Geospatial modelling of Forest Canopy Density and Landscape Assessment in Omo Biosphere Reserve, South-western Nigeria

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Abstract

Forest has an important role in the global carbon cycle that covers over one-fourth of the world's geographical area. It is one of the major natural resources and magnificent terrestrial ecosystems of the world. Forest Canopy Density (FCD) is imperative in the assessment of forest status and is a primary indicator of potential management interventions. Landsat images of 1990 and 2018 were used in this study. Remote Sensing has demonstrated to be very cost-effective in mapping and monitoring changes in forests, and other environmental issues. Forest cover change and fragmentation were analysed using FCD and Landscape metrics. The FCD was obtained from the combination of data from the Advance Vegetation Density Index (AVI), Bare Soil Index (BI), and Forest Shadow Index (FSI). Four categories of change were identified in the reserve, no change, growth, degradation and deforestation. There was no change in 222.57 ha (52.98%), growth had 81.54 ha (0.69%), degradation with 116.01 ha (27.61%) and deforestation with the least change with 0.81 ha (0.19%). Degradation with a change rate of 0.97% contributed more in terms of change. There is a slight increase in the values of the three diversity indices (SHDI, SHEI, SIDI) while a high degree of homogeneity is recorded in the no forest class and the three others classes were fragmented. Understanding the dynamics of the forests is important in mitigating climate change and support for biological resources.

Keywords: *FCD, landscape metrics, deforestation, degradation, fragmentation*

1. Introduction

The management of forests as carbon reservoirs could support the protection of biological resources such as water, soil, habitat, and raw materials, etc. (Thornley et al., 2000). Forest conservation and sustainable forest management are key in mitigating climate change at all scales. Farming, industrialisation, urbanisation and mining activities have caused the loss of large forest areas resulting in a high rate of deforestation and forest degradation. Forest areas, forest density and greenness of an area are major issues for the ecosystem, biodiversity and so on (Banerjee et al., 2014).

Forest maps are an effective tool for identifying the state of forest resources and monitoring ongoing spatial processes in forested landscapes. One of the most important forest properties is the canopy cover and it provides habitats for many animal species (Akike et al., 2016).

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Conventional remote sensing methodology is based on qualitative analysis of information derived from “training areas” (*i.e.* ground-truth). This has certain disadvantages in terms of the time and cost required for training area establishment, and the accuracy of the results obtained. In response to these problems, a new methodology was developed during ITTO Project PD 32/93 Rev. 2 (F), “Rehabilitation of Logged-over Forests in Asia-Pacific Region, Sub-project III” (Rikimaru et al., 2002). The Forest Canopy Density (FCD) Mapping and monitoring Model utilizes forest canopy density as an essential parameter for the characterization of forest conditions. FCD data indicates the degree of degradation, thereby also indicating the intensity of rehabilitation treatment that may be required (Rikimaru, et al., 2002). Forest cover analysis is the first step in assessing forest fragmentation, as forest cover modifies the fragmentation pattern. There is link between forest fragmentation with forest cover changes (Gupta et al., 2018).

Landscapes are spatial entities of the earth’s surface explicitly defined by their structure, function and composition. They are dynamic geographical units composed of various structured elements that interact at different scales and ranges (Rajendran et al., 2015). Unlike traditional the ecosystem concept, the landscape concept focus on spatial heterogeneity and its impact on the ecological processes. The ecological processes that maintain complex landscapes at one scale can be different from other scales. Understanding the dynamism of landscape characteristics is vital for ecological stability and biodiversity conservation (Rajendran et al., 2015). Remote Sensing has demonstrated to be very cost-effective in mapping and monitoring changes in forests, and other environmental issues (Wang et al., 2009).

The focus of this study is to access the forest canopy density and landscape pattern of Omo biosphere reserve with specific objectives: (i) to examine the forest cover change between 1990 and 2018 using the forest canopy density model; (ii) to examine the rate of forest cover change; (iii) to analyse the forest landscape characterisation using landscape metric model within the study area.

2. Methodology

2.1 The study area

Omo Forest Reserve, which derives its name from River Omo that traverses it, is located between latitudes 6^{o} 42' to 7^{o} 05' N and longitude 4^{o} 12' to 4^{o} 35' E (Figure 1) Ogun state South-western Nigeria. Omo covers about 130 500 ha, which includes a 460 ha Strict Nature Reserve established in 1977 known as Omo Biosphere (Okali and Ola-Adams, 1987).

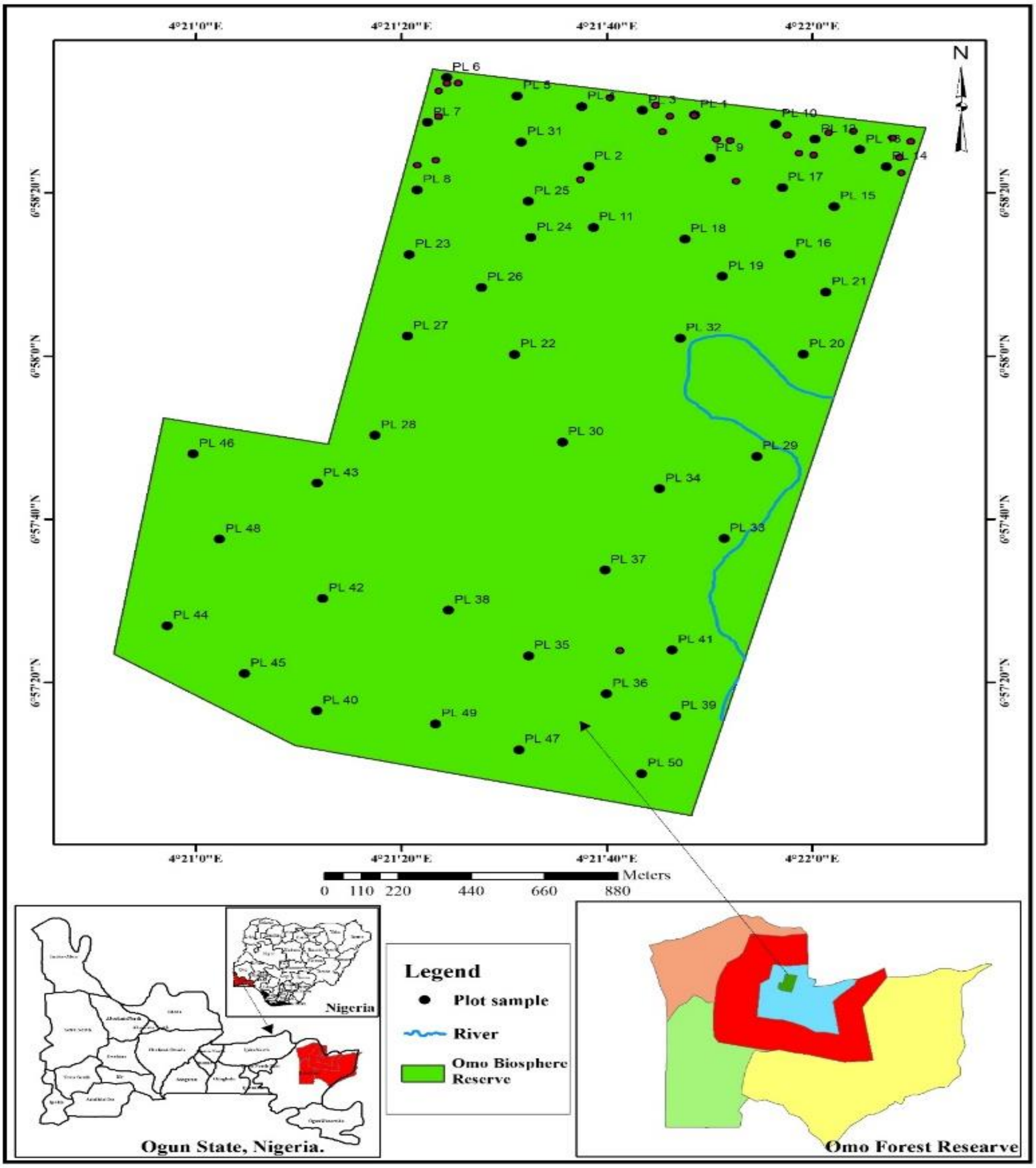

Figure.01. Location of Omo Biosphere Reserve in Omo Forest Reserve South-western Nigeria

