Assessment of Forest Rehabilitation and Restocking Along Mt. Kenya East Forest Reserve Using Remote Sensing Data

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Abstract

The nationwide ban on harvesting of forest products in 1999 was aimed at promoting regeneration of forest resources in Kenya after years of uncontrolled intensive logging. This was followed by massive tree planting programs spearheaded by the Kenya Forest Services (KFS) and other stakeholders. It is estimated that millions of tree seedlings were availed to support the program. One of the heavily affected forests was Mount Kenya Forest Reserve gazetted in 1932. The diverse tree species and its proximity to human settlements has made this important national water tower vulnerable to deforestation and illegal logging. Despite development of a ten year Mt. Kenya ecosystem management plan (2010-2020) to address threats to Mount Kenya's natural resources, comprehensive mapping of degraded areas to inform rehabilitation program has not been carried out along the perceived forest-human activity transition zone. This study sought to assess effectiveness of rehabilitation efforts moreso restocking after the 10-year ban. This will ascertain success or failure of such an ambitious program and inform probable causes and if possible advise on the way forward. Geospatial approaches and tools were integrated in data collection, analysis and presentation. Such tools especially remote sensing and GIS have been applied in forest cover spatial extent mapping as well as forest change detection analysis.

Key words: Remote Sensing, Mt. Kenya, Ban, Restocking, KFS.

Overview and Background Information

Globally, forests are an important natural resource providing safe habitats for biodiversity, food for humanity as well as livelihood to many people. As such management, protection and restoration of forests is crucial for continuation of social, ecological and economic benefits sundry (FAO, 2015; Gamfeldt et al., 2013). Internationally, excessive exploitation of forest resources has resulted to loss of global forest cover with an estimated 129 million hectares cleared between 1990 and 2015 (FAO, 2016). This points to the alarming rate of deforestation calling for more attention on management and development of forests. Although there exist international treaties and directives on forest management, locally forests continue to face threats from population pressure related outcome and climate change risks. This calls for re-evaluation of forests conservation and associated land use management practices at locally to understand spatial and temporal dynamics of forest management approaches across the many forest blocks in the country.

Kenya has diverse forest types ranging from the lowland tropical rainforest, montaine forests to coastal mangrove types existing in different altitudes. Assessment of the different forest conservation approaches across the country will inform good management practices for sustainable development of national forest resources. Given the high rates of deforestation in 1990s, a nationwide ban on harvesting of forest resources was realized in 1999 coming into effect in the year 2000. This move aimed at promoting regeneration of forests in the country after years of uncontrolled logging. Massive tree planting programs were then initiated by the Kenya Forest Services and sector specific stakeholders with millions of tree plants species availed across the country for restocking and rehabilitation to date. For effective management of these diverse forest clusters, information on their spatial extents, altitudinal location and regions of degradation is important. Recently constituted taskforce using aerial surveys to assess status of National forests pointed out wanton destruction of the forest cover through illegal logging and excision rights allotment. Their findings are consistent with many studies done in the region and country (Soini, 2002; Nkako et al, 2005).

Locally most studies in forest change analysis have focused on monitoring forest cover change through deforestation using optical remote sensing imageries (Baldyga et al, 2007; Ochego, 2003). Satellite remote sensing technologies have gained popularity in the field of forest studies due to its synoptic and continuous earth observation. These characteristics make remote sensing less costly and effective in monitoring and assessment of forest dynamics on a temporal scale. For instance, remote sensing data has been used widely in forest mapping (Wagner et al., 2003; Dwyer et al., 2000) and Forest Change Detection (Ahmed et al, 2018; Gimeno et al., 2002) among others. Understanding changes in forest cover is important for operational forest management especially those aimed at assessing success of forest rehabilitation and restocking programs (Dostálová, et al, 2016; Johannes, et al, 2017). In most instances, forest cover dynamics arise from fires, diseases and illegal logging all which interplay to influence deforestation and regeneration of forests globally. These activities are reportedly common along forest border zones in all Kenyan forest complexes. The Mount Kenya Forest Reserve gazetted in 1932 is under the jurisdiction of Kenya Forest Service to especially ensure establishment of plantations in areas where harvesting of indigenous stands have occurred. Despite development of a ten year Mt. Kenya ecosystem management plan (2010-2020) to address threats impacting on Mount Kenya's natural resources, comprehensive mapping of degraded areas to inform rehabilitation program has not been carried out along the perceived forest-human activity zones. One of the action plan envisaged in the ten year management plan is to carry out assessment of forest degraded areas to inform the type of enrichment plantation. Effective reforestation requires assessment of target enrichment areas to identify forest dynamics such as tree density on a spatial-temporal dimension.

