment. Low positive values indicated sparse vegetation or bare land, while negative values represented built-up areas and rocky outcrops. Relatively high positive values corresponded to forested areas. The distribution and reduction of NDVI values, leading to the disappearance of green colour from 1987 to 2019, substantiate the ongoing loss of forest cover and vitality within the forest reserve. This trend aligns with the results of the land cover change detection analysis presented in Table 4. In 1987, the NDVI values reached a maximum of 0.52, which gradually declined over the subsequent years, reaching 0.44 by 2019. Similarly, the minimum NDVI values decreased from −0.01 in 1987 to −0.38 by 2019. Areas with negative and low positive NDVI values, typically denoted by a yellow color, expanded significantly over the years. This expansion vividly demonstrates the notable increase in built-up and bare land within the forest area, particularly over the last two decades.

3.5. Digital Elevation Model (DEM) of Oba Hills Forest Reserve

A Digital Elevation Model (DEM) and a topographical map were generated for Oba Hills Forest Reserve, as depicted in Figure 5. Table 7 presents a summary

Table 7. Descriptive statistics of DEM of Oba hills forest reserve.

Statistics	Elevation (asl)	Category of Elevations	Frequency	Percent
No. of observations	3357	Low (291 - 350)	3038	90.5
Mean	278.190	Medium (351 - 480)	258	7.7
Standard Error	1.266	High (481 - 602)	61	1.8
Median	261.394	Total	3357	100.0
Mode	236.268			
Std. Deviation	61.474			
Skewness	2.383			
Kurtosis	6.586			
Std. Error of Kurtosis	0.101			
Range	382.414			
Minimum	219.078			
Maximum	601.492			