The climate is tropical and it is characterized by wet (February to November) and dry (December and January) seasons. The temperature ranges between 21-34 °C while the annual rainfall ranges between 150 and 3000 mm (Larinde *et al*., 2011; Adedeji *et al*., 2015).

2.2 Data acquisition and analysis

Landsat satellite images of 5th January 1990 (Landsat TM) and 19th January 2018 (Landsat 8 OLI) in path 190 and row 55, were acquired from the official website of the United States Geological Survey (USGS). The satellite images obtained were subjected to radiometric calibration to adjust the data for use in quantitative analysis (Agbor et al., 2017). The images used in this study were first converted to Top of Atmosphere (TOA) radiance using equation 1 (Giannini et al., 2015).

$$L\lambda=\left(\frac{(L_{MAX}\lambda-L_{MIN}\lambda)}{Q_{CAL}\lambda}\right)Q_{CAL}+L_{MIN}\lambda \tag{1}$$

The above expression does not consider the atmospheric effects, therefore there is a need to convert images from radiance to reflectance measures, using equation 2 ((Giannini *et al*, 2015).

$$\rho^{\lambda}=\frac{\pi * TOA\mathrm{r} * \mathrm{d}^{2}}{\mathrm{E}_{\mathrm{Esun}^{\lambda}} * \mathrm{Cos}\,\theta_{sz}} \tag{2}$$

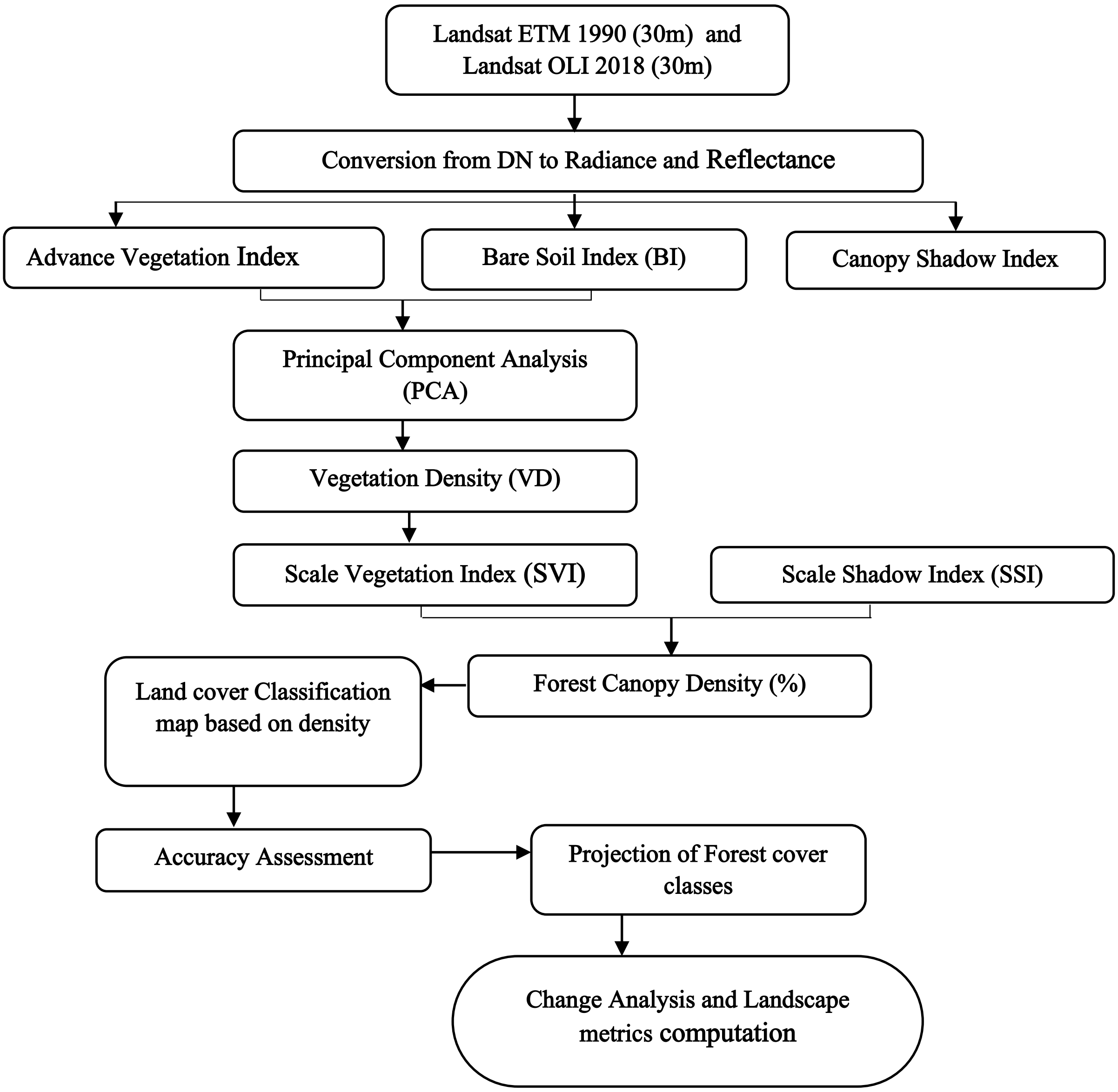

Figure 02. Flow Chart of the Methodology

2.2.1. Forest Canopy Density Model

The Forest Canopy Density model utilizes forest canopy density as an important parameter for the assessment of forest conditions. This model involves bio-spectral phenomenon modelling and analysis utilizing data derived from four indices (Azizia, 2008 and Akike, 2016): Advanced Vegetation Index (AVI), Bare Soil Index (BI), Shadow Index or Scaled Shadow Index (SI, SSI) and Thermal Index (TI) (Azizia, 2008 and Akike and Samanta, 2016). The four indices were calculated using equations 3 to 8.

