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Land Cover and Land Use Mapping and Change Detection of Mau Complex in Kenya Using Geospatial Technology

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Abstract: ***The significance of the Mau complex is viewed within the context of the enormous biodiversity of flora and fauna. We evaluate land cover and use changes from 1973 to year 2010 through creation of geospatial tool for change detection. Analysis is carried out on trend of changes over this period with focus of identifying human activities responsible for these changes as well as the environmental impacts associated with the changes. Supervised classification has been applied on Landsat images of 1973, 1986, 2000 and 2010 with classification scheme of three main classes namely - forestland, other vegetation, and non-vegetated land. Post classification of both visual and area comparisons were done to get information on the trends, rates and magnitude of land cover and land use changes in the Mau forest complex over time. A variation in the greenness of the vegetation present in the pixel over time was done through normalized difference in vegetation index (NDVI) with density slices ranging from 0.25 µm to 1.00 µm (range of vegetation cover). The results of the study have showed that changes in land use and land cover had occurred in all the 22 blocks of Mau forest complex and resulted in the reduction of forest cover. It was further revealed that there was relationship between increase in population and decrease in forest cover and that, steep slopes were cleared of their forest as land use changed and subsequent loss of biodiversity and partly led to reduction in rainfall and subsequent decrease in river discharge.***

Keywords: Change detection, GIS, Remote sensing, geospatial tool, land cover, NDVI.

1. Introduction

Land use affects land cover and changes in land cover affect land use. A change in either, however, is not necessarily the product of the other. Changes in land cover by land use do not necessarily imply a degradation of the land. However, many shifting land use patterns, driven by a variety of social causes, result in land cover changes that affect biodiversity, water and radiation budgets, trace gas emissions and other processes that, cumulatively, affect global climate and biosphere [1]. There are also incidental impacts on land cover from other human activities such as forests and lakes damaged by acid rain from fossil fuel combustion and crops near cities damaged by tropospheric ozone resulting from automobile exhaust [2].

The loss of rainforests throughout the tropical regions of the world as a result of deforestation for timber resources and conversion to agricultural lands has become a topic of global attention with the aid of widespread media coverage [3]. Despite these, there has been significant historical global changes in land cover and land use which occurred between 1700 and 1990 when the area of cropland expanded from about 3.5 million km2 to some 16.5 million km [4]; and the Mau complex is no exception of such activities.

Reduction in forest cover in Kenya has contributed to diminishing livelihoods of many Kenyans caused by reduced land productivity, famine and drought. Though most of Kenya's forests have been decimated by degradation among other factors, the Mau forest complex and in particular that of the Maasai Mau has been the most affected and has receded drastically over time [5]. It is believed that encroachment as well as irregular forest land allocation has been exacerbating an already serious situation.

Continued destruction of the forests is leading to a water crisis in that, perennial rivers are becoming seasonal, storm flow and downstream flooding are increasing and in some places, the aquifer has dropped by 100 metres while wells and springs are drying up [6]. The impacts are negatively felt on major natural assets and development investments, including Lake Nakuru National Park, Maasai Mara National Reserve, Sondu-Miriu Hydropower Scheme (60MW), Geothermal plants near Naivasha, small hydropower plants in the Kericho tea estates (4MW) and the tea growing areas in Kericho Highlands [7].

Land use is never static but constantly changes in response to the dynamic interaction between underlying drivers and proximate causes[8]. The conceptual understanding of proximate causes1 and underlying forces has a crucial importance to identifying the causes of land use and land cover in relation to population growth dynamics and associated human activities [9].

High- resolution aerial surveys of selected forests in the Aberdares, Mt. Kenya, Mt. Elgon, and the Mau complex revealed that deforestation and general degradation was taking place on a more local scale significantly due to unplanned forest exploitation [10]. This study therefore, examines the Mau complex by adopting four approaches namely:

- Detecting the changes that have occurred
- Identifying the nature of the change
- Measuring the area extent of the change
- Assessing the spatial pattern of the change

2. Mau Study Area

The Mau forest complex is situated in the south western part of Kenya and is found within the great Rift Valley. It lies between latitudes 00 19'N and 00 93'S and longitudes 350 29' and 360 10' east. Mau forest complex covers approximately 416,542 hectares and is the largest closed canopy montane forest conservation in East Africa as illustrated in Fig.1 and Fig.2 respectively. Prior to its degradation, it was larger than Mt. Kenya and the Aberdare forests combined. Its expanse spreads in seven counties including Nakuru, Kericho, Bomet, Narok, Baringo Uasin Gishu and Nandi (Kenya Forest Service, 2010). All the forest blocks in the Mau Forest complex are gazetted except the Maasai Mau and are managed by the Kenya Forest Service except the Maasai Mau forest which is Trust land and is managed by the Narok county council.

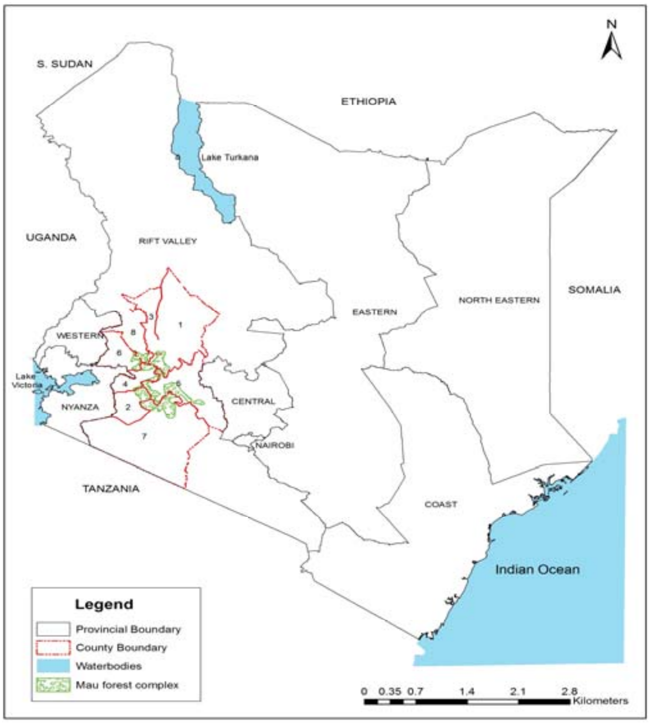

Figure 1: Location of Mau Forest Complex in Kenya
Source: Survey of Kenya, 2011

The northern blocks comprise of mount Londiani, Tinderet, Northern Tinderet, Timboroa, Nabkoi, Kilombe Hill, Metkei, Maji Mazuri, Chemorogok and Lembus forests while Eburru forest is found to the eastern part of Narok County. Eastern Mau forest lies between Rongai-Njoro plain and the upper slopes of the Mau hills. The south western block occupies parts of Kericho and Bomet counties and include Transmara and Ol Posimoru while the Maasai Mau is in the southern part with its southern boundary 17 km north of Narok Town and is the only ungazetted of the 22 blocks. The central blocks include the Mau Narok and South Molo forests. Proximate causes include agricultural expansion, wood extraction, infrastructural expansion and others that change the physical state of land cover.

