academicJournals

Vol. 6(5), pp. 159-171, July, 2013
DOI: 10.5897/JGRP12.063
ISSN 2070-1845 © 2013 Academic Journals
http://www.academicjournals.org/JGRP

Journal of Geography and Regional Planning

Full Length Research Paper

GIS based forest cover change and vulnerability analysis: A case study of the Nandi North forest zone

Sheila Aswani Wachiye[1]*, David Ndegwa Kuria[2] and Douglas Musiega[3]

[1]Geomatic Engineering and Geospatial Information Systems Department, Jomo Kenyatta University of Agriculture and Technology, P. O. Box 62000 – 00200, Nairobi, Kenya.
[2]Geomatic Engineering and Geospatial Information Science Department, Kimathi University College of Technology, P. O. Box 657 – 10100, Nyeri, Kenya.
[3]Jomo Kenyatta University of Agriculture and Technology, Kakamega Campus, University of Agriculture and Technology, P. O. Box 62000 – 00200, Nairobi, Kenya.

Accepted 24 June, 2013

This study investigates the patterns of land use change, the reasons for those changes and the vulnerability of forests in Nandi North forest zone in Kenya between the years 1986 to 1995 and 1995 to 2006. Landsat TM images of 1986, 1995 and ETM+ of 2006 were used to create single image depicting the sequence of land use change for the period between 1986 and 2006. The spatial relationship between forest cover change and the causes was determined based on the ground truthing and additional literature from the zonal forest officer and the zone management plan where a total of seven classes including dense natural forest, sparse forest, grassland, agricultural land, plantation forest, tea plantation and built up area was used for classification. Both unsupervised and supervised classifications were carried out using a false colour composite image for interpretation. Out of the seven classes, the results indicate an increase in agriculture over the study period while natural forests were reducing. Extreme poverty, planned deforestation for development needs, and unsustainable forest practices such as illegal logging, charcoal burning and encroachment were seen as key drivers of land use change as indicated by the information from the officer. Accessibility to the forest was a key threat to the existence of the forest. This is seen in the result where forest zones with gentle slopes and flat areas, lower elevation, close to roads and settlement had higher probability for conversion to other land uses due to easier access to them compared to steep slopes, with high elevation and which are from roads and settlement. The resulting vulnerability map categorized the forest into four degrees of varying vulnerability namely: highly vulnerable, moderately vulnerable, vulnerable and least vulnerable starting from the easily accessible to least accessible. The resultant map is important in forest conservation by the forest department as areas highly vulnerable can be put into high consideration at the same time involving the community adjacent to be involved in the management process.

Key words: Forest cover, LULC, change detection, vulnerability, GIS.

INTRODUCTION

Forests and woodlands are significant land cover covering nearly 40% of the total earth's surface, and are the most biologically diverse ecosystems in the world this is according to WRI, IUCN and UNEP, 1992. In the

*Corresponding author. E-mail: sheilaswani@yahoo.co.uk, sawachiye@gmail.com.

tropics, forest resources are very vital in sustaining the livelihoods of millions of people. These roles range from maintaining the ecological balance, providing fuel wood, habitat to important wildlife, soil and water conservation and purification of air. However, continued access to forest resources is increasingly getting challenged through deforestation and or forest degradation (Michael and Janet, 2003). For several centuries the world's forests have been under strain due to escalating human population (UNEP, 2001). These activities have resulted in loss of biodiversity, degradation of water catchments and increase in greenhouse gases which have far reaching effects. This has been blamed on poor monitoring and rule enforcement embedded in the institutions of management (Ayhan et al., 2004).

Deforestation and forest degradation resulting from unsustainable utilization affects the continued provision of ecosystem services, puts in the balance the livelihoods of them who depend primarily on the forests for survival (Monica et al., 2010). FAO (2009) defines deforestation as the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold. Forest degradation is the change within the forests that negatively affect the structure and the function of the stand or site, and thereby lower its capacity to supply products and services (Skole and Tucker, 1993). Depletion of forest affects many sectors of a country's economic. This includes the extinction of biotic communities leading to loss of biodiversity, soil erosion, global warming and loss in income to adjacent local community (Lung and Schaab, 2009).

High rates of deforestation have been recorded in developing countries through the conversion of forest and woodlands into mainly farmlands (Michael and Janet, 2003). Forest cover change as a result of forest deforestation and degradation caused by different drivers acting at different levels of operation. These includes natural or/and anthropogenic factors acting at different times scales (FAO, 2001). The natural ones are either gradual, such as evolutionary or rapid such as volcanic eruption. Despite this human induced change, forest cover change are the most rapid driven by greed and need resulting into adverse effects including climate change, water balances disruption and soil erosion and ecological fragmentation.

It follows that sustaining these resources in the face of demographic and economic pressure is pegged on the success of the institution, cooperation of the forest adjacent communities and a good understanding of the trends in forest dynamics and vulnerability. The last quarter of the previous century has seen increase in population and poverty levels especially among the rural communities coupled with diminishing options of means to livelihood. These developments exerted more pressure on the forest and institutions governing their utilization leading to degradation. This fuelled the need to have a better understanding of trends in change and the risks levels associated with the forests.

Forests in Kenya

FAO (2009) indicates that Africa's forests cover is about 21.4% of the total land area. In East Africa, around 13% of the land mass is covered by forests and woodlands thus making these resources quite limited and threatened. Kenya is the most forested country in the East Africa region (UNEP, 2006) where forest and woodland cover about 17 million hectares, which roughly is equal to a third of the regions land area. The forest landscape in Kenya is characterized by big changes both in forest cover and management. The degree is significantly important in the conservation of biodiversity, water resources and soil resources.

In Kenya, there are a number of key drivers behind degradation and deforestation of forestry resources, some studies by Ongeno and Opanga (2009) have contributed to the understanding some of these factors in forests . Despite this, only a few studies have their base on qualitative evaluation of forest dynamics. Most of these studies examined causes, and results of deforestation. Information of the rate, spatial trend of the deforestation and vulnerable areas to change is limited. Indeed many interventions such as policy and legislative reforms such as adoption of forest decentralized management have been implemented.

Sustainable forest management (SFM) concept was developed to stem the impacts of degradation and deforestation. It was designed to sustainably utilize and manage forest resource without compromising the needs of future. In Kenya, this was piloted under the banner participatory forest management (PFM) in 1998 in Arabuko Sokoke forest. This was part of the yet to start and now continuous process of decentralization as envisioned in the New Forest Act 2005. This arrangement brought on board the local communities under community forest associations (CFA) to take part into management of forests at local level. Through this arrangement it is believed that the local communities can easily gain monetarily from the forest and thus improving their livelihoods and at the same time conserve the forest. PFM gives the local communities to engage into activities that generate income and help conserve the forest such as eco-tourism, and beekeeping amongst others.

The Nandi north zone forests in the Rift Valley province of Kenya has fairly fertile soils good for agriculture, but the ever growing population, leading to squatter settlement on forest land has exerted more pressure to the forest for considerable time. The results of the pressure has been encroachment and general degradation of the forest which is home to some important indigenous tree species such as *Brachyleniahuillensis* and forms part of the largest water catchment in Kenya (Mau) with rivers like Yala originating from this forest

(KFS, 1994). In order to understand the forces and processes of forest cover changes, integrated synthesis of socioeconomic and biophysical data is essential. This study incorporates remote sensing for mapping change. It also integrates biophysical, and livelihoods data to interpret the forest change trends revealed by digital image analysis and vulnerability modeling to identify high risk areas for future intervention.