2.2.2. Advanced Vegetation Index (AVI)

This index was calculated using Equations 3 and 4 (Azizia, 2008 and Akike et al, 2016).

$$\mathrm{AVI} = \sqrt[3]{\{(\mathrm{B6}+1)(65536-\mathrm{B4})(\mathrm{B5}-\mathrm{B4})\}} \text{ for OLI (Landsat 8)} \tag{3}$$

Or

$$\mathrm{AVI} = \sqrt[3]{\{(\mathrm{B5}+1)(256\text{-}\mathrm{B3})(\mathrm{B5}\text{-}\mathrm{B3})\}} \text{ for ETM (Landsat 5 or 7)} \tag{4}$$

2.2.3. Bare Soil Index (BI)

BI was calculated using equations 5 and 6 (Akike et al., 2016 and Saei et al., 2000).

$$BI = \frac{(B6+B4)-(B5+B2)}{(B6+B4)+(B5+B2)} * 100 + 100 \text{ for OLI (Landsat 8)} \tag{5}$$

Or

$$BI = \frac{(B5+B3)-(B4+B1)}{(B5+B3)+(B4+B1)} * 100 + 100 \text{ for ETM (Landsat 5 or 7)} \tag{6}$$

2.2.4. Shadow Index (SI)

SI was calculated using equations 7 and 8

$$\mathrm{SI} = \sqrt[3]{((65536+\mathrm{B2}) * (65536\text{-}\mathrm{B3}) * (65536\text{-}\mathrm{B4}))} \text{ for OLI} \tag{7}$$

Or

$$\mathrm{SI} = \sqrt[3]{((65536+\mathrm{B1}) * (65536\text{-}\mathrm{B2}) * (65536\text{-}\mathrm{B3}))} \text{ for ETM} \tag{8}$$

The source of thermal information is the infrared band of Landsat data (bands 6 and 10). Land Surface Temperature (LST) retrieval was carried out through three phases (Giannini et al., 2015). All the image bands are quantized as 8-bit data except Landsat 8 which is 16 bit, thus; all information is stored in DN which were then converted to radiance with a linear equation (9) given as:

$$Y = mx + b \tag{9}$$

Where:
Y=TOAr (Top of Atmosphere) radiance-the radiance measured by the sensor
m=Radiance multiplicative value
x=Raw band
b=Radiance additive value

By applying the inverse of the Planck function, thermal bands radiance values were converted to a brightness temperature value using equation 10 (Giannini et al., 2015). This is satellite temperature in Kelvin.

$$BT = \frac{k2}{\left(\ln\left(\frac{k1}{TOAr}+1\right)\right)} \tag{10}$$

Where:
BT=º Kelvin
TOAr=Top of Atmosphere radiance
K1=calibration constant 1 (607.76 for TM), (666.09 for ETM+) and (774.89 for OLI band 10)
K2=calibration constant 2 (1260.56 for TM), (1282.71 for ETM+) and (1321.08 for OLI band 10)
Surface temperature=BT–273.15

2.2.5. Vegetation density (VD)

The principal component analysis was used to calculate the vegetation density (VD) by synthesizing Advanced Vegetation Index with the Bare Soil Index. The value was scaled from 0 to 100%. The 100% shows the area of the high forest while the 0% indicate the areas of no vegetation (Rikimaru, 1996; Saei and Abkar, 2004).

2.2.6. Scaled shadow index (SSI)

SSI is was calculated from the Canopy shadow index (SI) by using a linear transformation. The value of SSI was also scaled from 0 to 100%. SSI by 100% responds with the highest possible shadow whereas 0% responds the opposite. SI is important in forestry and crop monitoring because the canopy shadow provides some information on tree and plants arrangement.

2.2.7. Integration process to achieve FCD model

Integration of VD and SSI means transformation for forest canopy density value. Both parameters have dimensions and have percentage scale units of density. It is possible to synthesize both indices safely by employing the corresponding scale and unit of each. FCD was calculated using equation 11.

$$FCD = \sqrt{(SVD * SSI + 1)} - 1 \tag{11}$$

2.3. Landscape Metrics and Diversity Analysis

Several studies in landscape ecology emphasized the use of spatio-temporal satellite data along with landscape metrics in landscape evaluation and policymaking. Remote Sensing data will be primarily utilized to create the necessary database for two time periods, 1990 and 2018. Landscape Metrics and Diversity Analysis.

The LecoS plugin in Quantum GIS (QGIS) was used for the land metrics and diversity analysis. The result of the Forest Canopy Density model of 1990 and 2018 was the input images for the analysis. Shannon Diversity Index expresses, Simpson Diversity index and Shannon Evenness Index (Equitability) was used to determining the level of diversity and evenness in the Omo biosphere and the entire reserve. The degree of fragmentation and dominance or homogeneity was examined using the following indices Land Cover, Landscape proportion, Edge length, Number of Patches, Patch Density, Greatest patch area, Landscape division, Effective mesh size and Splitting index. Calculated coefficients can be classified according to the type of evaluated characteristic into categories of indices: of shape, size, diversity, edges and proximity (Stejskalova et al., 2012). Statistically, many of the metrics are correlated and can be depicted in concise form according to the structural characteristics (Rajendran et al, 2015). Table 1 shows the indices, acronyms used and a short description of each indicator.

Table 01. Landscape metrics used in the study

Metric	Abbreviation	Description
Land Cover	LC	Equals the number of cells for each class based on a classified land cover matrix. The resulting values were multiplied by the cell's value; (ha)
Landscape proportion	LP	Landscape proportion (LP) quantifies proportional abundance of a certain class in the total landscape area(0<LP≤100); %
Edge Length	EL	Equals the total length of all patches from a specific class. The resulting values were, of course, multiplied with the cell's value; (m).
Edge Density	ED	Edge Density equals the sum of the lengths of all edge segments involving the corresponding patch type, divided by the total landscape area ; (m/ha)
Number of Patches	NP	Express the number of patches identified for each class; (no.).
Patch density	PD	Equals the number of patches of the corresponding patch type divided by total landscape area; (no. /100 ha).
Greatest patch area	GPA	Greatest Patch Area identifies the area under the single largest patch in a given landscape. It is a measure of dominance i.e. degree of homogeneity
Mean Patch area	MPA	The mean Patch area serves as a fragmentation index. A landscape with a smaller mean patch area for the target patch type than another landscape might be considered more fragmented.
Over all Core area	OC	Total core area (ha) or the percentage of the landscape comprised of core area at the class or landscape level. The core area is a compound measure of shape, area and edge depth
Landscape division	LD	Landscape Division is defined as the probability that two randomly chosen places in the landscape to be found in the same patch.
Effective mesh size	m	The probability that two randomly chosen cells are connected (to be included into the same patch); (ha).
Splitting index	S	The number of patches one gets when dividing the total region into parts of equal size in such a way that this new configuration leads to the same degree of landscape division desired; (nr.).
Shannon's Diversity Index	SHDI	Based on information theory; represents the amount of "information" per individual (or patch type, in this case); larger values indicate a greater number of patch types and/or greater evenness among patch types.
Shannon Equitability Index	SHEI	Shannon Equitability (Evenness) Index expresses the dominance of patches within the total area.

