

Characterization of Forest Degradation beyond Canopy Cover Change in Mau Forest, Kenya

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Abstract

Monitoring Forest degradation is evidence enough to show a country's commitment to monitor the forest trend both for national and local decision-making and international reporting processes. Unlike deforestation which is easier to point out, monitoring forest degradation is quite a challenge since there is no universal definition and thus no clear monitoring methods apart from the canopy cover change. This research, therefore, sought to look at the degradation trends in the Mau forest complex between 1995-2020 with the aim of finding out whether monitoring canopy density changes over time and quantifying these changes in terms of biomass loss could be a good approach in monitoring forest degradation. Forest Canopy Density (FCD) model was adopted focusing on using vegetation indices describing biophysical conditions of Vegetation, Shadow and Bareness to monitor changes in canopy density as a parameter for describing forest degradation in the forest blocks of Maasai Mau and Olpusimoru in Mau forest complex. Results indicated how different vegetation indices responded to changes in the vegetation density and eventually changes in the canopy density values which were converted in terms of biomass loss. The study showed that forest degradation results in an average annual loss of forest biomass equivalent to 138.54 tons/ha/yr, which was distributed as 200.41 tons/ha/yr between 2002 to 2005, 129.34 tons/ha/yr between 2005 to 2010, 85.98 tons/ha/yr between 2010 to 2015 and 138.43 tons/ha/yr between 2015 to 2020. The forest Canopy Density model proved to be a good tool for monitoring forest degradation since it combines different biophysical indices with different characteristics capturing what is happening below the canopy.

Keywords

Forest Degradation, Canopy Density, Vegetation Indices, Biomass Loss,

1. Introduction

Globally, there has been a concern about the reducing forest area which is attributed to Deforestation and Forest degradation. In the period 1990-2015, the global primary forest area declined by 2.5% and by 10% in the tropics; this being ascribed to deforestation and forest degradation (Morales-Hidalgo *et al.*, 2015). Deforestation which is the outright conversion of forestland for other use is easier to define while on the other hand, Forest degradation is perceived differently by various stakeholders with different objectives. For instance, it is defined as a loss of carbon stock within a forestland remaining forestland (IPCC, 2003). On the other hand, (Lund, 2009) states that forest degradation is usually associated with a reduction of vegetative cover and especially trees, while United Nations Convention on Climate Change (UNFCCC) Reducing Emissions from Deforestation and forest Degradation (REDD+) states that forest degradation entails any direct, anthropogenic-induced and persistent loss in carbon density over time in forest land remaining forest (IPCC, 2003). In Kenya, the REDD+ Forest Reference Level (FRL) process defines forest degradation to mean carbon stock changes associated with forest canopy changes from high canopy coverage to moderate and low canopy coverage in Natural forests such as Montane forests, Western rain forests and Bamboo, Mangrove and Coastal forest, and Dryland forest (MoEF, 2020). Further review found out that forest degradation is perceived differently by various nations and international processes with canopy cover mostly used as an indicator; and at the same time perceived differently by various stakeholders who have different objectives based on factors such as; biodiversity conservation, carbon sequestration, wood production, soil conservation, cultural values and recreation (Simula, 2009).

Forest degradation alongside deforestation is therefore considered to be a leading contributing factor to climate change because most of the carbon released in the atmosphere is stored on the tree stalks. In Africa for instance, the annual rate of forest degradation is almost 50% of the annual rate of deforestation (Lambin *et al.*, 2003). In the Brazilian Amazon forest, degradation is responsible for 20% of total emissions while in Indonesia, forest stock decreased by 6% per year from 1990-2005, and 2/3 was caused by forest degradation while only 1/3 by deforestation (Asner *et al.*, 2005; Marklund & Schoene, 2006). Additionally, data on quantitative changes associated with forest degradation are missing and there is a low capacity for monitoring and reporting on emissions from forest degradation in many developing countries. At the same time, methods of mapping forest degradation are a high priority and a crucial missing link in most countries' carbon accounting systems Kenya included (Herold, 2009). Both forest and land degradation therefore, has been

serious problems in developing countries. Besides findings from a number of studies indicating the role of forest degradation in compromising forest ecosystem services which further contributes to GHG emissions, universally, harmonizing what indicators point out forest degradation and what methods could be applied to monitor the same apart from the canopy cover change is evidently missing. Therefore, this study focused on analyzing parameters that could be applied to monitor forest degradation trends in Mau forest with the specific objectives being:

- 1) To investigate the canopy density changes in the study area between 1995-2020.
- 2) To quantify the canopy density changes in terms of biomass loss in the study area between 1995-2020.

2. Materials and Methods

2.1. Study Area

The study was done in the Mau forest complex with a focus on Maasai Mau and Olposimoru forest blocks (**Figure 1**) which have experienced a number of actions, the most recent ones being; forceful evictions, reduced water levels in Mara River, that has its catchment in these forest blocks and the massive Rehabilitation/ Restoration process that was carried out. At the same time, the Maasai Mau block had previously been identified as one of the blocks with a declining trend in vegetation density attributed to forest encroachment (*Kinyanjui et al., 2011*). While the ongoing disturbances in both the edges and the interior of the Mau forest result in continuous fragmentation (*Bewernick et al., 2016*).

2.2. Data

Analysis of Continuous (Near-real time) optical data was done for monitoring of canopy density change through time series. Landsat 5, 7 and 8 images were selected to enable analysis of the historical trends while secondary datasets were also sourced from the relevant institutions. The study adopted a model that was developed by (*Rikimaru et al., 2002*) known as the Forest Canopy Density (FCD) to monitor forest cover density. The whole process was automated by using Google Earth Engine (GEE) platform for analysis. A script was generated and image pre-processing and processing was done by coding all the formulas in a script and running the scripts in GEE to get outputs which were then downloaded for further analysis (**Figure 2**).