There have been no extra terrestrial based assessments of Mt. Kenya forest dynamics after the ban especially along the degraded Eastern and South Eastern forest border zones. This has limited effective monitoring of the success rate of forest tree establishment after years of expansive tree cover restoration process. Every year national, regional and local tree planting activities are carried out by institutions, corporate and individuals around Mt. Kenya Forest Reserve. Although some successes have been achieved to this end, it is not known which areas of the forest have regenerated after restocking and the effects of these strategies on the overall forest rehabilitation generally. Despite Mt.Kenya forest reserve being a protected area, management of this forest is faced with threats of illegal logging and forest resource depletion along the populated low elevation areas of the forest reserve.

Previous studies done on Mt.Kenya forest using Landsat imageries have shown consistent patterns of increased forest loss over time. According to Yi-Hua, 2011, between 1980 and 2000, Mt. Kenya forest cover decreased to about 12.7 %, while Ngigi &Tateishi in 2004 observed a 2 % drop in forest cover between 1987 and 2000. A study by Ndegwa, (2005) indicated that about 17.5 % of the Montaine forest was destroyed between 1978 and 2002. These findings confirm the fact that Mt. Kenya forest is under threat from urbanisation and agricultural land use practices. The greatest limitation towards effective monitoring of forests in the country is the over dependence on snap shoot field data and the focus on forest degradation as though it were the only major threat to local forest development. This clearly shows a gap and need to re-shift attention from forest degradation and it drivers to matters of forest restocking, rehabilitation and regeneration. Integration of remote sensing imageries with field data will provide approaches essential for quantification of forest areas under regeneration and rehabilitation as indicated in this study.

This study seeks to assess the effectiveness of plantation establishment activities in the degraded areas under the forest resource management program within Mt.Kenya ecosystem management plan. Most studies carried out in the Mt.Kenya region have applied optical remote sensing imageries to map the extent of forest cover loss between

1978 and 2002. Use of optical sensors in the acquisition of high quality cloud-free imageries is hampered by presence of frequent cloudy conditions in the area. This leads to misclassification of land cover and land use features (Asner, 2001; Yi-Hua, 2011). Due to these challenges, this study will use Landsat 8 OLI Low Cloud Cover Data (LCCD) to derive forest area under target enrichment based on the initially identified low tree density patches. Although SAR data are not affected by cloud coverage, weather or light condition, they have not been widely used in tropical forest mapping though they are effective in forest biomass estimation; forest cover mapping and discriminating forests from other land cover (Hamdan et al, 2017).

In particular, the new Synthetic Aperture Radar sentinel 1A satellite data from European Space Agency has gained popularity of use in forestry studies especially derivation of forest area (Dostálová et al, 2016) and forest change detection analysis (Olesk et al., 2015) in Europe. However, although SAR data is promising compared to optical ones, their use is pegged on having knowledge on Radar nomenclature and availability of specifically designed tools to handle radar data image processing as well as analysis.

Study Area

Mount Kenya Forest reserve, also gazetted in 2000 as a national reserve co-managed by Kenya wildlife service and Kenya Forest service respectively. It is a protected area for its biodiversity and water catchment values. This study was carried out along the Eastern and South Eastern Forest Border zone(Fig.1). This belt has minimal potential for tourism development and comprises of community lands and forest resource dependent population. The zone is often threatened by human activities of illegal logging and charcoal burning owing to its proximity to permitted settlement areas. It contains Nyayo Tea plantation Zones and is often a target for farm forestry activities.