Simpson Diversity Index	SIDI	Simpson Diversity Index represents the probability that any two pixels selected at random would be different patch types. The larger the value the greater the likelihood that any 2 randomly drawn cells would be different patch types

3. Results

3.1 Forest Cover Change Analysis

The results of the Advance Vegetation Index (AVI), Bare Surface Index (BSI), Shadow Index (SI), Thermal Index (TI) and the Forest Canopy Density (FCD) for 1990 and 2018 are presented in Figures 03, 04, 05, 06 and 07 respectively. The Advance Vegetation Index (AVI) shows a positive relationship with the quantity of vegetation, which means the number of vegetation increases as the value of the AVI increases (Figure 03). The colours green and yellow are areas covered by vegetation while the colour red shows areas of non-forest which was mosaic of water body, rock outcrop and open space. As shown in Figure 4. Bare Surface Index (BSI) increases as the percentage of bare soil exposure of ground increases. The BSI showed the colour red as non-forest to determine the effect of soil exposure in the analysis. This index helps in separating the vegetation with a different background. This result showed that there were no remarkable changes in soil percentage over the years. The SI was utilised for spectral information on the forest shadow itself and thermal information on the forest influenced by the shadow. The SI takes care of the cooling effect inside the forest and evaporation from the leaf structure. The tree arrangement has a low shadow casting than matured tree arrangement. The result in Figure 5 showed that there were no remarkable changes in shadow percentage created by tree canopy over the years. Inside the forest stand, the canopy cover blocked the incoming solar radiation and it is the reason for the cool temperature inside the forest. The soil area is characterised by high temperatures. The combination of the Thermal Index (TI) with Shadow Index (SI) was helpful in black soil detection. The result shows that changes in the land surface temperature over the years in the Omo biosphere was insignificant (Figure 06). The Forest Canopy Density model integrates these indices to take into account all factors responsible for deficiency in using a single vegetation index to analyse forest cover.

The AVI and BSI both have a negative relationship with each other, a high AVI value shows high vegetation vigour, and similarly, high BSI shows soil exposure. Utilising the various spectral indices, vegetation density and scale shadow index, the forest canopy density map was produced for the years 1990 and 2018. It was thereafter utilised for the classification of the forest cover and its change detection.

Based on the percentage, each pixel was classified into four classes of forest canopy density: high forest density, mid forest density, low forest density and no forest. High forest density is an area having a value from 71% to 100%. In the same manner, 41-70%, 5-40% and below 5% were areas with mid forest density, low forest density, and no forest respectively (Figure 07). The maps described the distribution of forest resources in Omo Biosphere through the FCD model.

The statistics in Table 02 revealed that from 1990 to 2018, the no forest area decreases by 2.7 ha at the rate of 0.023% in Omo Biosphere being a strict nature reserve, which could be a result of forest regeneration. The changes in low forest areas are insignificant as the difference between 1990 and 2018 was 0.36 ha. The mid forest density had a significant increase of 42.66 ha at 0.36% change rate from 39.2% to 49.3% while the high-density area was the victim of the great increase in the mid forest density. It reduces from 221.58 ha to 181.98 ha at 0.34 change rate from 52.58% to 43.32%.