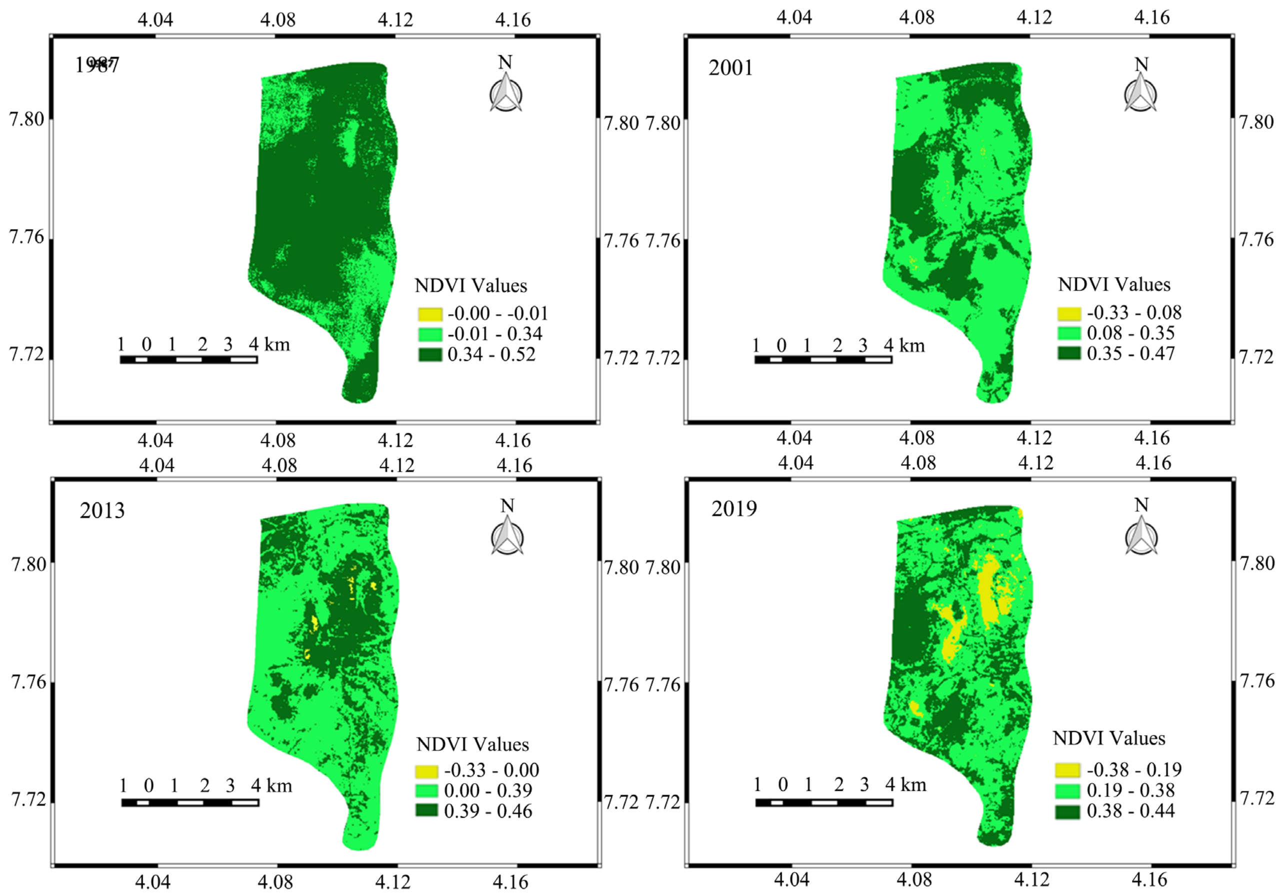
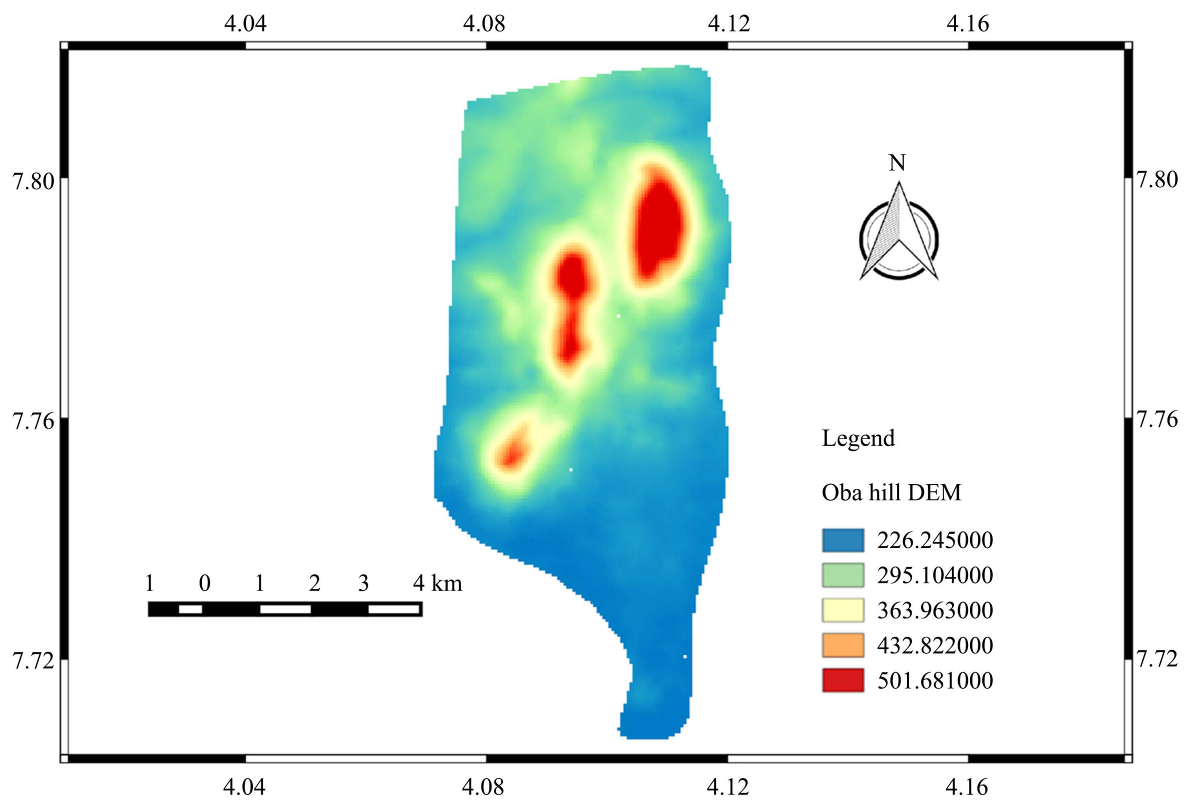