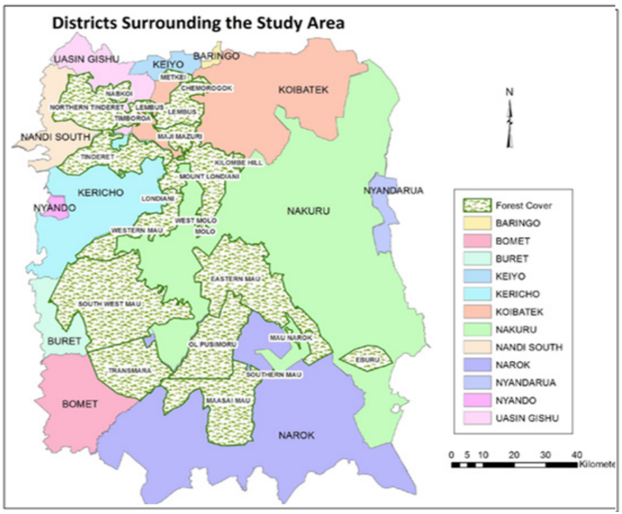

Figure 2: Landscape showing forest cover and neighbouring districts

The Mau complex has both surface and underground water resources. Nakuru County, rivers that originate from the Mau forest complex are Njoro, Nderit, Maka Makalia and Lamriak which drain into Lake Nakuru. The other rivers are Molo, Rongai, Kaumura and Nessuit which drain into Lakes Baringo and Bookie (Nakuru DDP., 1997-2001). Mara River originates from the Mau and drains through Narok County into Lake Victoria basin, covering a distance of 395 km and discharges into the Mara Bay of Lake Victoria in Tanzania as illustrated in Figure 3.

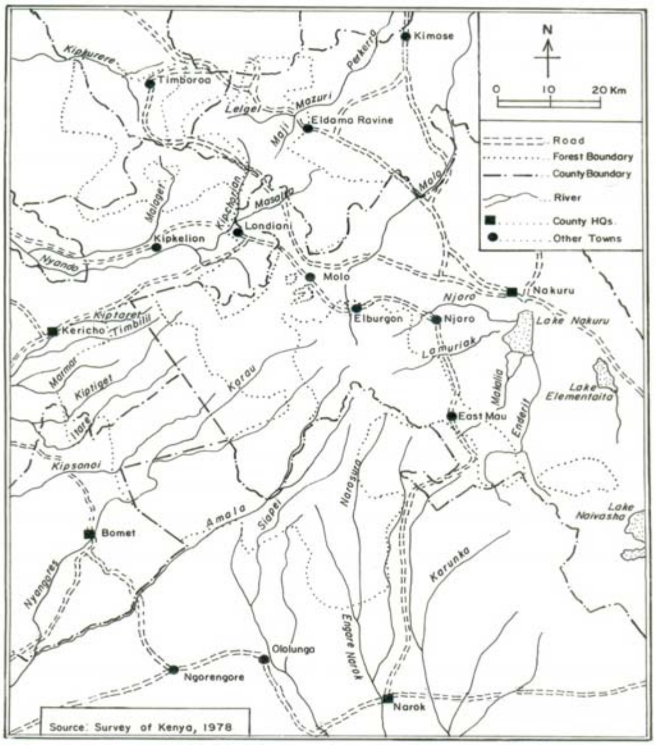

Figure 3: Major Rivers (upper parts) originating from the Mau forest complex

3. Methods and Data

Satellite imageries and topographical maps of the area together with geographical coordinates of selected ground control points were used for registration and image matching, classification and processing. ENVI 4.8 processing software was used for the development of land cover and land use classes and subsequently for change detection analysis of the study area. ArcGIS 10 was used for displaying and subsequent processing and enhancement of the images. It was also used for clipping out the area of interest (Mau forest complex) from the images using topographical maps of the area. The whole process thus, applied the use of Remote Sensing and an integrated GIS to evaluate the land cover and land use changes, trends, magnitudes and the emanating environmental impacts in the area for a period of about 37 years.

Evaluative and comparative techniques were used in the spatial analysis of land cover and land use changes in the Mau forest complex. All the 22 blocks of the complex were subjected to the land cover and land use analysis in which land cover classification, overlay operations and NDVI analysis were done. The year 1973 was taken as base year of study because the forest cover had not changed then but started changing thereafter due to anthropogenic processes that set in [11]. Landsat imageries were used due to their suitability for vegetation cover analysis especially vegetation discrimination, measurement of chlorophyll absorption and vegetation type and biomass content analysis. The Landsat imageries used were for 1973, 1986, 2000 and 2010, intervals we believed, were reasonable to give substantial changes in land cover as illustrated in Table 1.

Table 1: Data used in study

Data type	*Year of production*	*Source*
Landsat MSS Landsat TM Landsat TM Landsat ETM+	09/01/1973, Resolution 80x80 Metres 15/11/1986 at 30x30 M. resolution 18/12/2000, 30x30 Metres 11/2/2010, 30x30 Metres	Regional Centre for Mapping of Resources for Development, Kasarani in Nairobi
Topographical maps of Mau region at 1:50,000	1978	Survey of Kenya, Ruaraka in Nairobi
Geology and soils of main	1995	Kenya Soil Survey, Kabete
Slopes of Mau	1995	Kenya Soil Survey, Kabete
Land use	2005	Africover
Population data	1979, 1989, 1999, 2009	Kenya National Bureau of Statistics, Herufi House - Nairobi
Rainfall Data	1977, 1986, 2000, 2010	Kenya Meteorological Department, Dagoretti Corner in Nairobi.
DEM	1995	Kenya Soil Survey, Kabete - Nairobi

Ground control points taken by GPS[2] together with topographical maps of the area were used to geo-reference the images and supervised classification was done using ENVI 4.8 remote sensing software which gave three cover classes namely forest land, other vegetation and non-vegetated land which were quantified and overlaid spatial-temporally for change detection. NDVI analysis was done specifically to detect changes in plant health over time. Analyses involving the population, soils, land use, slopes and rainfall data were specifically done for Mount Londiani forest with the assumption that, what happened in Mount Londiani forest happened in the other forest blocks of Mau forest complex.

Land cover classification scheme was used to generate actual land cover and land use classes, quantification of cover classes and land cover change detection through overlay operations as well as detection of the changes through NDVI. The classification scheme was developed by using the Landsat imagery of 2000 and topographical map of 2004 at 1:50,000 of the Mau complex to identify details that appeared on both the topographical map and on the imagery and recorded them down. During field verification, the same details were identified in the field and their coordinates recorded and these were later used to recognize spectral signatures on ENVI 4.8 software.

The three classes used for this study were forestland, other vegetation, and Non-vegetated land from which we delineated training sites after the classification scheme had been developed. After the signatures for each land cover category had been defined, the software used these signatures to classify the remaining pixels. Thus, for each class outlined, mean values and variances of the DN[3]s for each band used to classify them were calculated from all the pixels enclosed in each site.

The NDVI values indicate the amount of green vegetation present in the pixel. Thus, higher NDVI values indicate more green vegetation and vice versa. The standard algorithm shown below was used for calculations giving valid results that fell between -1 and +1:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}},$$

Where NIR is band 4 and Red is band 3 of Landsat TM. For the purpose of this study, density slices were given ranging from 0.25 – 0.50 μm for sparsely vegetated areas to 0.50 – 0.75 μm for areas with reasonably dense vegetation to 0.75 – 1.00 μm for closed canopy forest. The density slices below 0.25 μm represented areas without vegetation and therefore were not included in the NDVI analysis

[2]Global positioning system of satellites for acquiring position on the ground using geographic coordinate system or Cartesian plane system.
[3]Digital number showing reflectance values recorded by satellite or camera on a phenomena.

In order to establish the land cover changes that occurred within the study area between 1973 and 2010, a post-classification change detection analysis of the four different dates of imageries was performed using ENVI 4.8 remote sensing software. For this purpose, the information classes of the 1973, 1986, 2000 and 2010 images were overlaid to get three overlay maps. That is, 1973 was overlaid on 1986, 1986 on 2000 and lastly 2000 on 2010 and the quantities of change in each class for each dataset computed in that sequence and changes in combined into one “change” image (comprising of the 1973-1986 -2000 -2010 period) in which each of the “from-to” land cover changes was extracted. Three “from-to” change matrices were obtained for the 1973-1986, 1986-2000 and 2000-2010 periods, in that order.

