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A Remote Sensing-based approach to Evaluation of Trends and Impacts of Land Surface changes in the Mara Ecosystem

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Abstract

The earth's land surface is a key component of the earth's climate system. Terrestrial plants, animals and human beings rely on the land surface for sustenance and existence. As such, the conditions prevailing on the land surface and its properties are essential to terrestrial life. Land cover is a major component of the land surface and changes to it constitute a form of land surface change. 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 land cover and consequently the land surface, that either positively or negatively feedback to the environment and climate. These feedbacks, in turn influence the land surface state and its properties as well as the response and adaptations by plants, animals and human beings. 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 surface-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 surface-atmosphere interactions and a climate change indicator which varies spatially and temporally as a function of other land surface properties and components such as vegetation cover, surface moisture, soil types and topography as well as atmospheric conditions primarily characterized by meteorological measures. Vegetation cover is a major constituent of land cover that is subject to changes occasioned by natural events such as precipitation and impacted by activities on the land surface such as foraging and clearing. The ability to monitor and characterize changes in Land Surface Temperature and vegetation cover allows for investigation of causes and enhances the ability to anticipate changes and put in place adaptation measures. Remote

Sensing provides us with the ability to monitor changes and establish trends and interrelationships between these and other land surface components and properties, thereby providing information on the state of the environment and climate change and variation.

This study uses a remote sensing approach in one of the most ecologically rich and diverse ecosystems to investigate the Land Cover Changes and in particular vegetation change and Land Surface Temperature (LST) changes as indicators of land surface change. Further, the study evaluates the relationship between Land Surface Temperature and vegetation cover in the region using NDVI as a parameter to characterize and assess vegetation. The study area is in the Mara ecosystem located in South Western Kenya. LANDSAT satellite images for 1985, 1995, 2003 and 2010 are used to derive NDVI, LST and Land Use/ Land Cover maps. 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, there is increase in Land Surface Temperature (LST) in the region.

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

1 INTRODUCTION

1.1. Background

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 (Suttie et al, 2005). 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 (DRSRS-FAO, 2010). It is therefore pertinent to Kenya's tourism industry, which is the third highest foreign exchange earner due to its wildlife.

Socio-economic changes, high population growth, cultural and government policy changes have led to changes in land use practices in the Mara ecosystem. These changes include increased permanent settlement, increased large-scale mechanized farming and increased placement of infrastructure to support tourism including lodges, camps, roads and airstrips. As a result, the Mara ecosystem has been modified greatly resulting in negative environmental feedbacks apparent in occurrence of extreme climatic events such as prolonged droughts and floods. This has resulted in human-wildlife conflicts, wildlife habitat destruction and species loss. Damage to existing infrastructure such as roads due to floods, increased scarcity of water resources and decreasing levels in the Mara River especially in the dry season, and increased prevalence of diseases like malaria are among many other observable consequences of a changing environment and climate in the Maasai Mara (http://www.nation.co.ke/News/Tourists-stranded-due-to-floods/-/1056/1742246/-/51hqmiz/-/index.html, http://news.bbc.co.uk/2/hi/africa/8057316.stm).

In order to exhaustively describe a climate system, the number of variables that need to be considered is very large and as such some approximations in the form of climate and weather models are necessary for practicality in climate change research, (Auffhammer et al, 2011). The main elements of climate may broadly be categorized as the atmosphere, land surface including water and solid land masses (hydrosphere and lithosphere) and living organisms (Biosphere). 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, (Walther et al, 2002; WWF, 1991).

Land use and 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 earth's surface and boundary layers thus influencing land surface-atmosphere interactions, (Yang, Z. L., 2004). As such, changes in land cover and land use are bound to influence meteorological parameters including precipitation, humidity and temperature and hence affect the Land surface, its properties and activities occurring on it. Changes in land use regimes in the Maasai Mara abound as a result of changes in the socio-economic, cultural and political environments and as the local population seeks to interact with the environment and derive benefits from it as generations before them have.

As the dominant and natural land cover is altered, the land surface-atmosphere interactions upon which many ecosystem services rely are also altered. Land Surface temperature is a land surface property and also an indicator of changes to the land surface. In evaluating the trends and effects of land surface changes in the Maasai Mara, this study chose to adopt Land Surface Temperature as an indicator due to the fact that it can be continuously measured over land since it is derived from satellite images without the need for extrapolation hence providing temporally and spatially continuous data. Further, Land Surface Temperature (LST) measurements enable for the properties of various types of land cover to be inferred based on their thermal response. LST can therefore be used to complement reference data and in the absence of other information as reference data in the classification of land cover. There are two meteorological stations around the study area, the Kisii and Narok Meteorological stations, which are approximately 164 Kilometres apart. The two stations are insufficient for making a valid generalization and may introduce errors and further fail to capture the prevalent conditions effectively.