Remote sensing and GIS in forest management

Following the advances in high resolution Remote Sensing Digital Data and Aerial Photography, mapping of the trends of cover changes have become relevant source of information for understanding land-cover pattern changes. Presently, with the supplement of ground information, remotely sensed data are the main source of information about land-use pattern changes. Various studies clearly demonstrated the potential of integrating remote sensing, GIS and field information for landscape assessment.

In particular to the assessment of forest cover usage, this technology helps us to see the revealing trends and interrelationships of the dynamics with socioeconomic and topographic factors. International and domestic forestry applications where remote sensing can be utilized are diverse and include sustainable development, biodiversity, land title and tenure (cadastre), monitoring deforestation, reforestation monitoring and managing, commercial logging operations, shoreline and watershed protection, biophysical monitoring (wildlife habitat assessment), and other environmental concerns. In this study information generated using both remote sensing and GIS to detect change on forest land cover over decades is used, also the vulnerability to change taking into consideration the underlying socioeconomic, physiographic/accessibility and institutional/organizational factors is investigated. Successive study on the trends of land-use and land-cover changes using Remote Sensing technologies and implementation of GIS mapping techniques help to understand the severity of changes and its effects.

Vulnerability to forest degradation/deforestation

In this study vulnerable area means area that is susceptible to change from forest to another land use type as a consequence of human activities. This study follows this definition and tried to assess areas in the study area that are likely to be deforested. In reality forest resources are degraded not only by human activities but also by other factors such as repeated natural fire, pest and diseases, natural disasters and war. Human activities are considered principally because of diverse sources of illegal activities such as illegal logging, fuel wood, non timber forest products (NTFPs) collection and hunting are recently the main factors that probably cause forest degradation in developing countries.

Basically, three principal elements are considered in the analysis of the susceptibility of forests to degradation. These are: i) socio-economic factors, ii) the forest resources themselves, which are subject to be degraded, and iii) accessibility to the forest resource, which is understood as how easy the local people can enter the forest and related to the natural factors such as: slope, elevation and distance from the river. Factors that constrain access to forests include distance from the road and distance form forest guard-station.

Accessibility to the forest resources which is one of the factors related to forest-people relationship is understood as how easily local people can go to the forest. The ease of access to the forest resource (that is forest area near to the road, settlement, river, low and less steep slope area, what else), to widely dispersed local market enables large number of people to generate income from forest products (Dien, 2004). If the forest area has very low human pressure, it is not very susceptible to forest degradation; in contrast, if the forest area is very rich in resource, easy to reach and not very far from residential areas, it becomes highly susceptibility to forest degradation. This study also includes organizational factors and their influence on susceptibility.

Thus the major objective of this study was to investigate the condition, causes of deforestation, vulnerability of the forest and prepare vulnerability map of Nandi North forest zone that will help in future management of the forest.

METHODOLOGY

The study area

North Nandi forest zone is located between longitude 34^o 51' 0" E and 35^o 10' 0" E and latitude 0^o 33' 30" N and 0^o 4' 30" N in the Great Rift valley at an altitude between 1700 and 2500 m above sea level. It borders Kakamega Zone to the North-west; Uasin Gishu to the North- east and Nandi South to the South- east (KFS management plan, 2010). The zone has two forests blocks, the north Nandi forest and the Kimondi forest covering a total of 18,054.4 ha found in two districts namely Nandi central and Nandi north districts as shown in Figure 1.

The area has a cool and moderate wet climate. It receives an average mean annual rainfall between 1,200 to 2,000 mm. The rainfall distribution is bimodal, with a principal wet season between March and June, and a subsidiary wet period in September-October. The distribution of rainfall is affected by topography and the south-westerly winds from the Lake Victoria. The eastern side of the zone receives the lowest rainfall while the southern parts receive higher amounts of rainfall.

Soils are well-drained and moderately fertile. The main soil types found in the area are sandy and clay loam with area like Kabiyet and Kilibwonni divisions having humic nitisols that is ideal for farming. The drainage system of the zone consist of five permanent rivers namely Kipkaren, Clare, Nonie, Kingwal and Yala with Kingwal swamp. Permanent streams can also be found all over the districts with most found in the Kilibwoni division. The drainage is

