Effects of Vegetation Change and Land Use/ Land Cover Change on Land Surface Temperature in the Mara Ecosystem

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Abstract: ***Human interactions with the environment are identified as one of the leading causes of climate change and variation. Modification, conversion and maintenance of land cover are all forms of anthropogenic interactions with the environment that result in a variety of vital changes to the environment that either positively or negatively feedback to the environment and climate. The identification and monitoring of these Land Use/ Land Cover Changes (LULCC) is therefore important since changes in land cover, occasioned more often than not by anthropogenic land use, alter land-atmosphere interactions upon which ecosystem services rely thus resulting in climate change and variation. Land Surface Temperature (LST) is a property of the land surface and refers to the temperature of the interface between the earth's land surface and the atmosphere. It is therefore an important variable in land-atmosphere interactions and a climate change indicator which varies over space and in time as a function of vegetation cover, surface moisture, soil types, topography and meteorological conditions. Normalized Difference Vegetation Index (NDVI) is a numerical indicator derived from the Visible (Red) and Near Infrared (NIR) bands of the electromagnetic spectrum used in remote sensing to assess the concentration of green leaf vegetation and plant phenology. It is also an accepted and widely used parameter in characterization and assessment of vegetation change. This study uses a remote sensing approach in one of the most ecologically rich and diverse ecosystems to investigate the effect of Land Use/ Land Cover Change and in particular vegetation change on Land Surface Temperature (LST). The study area is in the Mara ecosystem located in South Western Kenya. LANDSAT satellite images for 1985, 1995, 2003 and 2010 were used to derive NDVI and LST. We found that human related Land Use/ Land Cover Change (LULCC) in the form of conversion of land for cultivation purposes has been and is taking place around the Maasai Mara National Reserve (MMNR). We also found that a negative correlation exists between LST and NDVI thus indicating that with decrease in vegetation cover and conversion to cultivated land, there is increase in Land Surface Temperature (LST).***

Keywords: Climate Change, Land Surface Temperature, Land Use/ Land Cover Change, Normalized Difference Vegetation Index *(NDVI)*

1. Introduction

The Mara ecosystem is part of the larger Serengeti – Mara ecosystem, which is one of two of the highest diversity patches of medium to large mammal species in Eastern Africa and possibly the world [5]. The Mara ecosystem consists of the Maasai Mara National Reserve (MMNR), which is a protected area (IUCN Category II), and the surrounding group ranches, located in South Western Kenya straddling Narok and Trans Mara districts. The ecosystem is crucial to the survival of the entire Mara-Serengeti ecosystem, covering Northern Tanzania and Southern Kenya, since it forms the dispersal area for the Serengeti migratory wildlife during the dry season as well as sustaining a high population of livestock [4]. It is therefore pertinent to Kenya's tourism industry, which is the third highest foreign exchange earner due to its wildlife.

Socio-economic changes, population increase due to better health and in-migration, cultural and government policy changes have led to important changes in land use practices in the Mara ecosystem. These changes include increased permanent settlement, increased large-scale mechanized farming and increased infrastructure development to support tourism including lodges, camps, roads and airstrips. As a result, the Mara ecosystem has been modified greatly resulting in negative environmental feedbacks as evidenced by extreme climatic events such as prolonged droughts and flooding. These and other climate feedbacks have resulted in human-wildlife conflict, wildlife habitat destruction and species loss.

In order to exhaustively describe a climate system, the number of variables that need to be considered is extremely large and as such some approximations in the form of climate and weather models are necessary for practicality in climate change research [1]. The main elements of climate may broadly be categorized as the atmosphere, land surface including water and solid land masses, and living organisms. Specific climatic variables which govern climate include among others, meteorological elements such as temperature, precipitation and atmospheric pressure and land surface elements such as land cover, biomass, albedo and reflectance. Climate change impacts and ecological responses are highly spatially heterogeneous, hence the need for more localized studies. There have been relatively few studies on climate change impacts in protected areas to confirm or disprove predictions made based on global and regional climate models hence the need for this study, [6].