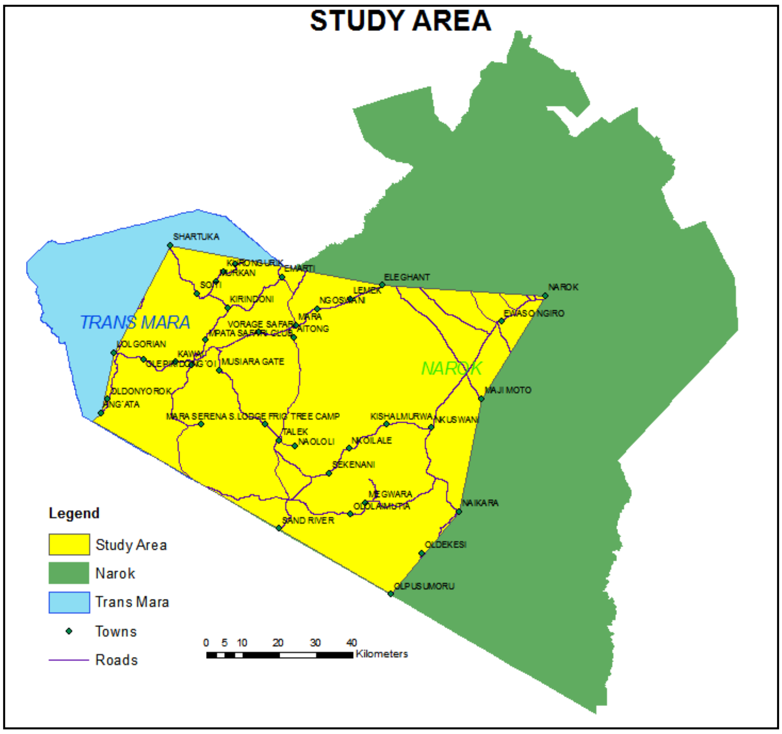
Land Surface Temperature is regulated by the land surface and land cover and thus influenced by surface albedo, surface conductance, amount of water available for evaporative cooling, wind speed and surface roughness which regulates both sensible and latent heat fluxes (Van Leeuwen et al, 2011). Vegetation influences surface albedo and other land surface properties. The application of LST in tropical forest-cover change detection confirms the link between vegetation and LST and reaffirms the importance of LST as a complementary source of data to NDVI, (Van Leeuwen et al, 2011). Research has shown that a negative correlation exists between LST and Normalized Difference Vegetation Index (NDVI) which has for a long time been used by scientists as a measure and indicator of vegetation cover and plant vigour. Unchecked and unplanned land use leads to decrease in vegetation cover hence the negative correlation.

Since the mid-70s, concerns over the influence of land surface processes on climate, especially land cover change occasioned by human settlement, have dominated climate change research studies, (Pielke Sr et al, 2003; Marland et al, 2004; Pitman et al, 2005). The effects of land cover change on albedo as a result of surface-atmosphere energy exchanges, terrestrial ecosystems as sources of carbon and as carbon sinks, contribution of local evapotranspiration to the water cycle, all as a function of land cover are just but a few of the studies that have been carried out in an effort to understand the link between land surface changes and climatic changes, (Lambin et al, 2003). This study aims to investigate the land cover, vegetation and Land Surface Temperature (LST) change trends, inter-relationships if any and their impacts in a study area within the Mara ecosystem using a Remote Sensing-based approach

1.2. Study Area

The study area is located in South-western Kenya and straddles Narok and Trans Mara districts in Rift Valley Province. It was selected with a view to encompass major towns and trading centres (urban centres) in close proximity and directly connected to the Maasai Mara National Reserve (MMNR) via the roads network. The ecological responses observed within the MMNR are as a result of both internal and external forcings, the study area was thus extended outward from the protected area boundary. The study area therefore 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. It is approximately 6466 Km^2.

Figure 1: Study Area



Average annual rainfall in the region ranges from 500 to 1800 mm per year and average temperatures range between a maximum of 28°C and 8°C. It has varied habitats including grasslands, riverine forests, scrub and shrubs, acacia woodland, non-deciduous thicket and boulder strewn escarpment. There are approximately 2.5 million large herbivores and smaller species believed to inhabit it and the Maasai Mara National Reserve (MMNR) which is a protected area occupies approximately 25% of the Mara, (FAO, 2010). The regions abounding the Maasai Mara National Reserve (MMNR) are pastoral and agricultural lands under two main land tenures; Group ranches and Individual land holdings. 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 in-migration 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.

2 DATA AND METHODS

2.1. Data

The study involved data acquisition, processing, analysis and interpretation activities. The years of study selected were 1985, 1995 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 (NIR), Bands 5 and 7 in the reflective Short wave Infrared (SWIR) and Band 6 is in the emissive thermal Infrared (TIR) 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, 2003 and 2010. The spatial resolution of LANDSAT imagery and the fact that it is multispectral makes it a suitable source of data for environmental and climate studies since various band combinations provide information on the land surface and its properties. The software used in the study include; ERDAS Imagine 9.1, ArcGIS 10, ENVI and IBM SPSS Statistics.

Table I: 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 (ETM)	15	0.52-0.90	16

The data acquired for the study is as outlined in *Table 2* below. Scanned topographical maps were also acquired from Survey of Kenya (SOK) and were used to digitize and extract the analysis area.

Table II: 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

2.2. Methods

Land Surface Temperature (LST or T_s) 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, Equation [1], then applying the LANDSAT specific estimate of the Planck curve to the DNs, Equation [2], (Chander and Markham, 2003).

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

Where:

L_λ – At-sensor spectral radiance in W/ (m^2.sr.μm)
DN - Quantized calibrated pixel value in DNs
QCALMIN - Minimum quantized calibrated pixel value
QCALMAX - Maximum quantized calibrated value
LMAX- Spectral radiance scaled to Q_{calmax}
LMIN – Spectral radiance scaled to Q_{calmin}

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L} + 1\right)} \qquad [2]$$

Where:

T – Effective at-satellite temperature in Kelvin
K_1 - Calibration constant 1
K_2 - Calibration constant 2
L - Spectral radiance in watts/(meter squared * ster* m)

Table III: LANDSAT Specific constants

SENSOR	**K1** (watts/(m^2sterμm))	**K2** (Kelvin)

LANDSAT TM	**607.76**	**1260.56**
LANDSAT ETM	**666.09**	**1282.71**

NDVI was derived from TM Band 3 and TM Band 4 using Equation [3] below which was implemented in ENVI Band Math.

$NDVI=(NIR-Red)(NIR+Red)$ **[3]**

Where:

NIR – Near Infrared TM Band 4 reflectance

Red – Visible TM Band 3 reflectance

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 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 shown in Table IV. Visual interpretation using shape and texture and further aided by the LST and NDVI images were also used. 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.

Table IV: False Colour Composites used in feature identification

BANDS	LAND COVER TYPE	COLOUR
4,3,2	Water	Blue
	Crops and Sparse Vegetation	Pinkish
	Forests and Wetland Vegetation	Dark Red
	Bare Earth	White to Light Gray
4,5,1	Vegetation	Red to Orange
	Bare Earth	Green
	Recently cut areas	Bright Blue
	New Vegetation Growth	Reddish

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 historical images and compared against the classified image points. The results of the accuracy assessment are shown in table V.