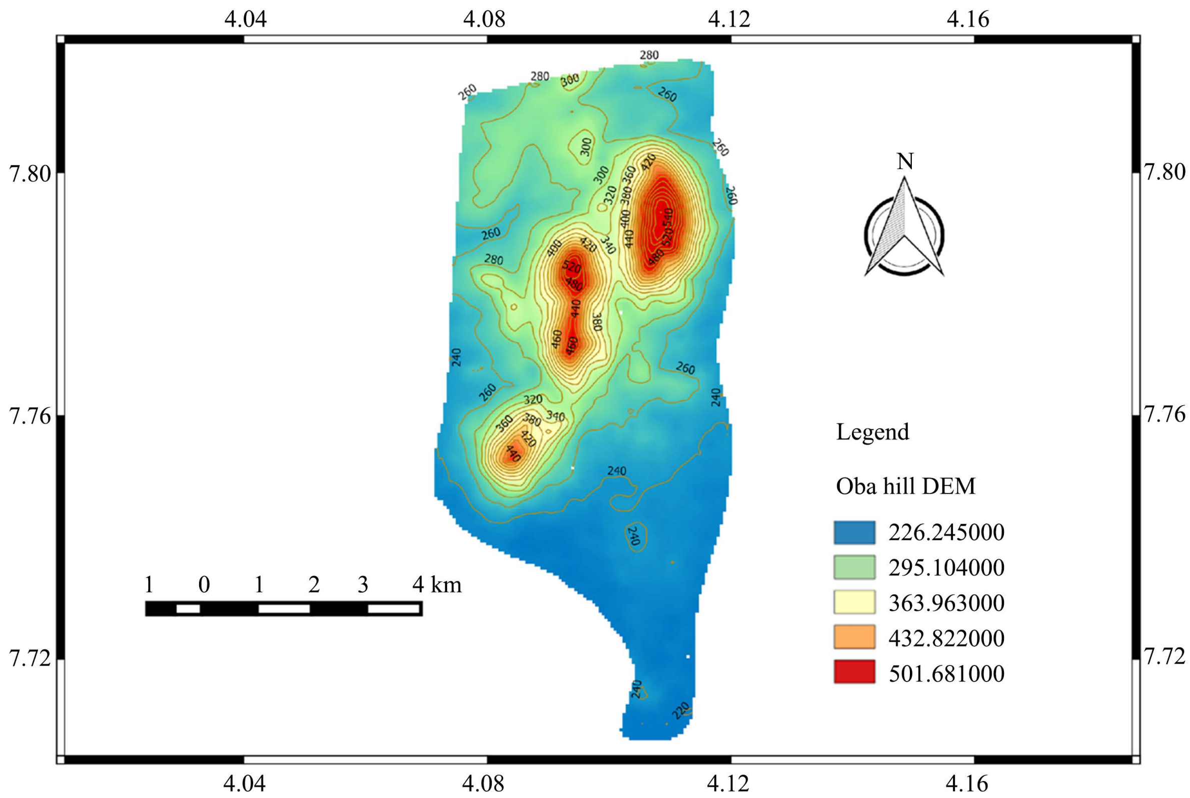