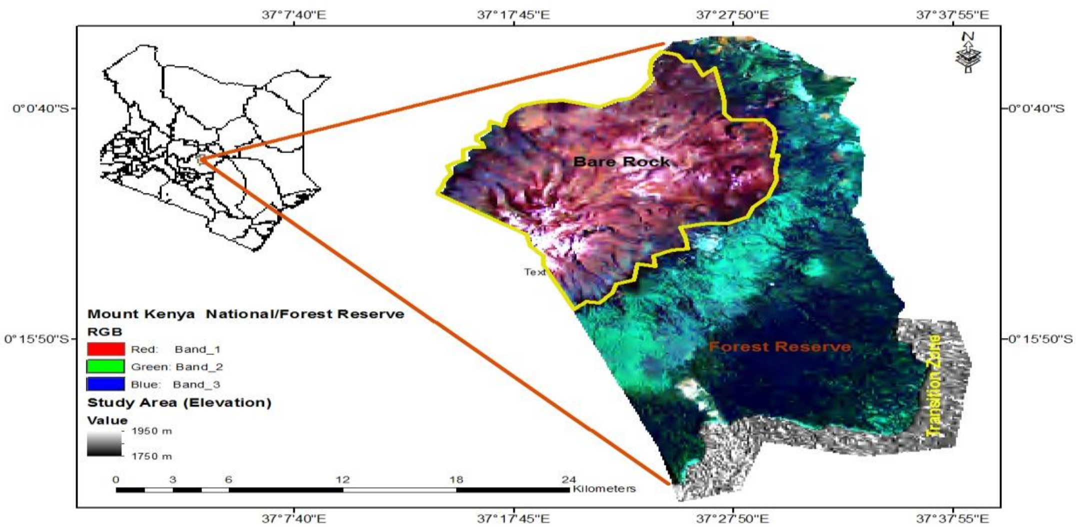


Figure 1: Location of the Study

Data, Materials and Methods

Data and Materials

Multispectral Landsat 5 TM and Landsat 7 ETM+ Path 168 and Row 60 for the study area were downloaded from US geological Survey official website (http: // www.earthexplorer.usgs.gov). Images for 2011, 2015 and 2018 with less than 6 % cloud cover were selected, downloaded and used in this study. All images were acquired during January a dry month inorder to reduce reflectance attenuation associated with seasonal variation. Visible and Near-infrared wavelength bands were used to map the greennes of forest (Table.1). A 30m ASTER digital elevation model of the area was used to extract slope and elevation. Roads and towns data used was obtained from Kenya Open data portal as shapefiles. Satellite image processing was done using Idrisi Kilimanjaro and GIS analysis was carried in QGIS version 2.14.1 Essen. Land use/ land cover validation data was collected from both field visits and high resolution google earth images.

Table1: Landsat images and their bands used in calculating Normalised Digital Vegetation Index

Image	Wavelength(micrometers)	Date	Resolution
Landsat 7 ETM+		21st January 2018	30m
Band3:	Red (0.63-0.69)		
Band4:	NIR (0.77-0.90)		
Landsat 7ETM+		29thJanuary 2015	30m
Band3:	Red (0.63-0.69)		
Band4:	NIR (0.77-0.90)		
Landsat 5 TM		10th January 2011	30m
Band3:	Red(0.63-0.69)		
Band4:	NIR(0.76-0.90)		

Methods

Extraction of Study Area

Area of interest comprised of the Eastern and SouthEastern blocks of Mount.Kenya forest. The area consist of the expansive montaine forest across Meru,Tharaka Nithi and Embu counties. Images of 2011, 2015 and 2018 were then subsetted to get the desired study area. ASTER digital elevation model image of 2018 was clipped to the study area to give the forest altitudinal height.

Image Processing and NDVI Calculation

The 3 pairs of subset Landsat images were pre processed to correct for atmosphere errors using cost(t) atmopsheric correction model in Idrisi Kilimanjaro image processing software. Band 3 for red and band 4 for Near infrared were used to discriminate the forest vegetation from non vegetation land use/cover. The study used Normalised Difference Vegetation Index(NDVI) to quantify forest vegetation abudance by measuring greeness. Although there are other vegetation discrimination indexes for mapping vegetation, NDVI was used because it is easier and straight forward to use compared to others and that is has been applied widely in discriminating vegetation from other landuses/cover (Pettorelli et al., 2005; Mancino et al, 2014; Slimani et al., 2017).