2.3. Methods of Analysis

The focus was on the Forest Canopy Density as a parameter to describe different forest conditions by looking at the Vegetation, Shadow, and Bareness. Equations for the Bio-physical indices (FCD indices) of Advanced Vegetation Index (AVI), Scaled Shadow Index (SI) and Bare soil Index (BI) were used to extract information for detecting and monitoring forest degradation using near real-time data with the formulas of each index being coded into a developed script as shown below:

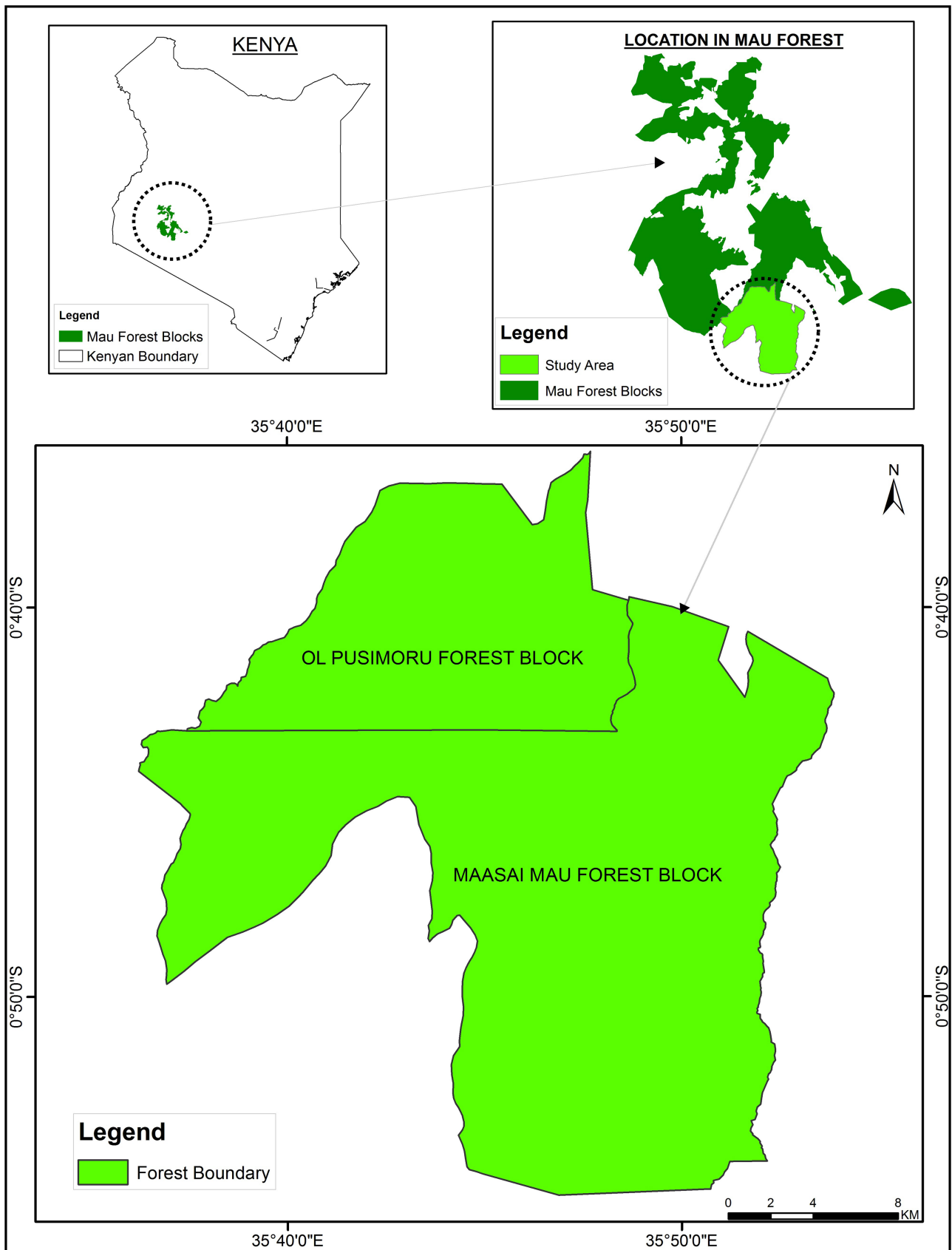


Figure 1. Location of the study area.