Using the population figures and administrative units, we developed population density maps for the sub-locations for the years 1979, 1989, 1999 and 2009 which gave the patterns and trends of change in population densities over time. The time series density maps were placed side by side with the time series land cover maps to establish the relationship between change in density and change in forest cover. Thus, 1979 population density was compared with 1986 land cover, 1989 with 1986 land cover, 1999 with 2000 land cover, and 2009 with 2010 land cover. Population density maps were again placed and compared with land use map in order to check how change in population densities had influenced the various land use types and the likely consequences.

4. Results and Discussion

4.1 Post classification visual comparison

Thematic cover classes for 1973, 1986, 2000 and 2010 Mau Landsat imageries were generated. From the 1973 thematic map (Fig. 4), the forest was intact with most of the forest being under closed canopy and a small portion under other vegetation with even a smaller part under non-vegetated cover. Non-vegetated areas included built up areas, bare land and even newly prepared farms.

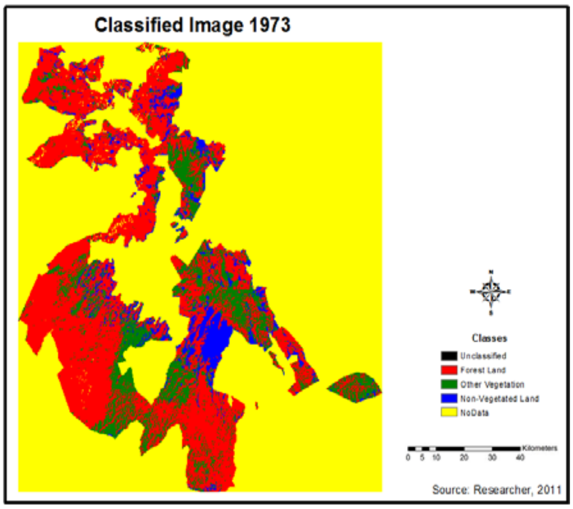

Figure 4:.Land cover and land use map of the Mau in 1973

The 1986 thematic class map showed a lot of decrease in coverage of the areas under forest and other vegetation while area under non-vegetation increased (Fig.5). The areas under non-vegetation increased so much in the Eastern Mau, Mount Londiani, Maji Mazuri, Molo, Tinderet and South West Mau forests, among others. These areas were probably being opened up for agriculture and logging for the timber industries that had just been set up after Kenya’s attainment of independence. Urban centres were also being set up to host the timber industries, agricultural processing industries and an ever increasing population that was coming from outside this region to work in the factories being set up. Such urban centres were Kericho, Londiani, maji mazuri, molo, Timboroa, Elburgon and others.

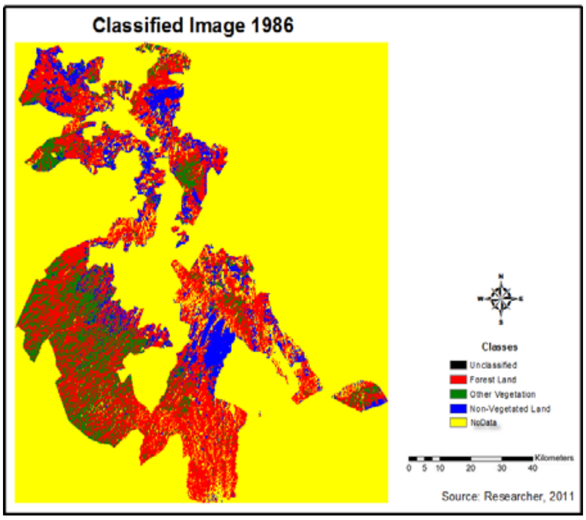

Figure 5: Land cover and land use map of the Mau in 1973

The period between 1986 and 2000 showed the worst degradation of the forest when compared with the other periods during the study (Fig. 6). Much of the degradation of the forests was still witnessed in the northern and central blocks as well as in Eastern Mau and Eburru forests. Various reports reviewed in this study singled out land grabbing and illegal land allocation as the main course of forest degradation in the Mau forest complex during this period. It was during this period that Molo forest was completely cleared of its forest and turned into farmland and settlement.

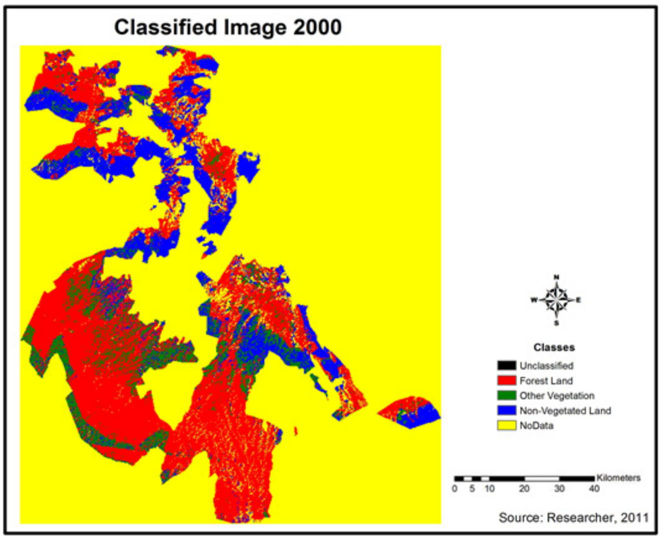

Figure 6: Land cover and land use map of the Mau in 2000

The period between 2000 and 2010 (Fig. 7), indicated a lot of improvement in the area under other vegetation and a decrease in the area under non-vegetation. While legal excision of the Maasai Mau to settle the landless plus other illegal allocations took place during this period, the area under vegetation cover increased while that under non-vegetation decreased due to the initiatives of the Mau rehabilitation Secretariat that led to the eviction of squatters, repossessing land illegally got and planting of trees in the areas that were under non-vegetation.

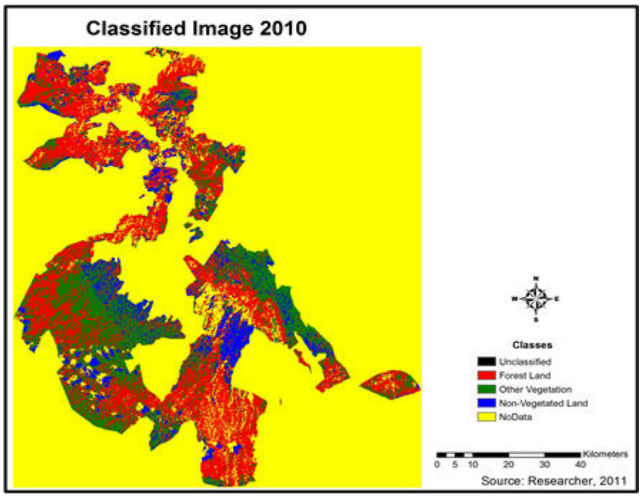

Figure 7: Land cover and land use map of the Mau in 2010

4.2 Post Classification Area Comparison

In 1973, closed canopy forest occupied the highest class with 68% of the total classes. The other vegetation occupied about 22% of the classes while non-vegetated land was 10%. Clearance of forest land for forest products and other human needs for the forest land were established when land cover and land use for 1973 and 1986 were compared. Forest land was 63.8% in 1986 while area under other vegetation was 20.1%, a reduction of 4.2% and 1.86% respectively from the coverage in 1973. During the same period, non-vegetated land changed from 10% to 17.1%, an increase of about 7% representing land cleared for timber, farming and settlement, especially the urban centres which accommodated the upcoming industries and the required labour force plus other commercial activities.

The period between 1986 and 2000 had a lot of anthropogenic activities that in the end resulted in negative impacts on the forest and the environment. While the area under closed canopy reduced by about 1.2% during these 14 years, the area under other vegetation reduced by about 6% and area under non-vegetated land increased by about 7.2%. This means that, more clearance was done in the area under other vegetation than in the closed canopy forest but both resulted in the increase in the area under non-vegetated land. It was during this period that the introduction of the Nyayo Tea Zone had some parts of the forest, not only in the Mau excised for growing of tea. Irregular forest land allocation to individuals by the political regime of that time also consumed a big part of the forest. The Molo forest disappeared, Eastern Mau, South-West Mau among others highly degraded with some parts becoming wasteland. Table 2 illustrates time series land cover class quantification for 1973, 1986, 2000 and 2010 imageries.