Table V: Accuracy Assessment results

YEAR	CLASS NAME	PRODUCER'S ACCURACY %	USER'S ACCURACY

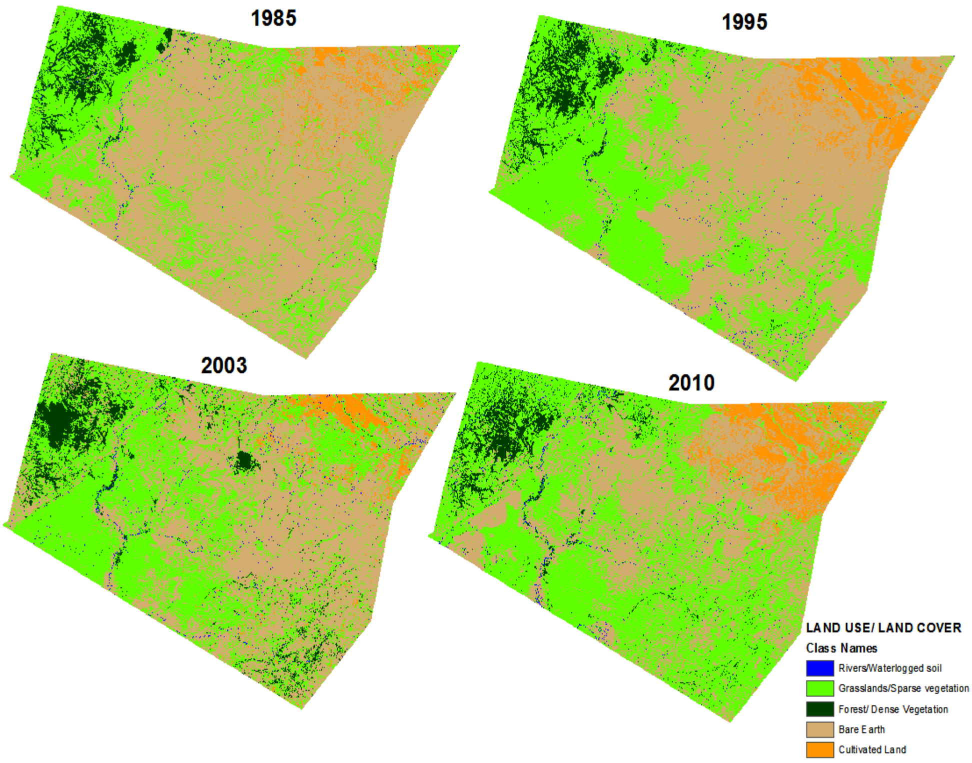
			%
1985	Water	83.33	83.33
	Forest/ Dense vegetation	87.50	77.70
	Grasslands/ Sparse vegetation	66.67	50.00
	Bare Earth	75.00	90.00
	Cultivated Land	83.33	71.43
	Overall Accuracy %	**78**	
1995	Water	81.82	56.25
	Forest/ Dense vegetation	46.15	54.55
	Grasslands/ Sparse vegetation	52.94	81.82
	Bare Earth	61.90	81.25
	Cultivated Land	92.86	59.09
	Overall Accuracy %	**65.79**	
2003	Water	87.50	70.00
	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	Water	88.89	72.73
	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. The RGB composites were 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.

3 RESULTS, ANALYSIS AND DISCUSSION

Land Use/ Land Cover (LULC) maps for 1985, 1995, 2003 and 2010 are shown in *Figure 3.*

Figure 2: Land Use/ Land Cover Maps



The LULC maps show a progressive increase in land under cultivation or agriculture 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 may be as a result of the above normal precipitation received in the study area in the month of January 2003, *See Table VI*. Visual inspection of the Land Use/ Land Cover maps also indicates a progressive increase in grasslands or sparse vegetation and a decrease in bare earth. This may be as a result of increased precipitation in 2003 and 2010.

Table VI: Meteorological data

YEAR	MONTH	Precipitation	Max.	Min. Temp	Diurnal Range
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	38.1	25.4	9.7	15.7

Figure 4 shows the specific Land Use/ Land Cover changes while *Figure 5* is a graph showing the land cover changes by acreage. 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: Land cover change maps