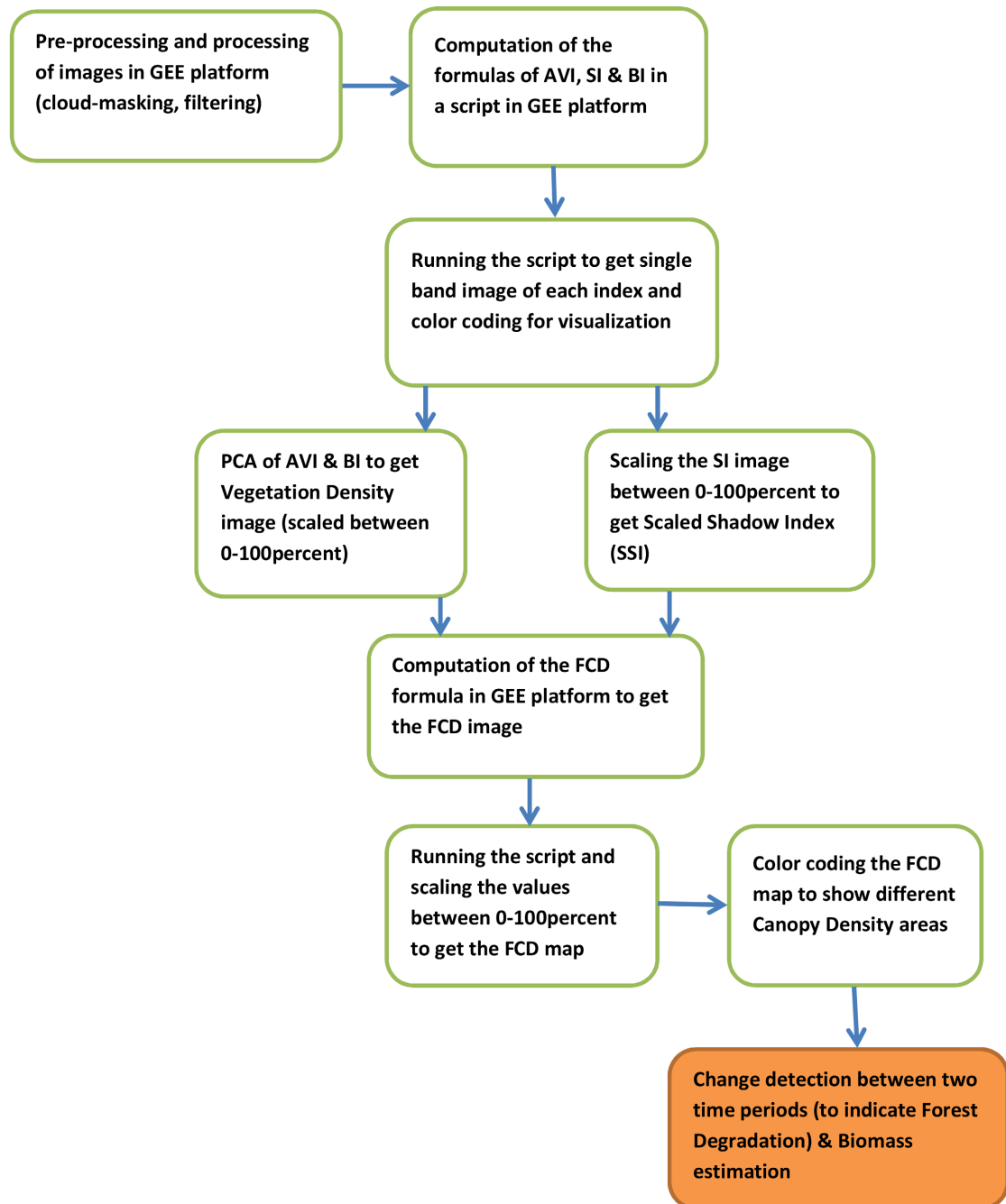


Figure 2. Methods process.

$$\text{Advanced Vegetation Index} = [\text{NIR} * (1 - \text{RED}) * (\text{NIR} - \text{RED})]^{1/3} \quad (\text{a})$$

$$\text{Shadow Index} = (1 - \text{BLUE})(1 - \text{GREEN})(1 - \text{RED}) \quad (\text{b})$$

$$\text{Bare Soil Index} = \frac{(\text{SWIR} - \text{RED}) - (\text{NIR} - \text{BLUE})}{(\text{SWIR} - \text{RED}) + (\text{NIR} + \text{BLUE})} * 100 + 100 \quad (\text{c})$$

After processing the indices data, Vegetation Density (VD) output was generated by getting the Principal Component Analysis (PCA) of the AVI and BI images

and the values normalized between 0 - 100 percent. The Shadow Index values were also normalized between 0 - 100 percent to get the Scaled Shadow Index image. These two products were then called into the GEE platform through coding the FCD formula in the script as;

$$\text{FCD} = \left[\text{Vegetation Density (VD)} * \text{Scaled Shadow Index (SSI)} + 1 \right]^{\frac{1}{2}} - 1 \quad (\text{d})$$

The FCD output (a single band image) with normalized values between 0 - 100 percent was obtained and then color coded in Envi for visualization.

To further investigate and quantify degradation, change analysis was done and total change areas were calculated and converted in terms of biomass loss adopting the forest stock data and allometric equations from previous work done by the Kenya Forest Service (KFS) (MoEF, 2020).

2.4. Data Analysis

2.4.1. Vegetation Indices and Forest Canopy Density Analysis

Values obtained in the indices maps were classified as Very high, High, Moderate, Low and Very low to represent the different vegetation cover types. The vegetation Density map had scaled values with 0 representing areas with low vegetation and 100 areas with dense vegetation. The FCD values were classified to describe different vegetation covers as adopted in a study by (Sahana *et al.*, 2015) and modified for the purposes of this study. Therefore FCD Values more than 80% were categorized as very high canopy density, 70% - 80% as high, 60% - 70% as moderate canopy density, while 50% - 60% and 1% - 50% as low and very low canopy density respectively (Table 1). Further analysis for forest degradation however only focused on the very high, high and moderate canopy density values.

2.4.2. Trend Analysis

To enable trend analysis, the area for each density class was calculated in Hectares using ERDAS IMAGINE and then converted into a percentage to show the proportion of each category. This was done for both the yearly trend and for the dry months (Jan, Feb & Mar). For the yearly trend, images were selected for 1995 then from 2002 on a yearly basis up to 2020 with years between 1995 and 2002 being left out since they were missing some bands required in the analysis

Table 1. Table showing the Canopy density classes, values and description of the vegetation cover.