Figure 4. NDVI maps of Oba hills forest reserve (1987-2019).



(a)



(b)

Figure 5. (a) Digital elevation model and (b) Topographical map of Oba hills forest reserve.

of the descriptive statistics for the DEM. Elevations within the reserve spanned from 219 meters above sea level (asl) to 601 meters asl, with a mean elevation of 278.2 meters asl. The total number of 3357 point coordinates was obtained for the DEM. The distribution of elevations is also detailed in **Table 7**. The positive skewness of the elevation distribution indicates a greater prevalence of lower elevations compared to higher ones. As illustrated in **Figure 5**, the colour gradient transitions from blue, representing lower elevations, to red, signifying higher elevations. A notable 90.4% of elevations fall within the range of 219 to 350 meters asl, constituting the lowest elevation range. Medium elevations, ranging from 351 to 480 meters asl, cover about 7.7%, while high elevations between 481 and 602 meters asl are present. Higher elevations are primarily concentrated towards the central and upper-right portions of the reserve. Additionally, the topographic map of the study area offers further insight into the reserve's terrain. It reveals pronounced steepness in the vicinity of higher elevational zones, as evidenced by closely spaced contours.

4. Discussion

Oba Hills Forest Reserve exhibits distinct land use/land cover classes, namely Forest, Bare land, and Built-up. The Bare Land category encompasses areas previously covered by forests that have been converted for agricultural activities, along with sandy areas, exposed rocks, open land, transition zones, and areas with sparse grasses. Over decades, global concern has grown over the reduction in forest area due to population growth and human activities on forest land, particularly across tropical regions. This includes the conversion of forest land for non-forest uses [4] [47] [48]. Oba Hills Forest Reserve is not exempt from this recurring phenomenon, as its forest cover has progressively diminished over the years. Analysis of land use/land cover patterns within the reserve reveals that the forested area decreased from 2773.17 ha in 1987 to 2317.77 ha in 2019, translating to a loss of 455.4 ha over a 32-year period. Despite its designation as a protected forest, the reserve experiences a remarkably high average rate of forest cover loss, equivalent to 14 hectares per year. This reduction in forested area has facilitated an increase in bare lands over time, with the area of bare land surpassing that of forest cover and accounting for nearly 52% of the entire reserve by 2019. The Oba Hills Forest Reserve is characterized by conglomerates of rocks, with some areas expected to be forested instead naturally covered with rocky outcrops. This phenomenon has likely contributed to the significant share of bare land cover (approximately 43%) since 1987, aside from early anthropogenic degradation factors. The analysis, corroborated by ground truthing, indicates that the bare land category, including converted agricultural lands, open soil, and grassland, has considerably expanded over the years. The area increased from 2156.8 ha in 1987 to 2554.92 ha in 2019, reflecting a gain of over 398 ha.

Accuracy assessment plays a vital role in both land cover classification and change detection analysis, as it enables us to evaluate the validity and accuracy of the produced maps by assessing errors within each class and across the entire classified image [38] [49]. To achieve an excellent land cover classification, it is recommended to target a standard accuracy range of 85% - 100% [37]. Our analysis demonstrates outstanding classification results, with consistently high overall accuracy rates ranging from approximately 89% to 99% and satisfactory Kappa coefficients within the range of 0.75 to 0.99 across the evaluation periods. These accuracy ranges confirm the excellent and valid classification of the study area's LULC, which can be attributed to the use of the supervised Maximum Likelihood classification technique that is widely recognized for its very high accuracy level compared to other classification algorithms such as the minimum distance classifier [50]. This technique has been adopted in various land cover mapping studies [39] [45]. Our accuracy results for Oba Hills Forest Reserve closely align with those observed in these studies.

NDVI remains a crucial remotely sensed vegetation index for assessing the qualitative and quantitative dynamics of vegetation cover and vitality [39] [51]. Our NDVI analysis of the vegetation dynamics of Oba Hills Forest Reserve confirms an escalating increase in bare land and built-up areas, paralleled by a commensurate decline in forest cover. This trend is evident through decreasing NDVI values over the years, signifying a progressive depletion in the health, growth dynamics, and vegetation density of the forest reserve. The distribution of NDVI values we obtained (−0.38 to 0.52) aligns with findings from similar studies, e.g., [23] [39] [42].

As the livelihood needs forest-dependent communities rise, there is a likelihood of further transitioning the reserve for agricultural activities. Agriculture serves as the primary source of livelihood for surrounding communities, driving demand for land for agricultural and grazing activities as well as increasing need for fuelwood and timber for energy and household uses. This exacerbates forest depletion within the reserve [34]. Agriculture has been observed and reported to be a major driver of deforestation in most reserves, especially in southwestern states of Nigeria, owing to the richness of the soil, the relatively supporting climatic conditions and the high distribution of people with farming as their primary production [52]. Similarly, [21] observed that anthropogenic activities such as forest conversion to farmland, grassland, bare land, and built-up areas led to immense reduction in forest ecosystem in Shasha forest reserve. Consequently, forest cover loss is often offset by gains in other land use/land cover categories. [23] reported the complete depletion of natural forest cover and increasing loss of remnant plantation forests at −0.18% km^2/yr, attributed to excessive timber felling without reintroduction, fires, and high dependence of communities on forest lands for subsistence, as well as inadequate forest monitoring. Land cover change studies across Southwest Nigeria, including [10] and [30], emphasized direct factors like crop cultivation, lumbering/commercial logging, fuelwood and polewood extraction, and charcoal production contributing to considerable deforestation and forest degradation rates in the region. [53] further asserted that most forest reserves in the country were on the verge of disappearance. Such increasing forest cover losses directly impact biodiversity and climate change, increase risks of soil erosion and drought, as well as limit livelihood potentials of the people. It therefore becomes essential to improve forest monitoring, tackling the drivers of deforestation, while developing effective co-management strategies that encourage local community participation in forest management and conservation efforts.