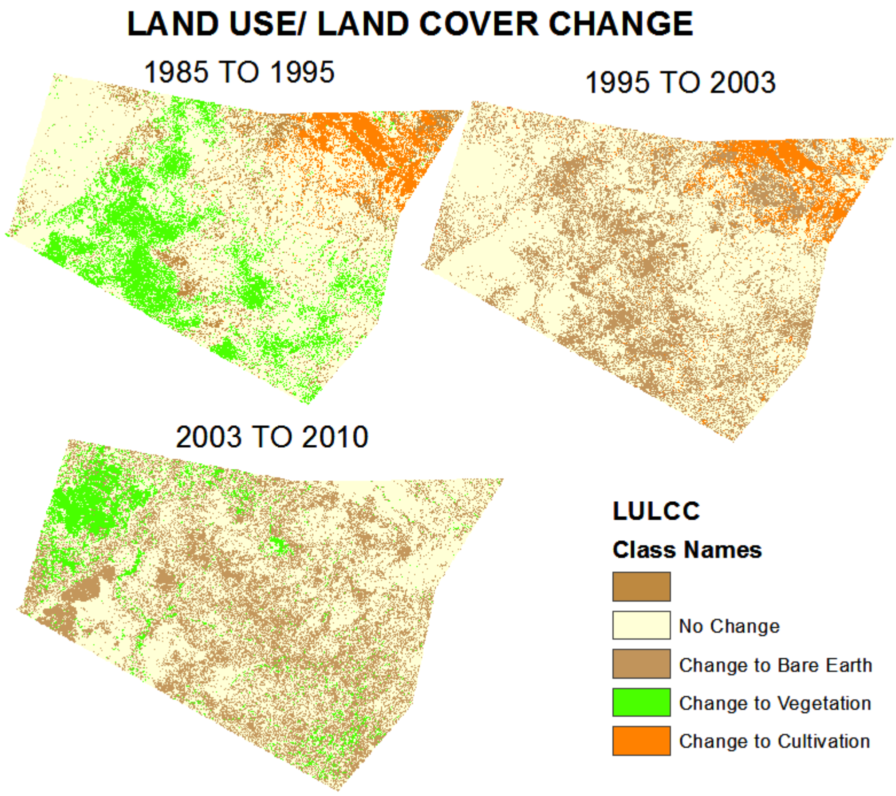
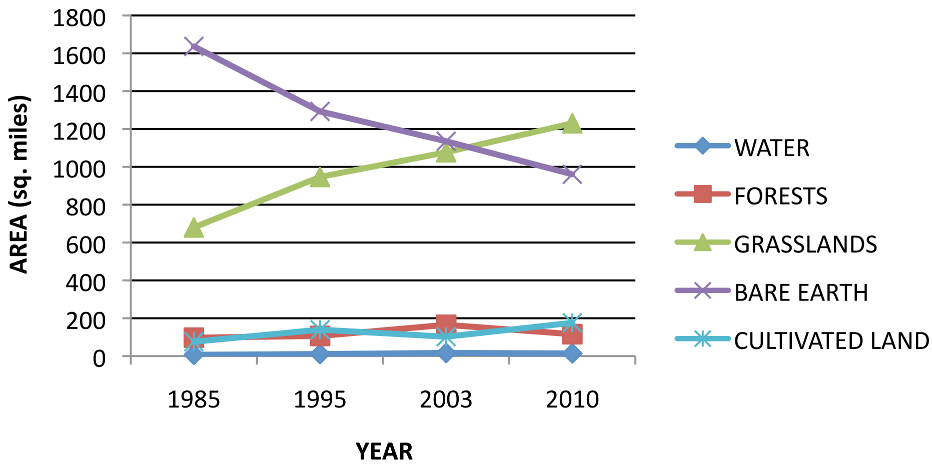
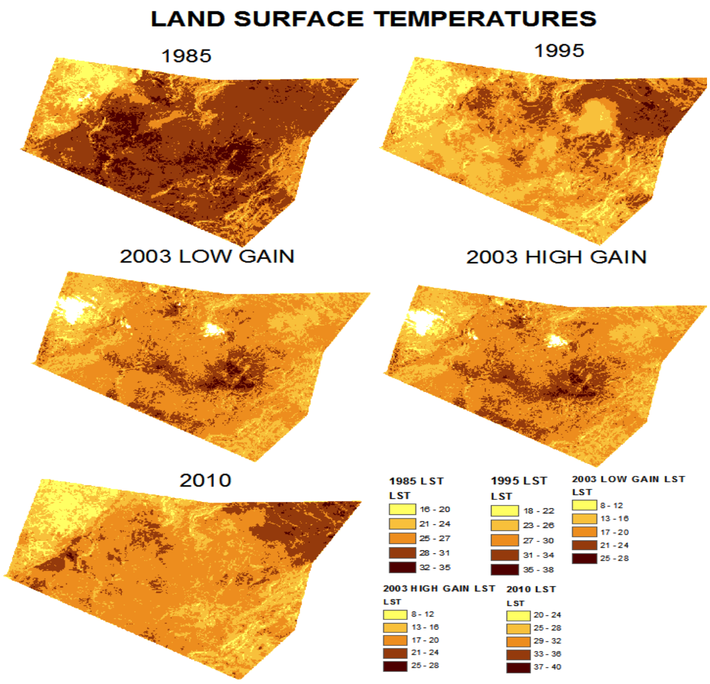


Figure 4: Graph of Land cover changes by acreage



Land Surface Temperature (LST) maps were generated for each of the years of study as depicted in *Figure 6*.

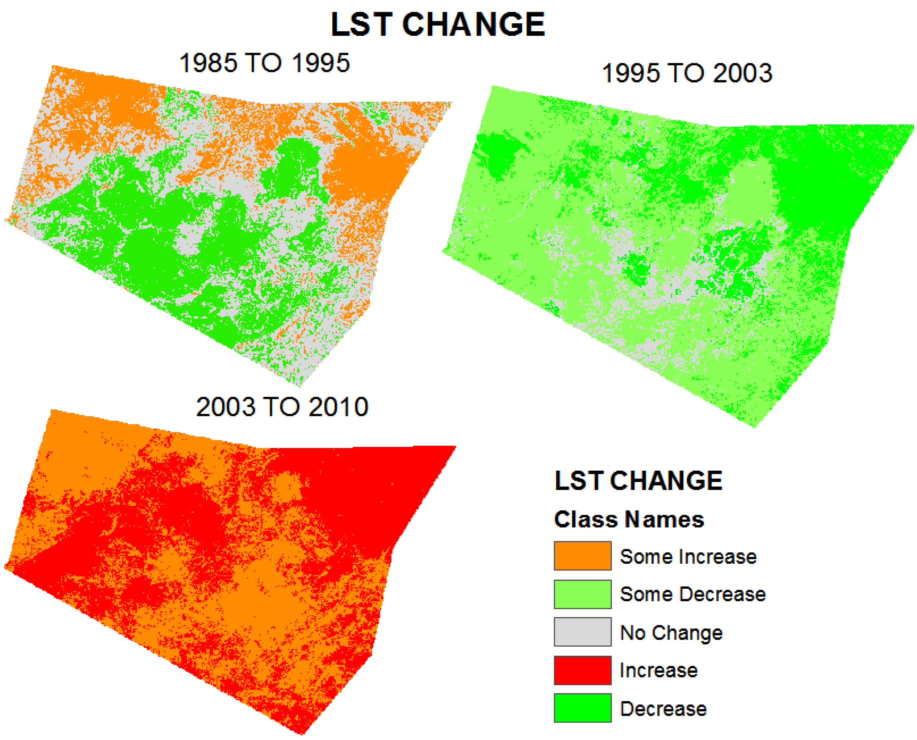
Figure 5: Land Surface Temperature trends



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.