(Sahana <i>et al.</i> , 2015) values	FCD Values (modified from (Sahana <i>et al.</i> , 2015) ^a	Canopy density	Color in the map	Description of the Vegetation cover
<20%	1% - 50%	Very low	Red	Bare/Grassland/Cropland
20% - 40%	50% - 60%	Low	Olive Green	Shrubland
40% - 60%	60% - 70%	Medium	Green	Open Forest
60% - 80%	70% - 80%	High	Light Green	Moderate Forest
>80%	>80%	Very high	Dark Green	Dense Forest

^aFCD values as modified from a study by Sahana *et al.*, 2015.

process. For dry months, images were selected on a yearly basis from 2000 to 2020 then averaged to get the trend.

A five-year interval was adopted for monitoring changes in the canopy density for the time period 2002-2005, 2005-2010, 2010-2015 and 2015-2020, with the change monitoring focusing on comparing changes in FCD maps of two time periods. This process was also done in ERDAS IMAGINE.

Total areas of changes between very high, high and moderate canopy density were calculated and converted in terms of biomass loss. The five-year analysis period was to show the trend from 2002-2020 with the first analysis period being 3 years (i.e., from 2002-2005).

2.4.3. Conversion of Change Data to Biomass Loss

Values for above-ground biomass (ABG) and below-ground biomass (BGB) from Kenya Forest Service were adopted for the study (Table 2). This data was generated from forest stock data collected in forest inventory and locally acceptable allometric equations which assigned biomass stock to different forest strata. Biomass stock change was therefore calculated by multiplying the total biomass stock and the changing area as obtained from changes in the two time periods (Table 3).

3. Results

3.1. Vegetation Indices and Forest Canopy Density Outputs

The AVI, BI and SI outputs were generated for all the years under review. The outputs were then color coded as per the adopted colour values for visualization and interpretation purposes as shown in (Figure 3). FCD outputs were also

Table 2. Biomass values as adopted from Kenya Forest Service (KFS).

Canopy Coverage/Canopy Density values	Above Ground (ABG)	Below Ground (BGB)	CALCULATED TOTAL
	Biomass stock (Tonnes/ha)	Biomass stock (Tonnes/ha)	Biomass stock (Tonnes/ha)
Dense (Very high)	244.8	90.58	335.38
Moderate (High)	58.43	21.62	80.05
Open (Moderate)	23.26	8.61	31.87

Table 3. Biomass trend analysis.

Canopy Density Change	BIOMASS Stock change (Tonnes)			
	2002_2005	2005_2010	2010_2015	2015_2020
High to moderate	116,668	224,143	152,873	90,641
Very High to moderate	330,003	449,838	74,572	49,196
Very High to High	1,192,609	4,162,492	598,131	3,440,272
TOTAL	1,639,280	4,836,473	825,577	3,580,109
TOTAL LOSS ANNUALLY	546,427	967,295	165,115	716,022
Total loss/ha/yr	200.41	129.34	85.98	138.43