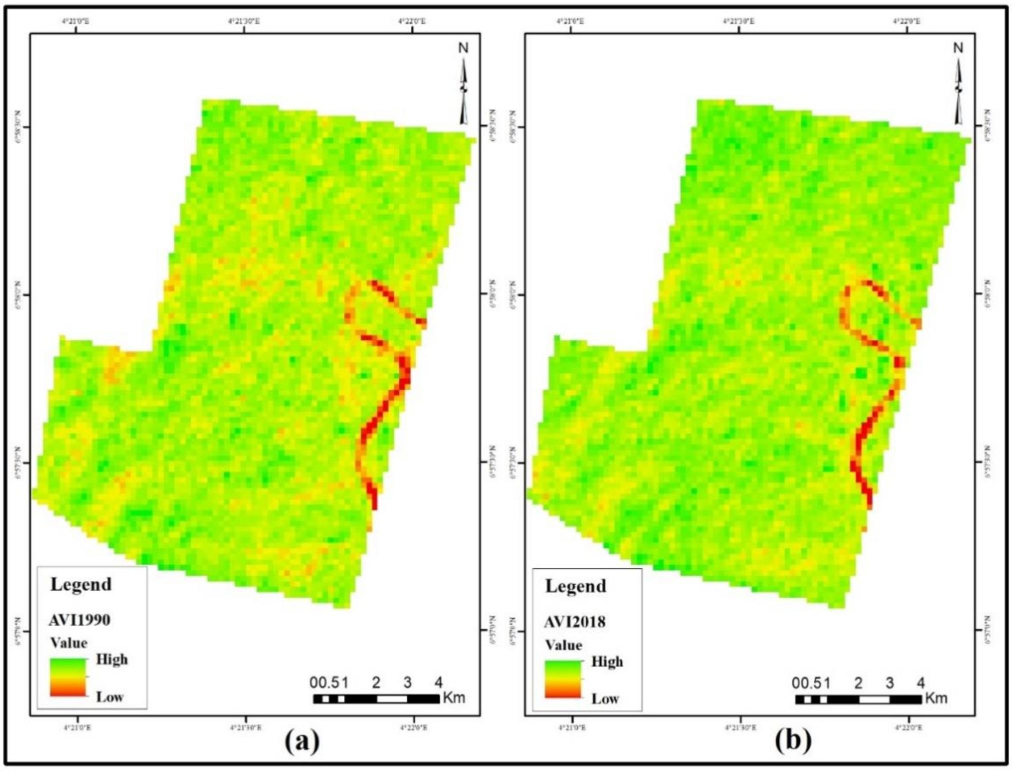

Figure 03. Advance Vegetation Index of 1990 (a) and 2018 (b) of Omo Biosphere

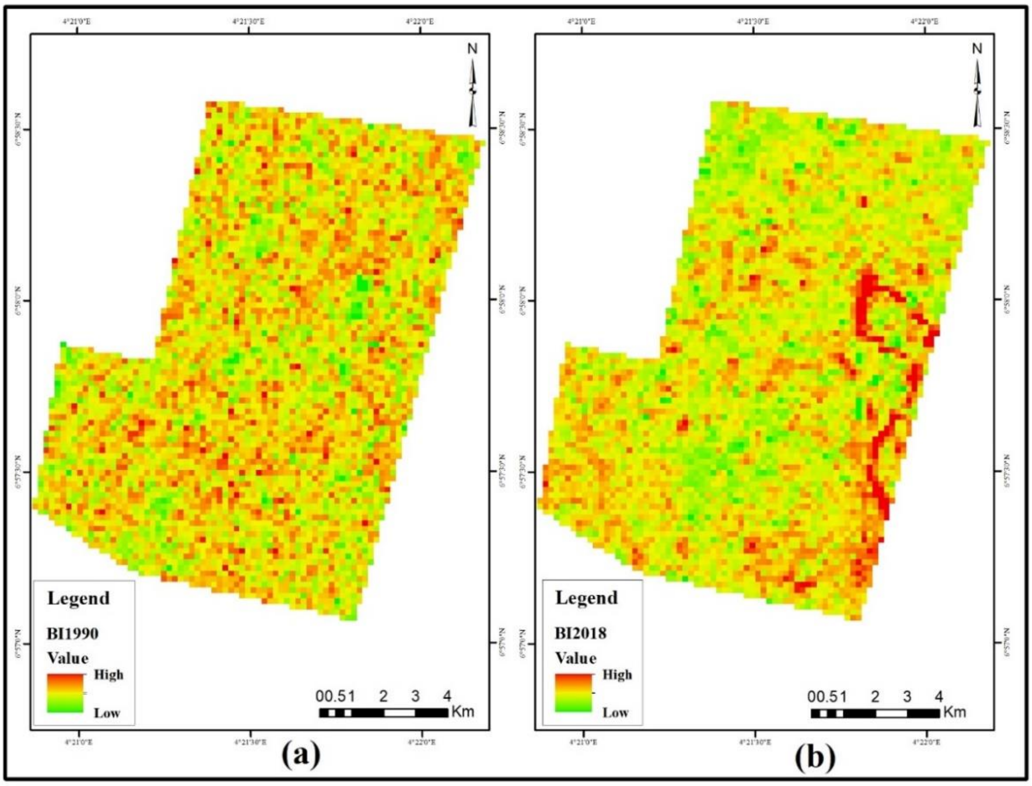

Figure 04. Bare Soil Index of 1990 (a) and 2018 (b) Omo Biosphere

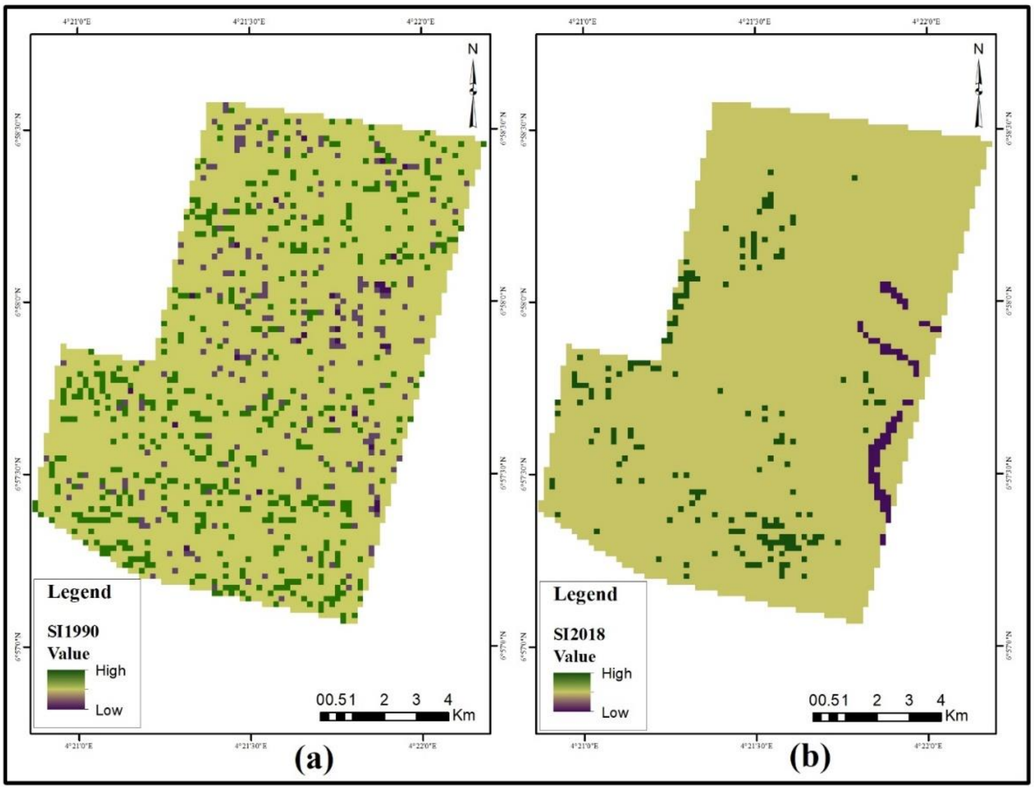

Figure 05. Shadow Index of 1990 (a) and 2018 (b) of Omo Biosphere

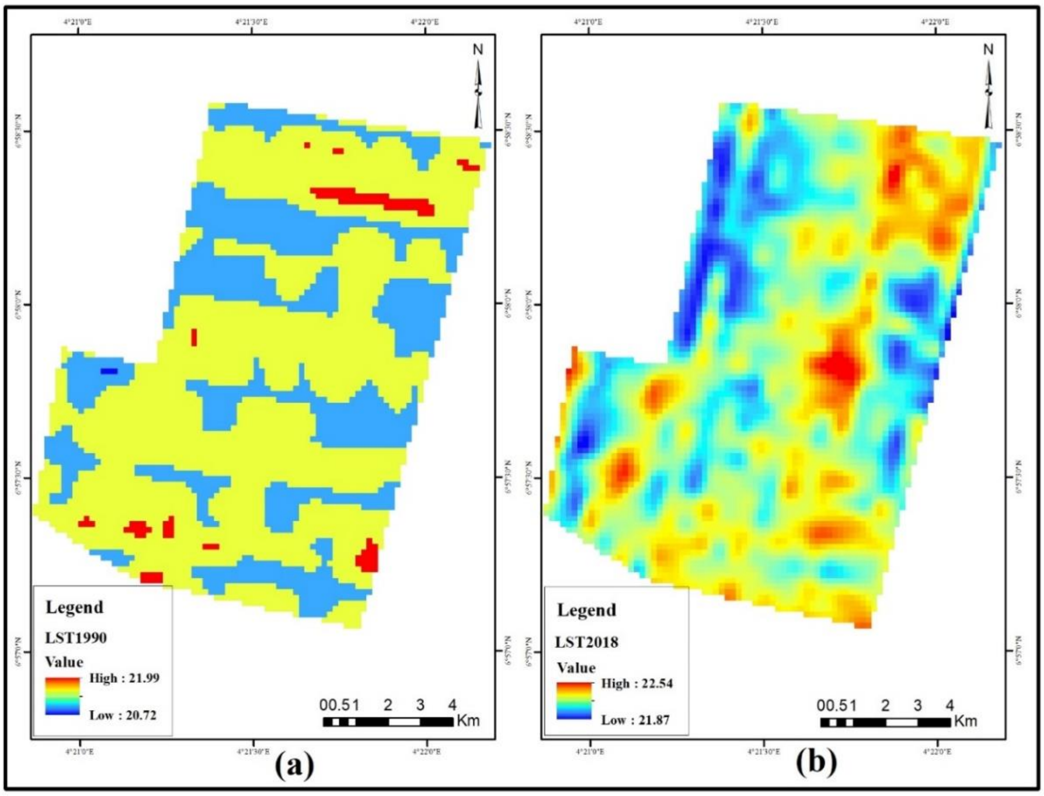

Figure 06. Thermal Index of 1990 (a) and 2018 (b) of Omo Biosphere

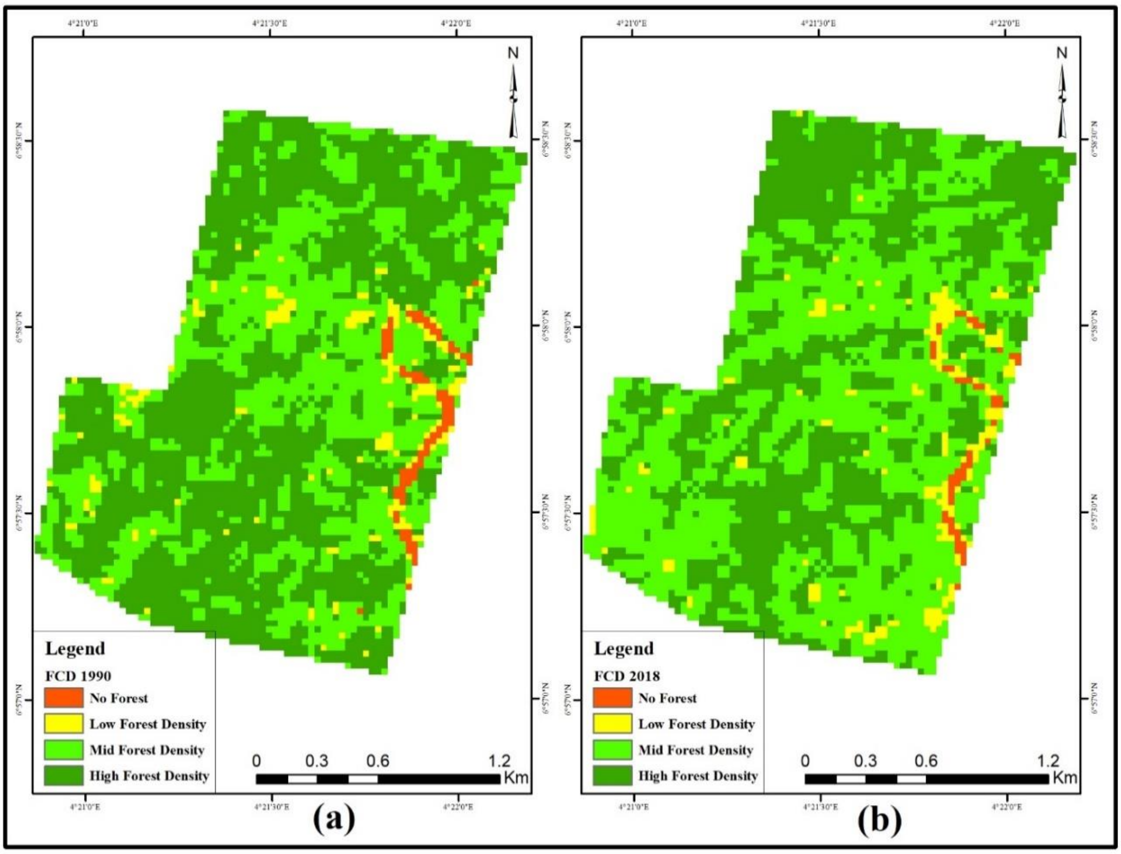

Figure 07. Forest Canopy Density of 1990 (a) and 2018 (b) of Omo Biosphere

Table 02. Area of Forest Cover Classes of Omo Biosphere Reserve

Class	1990 Area (ha)	%	2018 Area (ha)	%	Area Diff. (ha)	Change Rate (%)
No Forest	8.64	2.057	5.94	1.414	-2.7	0.023
Low Forest Density	25.56	6.084	25.2	5.998	-0.36	0.003
Mid Forest Density	164.34	39.117	207	49.271	42.66	0.362
High Forest Density	221.58	52.742	181.98	43.316	-39.6	0.336
Total	420.12	100	420.12	100	_	_

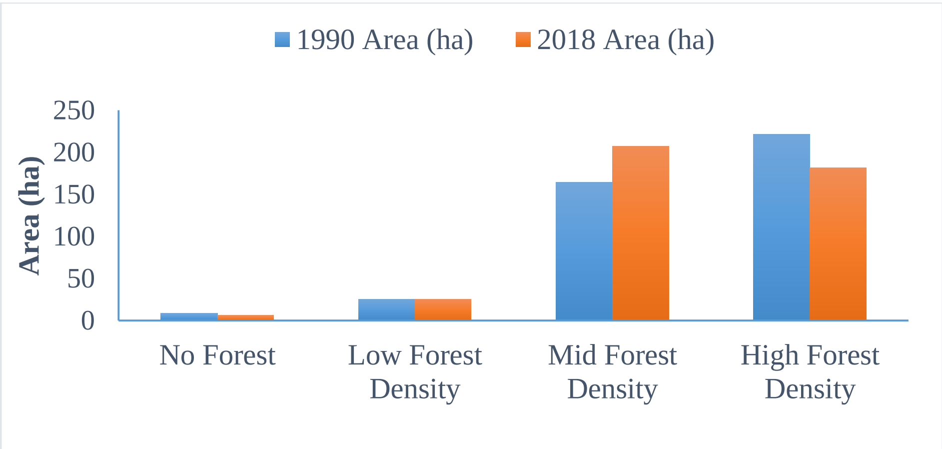

Figure 08. Area of Forest Density Classes of Omo Biosphere

3.2. Accuracy Assessment

Accuracy assessment of the classified image has been verified from field verification data Table 03. The overall accuracy for classification was 90% and 92.8% and Kappa statistics of 86.2% and 90.2% for 1990 and 2018 respectively.

Table 03. Kappa Statistics of the classified images

	1990		**2018**	
Class Name	*Pa*	*Ua*	*Pa*	*Ua*
No Forest	100	100	81.8	90
Low Forest Density	86.67	81.25	93.3	93.3
Mid Forest Density	88	91.67	95.8	92
High Forest Density	90	90	95	95
Overall Accuracy	90		92.8	
Kappa Statistics (*k*)	86.2		90.2	

**Pa*=Producer's accuracy
**Ua*=User's Accuracy

3.3. Forest Cover Change Detection of Omo Biosphere Reserve

Classified forest canopy density images in 1990 and 2018 were cross-classified and a tabular matrix (Table 4) shows the number of pixels that correspond to each combination of categories in the two (column-row) images was compared. The tabular matrix is expressed in terms of the proportion of the total number of pixels. From Table 5, four categories of change were identified in the Omo biosphere; no change, growth, degradation and deforestation. There was no change in 222.57 ha (52.98%) of the biosphere, no forest to low forest density, low forest density to mid forest density and mid forest density to high forest density growth occurred in 81.54 ha at a change rate of 0.69. 116.01 ha of the forest were degraded from high-density forest to mid-density and from mid-density to low density, which is 27.61% of the reserve. Figure 10a showed the change map of the biosphere from 1990 to 2018. The colour blue on the map represent areas that were no forest, low forest, mid forest and high forest densities in 1990 and are still the same in 2018 while the colour black on the map represent areas that were changed from one class to another. Figures 10b, c and d were the different changes that the forest went through for 28 years. Figure 10b showed the portion of the reserve that grows from no forest area to low forest, mid forest and high forest while Figure 10c showed the areas that went through degradation from high forest to mid forest and low forest. Figure 10d showed a little portion of the reserve toward the eastern part of the biosphere that was deforested, that is, moving from low forest to no forest class.