Table 2: Thematic Cover Class Areas for 1973, 1986, 2000 and 2010 classified imageries

Class Category	*Area*			
Cover Type (Class)	AREA (HA) 1973	AREA (HA) 1986	AREA (Ha) 2000	AREA (Ha) 2010
Forestland	286426.08 68%	239994.05 62.8%	243913.15 61.6%	207868.59 53.9%
Other vegetation	92483.64 22%	76844.94 20.1%	55998.46 14.1%	132961.68 34.5%
Non- vegetated land	42167.88 10%	65505.20 17.1%	96250.57 24.3%	44560.71 11.5%

Due to legal excision of the Maasai Mau (2001) and the illegal allocations just before the 2002 general elections, the forest land under closed canopy reduced from 61.6% in 2000 to 53.9% in 2010. Fortunately, the general outcry from various stakeholders for conservation of the Mau complex and the ultimate involvement of the Mau rehabilitation secretariat, championed by the office of the Prime Minister led to the increase in the area under other vegetation from 14.1% in 2000 to 34.5% (about 20.4% increase) in 2010. This increase in the area under other vegetation resulted in the decrease in the area under non-vegetation which reduced by about 12.3% as illustrated in Fig.8.

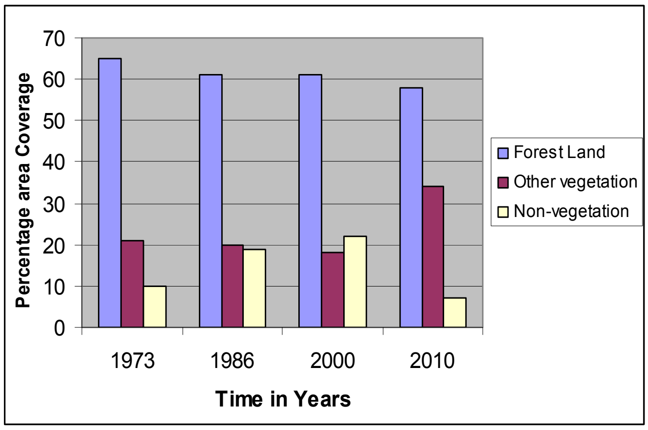

Figure 8: Percentage cover class areas against time

The results of the NDVI used to complement the cover classification exercise revealed a general degradation in plant health in the Mau forests over time. The three density slice classes used were 0.25 – 0.50 µm for sparsely (least healthy) vegetated areas; 0.50 – 0.75 µm for areas with moderately dense (healthy) vegetation and 0.75 – 1.00 µm for dense (healthiest) forest all of which revealed the same trend of change with those of the cover classes (Table 3, graph in Fig. 9).

The density slice class 0.75 – 1.00 µm reduced all through (1986 – 2010) and this is the areas under forest cover which also decreased due to reasons already stated (Table 3). The area under 0.50 – 0.75 µm increased during the study period and this could not be accounted for in terms of regeneration and planting of trees alone but also in terms of acreages of crops in the farms. The area under 0.25 – 0.50 µm class increased from 1986 to 2000 but decreased in 2010, also as a result of regeneration, planting of trees and presence and absence of crops in the farms. The percentage accounting for vegetation excluding crops must have experienced decrease as forest cover and area under other vegetation decreased.

Table 3: Density Slice Class Areas for the 1986, 200 and 2010 Landsat imageries

Class Category(µm)	*1986 Area (Km2)*	*2000 Area (Km2)*	*2010 Area (Km2)*
0.7500 to 1.0000	16,882.79 38.09%	16,882.79 37.80%	15,239.74 37.1%
0.5000 to 0.7500	14,386.23 32.5%	14,269.90 32.95%	13,765.82 33.5%
0.2500 to 0.5000	13,057.30 29.5%	13,512.44 30.3%	12,120.03 29.5%

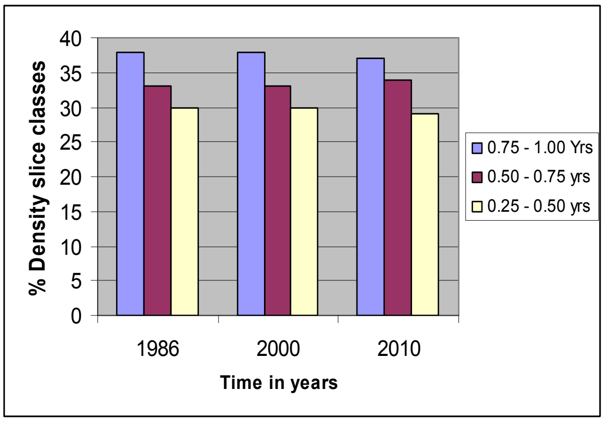

Figure 9: Percentage density slice classes against time

4.3 Trend, Magnitude and Rate of Land Cover Change

Between 1973 and 1986, forest cover had decreased by 46432.03 hectares (-4.2%), other vegetation decreased by 15638.70 hectares (-1.86%) while non-vegetated land increased by 23337.32 hectares (7.0%). The forest land and land under other vegetation was being lost to non-vegetated activities. Farming, logging and settlement especially in the upcoming urban centres contributed to this change.

Between 1986 and 2000, the forest cover increased by 3919.10 hectares (1.2%), area under other vegetation further decreased by 20846.48 hectares (-6.0%) while area under non-vegetated cover increased by 30745.37 hectares (7.2%). During the period 2000 to 2010, the area under forest decreased by 36044.10 hectares (-8.7%) while area under other vegetation increased by 77963.56 hectares (20.4%) and area under non-vegetated land decreased by 51689.86 hectares (-12.3%).

Between 1973 and 1986, there was an annual rate of change in forest land of -3571.69 hectares; area under other vegetation had an annual rate of change of -1202.92 hectares while the area under non-vegetation changed at an annual rate of 1795.15 hectares. The period between 1986 and 2000 had a positive annual rate of change in the area under forest of 279.93 hectares, an annual rate of change in the area under other vegetation of -1489 hectares while the area under non-vegetation increased at annual rate of 2196.07 hectares. Negative sign means a reduction in land cover under study.

The area under forest experienced an annual rate of change of -3604.4 hectares during the period 2000 to 2010. During the same period, the area under other vegetation changed at the rate of 7796.3 hectares per annum while the area under non-vegetation experienced a rate of change of -5168.99 hectares per annum. Table 4 below illustrates the magnitudes and trends of land cover change while Table 5 shows the annual rates of change for the years under study.

Table 4: Trends and Magnitude of Land Cover Change

	1973 – 1986		1986 – 2000		2000-2010	
Land cover category	Areas (Ha)	% change	Areas (Ha)	% change	Areas (Ha)	% change
Forest land	-46432.03	-4.2	3919.1	1.2	-36044.6	-8.7
Other vegetation	-15638.7	-1.86	-20846.48	-6	77963.22	20.4
Non-vegetated land	23337.32	7	30745.37	7.2	-51689	-12.3

Table 5: Annual Rates of Change in Land Cover Category

	Annual Rate Change		
Land cover category	1973 – 1986 (Ha)	1986 – 2000 (Ha)	2000 – 2010 (Ha)
Forest land	-3571.69	279.93	-3604.4
Other vegetation	-1202.92	-1489	7796.3
Non-vegetated land	1795.15	2196.07	-5168.99

These changes could be justified by the fact that as human activities increased, more land was converted from other vegetation to agriculture, settlement and even clearance to get timber for construction, among others. These processes continued adding to the increase in areas under non-vegetated cover. The slight increase in the area under forest, this study believes was a matter of chance and not policy restriction. The graph in Fig.10 indicates changes in cover classes in hectares against time. The values above the zero x-axis represents cover types that had increased while the values below the zero x- axis represents the cover types that decreased over the same period. Outcry for conservation of the Mau and change in leadership are believed to have brought this positive result.