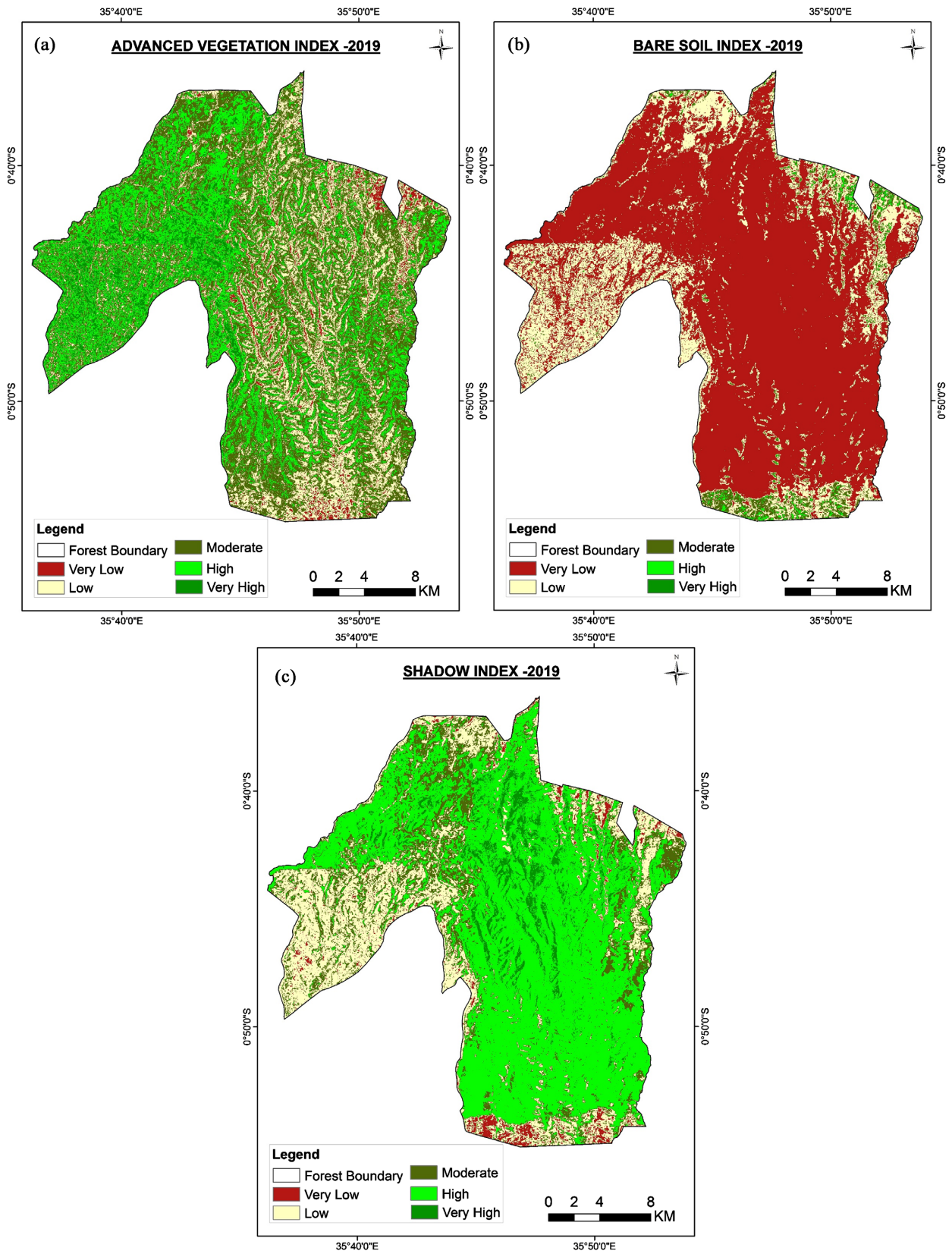


Figure 3. (a) Advanced vegetation index; (b) Bare soil index and; (c) Shadow index images for the study area.

generated for all the years under review and color coded for visualization to depict the vegetation changes over time (Figure 4).

3.2. Trend Analysis Outputs

Figure 5 shows the yearly trend analysis, while Figure 6 shows the Dry month's average trend analysis for the Forest Canopy Density. The results present FCD trends for Moderate, High and Very high Canopy Density values.

3.3. Change Analysis Outputs and Conversion to Biomass Loss

The change analysis data is presented as; areas that remained with the same canopy

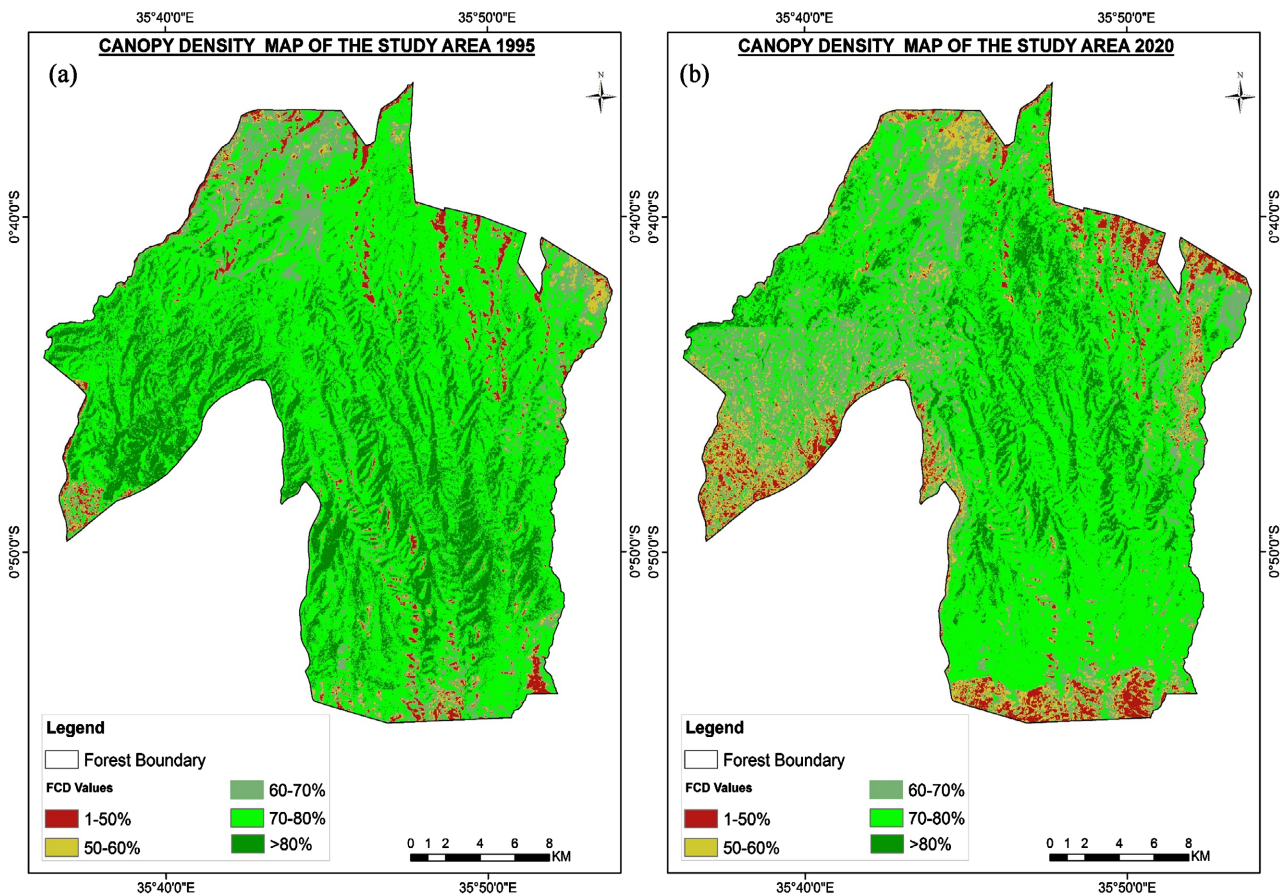


Figure 4. (a) Forest canopy density map in 1995 and; (b) Forest canopy density map in 2020.