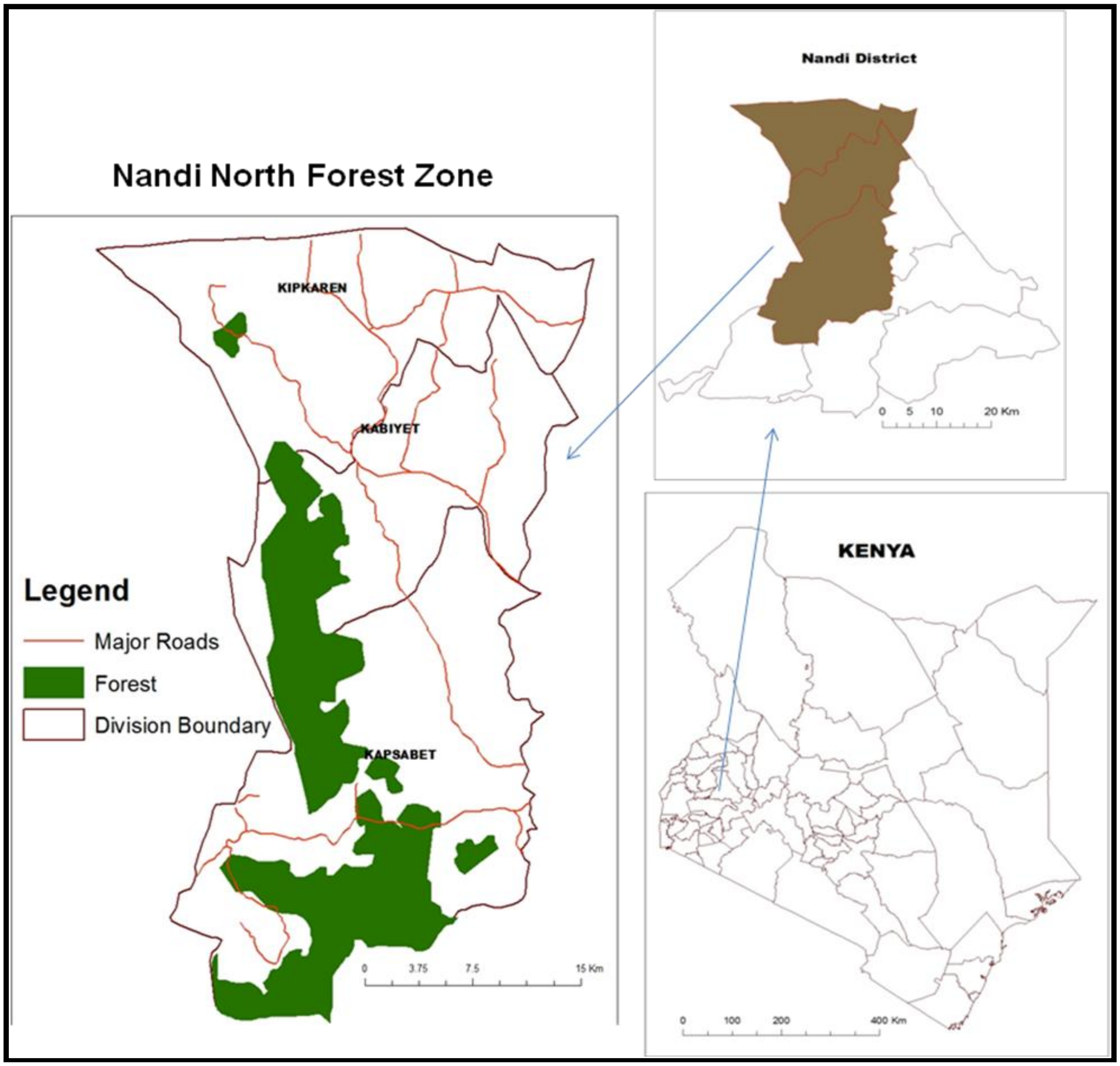

Figure 1. Map showing the Nandi North forest zone.

divided into two, those draining eastwards flow into the Kingwal and Kimondi river system then finally into river Yala. While those flowing westward flow through the south Nandi forest into Kakamega, Yala and finally into the Lake Victoria. The average discharge of springs in the forest is approximately 0.5 to 2 litres per second (KFS, 2010).

Data collection

Data used for this study was collected from field survey, literature review, satellite images and topographical maps. The field survey was conducted to give an overview of the physical condition of the study area, including topography, vegetation and land use type. GPS points of land cover types were taken, detailed information on previous forest cover types and general management practice. Information on forest livelihoods and conservation measures underway was gathered using a number of research tools such as formal interviews, focus group discussions and field observations. Literature was reviewed to identify knowledge gaps on forest conservation methods and measures put in place, other techniques used elsewhere and possible factors to incorporate in analysis.

Land-use/land-cover types at various times have been extracted from Landsat-TM, and ETM+. Slope and elevation information were obtained from a digital elevation model obtained from Africover portal of FAO website to determine the elevation of the zone. Boundary of the forest, rivers and various road category networks have been generated from 1: 50,000 scale topographic maps through manual digitizing. TM data has spatial resolution of 28.5 m and includes two middle-infrared and one thermal channel. These high-resolution scanners have seven spectral bands with a swath of 185-by-185 km area.

For the study area, a single scene, path 170 and row 60, taken in 1986 and 1995 by TM sensor on board Landsat 5 and for the image of 2006, an ETM+ Landsat-7, carried on-board the Enhanced Thematic Mapper plus (ETM+) instrument was used, both images were obtained from the Global Land Cover Facility (GLCF) online

Table 1. Land cover characteristics for the study area.

Land cover	Description
Dense forest	Near to primary forest with little human interference
Agricultural land	Includes rain fed farm lands
Plantation forest	Exotic tree species planted for commercial purposes.
Tea plantation	Farm lands with tea crop next to forest land
Built up	Area covered by houses or other buildings.
Grassland	Vegetation with grass all year round
Sparse forest	Scattered trees, shrubs and bushes within the area

imagery portal.

Methods

Pre-processing

Different image enhancement techniques were applied to improve the interpretability of different land-use/land-cover types in the study area. Thus, Pan Texture and Pan Sharpening (for ETM+ of 2000) and PCA and Texture analysis (for TM of 1986 and 1995) were performed to improve on the accuracy of interpretation and classification data.

Based on the reconnaissance survey with additional information from the zonal forest officer and the zone management plan a classification classes was developed for the study area. These includes seven classes namely dense natural forest, sparse forest, grassland, agricultural land, plantation forest, tea plantation and built up area as shown in Table 1. With these LULC types both unsupervised and supervised classification were used. The purpose for the classification was to assign all pixels in the image into the LULC types based on spectral characteristics. For this study a false colour composite image was used for interpretation, and classification done using maximum likelihood classifier which evaluates the highest possibility of a pixel belonging to a certain class.

Accuracy assessment

To verify the quality and reliability of the classification exercise, accuracy assessment was done. Topographic maps and a Global Positioning System (GPS) were used to obtain ground control point for accuracy test. A total of 140 points were obtained randomly, focusing on the distribution along the forest.

Post classification

In this process, images of every year was classified and labelled separately. The classified images were then compared to determine the change that had taken place between the two images using a change matrix. This enabled the changed areas to be extracted and by how much through the computation of change maps and change matrix statistics. With this information it was easy to quantify and explain the change in the forest cover.

Mean annual rates of forest cover change (MARFCC) between different image dates were computed based on the time series classified images using the equation below:

$$MARFCC\ (\%) = \frac{Forest\ Area\ at\ t_2 - Forest\ Area\ at\ t_1}{Forest\ Area\ at\ t_1 * (t_2 - t_1)} * 100$$

Where: t_1 = the year in which the older image was captured; t_2 = the year in which the recent image was captured

Forest vulnerability map preparation

In this study vulnerable area refers to areas susceptible to change from natural forest to other land cover as a result of human action. The factors identified by community members during focus group discussions as responsible for forest degradation were mapped and given a spatial extent so that they could be overlaid and weighted resulting into a vulnerable map as in the flowchart in Figure 2. The factors; accessibility to roads, elevation, proximity to guard station and population were analysed. The proximity data sets were subjected to distance analysis and reclassified in Arc GIS 10.

1. Elevation - The role of elevation in constraining accessibility to the forest was analysed. The forest was classified into classes of elevation and the impact assessed. Four classes were identified from low to very high as used that is 1300 to 1600, 1600 to 1900, 1900 to 2200 and >2200 respectively.
2. Distance from roads - The closer the forest is to the road the most vulnerable it is to vulnerability, thus distance from roads to forest was classified into five classes: 0 to 200, 201 to 400, 401 to 600, 600 to 800 and 800 to 1000 m from very high to very low respectively.
3. Distance from Guard station - Distance from guard station was rasterized and categorised into four classes based on distance from the forest station. Within 1 km from the station the guards are able to control the accessibility compared to more than 2 km from the station thus making the forest 2 km from the station highly vulnerable to human activities.
4. Population map - Population figures derived from the central bureau of statistics from the 1999 census were projected to 2006 approximations using the annual growth rate of the District. This population statistic was later divided by the locational area in order to compute population density per location which was then reclassified into classes.