Land use/ land cover changes (LULCC) are complex processes involving multiple driving forces that are location specific and context dependant. Land use/ land cover changes are also spatially and temporally dynamic. Changing land cover alters the sensible and latent heat fluxes that exist within and between the earths's surface and boundary layers thus influencing land surface-atmosphere interactions [8]. As such, changes in land cover and land use are bound to influence meteorological parameters including precipitation, humidity and temperature. Land surface properties are also affected. Land Surface Temperature (LST) is one of the land surface properties that is affected by Land Use/ Land Cover Changes and is measureable continuously over space using remote sensing methods. This is in contrast to the conventional meteorological temperature measurements which are obtained at stations and as such non-contiguous and requiring extrapolation.

Land Surface Temperature (LST) refers to the temperature of the interface between the earth's land surface and the atmosphere. LST may therefore be considered to be a property of the land surface and as such an important variable in land-atmosphere interactions. LST varies over space and in time as a function of vegetation cover, surface moisture, soil types, topography and meteorological conditions [3]. Changes in land cover and in particular vegetation changes impact Land Surface Temperature. Remote Sensing provides means by which to continuously the changes occurring on the earth's surface and carry out change detection analysis. Further Remote Sensing enables the detection of vegetation, differentiation by type or nature and analysis of the state of the vegetation.

Normalized Difference Vegetation Index (NDVI) is a coarse measure or estimate of vegetative cover and vegetation conditions. It has been widely used as an early warning on droughts and famines and in ecological zone identification [7]. NDVI can therefore be used as an indicator of climate change, given that it is a measure of vegetation which is one of the major components of land cover.

2. Study Area

The Maasai Mara ecosystem in Southwestern Kenya lies in the Great Rift Valley and has varied habitats including grasslands, riverine vegetation, forests, scrub and shrubs, acacia woodland, non-deciduous thicket and boulder strewn escarpment. The population of wildlife and livestock as at the 2002 Mara count conducted by the Mara Count Foundation was 400,000. The human population growth is above average due to immigration and local growth, with an estimated 94% population density increase, with population density increasing from 0.8 people/ km^2 in 1950, to 14.7 people/Km^2 in 2002. The landscape is spatially heterogeneous and has both highlands and lowlands, altitude ranging from 900 metres to 3000 metres above sea level. Rainfall ranges from about 500mm annually in the lowlands to about 1600mm per year in the highlands.

The study area includes the MMNR and the area bounded by Narok Town to the North-east, Kilgoris to the North –west, Lemek to the North, Lolgorian to the West, Maji Moto to the east and Ang'ata and Olposumoru to the South-west and South-east of MMNR respectively. The project study and analysis area is approximately 6466 Km^2.