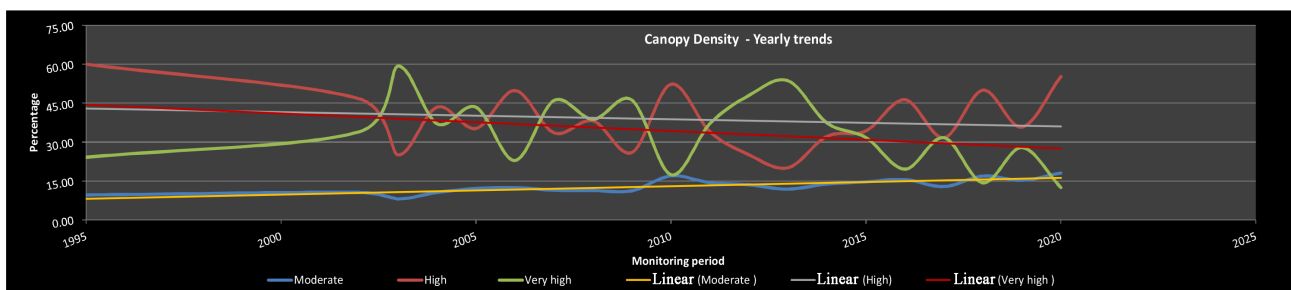


Figure 5. Yearly canopy density trend.

density values (No change), changes to the medium, high and very high canopy density values (Gain), changes from very high density values to high and medium canopy density values or from high to medium canopy density values (Forest Degradation) and changes from very high, high and medium density values to very low and low values (Deforestation) (Figure 7).

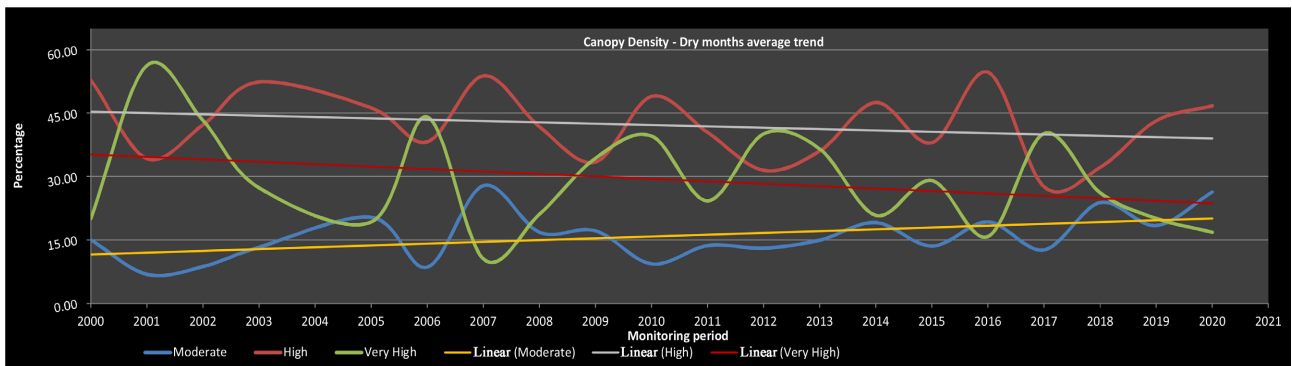


Figure 6. Dry months average canopy density trend.

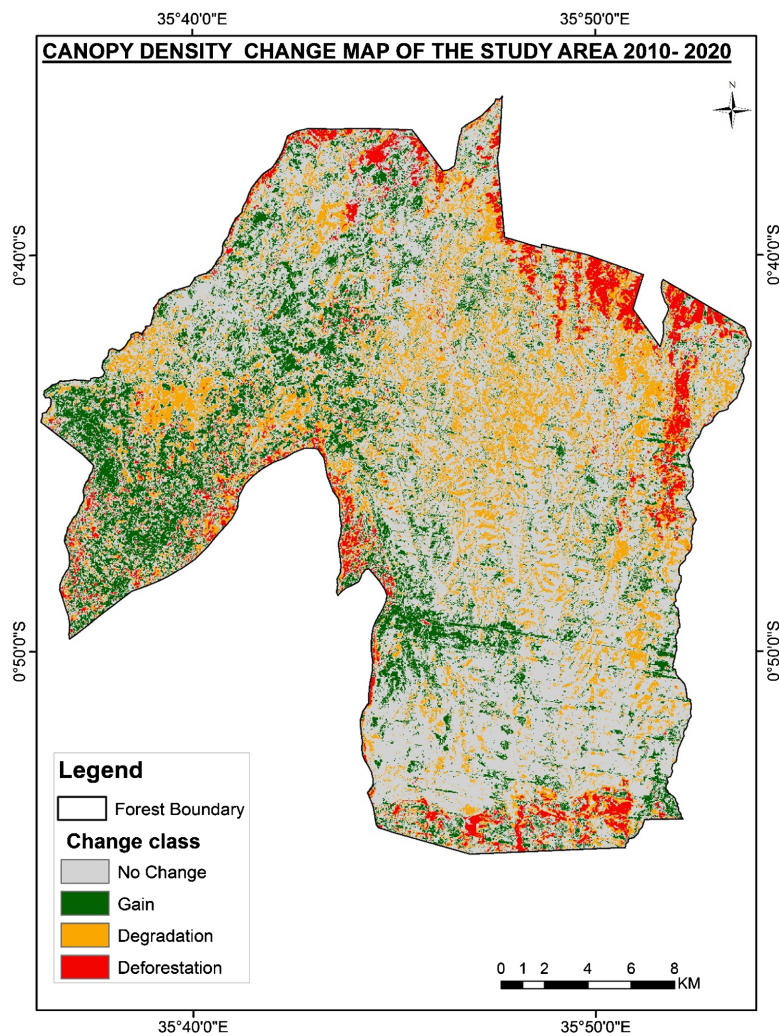


Figure 7. Map showing canopy density changes.