RESULTS

Land cover of North Nandi zone

The land cover maps of the year 1986, 1995 and 2006 are as shown in Figure 3. From the results, Agricultural land occupies the highest area of 70345.98 ha at 66% of the total area of study in 1986 which increases to 72077.67 ha in 1995 to 73929.9 ha in 2006 which is a percentage of 69%. Sparse forest covers a total area of 15826.95 ha, which is 15% in 1986 and decreases to

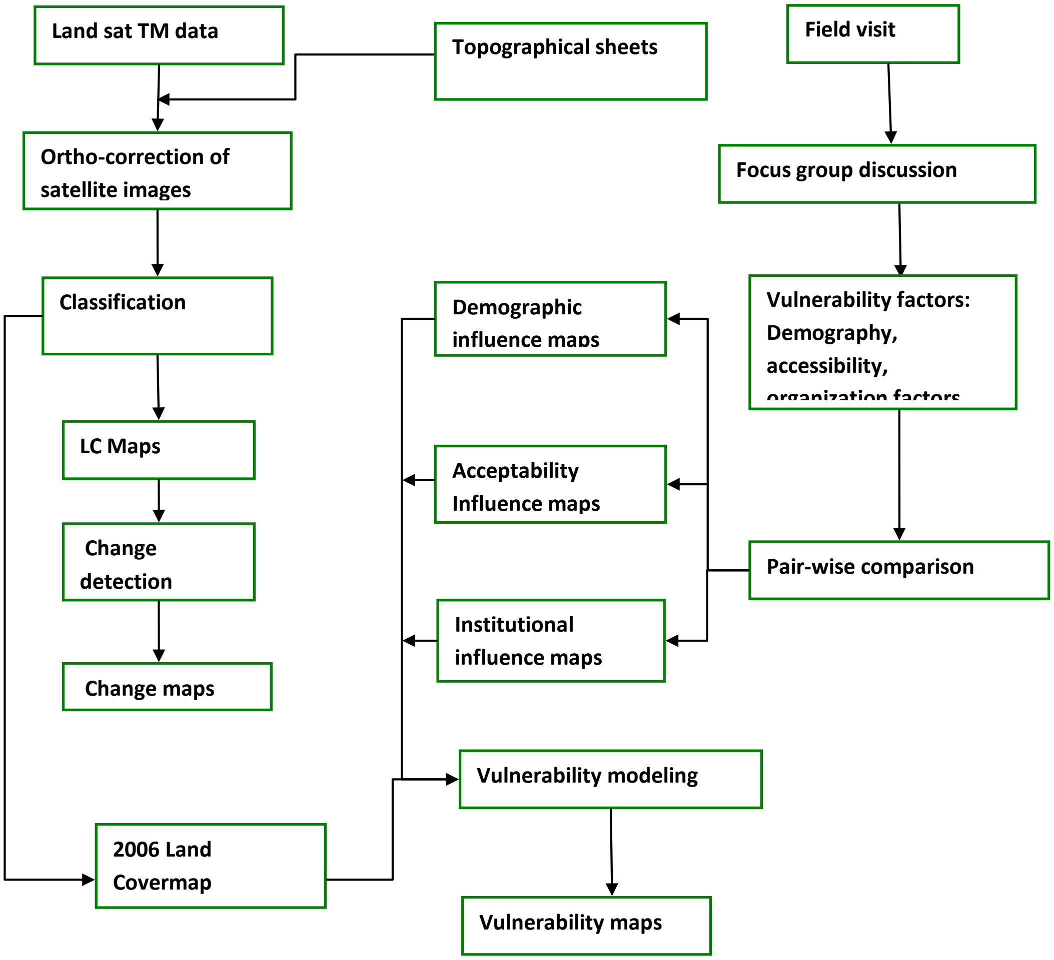

Figure 2. Flowchart of the research methods.

14887.89 ha in 1995 and then to 13816.62 ha in 2006 while natural forest covers an area of 15023.61 ha, 14% of the zone by 1986.

The area under forest decreases to 14922.99 ha in 1995 and then to 12458.34 ha in 2006, which is a total area of 2565.27 ha of land lost to other land cover. Plantation forest covers an area of 1084.86 ha in 1986, 1283.31 in 1995 and 650.07 ha in 2006 showing a decrease in area covered by this type of forest. Grassland also decrease from 3331.71 ha in 1986 to 2376.99 ha in 1995 and then increases to 3768.3 in 2006 while tea plantation and built-up areas shows continued increase from 955.44 ha in 1986 to 1511.28 ha in 2006 and from 536.67 ha in 1986 to 973.71 ha in 2006 respectively.

Accuracy assessment

Accuracy assessment on the classified images was done for the study area on all the years and an accuracy report was obtained with an error matrix and a kappa statistics. For the year 1986 an overall classification accuracy of 81.21% and kappa statistics of 0.7717 was achieved, for 1995 image an overall classification accuracy of 87.25% and 0.8374 overall kappa statistics. Overall classification accuracy for 2006 was 88.59% with a kappa statistic of 0.8616.

Change detection

Land cover change between 1986 to 1995

Table 3 provides a summary of major LULC change that took place from 1986 to 1995 within Nandi North forest zone to other land cover. The diagonal value of the table gives the LULC that did not change while the horizontal and vertical gives the values of 1986 and 1995 change matrix respectively.

High natural forest made the highest conversion to sparse forest/ shrub land losing an area of 1370.97 and 223.38 ha into agriculture. Plantation forest and tea plantation gains a total of 166.86 and 48.96 ha respectively from natural dense forest with grassland, swamp and built-up areas gaining a total of 8.82, 7.74 and 0.63 ha respectively.

Land cover change between 1995 to 2006

Table 4 provides a summing up of major LULC change that took place from 1995 to 2006 within the forest zone. The LULC that did not change are contained in the diagonal value of the table, the horizontal value showing the land cover change for 1995 and the vertical values for land cover in 2006 matrix respectively.

The result shows a continued loss in the natural forest cover to other land cover especially sparse forest and agriculture which gains a total area of 2558.34 and 750.69 ha from natural forest respectively. Grassland gains 51.3 ha, tea plantation 16.29 ha, built-up areas 6.12 ha and plantation forest 3.78 ha.

Rate of natural forest cover change

Mean annual rates of forest cover change (MARFCC) between different image dates were computed based on the time series classified images using the equation as follows:

$$MARFCC\ (\%) = \frac{Forest\ Area\ at\ t_2 - Forest\ Area\ at\ t_1}{Forest\ Area\ at\ t_1 * (t_2 - t_1)} * 100 \quad (1)$$

Where: t_1 = the year in which the older image was captured; t_2 = the year in which the recent image was captured

= (523.617/7866618)*100%
= 0.00665%

It therefore follows that natural forest will be lost at a mean rate of 0.00665%.

Vulnerability modelling

Accessibility factors

Rasterized maps of roads, elevation were reclassified to give 30 m resolution used in weighted overlay analysis (Figure 4).

Distance from forest station (policing)

Presence of guards did not deter community members from accessing forests. This is probably as a result of participatory forest management that allowed members of community forest association to participate in forestry activities and thus through this they easily access the forest and can illegally clear trees. The resulting distance map after rasterising had very little.

Population

The resulting population density raster map after reclassification showed areas between the Nandi north forest block and Kimondi forest blocks as the most densely populated with the areas up North of Nandi north forest relatively less populated (Figure 5). This coincides with the findings of change detection that indicated the areas close to these densely populated zones had big changes in land cover.

The resulting reclassified maps from each vulnerably factor discussed above were weighted using pair-wise comparison data from the focus group discussion (Table 5). From the pair-wise analysis averages of each factors influence on the final vulnerability map was computed as shown in Table 5.

These averages were used to prepare the vulnerability map of the form:

Vulnerability map = 0.51*POP+0.47*ACC+0.02*POL (2)

Where: POP is population density, ACC is accessibility factor, POL is policing (guarding the forest). This was processed in overly tool of ArcGIS 10 software and resulted in a vulnerability map of Nandi North forest zone (Figure 6).