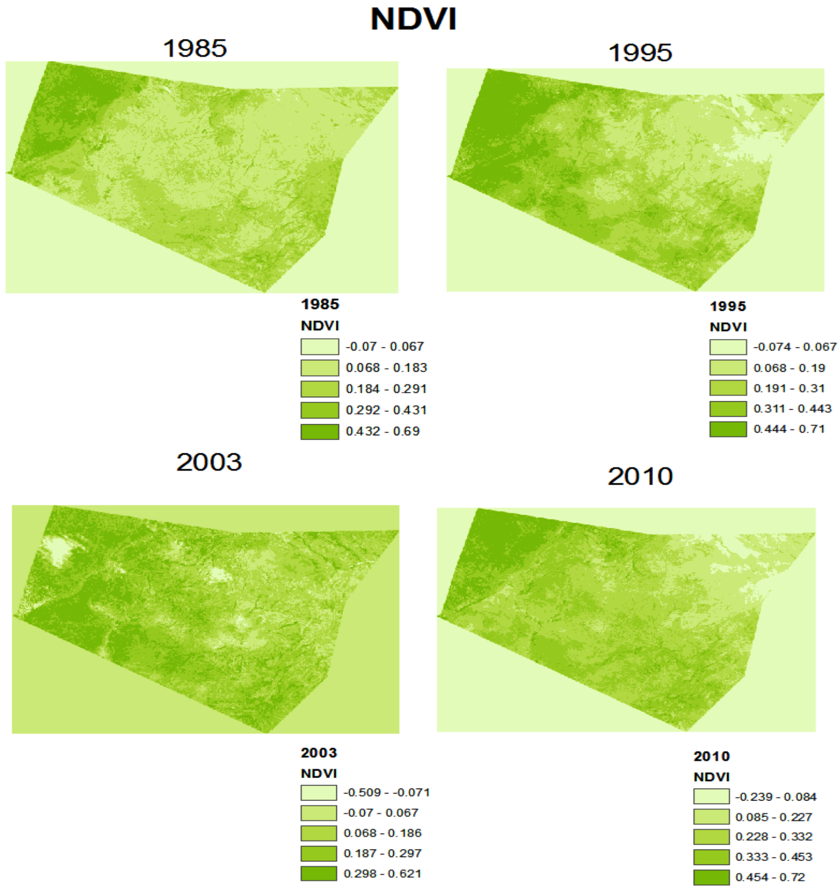
LST change maps, *Figure 7,* were generated in order to gain further insight in to the nature of LST change in the epochs of study over the study area. They indicate that most of the study area experienced a temperature decrease between the 1985 and 1995 LST images. However, there was some increase in temperature especially in the areas where there was Land Use/ Land Cover conversion to Bare Earth or Cultivated Land, *See Figures 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.

Figure 6: Land Surface Temperature change trends



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 highest NDVI values were in the areas under forest or dense vegetation cover while the least NDVI values occurred in areas under the Water class.

Figure 7: NDVI Trends



NDVI change evaluation for each year of study was carried out and maps depicting the changes between the epochs generated, *Figure 8*. 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. 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 Trends

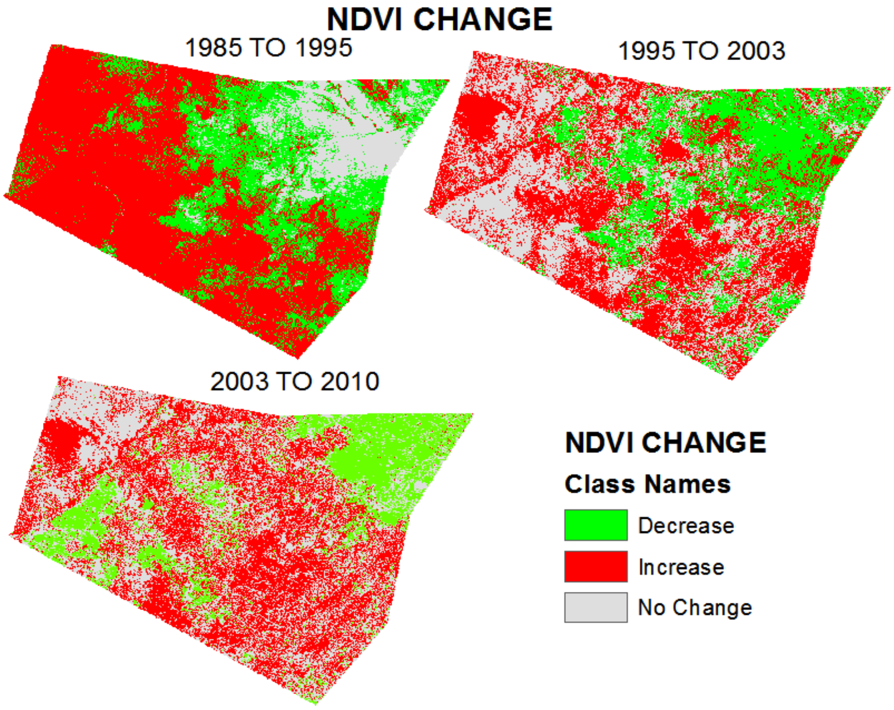
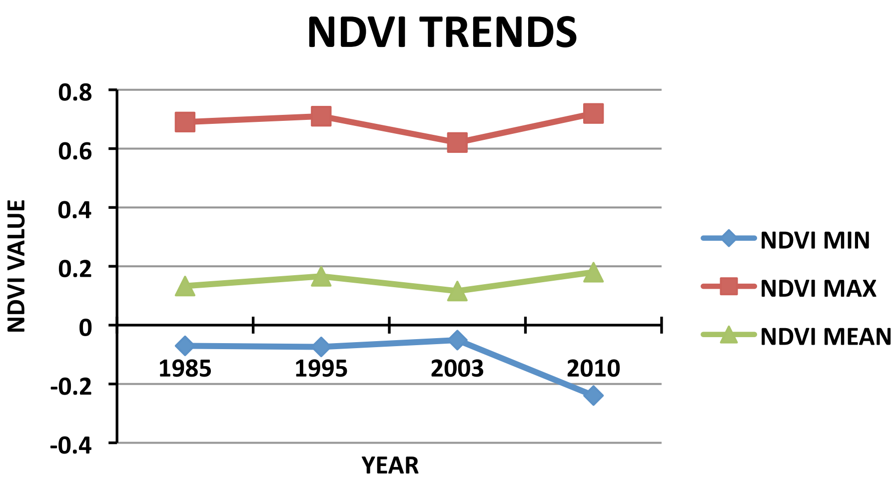