On the other hand, the results of conversion to biomass loss indicated a total of 1,639,280.29 tons biomass changed from the period 2002-2005 and this rose to 4,836,473.26 tons between the period 2005-2010 before dropping to 825,576.97 tons and rising again to 3,580,108.71 tons between 2010-2015 and 2015-2020 respectively (Table 3 and Figure 8). In estimating the annual biomass loss per hectare, the study showed that forest degradation results in an average annual loss of biomass equivalent to 138.54 tons/ha/yr, which was distributed as 200.41 tons/ha/yr between 2002 to 2005, 129.34 tons/ha/yr between 2005 to 2010, 85.98 tons/ha/yr between 2010 to 2015 and 138.43 tons/ha/yr between 2015 to 2020 (Figure 9). The peak degradation relates well with Kinyanjui (2011) who described significant declines in vegetation health and density in this area and a decline in biomass loss post this period may illustrate improving conservation measures.

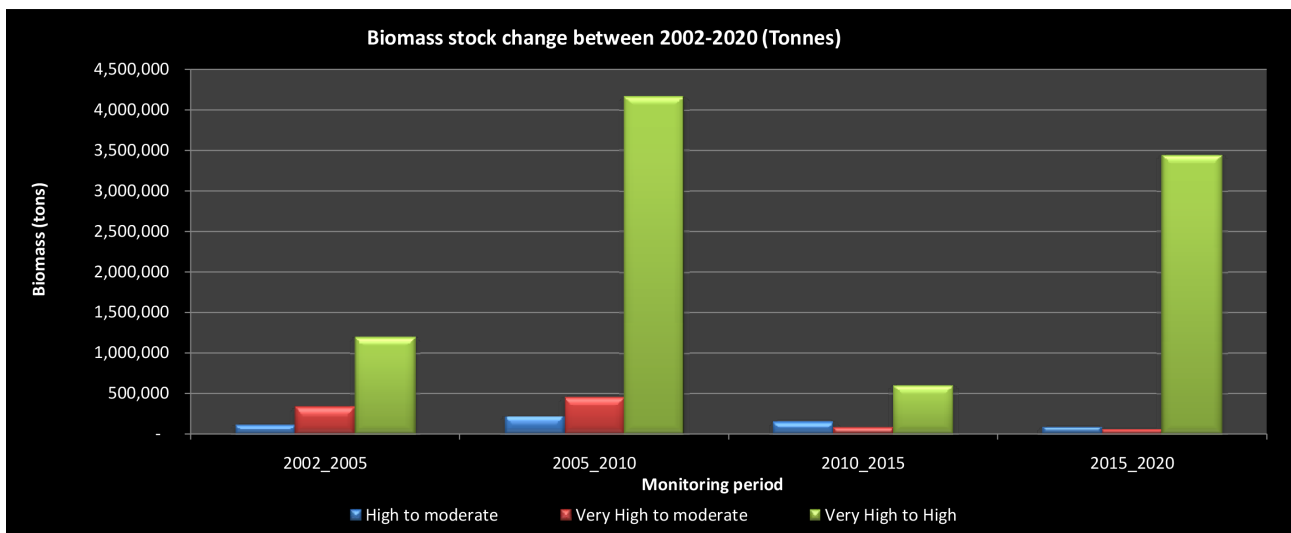


Figure 8. Biomass stock change between 2002-2020 (Tonnes).

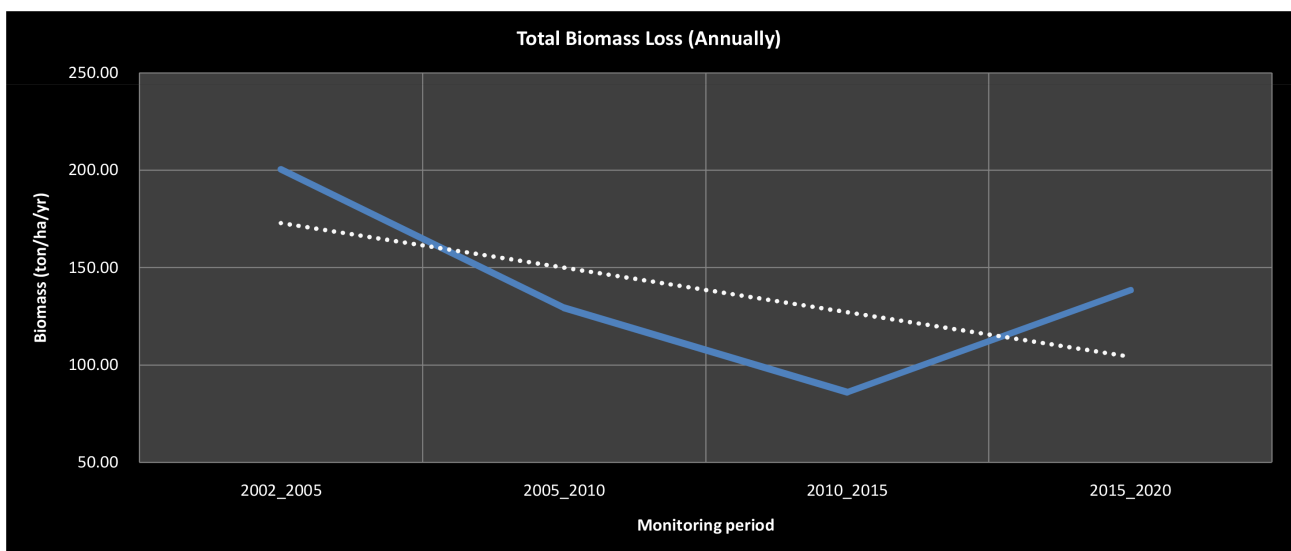


Figure 9. Annual trend of biomass loss during the monitoring period.