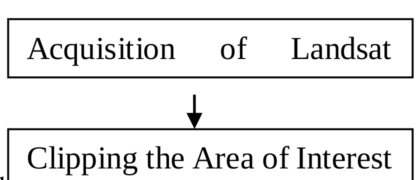
Vegetation Cover Density Classification

NDVI values for the resultant image derived maps of 2011, 2015 and 2018 ranged from 0.28 to 0.70. An appropriate NDVI threshold value to classify forest vegetation cover density was selected based on calculated NDVI values and visual interpretation of the high resolution Google earth images.

To classify the forest cover, NDVI values were categorised where the intensity of greenness was used to reclassify the vegetation types in the AOI.

Validation and Accuracy Assessment

Effective interpretation of the resultant NDVI images was based on integrated field data, google earth images, roads, towns and population data. These data helped to understand attributing causes of the observed forest vegetation changes especially along the permited settlement/forest areas



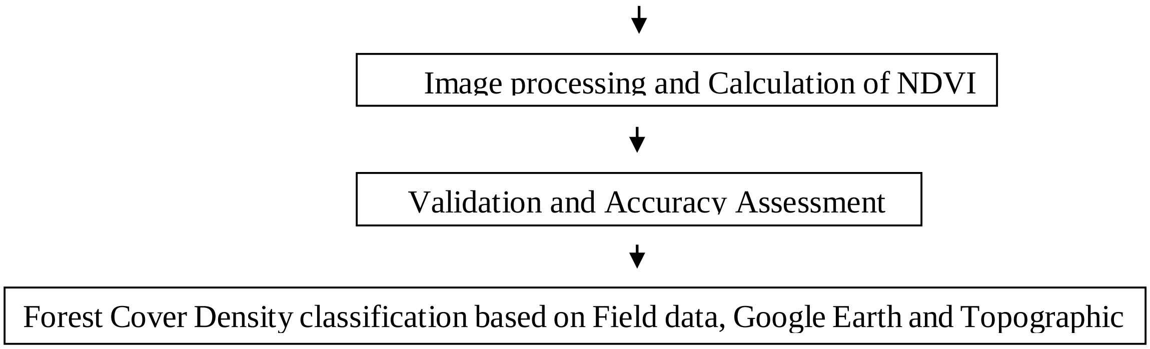


Figure 2: A Schema of the Image Processing and Spatial Data Analysis

Results and Discussion

Dynamics of Forest Density Cover

Forest cover density for 2011, 2015 and 2018 was classified as Non-vegetation(NDVI<0.31), Scanty vegetation(0.31<NDVI< 0.46) and dense vegetation(0.36<NDVI<0.69) based on the NDVI values. Analysis of the spatial distribution for vegetation cover along forest border showed that areas of high density were concentrated about 1000m from the border. The quantity of cover was not symmetrical across the three years under review. In 2011, 10250.73 ha of assorted shrubs were mapped compared to 8947.17 ha of the same in 2015. This represents 12.72 % decrease in low and medium dense vegetation. Similarly proportion of high dense vegetation showed a decline from 56639.25 ha(2011) to 50841.90ha (2015) and a total of 48796.74 ha in 2018(Table.2) This trend show a consistent decline of woody vegetation cover at a rate of 13.85% for the 7 year period (2011-2018). A look at the resultant NDVI maps of 2011, 2015 and 2018 shows a consistent loss of high valued forest woody species at least 2500 meters from the permitted forest border(Fig.3). This means illegal and selective harvesting of trees is still happening deep into the forest away from the forester watch stations along the south eastern and eastern Mt. Kenya forest blocks.