From the results, highly vulnerable areas lie along the edges of the forest which are easily accessible. Forest close to the urban areas such as Kapsabet and Kapsurur areas are also highly vulnerable due to a high demand of forest resources such as charcoal and land for settlements. The eastern side the North Nandi forest which is the upper forest is has less highly vulnerable areas due to high elevation that makes accessibility difficult to human. The shape of the forest makes it also highly vulnerable due to pressure from both sides thus the narrow the forest the highly vulnerable it is to be depleted.

DISCUSSION

Land cover mapping and change detection

The satellite images used in this study were able to extricate seven classes of land use. This was because of the medium spectral resolution of the images (28.5 m) making it difficult to discriminate among many other possible vegetation classes spectrally. The highest vegetation type in hectares was Agricultural land (Table 2) for the entire study period; this is because the area's economy is predominantly agricultural as shown from the data collected from the area.

In the first study period (1986 to 1995) natural forest

Table 2. Nandi North forest zone land cover area in hectares of the land cover in 1986 with the percentage coverage of each land cover class.

Land cover	1986		1995		2006	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Natural forest	15023.61	14	14922.99	14	12458.34	12
Plantation forest	1084.86	1	1283.31	1	650.07	1
Sparse forest	15826.95	15	14887.89	14	13816.62	13
Grassland	3331.71	3	2376.99	3	3768.3	1
Tea plantation	955.44	1	988.74	1	1511.28	3
Built-up areas	536.67	1	567.63	1	973.71	1
Agriculture land	70345.98	66	72077.67	67	73926.9	69

Table 3. Land cover change matrix between 1986 to 1995.

Land cover	NF	PF	SF	G	TP	BA	AL
Natural forest (NF)	**13203.45**	166.86	1370.97	8.82	48.96	1.17	223.38
Plantation forest (PF)	31.5	**379.8**	341.46	3.69	19.71	2.34	306.36
Sparse forest (SF)	1606.86	443.43	**6176.79**	121.68	210.24	16.29	7251.66
Grassland (G)	1.8	3.42	149.31	**200.7**	3.42	21.78	2951.28
Tea plantation (TP)	6.21	27.99	255.78	8.64	**408.87**	1.17	246.78
Built-up areas (BA)	1.08	2.97	70.83	21.69	6.57	**30.06**	403.47
Agriculture land (AL)	72.09	258.84	6522.75	2011.77	290.97	494.82	**60694.74**

Table 4. Land cover change matrix between 1995 to 2006.

Land cover	NF	PF	SF	G	TP	BA	AL
Natural forest (NF)	**11536.74**	3.78	2558.34	51.03	16.29	6.12	750.69
Plantation forest (PF)	37.08	**284.31**	456.03	39.51	38.79	1.8	425.79
Sparse forest (SF)	831.51	178.83	**4598.91**	803.34	387.09	89.19	7999.02
Grassland (G)	0.99	6.48	151.65	**194.31**	20.88	38.52	1964.16
Tea plantation (TP)	14.49	18.81	116.64	31.23	**493.47**	10.26	303.84
Built-up areas (BA)	0.09	1.17	17.01	26.37	3.78	**41.49**	477.72
Agriculture land (AL)	37.44	156.69	5918.04	2622.51	550.98	786.33	**62005.68**

Table 5. Price wise analysis averages.

Interview	Population	Accessibility	Policing	Consistency ratio
1	0.48	0.497	0.023	0.06
2	0.52	0.459	0.021	0.03
3	0.52	0.458	0.022	0.08
4	0.53	0.448	0.022	0.07
5	0.53	0.452	0.018	0.03
6	0.48	0.505	0.015	0.09
7	0.51	0.467	0.023	0.04
8	0.5	0.482	0.018	0.05
9	0.54	0.444	0.016	0.05
10	0.49	0.488	0.022	0.01
Average	0.51	0.47	0.02	

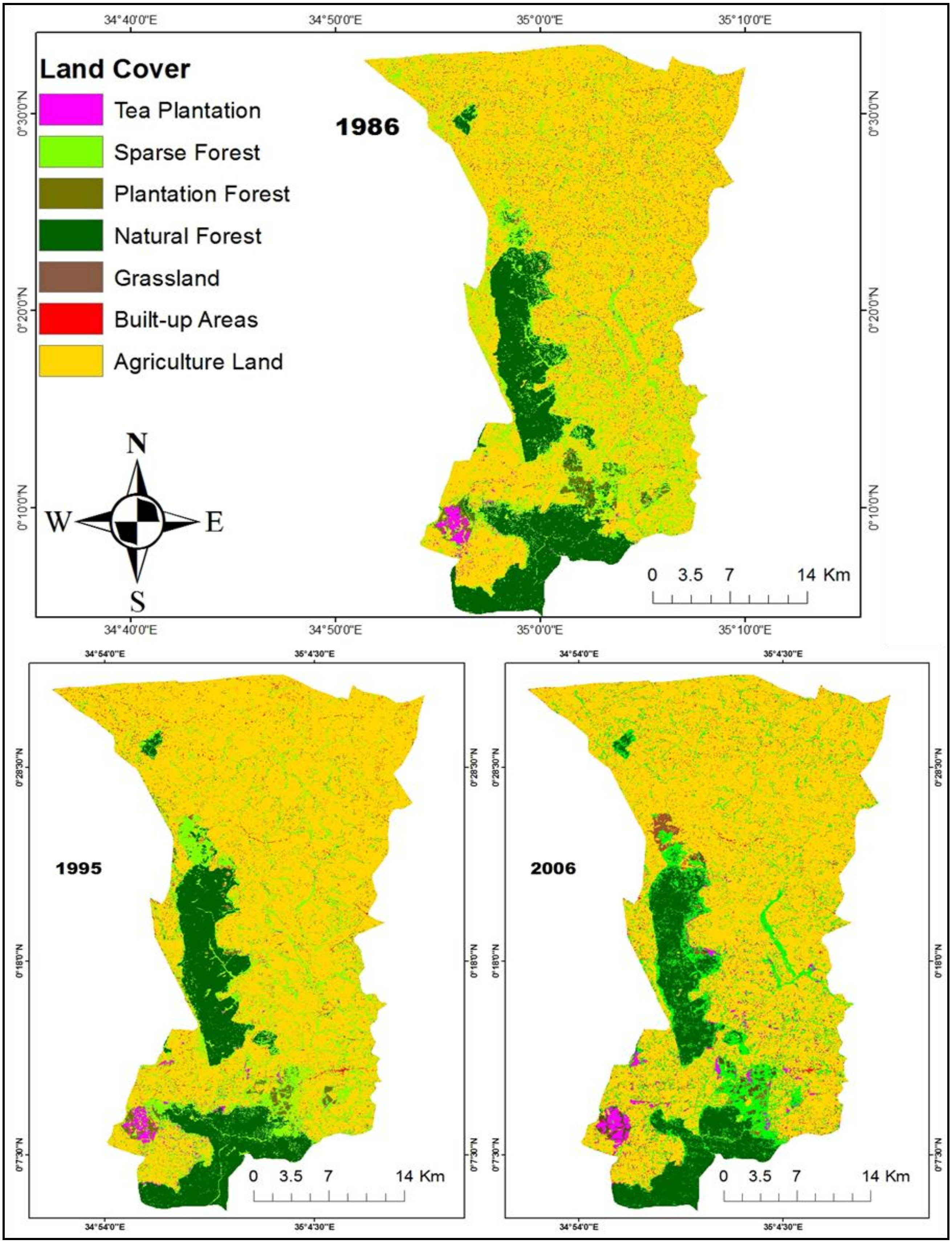

Figure 3. Land cover map of Nandi North forest zone.