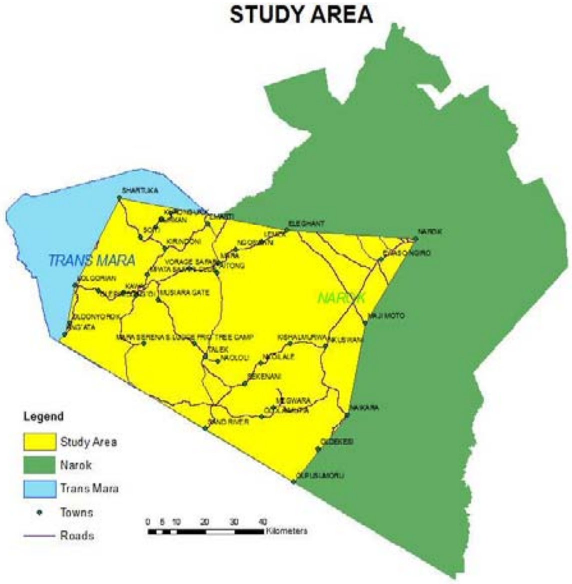

Figure 1: Study area

3. Data and Methodology

The study involved various activities including data acquisition, data processing and data analysis and interpretation. Scanned topographical maps of scale 1:50000 were obtained from Survey of Kenya and Wildlife data was obtained from the Department of Resource Survey and Remote Sensing (DRSRS). The years of study selected were 1985, 1995, 2003 and 2010, based on availability of quality data covering the study area. Choice of satellite imagery was based on spatial and radiometric resolution, availability of imagery in the years of study and affordability. LANDSAT satellite imagery was thus chosen as it is freely available, medium resolution, multispectral and good quality imagery in the years of study was available. LANDSAT has 7 spectral bands. Bands 1, 2 and 3 are in the reflective visible segment of the electromagnetic spectrum, Band 4 in the reflective Near Infrared, Bands 5 and 7 in the reflective Short wave Infrared and Band 6 is in the emissive thermal Infrared segment. The spatial resolution is 30 metres for all bands apart from Band 6 which has a spatial resolution of 120 metres (TM) and 60 metres (ETM+). LANDSAT TM imagery was used for 1985, 1995 and 2010, while ETM+ was used for 2003.

Table 1: LANDSAT Sensor Specifications

Band	*Spatial Resolution (m)*	*Spectral Resolution (μm)*	*Temporal Resolution (Days)*
1	30	0.45-0.52	16
2	30	0.53-0.61	16
3	30	0.63-0.69	16
4	30	0.78-0.90	16
5	30	1.55-1.75	16
6	120 (TM) 60 (ETM)	10.4-12.5	16
7	30	2.09-2.35	16
8	15	0.52-0.90	16

The LANDSAT TM and ETM+ images were downloaded from the USGS Earth Explorer portal and delivered in GeoTIFF file format.

Table 2: Data Acquired

Data	*Sensor*	*Spatial Res. (M)*	*No.of Bands*
1985 (09/01), 1995 (21/01 & 06/ 02) ,2010 (16/12)	LANDSAT TM	30, 120 (TIR)	7
2003 (19/01)	LANDSAT ETM+	15 (Panchromatic) 30, 60 (TIR)	8
Wildlife counts and distribution data (1985-2012)	N/A	N/A	N/A
Topographical Maps	N/A	1:50000 (Scale)	N/A

LANDSAT image pre-processing involving calibration, reprojection and subsetting the analysis area from the entire scene WRS 169/61 was carried out. Land Surface Temperature (LST) for the study area in the epochs of study was extracted from the thermal infrared (10.4 - 12.5 μm) band, Band 6, of the satellite images by first converting the image DNs to at-sensor radiance then applying the LANDSAT specific estimate of the Planck curve to the DNs [2]. Equations (1) and (2) were implemented in ERDAS Spatial Modeler.

$$L_{\lambda} = \left[\frac{LMAX-LMIN}{QCALMAX-QCALMIN}\right] * (DN - QCAL\,MIN) + LMIN \quad (1)$$

$$T = \frac{K_2}{ln\left[\frac{K_1}{L_\lambda}+1\right]} \quad (2)$$

NDVI was extracted from TM Band 3 and TM Band 4 using Equation (3) below implemented in ERDAS Spatial Modeler.

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (3)$$

A maximum likelihood supervised classification was carried out for each of the images in each epoch in order to obtain the land use/ land cover classes. The various types and forms of land use/ land cover in the study area were identified using False Colour Composites (FCCs) of various band combinations which enhance certain features, as well as visual interpretation using shape and texture and further aided by the LST and NDVI images. Initial Land Use/ Land Cover classes identified include: Water/ Rivers, Forest/ Dense Vegetation, Grasslands/ Sparse Vegetation, Bare Earth, Cultivated Land, recently cut areas, new vegetation growth. These classes were summarized to arrive at the main Land Use/ Land Cover classes of: Water/ rivers, forests/ dense vegetation, grasslands/ sparse vegetation, bare earth and land under cultivation.

Accuracy assessment informed by knowledge of the area and historical images from Google Earth was carried out after classification. Reference points were randomly selected from the original image and compared against the classified image points. The results of the accuracy assessment are shown in table V.