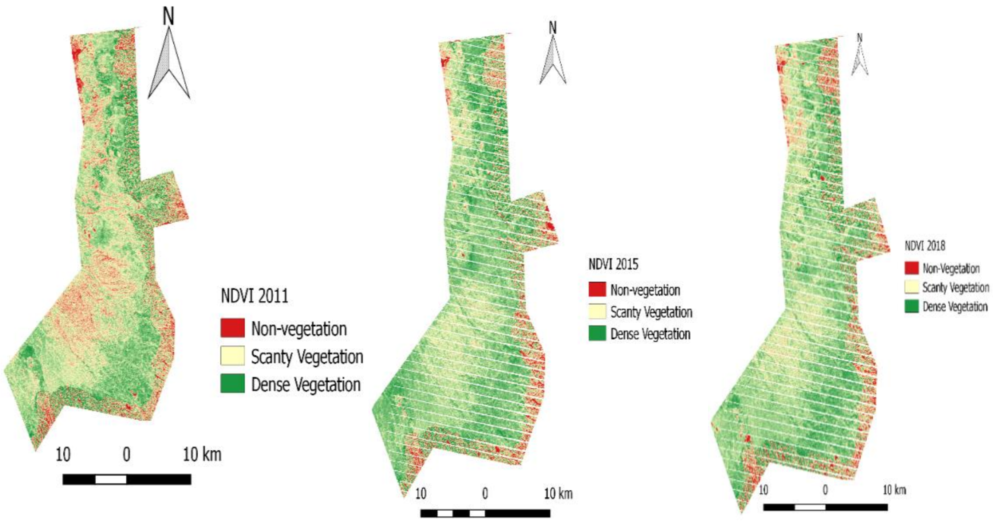


Figure 3: Maps of the Resultant NDVI values for 2011, 2015 and 2018

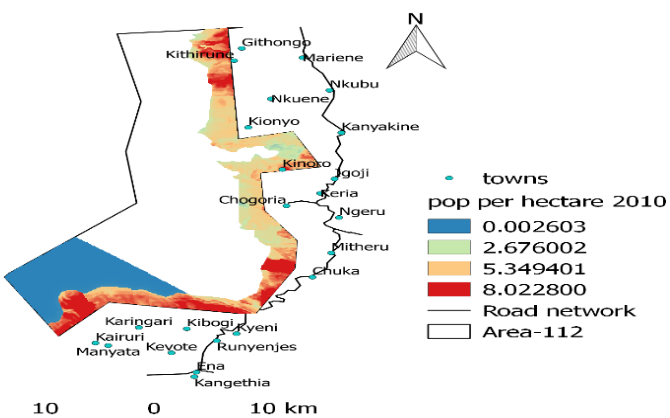
Table 2: Temporal Variation in Forest Density Area Cover in Hectares for 2011, 2015 and 2018.

Forest Cover	2011	2015	2018
	(ha)	(ha)	(ha)
Non Vegetation	4862538.81	4949868.42	4968897.93
Scanty Vegetation	10250.73	8947.17	10676.43
Dense Vegetation	56639.25	50841.90	48796.74

Cause Factors

Observed variations in forest cover show interesting patterns with scanty vegetation decreasing between 2011 and 2015 and later increasing . Dense forest vegetation cover showed a decrease across the seven year period(2018-2011). This can be attributed to encroached population and related human activities along the forest border zones. As can be seen there has been increase in population around the forest border areas between 2010 and 2015(figure.4).This increase is attributed to births and localised migrations of population to work in Nyayo tea zones and private tea farms overlooking the forest.

Low elevation,upgraded roads and close proximity of the forest blocks to towns and roadnetworks has contributed substantially to the observed variations along Embu, Chuka, Chogoria and Imenti forest blocks of Mt. Kenya ecosytstem(Figure.5). Woody trees which form the dense vegetation are found on gentle slopes. It is thence important to note that altitude and slope have contributed to the spatial distribution of the forest cover density variations identified in this study. This explains why restocking has been persistently done along the forest edges and at low elevation as these comprise hot spots areas mostly encroached by the communities neighbouring forests.