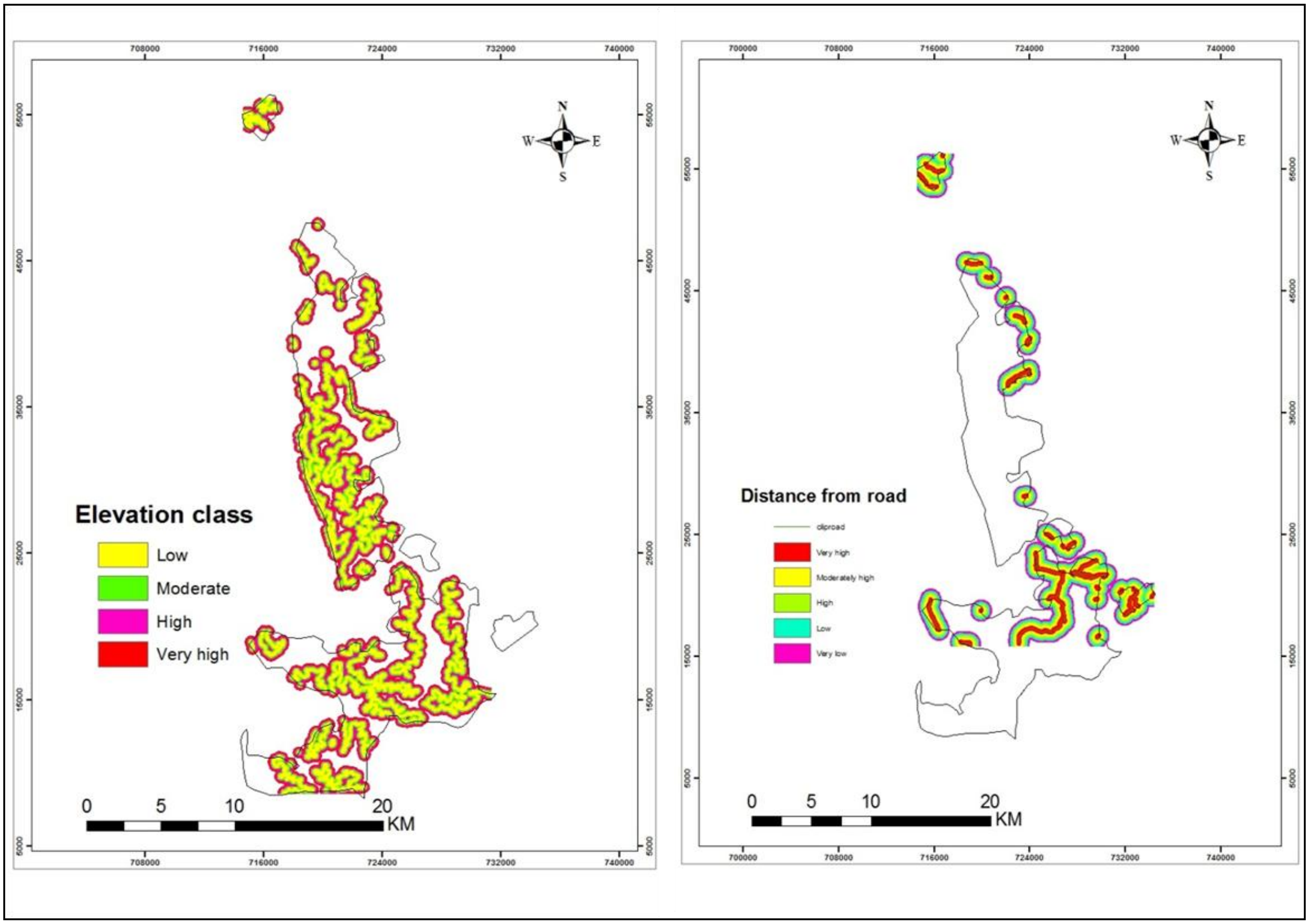

Figure 4. Elevation and road proximity maps.

lost 100.62 ha of land, Plantation forest gained 198.45 hectares, sparse forest lost 939.06 ha, grassland lost 954.72 ha, tea plantation gained 33.3 ha, built up areas gained 30.96 ha agriculture gained 1731.69 ha. During the second study period Natural forests lost 2464.65 ha, plantation forest lost 633.24 sparse forest lost 1071.27 ha, grassland gained 1391.31 ha, tea plantation gained 522.54 ha, built up areas gained 406.08 ha while agricultural land gained 1849.23 ha (Tables 3 and 4).

This finding indicates that natural forests have been decreasing throughout the study period which is primarily as a result of human activities. On the other hand plantation forest increased in the first period and reduced by half during the second period of study. This could be because of harvesting for the tea industry in the region.

Findings from this study indicate an upward rise in area under agriculture for the entire 20 years of study, this is due to continued encroachment on forest by squatters and also as an effect of Non- residential cultivation, a programme that was rolled out to replace shamba system which allowed individuals to grow crops in newly established plantations for some time until when the trees will be have formed the first canopy (KFS, 1994). Though it was successful in some areas in others it failed as farmers could deliberately kill the young trees so that they could continue cultivating the farms as they were very fertile with humus from the just harvested forest. This gave easy access to natural forests and because the soils and climate of this natural forests areas overlap to a high degree with those areas suitable for cultivation of agricultural crops and agricultural land being the most prized commodity in Kenya's briskly snowballing population even for the minorities who do not have alternatives for sustenance, one does not need a crystal ball to see where a landless person's priority will lie in any land-contest between forests and agriculture. This is further explained by the reduction in plantation forest (Tables 3 and 4) where 306.36 ha which was finally converted to agriculture between 1986 and 1995 and 425.79 ha between 1995 and 2006 study years.