The issue of forest conversion for settlements has become prominent around the world, exacerbated by population growth, urbanization, human migration and intrusion, and increasing pressure of rural communities to meet their habitation needs [30] [39] [42] [54]. While settlement expansion in forested areas may not have been reported or considered a substantive challenge and cause of forest cover loss in some extremely isolated or risky areas, as reported by [23], it has generally driven deforestation and forest loss [35] [54]. Such a trend has been observed in Oba Hills Forest Reserve as evidenced by increased built-up areas, contrary to the mapping findings of [34] in the reserve. The encroachment of settlements in forest ecosystems threatens further forest depletion, as it provides access for encroachment, illegal land grabbing, and degrading activities. The rise in built-up areas within the forest, from 0.50 ha to over 57 ha between the assessment years, underscores this concern. Such trends were similarly observed in other studies conducted in some forests in South-west Nigeria [55] and a protected area in Bangladesh [39], where they reported remarkable forest cover changes most predominantly due to settlement intensification and rural migration.

The digital elevation model (DEM) provides critical insights into terrain and elevation, which are vital environmental considerations for vegetation growth and forest management planning [56]. Oba Hills Forest Reserve has a very hilly terrain, depicted in the topographical map. Such a terrain may contribute to erosion and soil nutrient loss, hindering forest growth and regeneration and reducing vegetation diversity. The presence of extensive low-vegetation and deforested areas surrounding the hills corroborates this observation. From another perspective, as noted by [57], higher elevation areas typically experience lower temperatures, leading to shortened growing seasons and elevated precipitation levels along the altitudinal zone. These microclimates might have contributed to the significant encroachment of this region by farmers engaging in food crop production. Nevertheless, depending on which scenario is more relevant, proper forest management decisions and monitoring measures, guided by the DEM, are imperative to mitigate further degradation within the forest reserve.

5. Conclusions and Recommendations

This study delineated the main components of the Land use Land cover in Oba Hills Forest Reserve, extending beyond the forested land category. It encompasses built-up areas and bare land, which aggregates various land types such as agriculture, grasslands, open soil, and rocks. The reserve's distinct hilly terrain features rocky outcrops that contribute significantly to the composition of bare land, which has constituted a substantial portion of the forest reserve since 1987. However, notable changes in the land cover of the forest reserve have emerged between 1987 and 2019. A considerable portion of the previously forested land has been converted into non-forest land uses, predominantly bare land and built-up areas for buildings, farming structures and sheds. Remarkably, these changes occurred at a concerning rate of −14.2 hectares per year during the assessment period, primarily attributed to anthropogenic activities, involving deforestation and degradation of the forest cover, aggravated by the rugged, erosion-prone landscape. The observed changes can be traced to activities like indiscriminate tree felling, agricultural expansion, and settlement expansion within certain parts of the reserve, potentially leading to significant impacts on biodiversity, climate patterns, and local livelihoods. Nonetheless, although less noticeable through the classification mapping, our ground surveys have confirmed recent reforestation efforts in some previously deforested areas of the reserve. The outcomes of the LULC change analysis and the resulting maps from this study, therefore, serve as crucial decision-support tools for guiding reforestation and conservation initiatives. The developed digital elevation model (DEM) for the reserve further offers terrain insights that can guide strategies to mitigate environmental degradation risks inherent in such vulnerable forested terrains.

To ensure effective and sustainable management of the forest reserve and mitigate further forest losses to alternative land uses, proactive measures must be taken. Strategies include curbing illegal tree felling and agricultural encroachments through co-management strategies that foster community engagement and implementing robust monitoring and surveillance practices. Legislative measures should also be established to discourage unauthorized encroachments by farmers, herders, and poachers. Consequently, it is imperative for the state government to formulate and enforce effective policies for the sustainable management of the reserve. To avert potential flooding in the reserve and surrounding communities, proper forest management practices are essential. These practices should control the pace of deforestation and promote extensive reforestation and regeneration programs, thoughtfully considering the areas encompassing the hills to prevent future erosion and flooding risks. Lastly, a consistent monitoring mechanism must be established for the reserve, during and after the restoration process. Advanced monitoring tools such as higher resolution satellite imagery from sources could be utilized to swiftly detect future changes within the reserve.

Acknowledgements

We are grateful to the Department of Social and Environmental Forestry at the University of Ibadan for the technical support towards the geospatial analysis of this work. Our appreciation also goes to Osun State Ministry of Environment, Osogbo for allowing us to carry out this study in the reserve. We also thank the anonymous reviewer who provided some review comments and feedback on the initial draft of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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