Table 3: Accuracy assessment results

Year	*Class Name*	*Producer's Accuracy %*	*User's Accuracy %*
1985	Water	83.33	83.33
	Forest/ Dense Vegetation	87.50	77.70
	Grasslands/ Sparse Vegetation	66.67	50.00
	Bare Earth	75.00	90.00
	Cultivated Land	83.33	71.43
	Overall Accuracy %	**78**	
Year	Class Name	Producer's Accuracy %	User's Accuracy %
1995	Water	81.82	56.25
	Forest/ Dense Vegetation	46.15	54.55
	Grasslands/ Sparse Vegetation	52.94	81.82
	Bare Earth	61.90	81.25
	Cultivated Land	92.86	59.09
	Overall Accuracy %	**65.79**	
2003	Forest/ Dense Vegetation	75.00	60.00
	Grasslands/ Sparse Vegetation	60.00	85.71
	Bare Earth	72.73	57.14
	Cultivated Land	50.00	66.67
	Overall Accuracy %	**68.63**	
2010	Forest/ Dense Vegetation	75.00	60.00
	Grasslands/ Sparse Vegetation	60.00	60.00
	Bare Earth	55.56	83.33
	Cultivated Land	88.89	72.73
	Overall Accuracy %	**69.49**	

Change detection between consecutive years of study was carried out using RGB composites for the LULC, NDVI and LST images. RGB composites were created by layer stacking the images for every two consecutive years of study. The RGB composites were then classified using a supervised maximum likelihood classification method where the training data was derived using AOI's and spectral profiles. The changes in LST and NDVI were classified as Increase, some increase, decrease, some decrease or no change while those of Land Use/ Land Cover Change (LULCC) were classified as No Change, Change to Vegetation, Change to Bare Earth and Change to cultivated land, which were the dominant changes in land cover.

4. Results and Analysis

Land use/ land cover (LULC) maps derived from supervised classification for the 1985, 1995, 2003 and 2010 images are shown in Figure2.

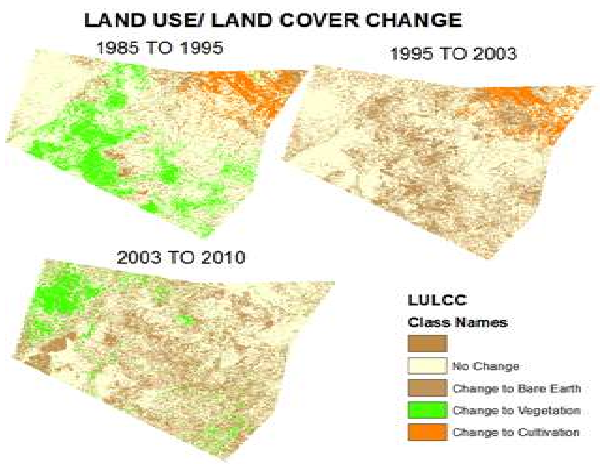

Figure 2: Land Use/ Land Cover Maps

The LULC maps show a progressive increase in land under cultivation or agricultural use over the years of study. However, in 2003, much of the land under cultivation was not bare as is characteristic of farmland in the region during the relatively dry DJF season. This is may be as a result of the above normal precipitation received in the study area in the month of January 2003, *See Table VI.*

Table 3: Meteorological Data *Source: Kenya Meteorological Department (KMD)*

Year	*Month*	*Precipitation*	*Max. Temp*	*Min. Temp*	*Diurnal Range (DTR)*
1985	Jan	10	27.5	4.9	22.6
1995	Feb	56.2	27.2	9.6	17.6
2003	Jan	103.6	26.1	8.9	17.2
2010	Dec	123.8	25.4	9.7	15.7

Visual inspection of the Land use/ Land cover maps also indicates an increase in grasslands or sparse vegetation and a decrease in bare earth. This may be as a result of increased precipitation, uncharacteristic of the usually dry DJF season. The 2003 image also shows an increase in Forest cover or dense vegetation. However, this is not the case as this was cloud cover which the classifier assigned the same class due to the similarity in spectral characteristics. There is also an increase in water cover in the 2003 image. This is due to collection of water in crevices and presence of seasonal rivers as a result of aforementioned above normal precipitation.