Though the change is showing a reducing trend this could be because the area under plantation forest was small and partly owned by private companies growing tea. The natural forest which comprises of indigenous

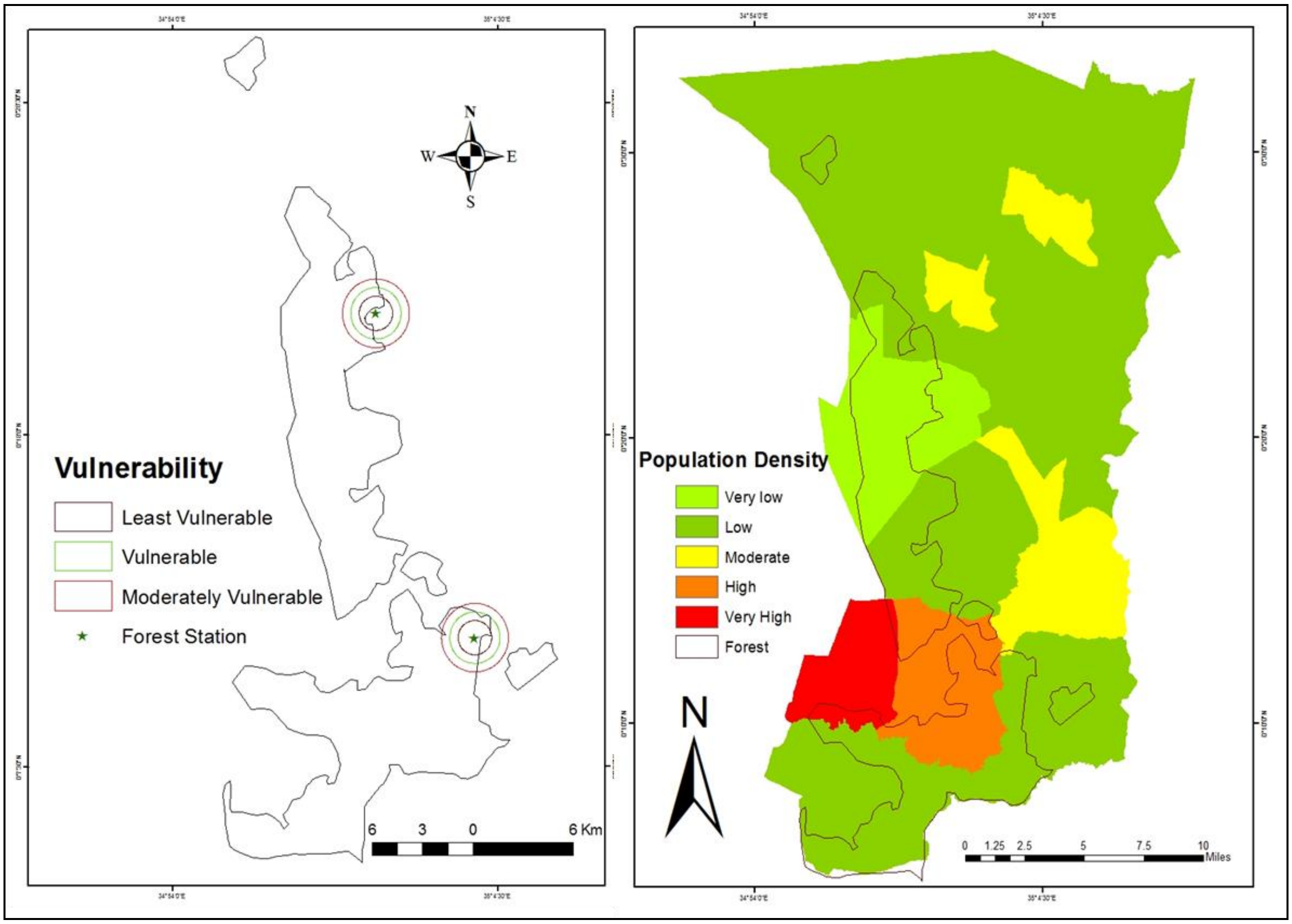

Figure 51. Distance from guard station and population density factor.

trees converted in the first study period by 1370.97 in the first study period and 2558.34 ha in the second study period to sparse forest. This was the largest conversion from natural forest to any other land use. Because most of the sparse forests have been moving from the periphery into the deeper side of the forest it follows therefore that majority of this sparse forest is actually degraded natural forests. This progressive shaving away of edges of the forest as parcels for settlement and degradation of the forest quality through illegal tree removal to settlement is continuously messing up few remaining low land forests which initially used to cover about 15% of western Kenya (KFS, 2010).

The degradation has been as a result of mostly poaching of valuable indigenous trees such as *Brachyleniahuillensis* and charcoal burning to provide charcoal to the growing population working in the tea industry and fuel wood for the squatters and general community living around the forest. Even after this forest has been reduced to sparse it is further converted to agricultural lands. For instance in the first study period alone 7251 ha of sparse forest were converted to agriculture and later on in 1995 to 2006 about 7999 ha of sparse forest was converted to agricultural land (Tables 3 and 4).

On a general note the forest has been changing drastically from natural forest to sparse forest then grassland and finally to agricultural land, a trend that is a characteristic of a systematic and gradual effects of activities by the forest adjacent communities. This is clearly shown in Tables 3 and 4 with the natural forest losing throughout the study period. This finding corroborates previous studies in the larger Mau water catchment (KFS, 2005) that recorded a massive decline in forest cover and hence blew the whistle of over destruction of the forests within the Mau catchment.

Though the overall mean annual rate of deforestation computed on natural forests is low (0.00665% compared to the national annual rate of forest loss of 3% this till poses a threat to the fragile natural forests and thus listed on Kenya's endangered forest lists. This rate was only computed for natural forest because other cover types like plantation are under different manage-ment operations that could be felled at any time during the study period and replanted and thus computing annual rate of deforestation will be erroneous. The sparse forest could not be computed because some clusters of sparse forests are on individual people's farms and thus