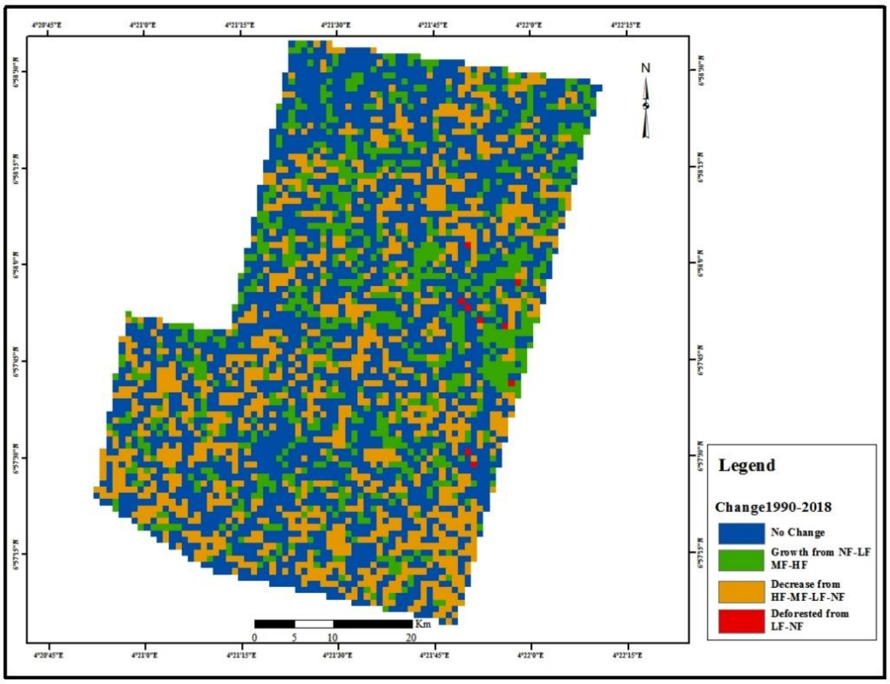

Figure 09. Forest Canopy Density Change from 1990-2018 in Omo Biosphere

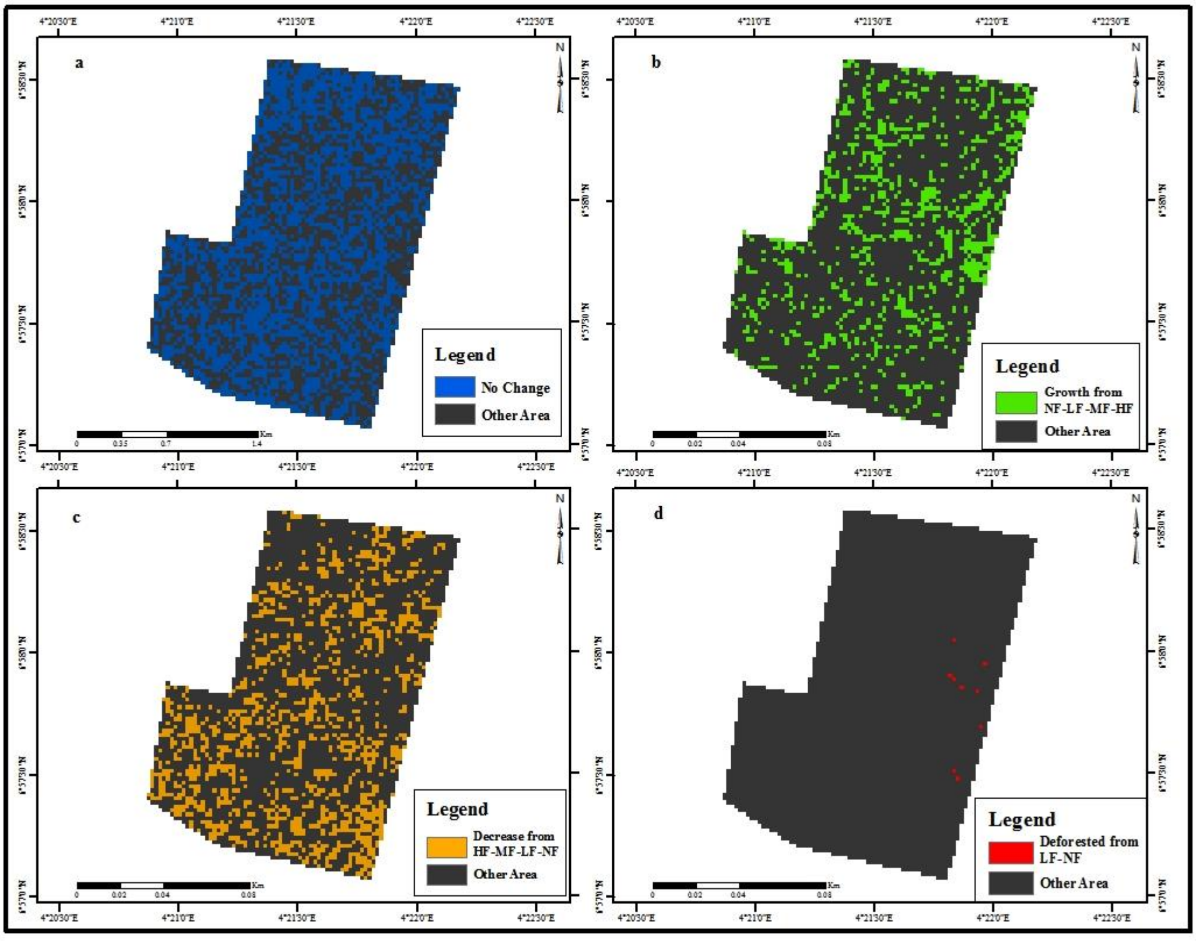

Figure 10a-d. Spatial Distribution of Changes of the four Classes (No Change (a), Growth (b), Degradation (c) and Deforestation (d) from 1990-2018 in Omo Biosphere

Table 04. Cross-Classification Change of 1990 and 2018 in Omo Biosphere

Category	Area (ha)	%	Change Rate
No Change	222.57	52.978	
Growth from NF- LF-MD-HF	81.54	19.409	0.693
Degradation from HF-MD-LF	116.01	27.614	0.986
Deforestation from LF-NF	0.81	0.193	0.007
Total	420.12	100	

Table 05. Summary of the Area Cross-Classification Change of 1990 and 2018 in Omo Biosphere

Class 1900	Class 2018	Changes	Number of Pixels	Area (ha)	%
No Forest	No Forest	NF-NF	57	5.13	1.2211
No Forest	Low Forest Density	NF-LF	24	2.16	0.5141
No Forest	Mid Forest Density	NF-MF	10	0.9	0.2142
No Forest	High Forest Density	NF-HF	5	0.45	0.1071
Low Forest Density	No Forest	LF-NF	9	0.81	0.1928
Low Forest Density	Low Forest Density	LF-LF	51	4.59	1.0925
Low Forest Density	Mid Forest Density	LF-MF	169	15.21	3.6204
Low Forest Density	High Forest Density	LF-HF	55	4.95	1.1782
Mid Forest Density	Low Forest Density	MF-LF	137	12.33	2.9349
Mid Forest Density	Mid Forest Density	MF-MF	1046	94.14	22.408
Mid Forest Density	High Forest Density	MF-HF	643	57.87	13.775
High Forest Density	Low Forest Density	HF-LF	68	6.12	1.4567
High Forest Density	Mid Forest Density	HF-MF	1075	96.75	23.029
High Forest Density	High Forest Density	HF-HF	1319	118.71	28.256

3.4. Landscape Metrics and Diversity Analysis

Table 06 shows the values resulting from the calculation of global indices performed for the two periods. In terms of diversity, there is a slight increase and decrease of the values of the three indices (SHDI, SHEI, SIDI) in the biosphere and the entire reserve, as a result of the increase of some classes are reported to the general distribution of the landscape. The slight decrease of the diversity values can be explained by an increase of the mid forest density which accounts for 49.3% of the biosphere (Table 02). However, the values of diversity and evenness remain relatively high, suggesting that the study area, which has favourable physical and geographical conditions, has a complex landscape with certain dominant species.

In terms of landscape configuration, features and functionality, some other landscape indices were calculated (Table 07). Unlike diversity indices, these were applied particularly to each class. Table 01 presents the indicators, the abbreviation used and a short description for each type.

Land Cover (LC) and Landscape Proportion (LP)-Significant changes were observed in the four classes both in the biosphere especially in mid forest density and high forest density classes. The *edge length (EL)* and *edge density (ED)*-The result showed a decrease of the two indices values for most classes, suggesting a tendency of landscape homogenization in the biosphere and an increase of the two indices values for most classes tending towards heterogeneity.