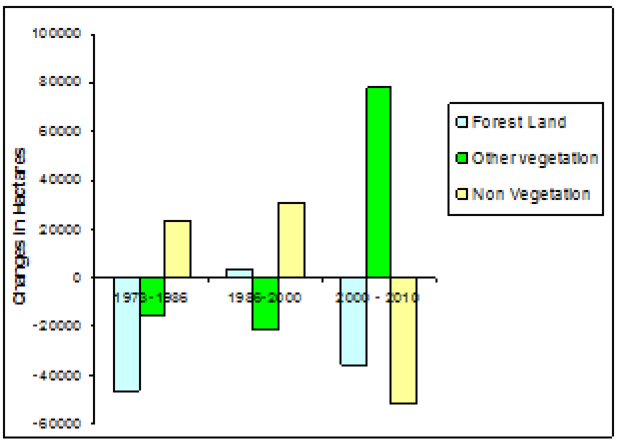

Figure 10: Coverage class changes with time

The NDVI results generated using density slices revealed same trend of change, save for the range 0.75 to 1.00 µm that did not change during the period 1986 to 2000. It had the same value for both 1986 and 2000 hence the value zero, which is not shown in the graph (Figure 4.8). During the same period (between 1986 and 2000), the vegetation whose density slice fell between 0.50 and 0.75 µm decreased by 116.33 km2 and area under 0.25 and 0.50 µm increased by 455.14 km2. Between 2000 and 2010, all the three classes of density slices decreased in coverage with most decrease being realized in the 0.75 to 1.00 class (1643.05 km2). The decrease in the 0.50 to 0.75 µm class was 504.08 km2 and that in the 0.25 to 0.75 µm class was 1392.42 km2. The quantitative changes in coverage for each density slice class for 1986, 2000 and 2010 Landsat imageries used (see Fig. 11). These results show that, as time went by, the greenness of the forest and general vegetative cover decreased as the trees became less healthy (less chlorophyll content) and less dense.

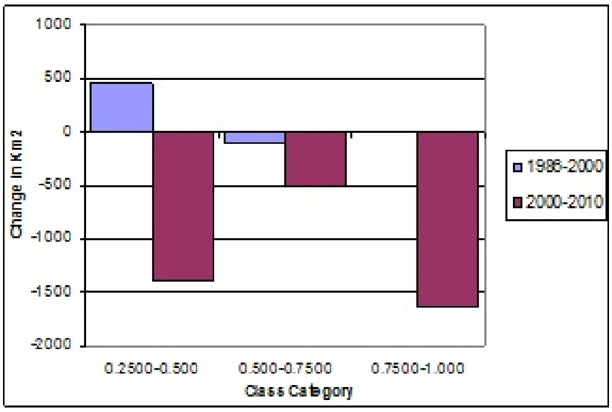

Figure 11: Coverage density slice changes with time

4.4. Thematic Class Overlays

The results of overlay operations revealed both the desirable and undesirable changes as well as classes that were relatively stable over time and these changes could help in making informed management decisions (Figures 12, 13, 14 and 15). In terms of location of change, the emphasis was on forest land and land under other vegetation. The changes between 1973 and 1986, 1986 and 2000, and lastly, 2000 and 2010 are presented in the Tables 6, 7 and 8

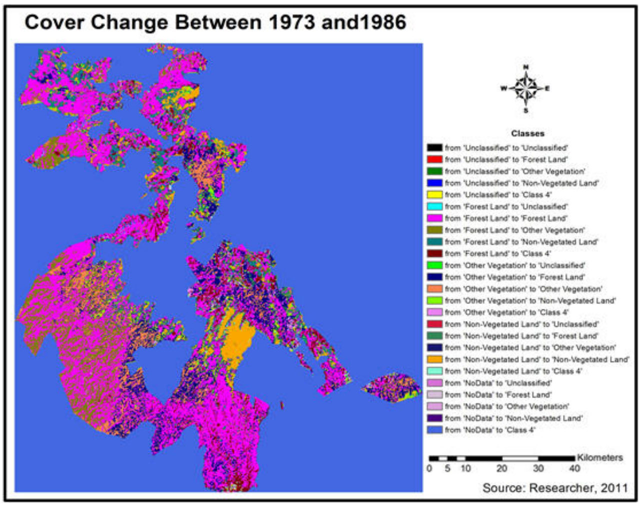

Figure 12: An overlay of 1973 and 1986 images

Table 6: Changes in Land Cover and Land Use between 1973 and1986

1973	1986	Area (Ha)	%
Forest Land	Forest Land	179057.02	42.34
Forest Land	Other Vegetation	47282.78	11.18
Forest Land	Non-Vegetated Land	29885.20	7.07
Forest Land	No-Data	31045.09	7.34
Other Vegetation	Forest Land	51855.42	12.26
Other Vegetation	Other Vegetation	25773.42	6.09
Other Vegetation	Non-Vegetated Land	8410.20	1.99
Other Vegetation	No-Data	6079.85	1.44
Non-Vegetated Land	Forest Land	11065.04	2.62
Non-Vegetated Land	Other Vegetation	2533.41	0.60
Non-Vegetated Land	Non-Vegetated Land	26412.99	6.25
Non-Vegetated Land	No-Data	1836.90	0.43
No-Data	Forest Land	973.56	0.23
No-Data	Other Vegetation	73.10	0.02
No-Data	Non-Vegetated Land	583.44	0.14

Fig. 12 shows how the land cover types namely forest land, other vegetation, non-vegetated land and no-data changed to and from each other between 1973 and 1986. From the attribute table (Table 6) above the results revealed that, forest land was converting at the highest rate to the other land cover types. Thus, 25.6% of the forest land was converted to the other land cover types while 15.7% of other vegetation, 3.6% of non-vegetated Land and 0.36% of no-data changed to the other land cover types. No-data represents the part that was covered by cloud at the time the image was taken and therefore the real cover could not be ascertained. Logging and farming were the main cause of deforestation.

Table 7: Changes in land use and land cover between 1986 and 2000

1986	2000	Area (Ha)	%
Forest Land	Forest Land	150606.01	10.98
Forest Land	Other Vegetation	28538.65	2.08
Forest Land	Non-Vegetated Land	48921.66	3.57
Forest Land	No-Data	15037.92	1.10
Other Vegetation	Forest Land	48500.18	3.54
Other Vegetation	Other Vegetation	13977.28	1.02
Other Vegetation	Non-Vegetated Land	10749.40	0.78
Other Vegetation	No-Data	2251.64	0.16
Non-Vegetated Land	Forest Land	26075.58	1.90
Non-Vegetated Land	Other Vegetation	9137.33	0.67
Non-Vegetated Land	Non-Vegetated Land	25079.36	1.83
Non-Vegetated Land	No-Data	4919.96	0.36
No-Data	Forest Land	20324.36	1.48
No-Data	Other Vegetation	3677.62	0.27
No-Data	Non-Vegetated Land	11404.88	0.83

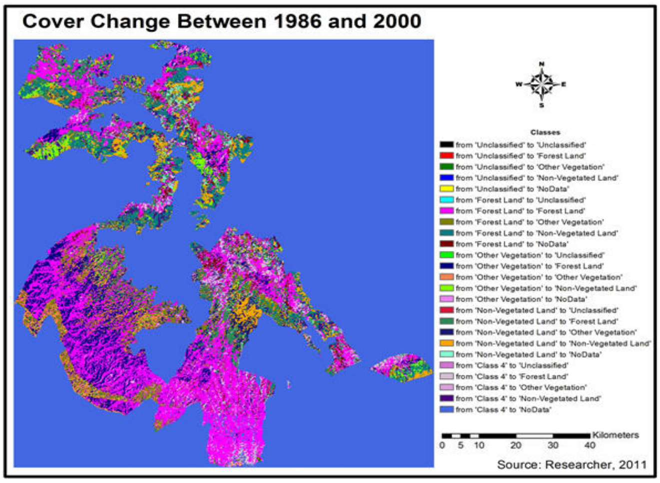

Figure 13: An overlay of 1986 and 2000 images

The above results (Table 7) show that forest land still gave most of its portion to other cover types. 6.75% of forest land changed to the other land cover types while 4.48% of other vegetation, 2.93% of non-vegetated land and 2.58% of No-data changed to the other land cover types. Forest land mainly changed to farm land but was captured either under other vegetation to show crops in the farms or under non-vegetated land to mean farms that were prepared and were waiting to be planted. Other vegetation was changed to forest where land had been left fallow and regenerated into thick vegetation cover while it changed to non-vegetated cover where crops had been harvested and no longer stood in the farms and or the farms prepared for another planting, although some changed to bare or waste land.