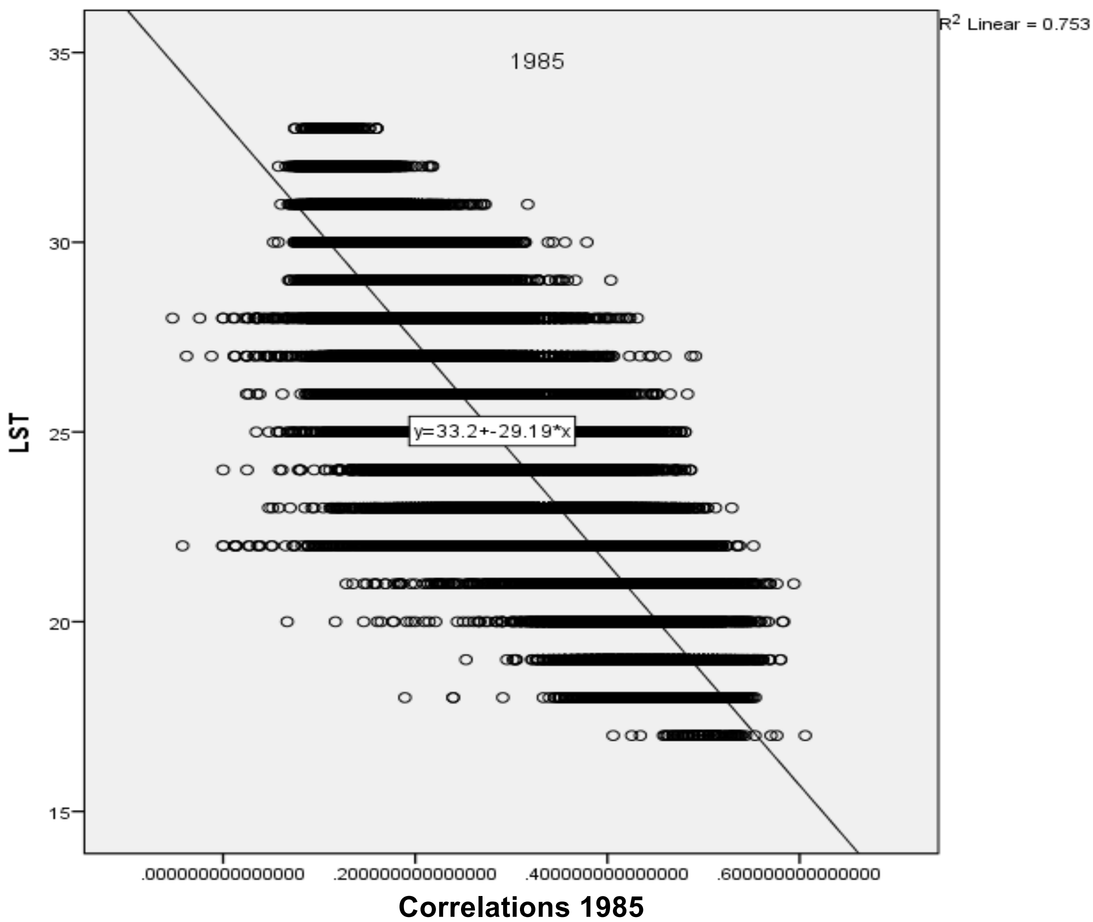
Figure 9 is a summary of the NDVI change trends and type.

Figure 9: Graph of NDVI change trends



The relationship between LST and NDVI was investigated in this study by carrying out correlation analysis of 149669 randomly selected points in all land cover classes in each epoch. The expected negatively correlated relationship between LST and NDVI appears to hold for all land covers in each epoch. LST and NDVI for 1985 and 1995 are highly negatively correlated and strongly associated, *See Figures 11 and 12.* Correlation analysis for 2003 and 2010 show a weak correlation, *See Figures 13 and 14*. The LST and NDVI patterns for 2003 and 2010 may be attributed to among other factors land cover and albedo. Studies linking NDVI, temperature and albedo in drought prone areas indicate that a decrease in NDVI results in an increase in albedo slightly earlier than the plant cover changes and increase in albedo results in a decrease in temperature. This appears to be the case for the study area in 2003 and 2010.