Figure 3 shows the specific Land use/ Land cover changes. Increase in area of land under cultivation was greatest between the 1985 and 1995 epochs and 1995 and 2003 epochs. This trend appears to have abated between 2003 and 2010 with very minimal changes in these years.

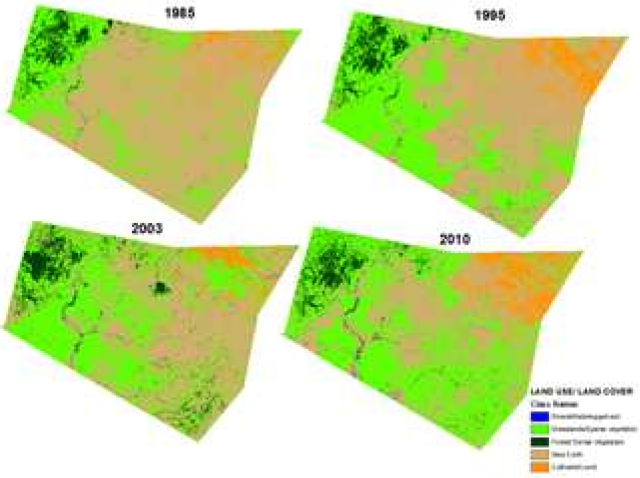

Figure 3: LULC Changes

Figure 4 is a graph of the Land use/ Land cover temporal change trends in terms of areal coverage for the years of study. The graph shows that the Land cover classes that changed the most in the study area are Bare Earth and Grasslands or Sparse Vegetation. There has also been significant change in land under cultivation and Forests or dense vegetation. However, the changes in Water as a land cover type are negligible.

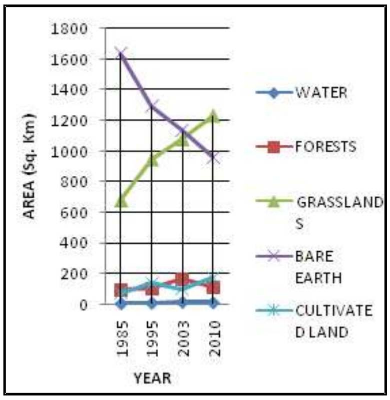

Figure 4: Graph of LULC change trends

Land Surface Temperature (LST) maps were generated for each of the years of study as depicted in Figure 5.