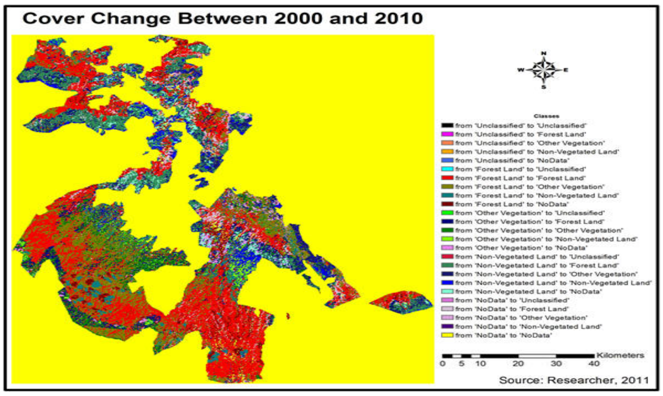

Figure 14: An overlay of 2000 and 2010 images

Table 8: Changes in land use and land cover between 2000 and 2010

2000	2010	Area (Ha)	%
Forest Land	Forest Land	126995.61	30.19
Forest Land	Other Vegetation	78056.90	18.56
Forest Land	Non-Vegetated	20569.91	4.89
Forest Land	No-Data	20380.25	4.85
Other Vegetation	Forest Land	20424.19	4.86
Other Vegetation	Other Vegetation	22947.77	5.46
Other Vegetation	Non-Vegetated	7460.68	1.77
Other Vegetation	No-Data	4408.73	1.05
Non-Vegetated	Forest Land	47213.49	11.23
Non-Vegetated	Other Vegetation	25619.91	6.09
Non-Vegetated	Non-Vegetated	13576.03	3.23
Non-Vegetated	No-Data	9651.15	2.29
No-Data	Forest Land	14814.55	3.52
No-Data	Other Vegetation	6303.63	1.50
No-Data	Non-Vegetated	2182.68	0.52

Attribute table (Table 8) shows that, 28.30% of forest land was converted to the other cover types, 7.68% of other vegetation, 19.61% of non-vegetated land and 5.54% of no-data changed to the other cover types. The big loss in forest land might have come about due to the excision of Maasai Mau forest in 2001 to settle the landless coupled with illegal allocations and encroachments. Non-vegetated land converted much to forest land and to other vegetation during this period as a result of tree planting and regeneration of vegetation that came as a result of evictions of squatters from the forest championed by the Mau Forest rehabilitation secretariat. In summary, the results of post classification visual comparison, post classification area comparison, land cover and land use change trends, rates and magnitudes as well as comparisons of the changes in percentage and quantity of the density slice classes with time all agree that, the Mau forest complex have extensively changed (degradation) in terms of forest cover and in the general health of the trees. Thus, forest conservation efforts should be continued if the enormous benefits of this forest ecosystem were to be achieved.

4.5 Population Density and Land Cover in Mount Londiani Forest

Since Mount Londiani forest forms parts of the administrative units in the surrounding, this study used the same population densities for those administrative units to factor in the densities in the forest itself. The figures 15, 16, 17, and 18 give results of the time series comparative analysis of the population densities and land cover changes of Mount Londiani forest.

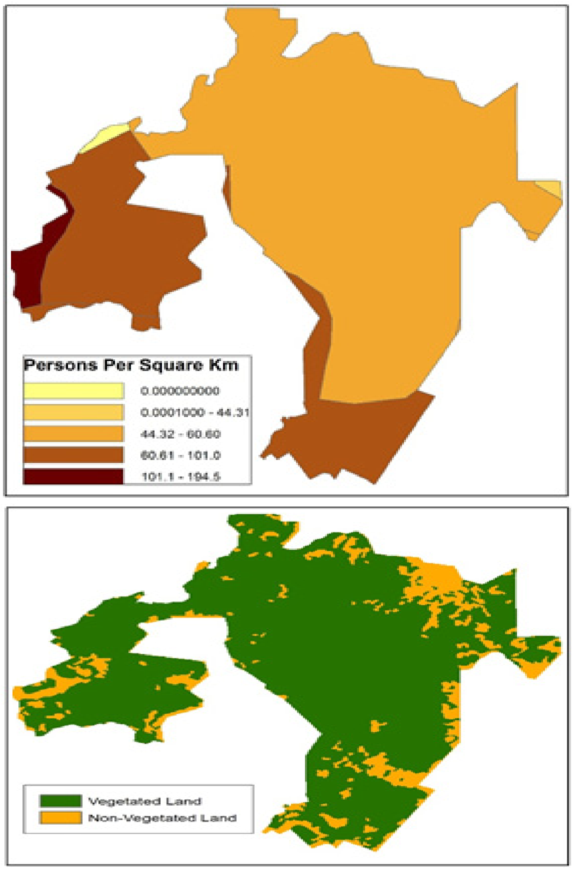

Figure 15: Population Density for 1973 and 1979 land cover

In 1973, the forest was not degraded since the interference by the local communities was still small due to low population densities. By 1979 the population densities had increased due to both natural increase and addition of people from outside areas who came to work in the urban centres such as Elburgon, Molo, Londiani, and Maji Mazuri especially in the timber industry and in agricultural sector. Thus, forest was cleared for urban settlement, timber to be processed in the factories and for agriculture as illustrated in Fig15.

Between 1979 and 1989 (Fig.15) the population densities were more than doubled and people started exerting pressure on the forest cover. More people from the surrounding areas started utilizing the forest for timber for house constructing, clearing the forest for agriculture and at the same time logging for industrial purposes, especially in the late 1970s and early 1980s. More forest was cleared to give room for urban settlement to accommodate the timber industries and the labour force for those factories. These activities resulted in deforestation which was witnessed in all the blocks of Mau complex. Figures 16 and 17 compares 1989 population density with 1986 land cover; 1999 density with 2000 cover respectively.