Number of Patches (NP) and *Patch Density (PD)*-A significant decrease was observed in mid forest density (MFD) of the biosphere from 120 to 47. This explained why MFD occupied 49% of the biosphere. All the classes in the Omo forest reserve had a decrease in PD except the no forest. Patch Density reflects the extent of landscape fragmentation and therefore crucial for landscape structure assessment. Comparison of classes with varying sizes showed decreasing PD in most of the classes, especially in the entire reserve. However, the rate of the decrease is moderate, thereby making the level of fragmentation insignificant for now. It was further explained following also the values of edge density. *Edge density*, with *patch number* and *patch density*, are representative for establishing the *fragmentation degree* of the landscape. The values obtained for the fragmentation (NP and, consequently, PD and ED) reveal a decrease in the study area's fragmentation degree, inducing a clustering tendency.

The greatest patch area (GPA) is related to the *degree of homogeneity or dominance* of the landscape. The results in Table 8 show that the high forest density (HFD) class with 1,244,700 m has the highest GPA in 1990 while mid-density forest (MFD) has the highest for 2018 with 1,748,700 m in the biosphere. *The mean patch area* is also higher for the categories mentioned above.

Landscape division, Effective mesh size and Splitting index (LD, m and s) are interconnected and measure the fragmentation degree of the landscape. These indicators were introduced by (Jaeger, 2000), as a result of the criticism over the simple measurements such as patch number or patch density, which presents some limitations for certain phases of the fragmentation process. They have the advantage, unlike other conventional indicators, that any omissions or additions of other small-sized patches do not influence the final result.

In this study, values of LD for all classes are high (above 0.9), reflecting a high degree of fragmentation of class types. Although landscape division and Mesh are perfectly correlated, inversely, both metrics are included because of the differences in units and interpretation. Split (s) is based on the cumulative patch area distribution and is interpreted as the effective mesh number, or several patches with a constant patch size when the corresponding patch type is subdivided into S patches, where S is the value of the splitting index (McGarigal et al., 2002). Jaeger (2000), defines the splitting index as the number of patches that resulted after dividing the total area into equal size parts so that this new configuration leads to the same degree of landscape division (LD). When its value is 1, the landscape is represented by a single patch, the value increasing as the landscape is divided into several patches. Considering these aspects, the interpretation of the result must take into account the correlation of these three complementary indicators.

The resulting values of the three indicators suggest different degrees of fragmentation for each class. Thus, the areas with a high degree of homogeneity are represented by MFD with a change record of 75,130.67 m in 1990 to 730,376.51 m in the Omo biosphere. In the entire reserve, a high degree of homogeneity is recorded in the no forest class and the three others classes were fragmented.

Table 06. Landscape Diversity Indices between 1990 and 2018 of Omo Biosphere

Metric	**1990**	**2018**
Shannon's Diversity Index	1.249	0.941
Shannon Equitability Index	0.776	0.678
Simpson Diversity Index	0.685	0.566

Table 07. Landscape Metrics Computed for Class Types for 1990 and 2018 in Omo Biosphere

Class	**LC (m)**	**LP (%)**	**EL (m)**	**ED**	**NP**	**PD**	**GPA (m)**	**MPA (m)**	**LD**	**m (m)**	**s**
NF 1990	86,400	0.012	5,940	0.0009	15	2.17E-06	34,200	5760	1	229.24	30,210.73
NF 2018	59,400	0.014	4,800	0.0011	10	2.38E-06	26,100	5,940	1	211.31	19,881.59
LFD 1990	25,5600	0.037	26,160	0.0038	123	1.78E-05	19,800	2,078	1	197.19	3,512,0.42
LFD 2018	252,000	0.06	24,120	0.0057	103	2.45E-05	27,000	2,447	1	450.39	9328.01
MFD 1990	1643,400	0.237	111,360	0.0161	120	1.73E-05	691,200	13,695	0.99	75130.76	92.18
MFD 2018	2,070,000	0.493	106,500	0.0253	47	1.12E-05	1,748,700	44,043	0.83	730376.6	5.75
HFD 1990	2,215,800	0.32	99,300	0.0143	66	9.53E-06	1,244,700	33,573	0.96	300081.4	23.08
HFD 2018	1,819,800	0.433	91,200	0.0217	85	2.02E-05	722,700	21,409	0.95	223219.3	18.82

4. Discussion

The knowledge of land use and land cover is important for many planning and management activities as it is considered an essential element for modelling and understanding the earth feature system (Akike et al., 2016). The result above reveals the capacity of the biosphere to sequestered carbon because the high and mid forest densities have the highest area occupied by forest over the years. Although, the result showed the biosphere suffered forest degradation rather than deforestation which can be attributed to logging or physical factors of rainstorm uprooting aged trees as noticed during the fieldwork. After logging, natural regeneration of a secondary forest takes place and can revert carbon (C) losses to recovering C stocks at a certain point in time (Henry et al., 2011). Very few studies reported the natural capacity of African ecosystems to regenerate after perturbations. Kotto-Same et al., (1997) reported that about 74 % of aboveground C was regenerated after a period of fallow of 18 years. According to the regression between the time of fallow and C stocks, the total system C would be equal to the original natural forest after 24 years (Kotto-Same et al., 1997). In a semi-deciduous forest of Ghana that was logged in the 1950s, inventory of forest with three types of forest management revealed that there was no significant difference in aboveground biomass among a natural protected forest, a forest that was logged in the 1950s and forest that was under tree shelter-wood system in the 1950s (Bombelli et al., 2009). Henry et al., (2011) reported that the increasing pressure of the timber companies and the farming activities often does not allow the forest to regenerate. But it is very difficult to estimate this. Extensive human encroachment, fragmentation and conversion of natural forest habitat quickly transformed the natural landscape into a cultural landscape at the foot of Bhutan and Bengal (Chamling et al., 2020).

The degree of landscape fragmentation is an important environmental indicator in the fields of biodiversity and sustainable development. In addition, information on the degree of landscape fragmentation is relevant in regional planning and for decisions about infrastructure placement or removal. Its analysis on different time series shows how strong the current trends are and what their direction is (Jaeger et al., 2006). This fundamental research will definitely help to make policy framing holistic management approach.

5. Conclusion

Forest conservation and sustainable forest management is key in mitigating climate change at all scales. The FCD model and landscape metrics analysis using the Remote Sensing and GIS technologies to estimate forest loss and degradation in this study has been noted to be a time and cost-effective method.

The result showed that the rate of forest degradation is more than deforestation in the reserve. A high degree of homogeneity is recorded in the no forest class and the three others classes were fragmented while values of diversity and evenness remain relatively high, suggesting that the study area, which has favourable physical and geographical conditions, has a complex landscape with certain dominant types.

The study determined that forest canopy density and diversity and fragmentation model are important for analysing the Spatio-temporal condition of the forest. This will help forest managers in decision making, monitoring biodiversity and conversation planning for sustainable forest management. Given the importance of natural forested areas and the pursuit to maintain sustainable forest management in the midst of growing natural resources extraction and other anthropogenic activities, the use of the FCD model and landscape ecology analysis to assess, estimate and quantify forest is recommended for use in forest management activities as it has proven to be a time and cost-effective method.

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