Figure 10: Scatter plot of LST against NDVI for 1985

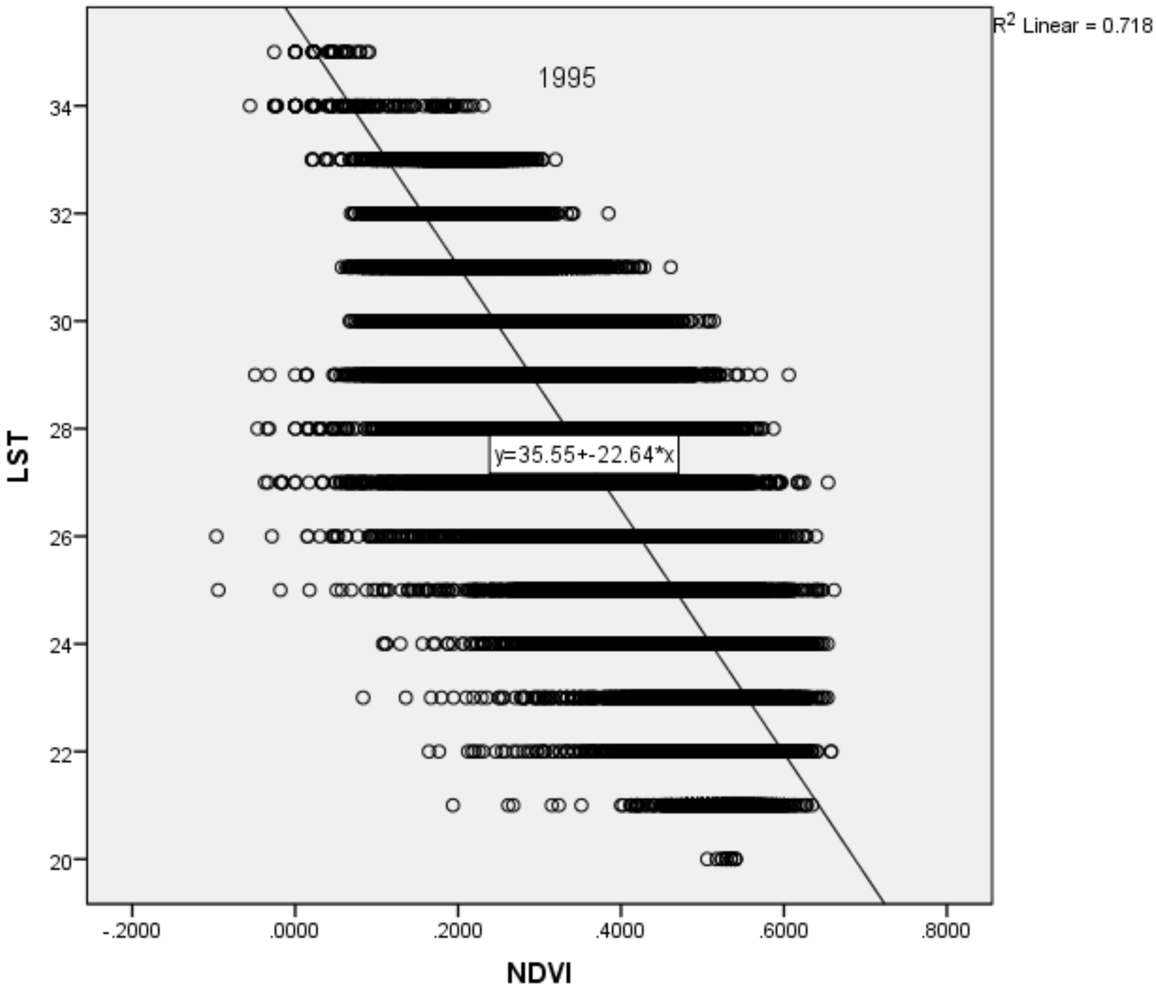


	LST	NDVI

LST	Pearson Correlation	1	-.868**
	Sig. (2-tailed)		.000
	N	149669	149669
NDVI	Pearson Correlation	-.868**	1
	Sig. (2-tailed)	.000	
	N	149669	149669

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 11: Scatter plot of LST against NDVI for 1995

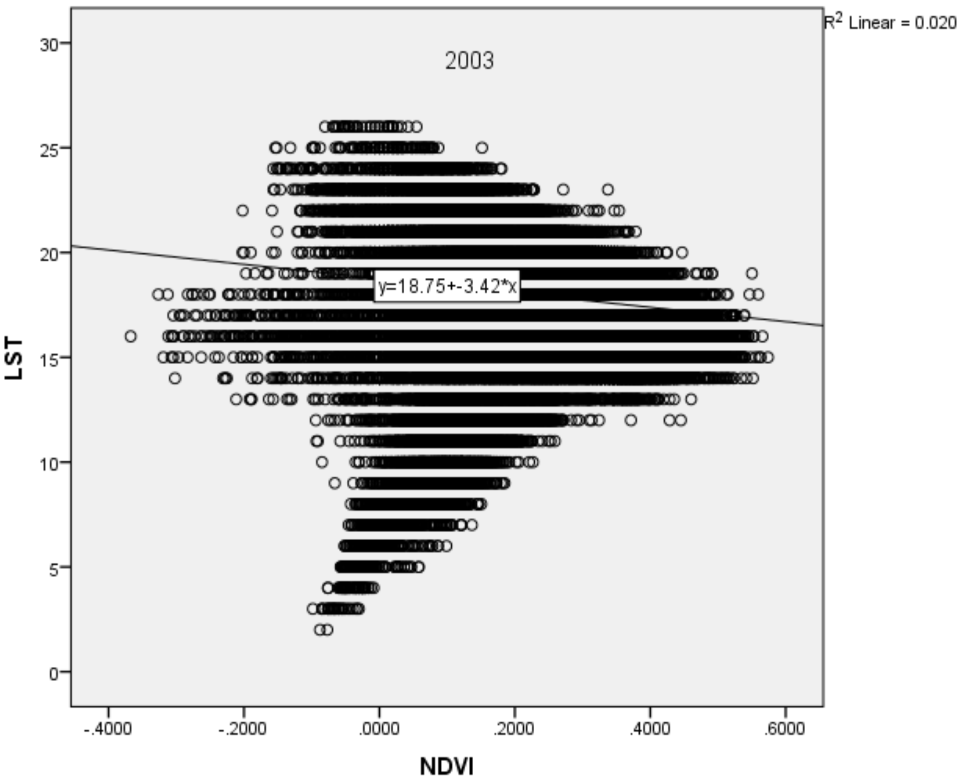


Correlations 1995

		NDVI	LST
NDVI	Pearson Correlation	1	-.847**
	Sig. (2-tailed)		.000
	N	149669	149669
LST	Pearson Correlation	-.847**	1
	Sig. (2-tailed)	.000	
	N	149669	149669