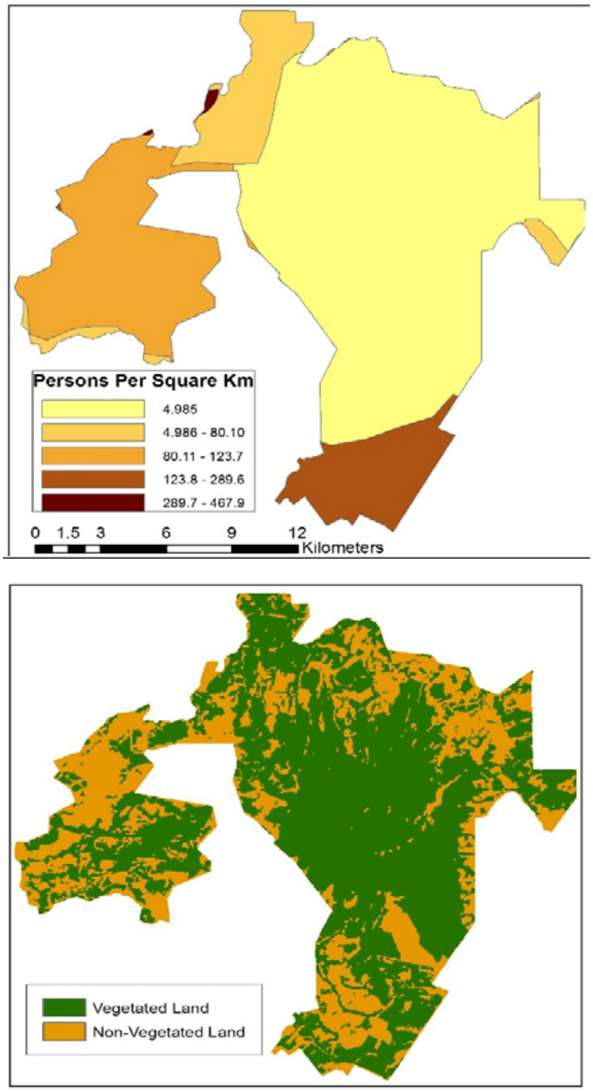

Figure 16: Population Density for 1989 and 1986 land cover
Source: Researcher, 2011

Between 1989 and 1999, the population densities increased further, almost doubling the 1989 figures. The change of forest land to non-vegetated land between 1986 and 2000 almost doubled as well. Most timber industries collapsed in the 1980s and even some of the urban centres that came up as a result of the industries ceased to be active e.g. Maji Mazuri. Though there was decline in the amount of timber used in the factories in the surrounding due to such collapse, the forest continued to be degraded as was witnessed in the 2000 image analysis results. This scenario was brought about by increase in population in the neighbourhood and interference by outsiders who used their political good will to illegally acquire forest land as illustrated in Fig 17.

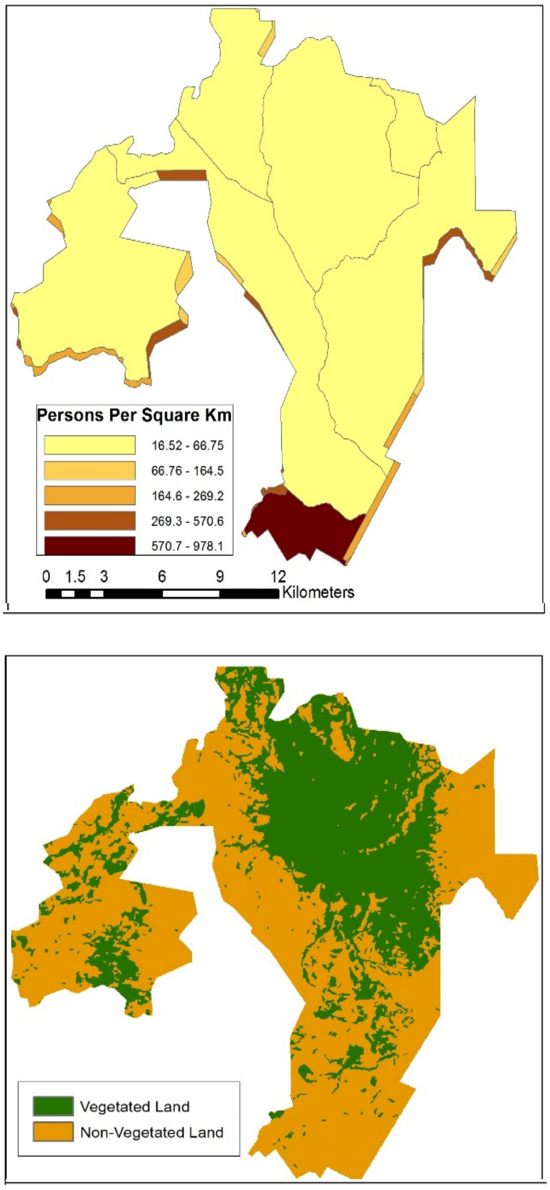

Figure 17: Population density for 1999 and 2000 Land cover

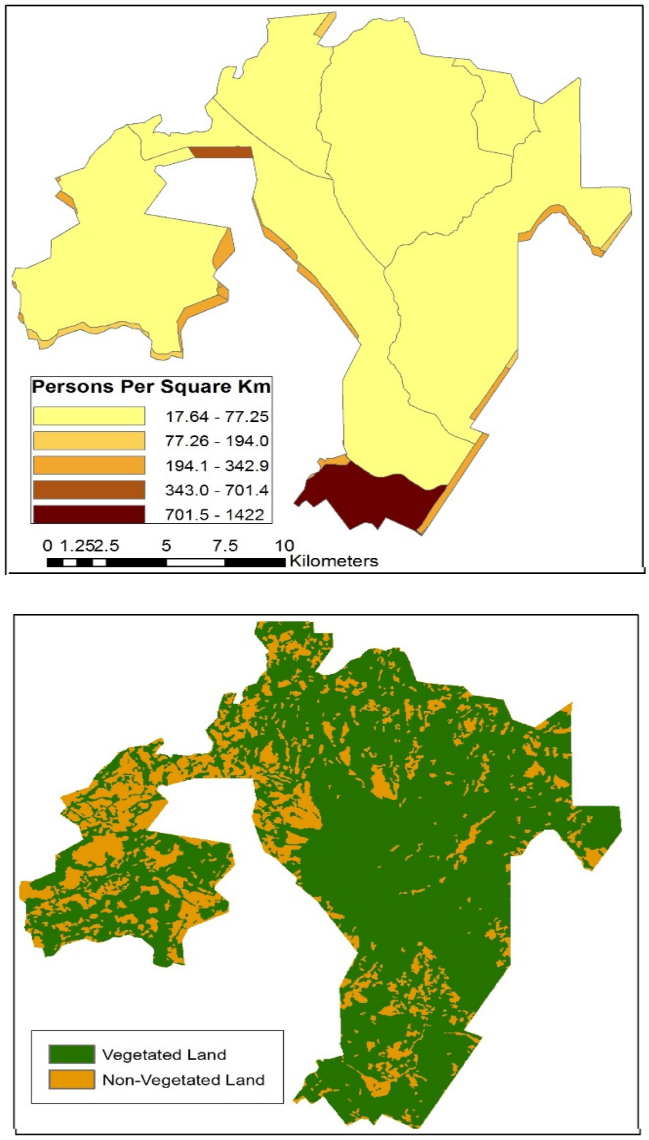

Figure 18: Population Density for 2009 and 2010 Land Cover

Between 1999 and 2009, the population densities increased even further from the 1999 figures. When the land covers for 2009 and 2010 were compared (Fig. 18), the latter was found to have had very good forest cover despite higher population densities. This increase in forest cover was attributed to tree planting and regeneration of vegetation which came about as a result of the evictions of squatters from the forest.

4.6 Land Use and Land Cover in the Mt. Londiani Forest 1973

By 1973, the Mau forest complex was mainly under forest and therefore the yellow parches (Fig. 19) generally did not come up as a result of change in land use but were merely open or bare land from the beginning rock out crops although some were settled areas. When the two maps were compared, the observation was that, there was no relationship between land use and land cover type. The areas marked as dense or sparse agriculture were actually under forest except where encroachment and illegal allocations had taken place (see Fig. 20). Lack of land use policy or failure to implement it in the area might have encouraged the invaders of the forest to discriminatively clear even the forest on steep slopes as could be seen in Fig. 19 and 20.