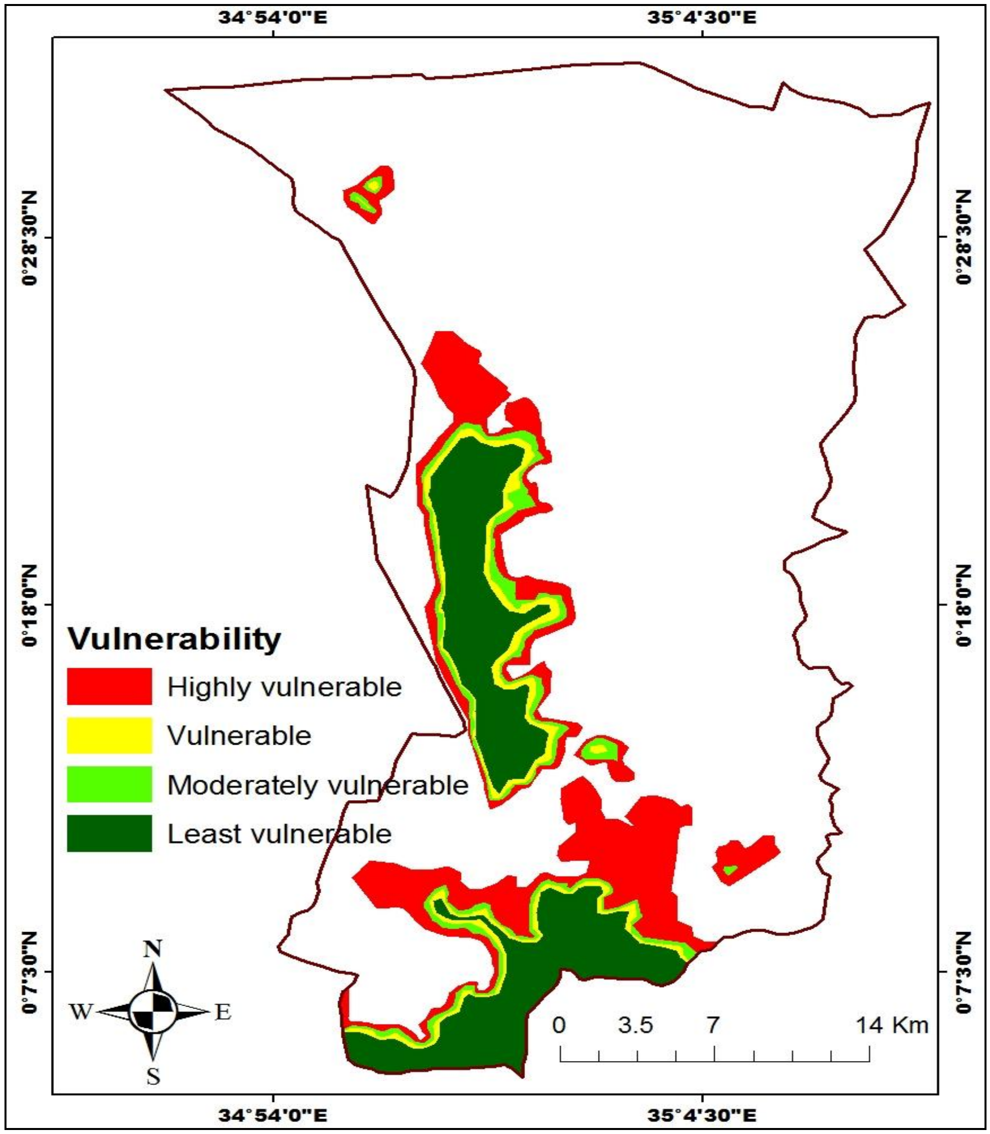

Figure 6. Forest vulnerability map.

their conversion is subject to the owner's decision.

There is a general trend of reduction in cover types of natural forests, plantation forests, sparse forests and an increase in built-up, grassland, tea and agricultural cover types across the two study periods. The least conversion from plantation was because most of the plantation forests are managed by tea processing companies which are privately owned and thus managed with a different management regime and objective. These plantations are managed professionally for curing tea leaves. This explains why there is a huge loss of natural forest cover type to others because its state owned characterised by massive destruction especially during the study period (Ongeno and Opanga, 2009). It is during time when concessions were given to private individuals and increase in numbers of squatters and thus large chunks of natural forests were harvested for their valuable timber of indigenous trees and to provide land for farming. These trends are thought to reduce especially with the enactment of Forest Act 2005 in 2007 which has clear stipulations on forest management.

Vulnerability

The results from the vulnerable map (Figure 6) indicate that risk degree varies from the boundary towards the inner side of the forest. This justifies the hypothesis that forests closer to settlements have higher probability of being harvested. Vulnerability is observed to reduce as you get deeper into the forest because during pair wise comparison where the local people were given an opportunity to assign weights to the threat factors.

Accessibility was given more weights and thus contributed heavily on the final vulnerability map. Accessibility included factors like, road network, slope and elevation these affects accessibility greatly. Other factors such as presence of policing (guarding the forest) scored least as the communities felt that the guards are actually not doing much could counteract efforts of illegal loggers. The vulnerability map had 9320 ha of forest under highly vulnerable degree of vulnerability, 2163 ha were moderately vulnerable, 1968 ha were vulnerable and 9626 ha are least vulnerable.

It is worth noting that the slope and elevation contributes greatly to extend of exploitation, as the forest on the hilly sides of the forest blocks were categorized as least vulnerable. It is therefore worth concluding that elevation and distance to a road network contributes a lot to deforestation. In conclusion, the closer the settlement, gentle slope and low elevation, the higher the probability to be deforested than those on steep slopes, far from the settlement and on high elevation.

Conclusion

Land use land cover prepared for the two study periods show big variability in land use. Agriculture which includes all rain fed cultivation is the highest land use type followed by natural forest and sparse forest then with grassland. Nandi forest zone has undergone a series of conversions from natural forest to sparse forest and later to agricultural farm lands at a relatively low mean annual rate. Agricultural activities seem to pose a threat to the existence of the forest. Northern side of Kimondi forest block just next to Nandi North block is worst hit.

It is clear that the factors contributing to forest loss and degradation are mainly man made as the forest cover change trends moved from closer to settlement into the forest. This is further supported by the trend of the vulnerability map indicating the forest closer to settlement and road as highly vulnerable. Though the mean annual rate of deforestation of the natural forest is relatively low (0.0067%) the rate of conversion of grassland to agricultural land was very high. The vulnerability map lays it clear that strategic measures should be undertaken starting from the periphery of the forests where the degree of vulnerability is very high.

Based on the interpretation of the of the vulnerability map it is important for the authorities to put up measures in place address the deforestation problem right from the settlements so as to impede the local communities from illegally harvesting the forest and by engaging them in a community based forest conservation activities. Remote sensing and GIS technology should be incorporated in forest management and conservation processes, as this will provide up-to-date information on forest status thus making monitoring and decision making easier and backed up with adequate data.

REFERENCES

Ayhan A, Ametin T, Bgurcan B (2004). Spatial And Temporal Analysis Of Forest Covers Change: Human Impacts And Natural Disturbances In Bartin Forests. Landscape Ecol. 19:631-646.

Dien V (2004). Susceptibility to Forest Degradation a Case Study of the Application of Remote Sensing and GIS in Bach Ma National Park, ThuaThien Hue Province-Vietnam. Enschede: International Institution for Geo-Information and Earth Observation.

FAO (2001). Global Forest Resources Assessment 2000: Main Report. FAO Forestry Paper 140.Rome.

FAO (2009). State of the World's Forests 2009'. Food and Agriculture Organization. Electronic Publishing Policy and Support Branch Communication Division.

KFS (2010). Kenya Forest Service Annual Report,

KFS (2005). Strategic Environmental Assessment of the Kenya Forests Act 2005. The International Bank for Reconstruction and Development / the World Bank 1818 H Street, NW Washington, DC 20433.

KFS (1994). Nandi North Management plan report.

Lung T, Schaab G (2009). 'A comparative assessment of land cover dynamics of three protected forest areas in tropical eastern Africa'. Environ. Monit. Assess. 161:531-548.

Michael CW, Janet LO (2003). A multi-scale assessment of human and environmental constraints on forest land cover change on the Oregon (USA) coast range. Kluwer Academic Publishers, Netherlands. Landscape Ecol. 19: 631-646.

Monica GT, Scott MP, Paul B, David NW (2010). Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA). Landscape Ecol. 18(5):449-464

Ongeno DO, Opanga PS, Opara AO (eds 2009). Forest landscapes and Kenya's Vision 2030, Proceedings of the 3rd annual forest society of Kenya (FSK) conference and annual general meeting held at the sunset hotel, Kisumu.

Skole DL, Tucker CJ (1993). Tropical deforestation and habitat fragmentation in the Amazon: satellite data from 1978 to 1988. Science 260:1905-190.

UNEP (2006). Africa Environment Outlook 2, Our Environment, Our Wealth', United Nations Environment Programme. .Malta: SMI (Distribution Services) Ltd.

UNEP (2001). An Assessment of the Status of the World's Remaining Closed Forests. Division of Early Warning and Assessment (DEWA).

WRI _ IUCN _ UNEP (1992). Global Biodiversity Strategy: Guidelines for Action to Save, Study and Use Earths Biotic Wealth Sustainably and Equitably.