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 12: Scatter plot of LST against NDVI for 2003

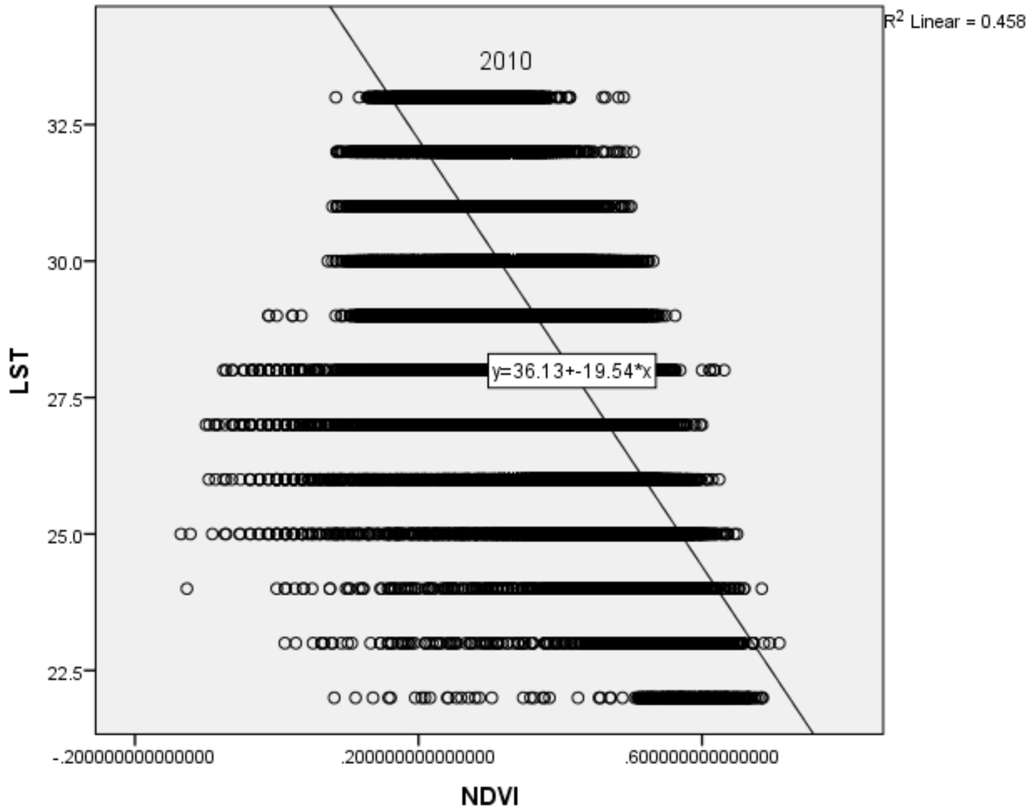


Correlations 2003

		LST	NDVI
LST	Pearson Correlation	1	-.140**
	Sig. (2-tailed)		.000
	N	149668	149668
NDVI	Pearson Correlation	-.140**	1
	Sig. (2-tailed)	.000	
	N	149668	149669

**. Correlation is significant at the 0.01 level (2-tailed).

Figure 13: Scatter plot of LST against NDVI for 2010



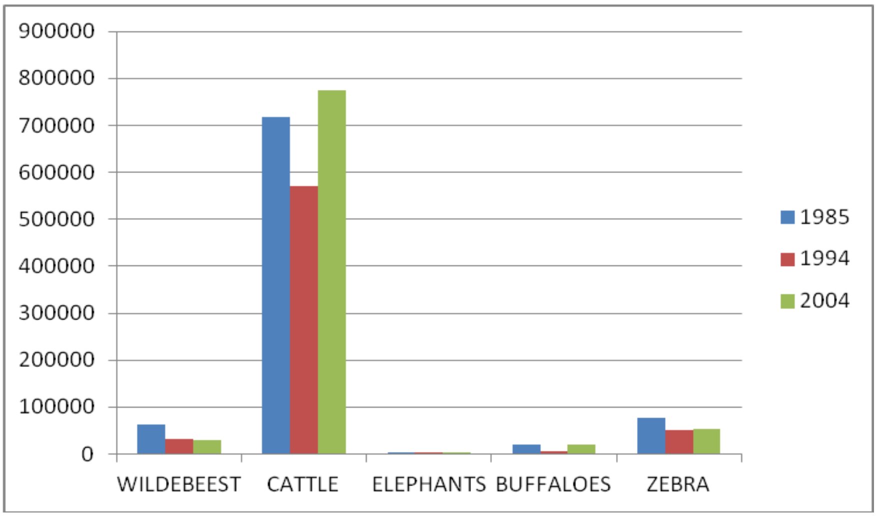
Correlations 2010

		LST	NDVI
LST	Pearson Correlation	1	-.676**
	Sig. (2-tailed)		.000
	N	149669	149669
NDVI	Pearson Correlation	-.676**	1
	Sig. (2-tailed)	.000	
	N	149669	149669

**. Correlation is significant at the 0.01 level (2-tailed).

Wildlife and livestock counts data obtained from DRSRS lacked the spatial component, thus 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.

Figure 14: Graph of wildlife population



The effects of drought on both livestock and wildlife in the Maasai Mara are evident in the Animal counts data. Significant decrease in the population of all wildlife species and livestock sampled in 1994 in the Mara may have been the first sign of the widespread 1995/96 drought. The 2010 drought also devastated the animal populations leading to an overall decrease in wildlife and livestock in the Mara as at the 2011 count, with the exception of Zebras and Wildebeests.

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*

4 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 with increased area of land under cultivation. Changes on the land surface have not only affected the human population but also the wildlife population. This study therefore demonstrates the effect and trends of land surface change 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 demonstrates effects on wildlife and livestock in the area that can be attributed in part to land surface changes.

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. This study incorporated meteorological 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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