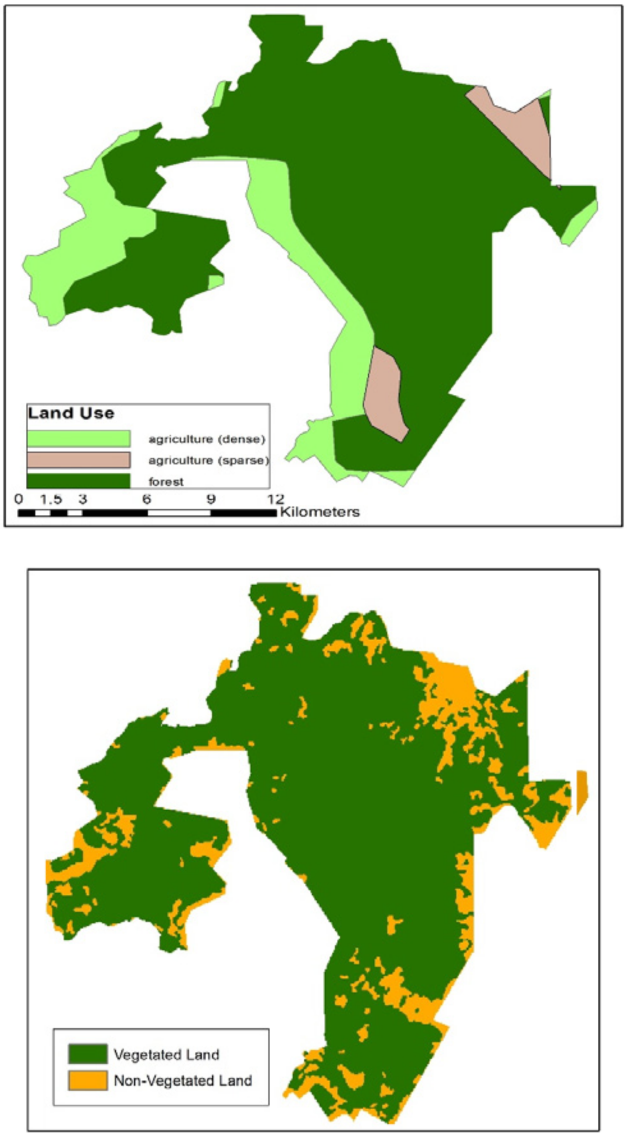

Figure 19: Land Use and Land Cover of 1973 of Mt. Londiani Forest

Source: Researcher, 2011

The year 2000 had worst regard for the manner in which land was used in that, more than half of the forest land cleared (Fig. 20) due to the reasons already mentioned.

In summary, Kenya lacked proper land use laws and policies which could give guidance and direction on how to use land. In the absence of such a document, this study came up with these investigations to assess the level of application of land use policies and to provide avenues for its enactment and or implementation where it was not existing and or used. The geo-database developed by this study will enhance the perception and understanding of those involved in forest resource management on how best to make informed decisions.

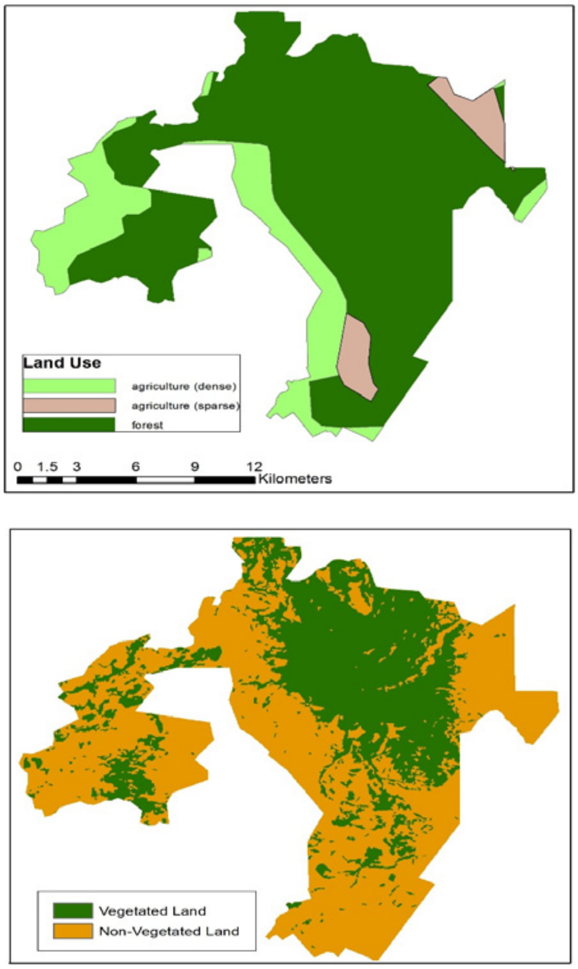

Figure 20: Land Use and Land Cover of 2000 of Mt. Londiani Forest

Source: Researcher, 2011

From the integrated analysis in Mount Londiani forest, it was found out that:

i) Population densities of the sub-locations had increased over the study period (1973-2010) and that, there was some relationship between increase in population densities and reductions in forest cover over time.
ii) The increase in population densities has had negative impacts on the forest cover in the Mau forest complex as the locals tended to depend on forest products for their well-being including farming, extracting building materials, wood fuel, and charcoal burning among others, as could be seen from the accompanied photographs. More forest degradation came as a result of increase in population densities, legal land excision as well as illegal land allocations by the past regimes.
iii) This study established that both gentle and steep slopes were cleared of their vegetation as land use changed both in the Mt. Londiani forest and the entire Mau forest complex.
iv) The rainfall totals and distribution had changed (reduced) over time and this reduction was not necessarily the result of deforestation but was influenced by other factors like the Congo Air masses, the Lake Victoria Basin, the Inter-Tropical Convergence Zone and the altitude.

5. Conclusions

Land Cover and Land Use Changes have occurred in the Mau forest complex over time both within and at the edge of the forests and were attributed mainly to increase in human population. The changes in land use and land cover resulted in the general degradation of the forest complex. The three cover classes used were forest land, other vegetation and non-vegetated land. The following facts were detected from the classes:

- It has emerged that from 1973 and 1986, forest cover decreased by 4.2%, area under other vegetation reduced by 1.86% while area under non-vegetation had an increase of 7.00%. The losses in forest cover and other vegetation was a gain to the area under non- vegetation. The period between 1986 and 2000, area under forest cover increased by 1.2% while area under other vegetation reduced by 6.00% and area under non-vegetation increased by 7.2%. That is, forest land was not interfered with this period and regenerated while other vegetation converted to non-vegetation.
- Between 2000 and 2010, forest cover decreased by 8.7% although areas under other vegetation and non-vegetated land changed positively during this period. The area under other vegetation increased by 20.4% while area under non-vegetation for the first time decreased by 12.3%.
- The annual rates of change in the three cover classes were not uniform but kept on changing in all the three periods under study. The changes were both negative and positive, although the changes that impacted negatively to the forest cover and the environment were more than those that impacted positively. The highest annual rate of change (reduction hence negative) in forest cover was during the period 2000 -2010 (i.e. 3604.4ha.) despite evictions and tree planting exercise that happened during this period. This could be explained by the fact that, most of the trees planted were captured under other vegetation and not forest land.
- The period between 2000 and 2010 brought most positive benefits to the Mau forest complex and its environment than the other periods despite the reduction in forest cover. This is because the area under other vegetation had the highest annual rate (increase hence positive) of change. In fact this is the only period this class had a positive change, meaning that, the approach to recovering the former closed forest canopy of Mau forest complex could succeed. The rate at which forest land was converting to other vegetation and non- vegetated land was higher than the rate at which the two were converting to forest land. That kind of scenario was disastrous and needed to be changed.

6. Future Scope for Research

This study established that, Mau forest complex had undergone a lot of changes in its land cover and land use over time due to different anthropogenic factors. However, further research should be done on the impacts of land cover and land use changes in the Mau on the livelihoods of the people within the regions hinterland to the Mau Ecosystem. It would also be important to investigate the impacts of livelihoods on riverine degradation in the Mau forest complex on the river discharge and sedimentation.

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