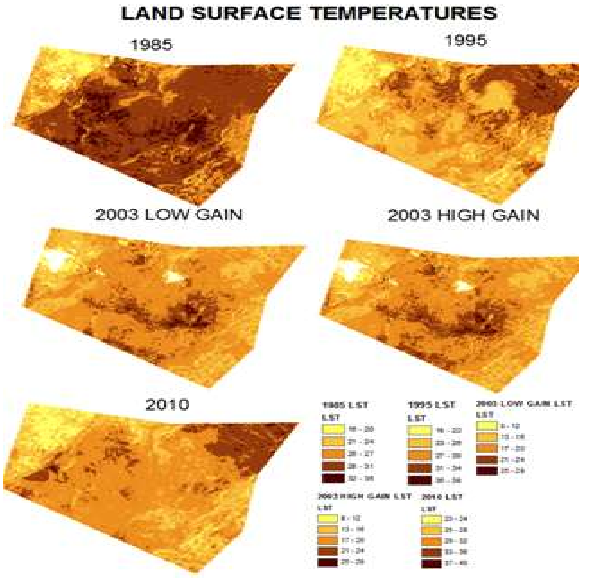

Figure 5: LST 1985, 1995, 2003 and 2010

Apart from in 2003, there was increase in both the maximum and minimum temperatures in 1985, 1995 and 2010. Issues with cloud cover in the 2003 image may have contributed to the decrease in average temperature. The areas closest to North Eastern, Central and Eastern parts of the study area appear to have the highest temperatures in all the years with the western part appearing to have lower temperatures. These areas are dominated by Bare Earth and Cultivated Land cover classes. The mean LST in 1985 was 27.9ºC with a maximum LST of 35ºC and minimum LST of 16ºC. In 1995, the mean LST was 27.1ºC, a maximum of 38ºC and minimum of 18ºC. This represents 2ºC and 3ºC increases in minimum and maximum LST and a 1ºC increase in Diurnal LST Range. The minimum and maximum LSTs in 2003 were 8ºC and 28ºC respectively for both the low gain and high gain images. This indicates that for the study area, surface brightness had minimal influence on the recorded at-sensor radiance given that the images were not subjected to any atmospheric corrections. The mean LST was 17.7ºC, a significant decrease in comparison to 1995, attributable to cloud cover and influence of precipitation events in January 2003. Minimum LST as derived from the December 2010 image was 20ºC and maximum LST was 40ºC, with an average temperature of 29.4ºC. The satellite derived LST information depicts similar trends to the ground meteorological measurements of Land Surface Air Temperature at the Narok weather station, *See Table VI*, where there is a progressive and significant increase in the minimum temperature. However, the ground measurements indicate a decrease in the maximum temperature thus leading to a decreasing Diurnal Temperature Range (DTR) contrary to the satellite derived LSTs which indicate an almost commensurate increase in maximum LST and the diurnal range. This contrast may be attributed to land use/ land cover changes since LST includes the influence or contributions of various land cover types and spatial heterogeneity. The meteorological data is derived from one station, hence not sufficient to make a generalization over the study area.

LST change maps, *Figure 6*, were generated in order to gain further insight in to the nature of LST change in the epochs of study over the study area. They indicate that most of the study area experienced a temperature decrease between the 1985 and 1995 LST images.

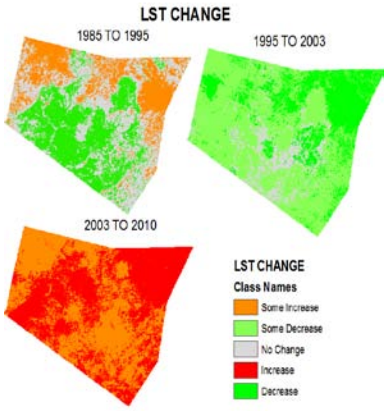

Figure 6: LST Change

However, there was some increase in temperature especially in the areas where there was Land use/ Land cover conversion to Bare Earth or Cultivated Land, *See Figure 3 and 6.* The LST changes between the 1995 and 2003 images indicate a massive decrease in LST over most of the study area. This change is also attributable to influence of cloud cover in the 2003 image. The LST change between the 2003 and 2010 images show a general increase over most of the study area.

The Normalized Difference Vegetation Index (NDVI) was extracted for each year of study and maps of NDVI were generated as shown in Figure 7. The minimum NDVI for the 1985 image was -0.070423 while the maximum NDVI was 0.69048. The highest NDVI values were in the areas under forest or dense vegetation cover while the least NDVI values occurred in areas with the Water class. For the 1995 image, the NDVI values ranged from a minimum of -0.074074 to a maximum of 0.71014. The mean NDVI was 0.166. This represents a 0.033 decrease between the two epochs. The 2003 image had the highest minimum NDVI of -0.050943 and the lowest maximum NDVI of 0.62069. The 2003 image also had the lowest mean NDVI of 0.116. The 2003 NDVI data may be attributed to precipitation which increased the amount of surface water at the time since 2003 has the highest water coverage, *See Table 7*, and the effects of cloud cover. The minimum NDVI for the 2010 image was –0.23944 while the maximum was 0.71951 and a mean of 0.18.