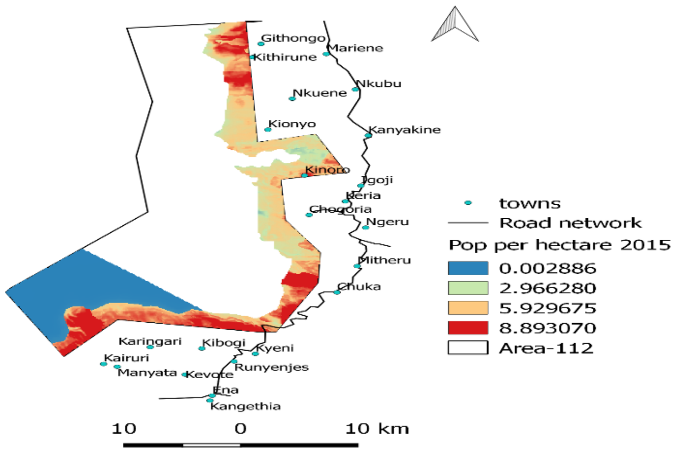


Figure 4: Increased Population Across the Forest Border Zones Between 2010 and 2015

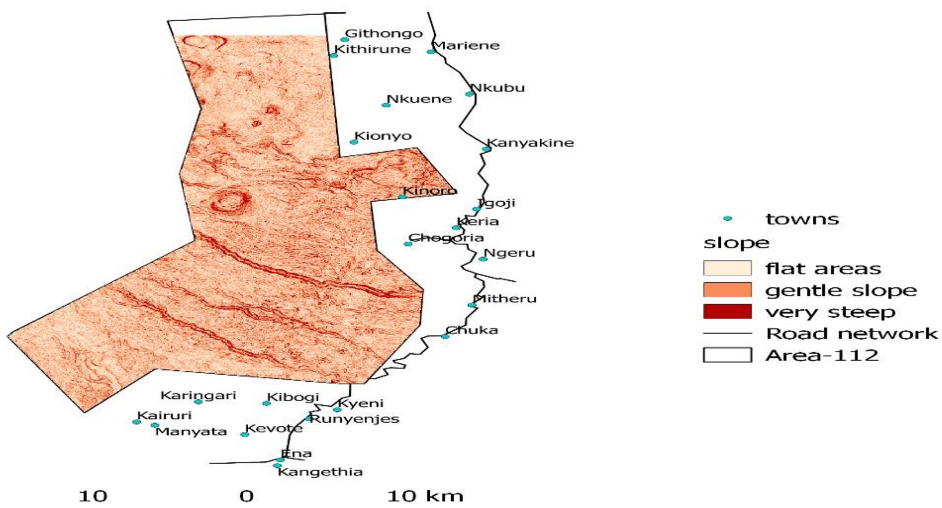


Figure 5: Spatial Location and Distribution of Slope, Urban Areas and Roads

Accuracy Assessment

Analysis of the spectral signature for forest vegetation types proved difficult to discriminate individual trees species. Mixing up of pixels due to problem of spectral similarity lead to development of general forest cover classes used during classification. Overall accuracy for the three NDVI maps as assesed using Kappa Index of Agreement (KIA) was 0.7892 (2011), 0.8512% (2015) and 0.7638 (2018). These accuracies were deemed good given that a critical value of 0.759(KIA) is considered acceptable. Producers accuracies of 0.77, 0.86 and 0.78 were recorded for the Non vegetation, Scanty vegetation and Dense vegetation cover classes while Users accuracy varied between 0.85 to 0.90 respectively. It is therefore advisable to use high resolution images more so radar imageries and the doing of adequate field surveys to assist in development of effective training sites.

Conclusion

The findings of this study showed an increase in shrubs and other low to medium density forest vegetation between 2011 and 2018. The increase realised was about 4.15% for the seven year period especially exotic trees planted in the patches within forest stands. The fact that dense forest tree cover has been reducing as revealed by this study especially those deep into the forest, highlights limitations of the current ground based forest beats and surveys. These approaches restrict forest managers to known areas and only to those served by access routes. Generaly, results of this study have shown the importance of integrating aerial and space born platform data in assessing and understanding dynamics of the evolving Mt.Kenya montaine forest cover. The study reveal mixed stories of success and failed reforestation cum restocking as shown by the proccessed, classified and analysed Landsat imageries. Some of the limitations with findings of this study are attributed to the season when the images were captured, image spatial resolutin and lack of adequate current ground truth information. The study proposes other studies to look at forest dynamics during wet seasons to help account for the greenness variation across dry and wet seasons.

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