4. Discussions

The FCD model combined data from the three different indices of AVI, BI and SI which are variables with different responses in all vegetation types. AVI tends to be very sensitive to a number of vegetation factors such as quantity and the topography of where the vegetation is found. Just like NDVI, areas with dense vegetation appeared to have very high AVI values; moderate vegetation had medium values while areas with no vegetation or bare soil had lower values. For the BI as a parameter, soil reflectance level is highly dependent on soil characteristics. It is prepared for analyzing soils and can be used to identify the difference between areas with the presence of vegetation and non-vegetated areas. Results show bare areas to be having very high values while the dense forested areas have very low values. The short wave infrared and the red spectral bands in this analysis quantify the soil mineral composition, while the blue and the near infrared spectral bands enhance the presence of vegetation. Soil moisture content is usually not constant during the vegetation growing season and differences in soil moisture content could therefore influence soil reflectance and consequently the vegetation index values. Shadows on the other hand are mostly caused by the interaction between light and objects, such as trees and buildings among others. Shadows in vegetation images represent a major contribution to the total reflectance of the canopy while canopy shadow characteristics are linked to the total spectral radiance. The arrangement of the crown in the forest determines the shadow pattern which consequently affects the vegetation's spectral reactions. SI variations also depend on the covering vegetation whether it is bare, having some vegetation cover or forested. In this analysis therefore, areas with dense forest (more shadow) have high SI values while areas with low vegetation cover (grassland and bare land) have lower SI values and thus, SI increases with the forest density.

The trend analysis for the very high canopy density values indicates a downward trend during the monitoring period in both yearly and monthly average scenarios (**Figure 5** & **Figure 6**). However, there were variations in both graphs which could be attributed to the seasonality impact of the time series data. Peaks were observed at different years and decreased at different points as well. Interestingly though, at the points where this forest type has a peak, the other two forest types have a decrease and vice versa. Noticeable as well, is that there was a steady decrease from the year 2014-2020 in both scenarios except for the year 2017. The steady decrease signifies that the forest is opening up either to the other relatively open forests or to the non-forest category classes.

High canopy density is the transition between very high and medium canopy density values. The trend in both scenarios also indicates a slight decrease as compared to the very high density values (**Figure 5** & **Figure 6**). This forest type had peaks at all points that the previous one had a decrease for instance; there was an increasing trend in both scenarios between 2017-2020 and the same period that the previous one was decreasing except for the year 2017. This there-

fore could also signify that the forest is actually opening up.

On the other hand, analysis of the moderate canopy density values indicates an upward trend during the monitoring period in both scenarios (**Figure 5 & Figure 6**). There were not as many variations as the other two forest types but whenever there was a decrease in the very dense canopy density values, there was an increase in the moderate canopy density and the high canopy density values. This indication of the forest opening up as presented by the results could therefore be taken as a sign of forest degradation.

In most instances, before a forest is fully converted to a non-forest category, it starts by opening up with a number of degradation activities beneath the canopy cover. This has however been a bit challenging to monitor from above since the crown cover tends to remain intact. The results, therefore, confirm that the FCD model is able to show how the different canopy densities in the forest were behaving or responding to the vegetation indices analyzed. At the same time, it confirms the decrease in forest areas with very high canopy density values at the expense of high and moderate canopy density values.

Further, analysis indicated that the conversion from very high canopy density to high canopy density values experienced the greatest biomass change followed by a conversion from very high canopy density to moderate canopy density and then high to moderate canopy density (**Figure 8**). This further agrees with the trend analysis data which revealed that the very high and the high canopy densities were decreasing while the moderate canopy density was increasing. Notably though the change from high to moderate canopy density was greater than the change from very high to moderate canopy density in the period 2010-2015 and 2015-2020 with the greatest biomass conversion being in the period 2005-2010.

The annual biomass loss per hectare on the other hand displayed a downward trend during the period 2005-2010 and 2010-2015 before rising again in the period 2015-2020 (**Figure 9**). As much as this could be due to the seasonality effect, it could also signify the response of the forest to different degradation activities and by extension the measures put in place by different management practices. The results also illustrate that canopy density change can be applied in monitoring forest degradation since irrespective of the landcover remaining forest from the previous year as is always depicted by only monitoring the forest canopy, the density may have changed from very high canopy density values to a lower canopy density values which equate to lower biomass on the ground.

5. Conclusions and Recommendations

5.1. Conclusion

Forest resources play a major role in socio-economic development and hence human overreliance on the forest ecosystem is a trend that will continue. Many current forest degradation challenges demonstrate a need for improving existing relationships between these resources and anthropogenic activities. The sustainability of most forest ecosystems therefore is mostly dependent on how humans

will manage them and this includes monitoring degradation in the forests for appropriate conservation and management measures. The challenge in Kenya, however, has always been how to quantify and monitor forest degradation especially in the natural forests.

The results of the study consequently indicate that different biophysical indices with different characteristics respond to changes in the vegetation density depicting that whatever disturbance caused to the vegetation can be captured from analysis of these vegetation indices to indicate changes that have occurred in the canopy density over a period of time. In addition, the study has demonstrated that changes in canopy density (but capturing what is happening below the canopy) can be quantified in terms of biomass loss with the forest canopy density changing from higher values to lower values being calculated in terms of the lost biomass.

5.2. Recommendations

1) The study illustrates that the Forest Canopy Density model can be a good tool to monitor forest degradation and can also help in singling out the hotspot areas. This could go a long way in solving the challenge of monitoring Forest Degradation for both national and international processes.

2) This analysis process could equally be applied in the emissions calculations since the amount of biomass loss generated could be converted to carbon and then to carbon dioxide equivalent and thus it can as well be adopted for the REDD+ process.

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Conflicts of Interest

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

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