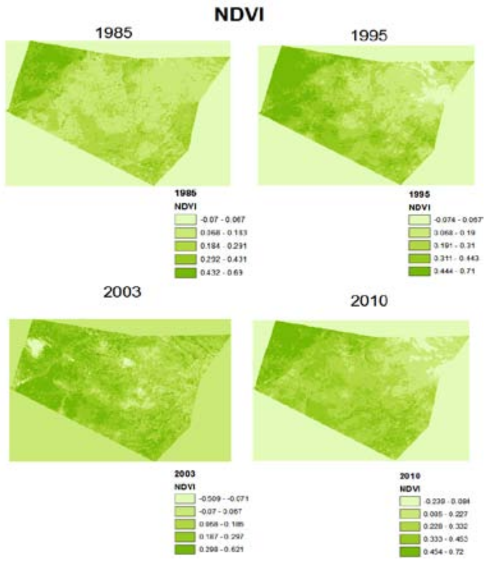

Figure 7: NDVI Maps

NDVI change evaluation for each year of study was carried out and maps depicting the changes between the epochs generated. The increase in NDVI was greatest between the 1985 and 1995 image with a 57.9% increase over the study area while the greatest decrease was between the 1995 and 2003 images, at 41.8%. These changes may be attributed to land cover change. The conversion of land cover to vegetation was greatest between 1985 and 1995 images and least between 1995 and 2003 where there was more conversion of land cover to bare earth than in other epochs. Visual inspection of the NDVI change images also reveals that in the North Eastern part of the study area where there was progressive conversion of land use to agricultural use, there was a continued decrease in NDVI in the 1995 to 2003 and 2003 to 2010 epochs.

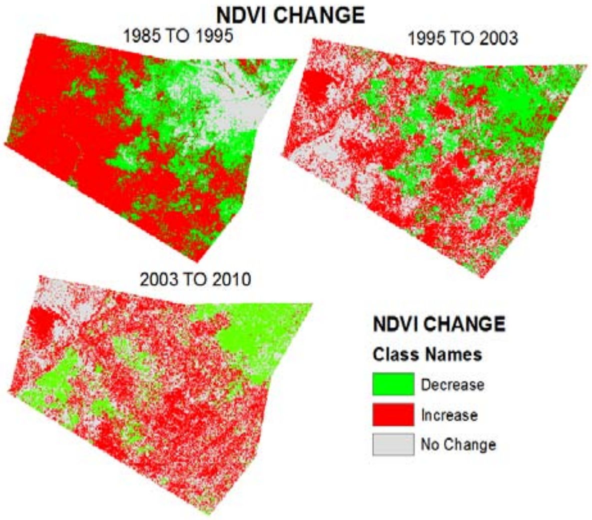

Figure 8: NDVI Change

Figure 9 is a summary of the NDVI change trends and type. The changes in the minimum, maximum and mean NDVI between 1985 and 1995 are positively correlated. However, between 1995 and 2003, the change in minimum NDVI is negatively correlated to the mean and maximum NDVI change. The same case applies to the 2003 to 2010 change period.

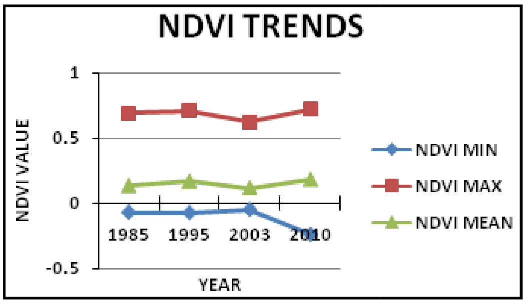

Figure 9: Graph of NDVI Trends

Wildlife and livestock counts data was obtained from DRSRS. Though the data lacked spatiality, a qualitative analysis was carried out. The livestock and wildlife counts indicate a major decrease in wildlife populations especially those of the large mammals. The wildebeest are the flagship species for the Maasai Mara National Reserve (MMNR) and are grazers hence reliant on vegetation. Other wildlife species that are negatively impacted by vegetation loss and Land use/ Land cover change are Elephants, Zebras and buffaloes. Apart from vegetation loss, these species are also affected by habitat fragmentation such as that occasioned by roads and human settlements and poaching. Elephants have long been poached for their tusks and their numbers drastically reduced from 2,037 in 1985 to 1,806 in 1994 in the Maasai Mara. However, the Government of Kenya's efforts to curb this practice by banning ivory trade paid off and the population increased to 4397 in 2004. However, their population had decreased at the next animal count in 2011 to 3,388. This decrease may be attributed to among other factors: drought resulting in loss of vegetation, accelerated human – wildlife conflicts due to land use change and competition for grazing resources with livestock. Elephants are also able to travel great distances and are therefore likely to migrate to other more conducive areas in the face of adversity.

The effects of drought on both livestock and wildlife in the Maasai Mara can be seen from the Animal counts data. The significant decrease in the population of all wildlife species and livestock sampled in this study in 1994, in the Narok and Trans Mara may have been the first sign of the widespread 1995/96 drought. The 2010 drought also devastated the animal populations and wildlife distribution maps generated from the 2011 animal count show concentration of wildlife within the MMNR. The migratory wildlife of Maasai Mara normally disperses in to the surrounding rangelands during the dry season and there is a substantial number of all-year round resident wildlife in the rangelands. However, the distribution maps of 2011 show that this was not the case and may be attributed to the lingering effects of the 2010 drought.

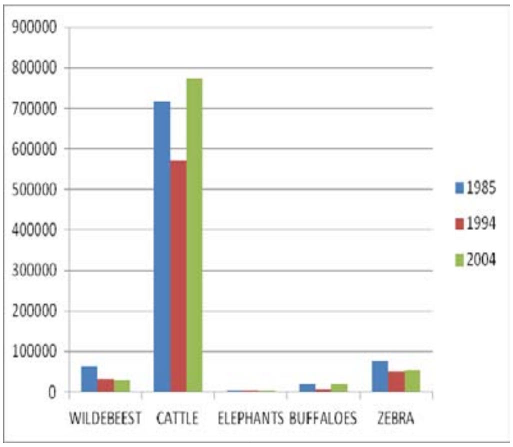

Figure 10: Graph of Wildlife population

Table VII: Animal and Wildlife counts for 1985, 1994, 2004 and 2011*(Source: DRSRS)*

Year	*Species*	*No. (Population Estimate)*
1985	Cattle	716,516
	Buffalo	20,832
	Elephant	2,037
	Zebra	78,044
	Wildebeest	62,314
1994	Cattle	569,856
	Buffalo	5,617
	Elephant	1,806
	Zebra	50,805
	Wildebeest	32,165
2004	Cattle	774,580
	Buffalo	19,685
	Elephant	4,397
	Zebra	53,486
	Wildebeest	30,651
2011	Cattle	630,103
	Buffalo	5,910
	Elephant	3,388
	Zebra	62,379
	Wildebeest	256,507

5. Conclusion and Recommendations

In this study, LANDSAT TM and ETM+ images were used to extract Land use/ Land cover (LULCC) classes Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) using a remote sensing approach. The results of this study demonstrate the increase in anthropogenic Land use/ Land cover in the study area which is part of the Maasai Mara ecosystem. These changes are attributed to both climatic and socio-economic factors. The Maasai are traditionally a pastoralist community but in the face of climate change and change in socio-economic conditions, their land use regimes have changed towards more agriculture and tourism related activities. Change in climatic and socio-economic conditions has not only affected the human population but also the wildlife population. This study therefore demonstrates the climate change trends in the MMNR and the rangelands surrounding it using LST, NDVI and Land use/ Land cover changes as indicators. Land use/ Land cover change has been shown to have an impact on Land Surface Temperature and NDVI. The study further shows the effects of a changing climate on wildlife and livestock in the area.

The satellite imagery used in this study is medium resolution (30 * 30 metres) thus discrimination and classification of land cover features at a larger scale was not possible. It is our recommendation that future studies incorporate high resolution data in order to allow for analysis of land use/ land cover change at a larger scale. Wildlife and livestock data with a spatial aspect would greatly enhance the value of future studies in this area due to amenability to GIS. Meteorological data provides information about important parameters by which to monitor climate change and variability. The Kenya Meteorological Department has a network of meteorological stations that collect this data and currently has 16 Class A stations country wide. This study incorporated data from two stations closest to the study area, that is, in Narok and Kisii. However, in order to make valid generalizations and conclusions using meteorological data, more data from more stations in close proximity to the study area would be necessary. We therefore recommend the densification of the meteorological stations network and enhancement of their capabilities for climate change monitoring.

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