Developing Country Studies
ISSN 2224-607X (Paper) ISSN 2225-0565 (Online)
Vol.5, No.8, 2015

The Extent of Spatial Temporal Variations in Land Use and its Implications on Forest Ecosystems: A Case of Nandi Hills Forests Kenya

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Abstract

Land cover change is probably the most exceptional form of global change in environment since it occurs at temporal and spatial scales directly applicable to our daily survival. The changes in land use, particularly when joined with climate change and variability, could impact on ecosystems and natural resources in complex ways. Over an extended period, almost 1.1 million km^2 of woodland and forest and 5.4 million km^2 of pasture and grassland have been transformed to other utilities in the recent centuries. According to Foley *et al.*, (2005), during this period, cropland has expanded by 10 million km^2. Changing land use patterns or transformations, motivated by a multiplicity of socio-economic causes, often lead to land cover changes that affects biodiversity, global temperatures, greenhouse gases accumulation and emissions, water budgets and other bio-geophysiochemical processes (Meyer & Turner, 1994). This paper sought to determine the extent to which Spatial Temporal Variations have impacted on the Forest Ecosystem in Kenya. The study employed both qualitative and quantitative methods and GIS and remote sensing was used for data collection. Results from the GIS data indicated a decrease in forest cover of 9.219 km^2 (17.95%). This is an implication of changing land use practices from forests to human settlements and agriculture as emergent land uses/land practices.

Keywords: Extent, Spatial Temporal Variations, Land Use, Implications, Forest Ecosystems, Nandi Hills Forests.

1. Introduction

The term 'temporal' in spatial analysis has a variety of meanings, each of which requires a diverse approach for the provision of a supporting analysis. Lately, work in spatio-temporal information has been about versioning transaction (Halls, 1995). Some researchers use GIS in search of an understanding of item relationships across time, past, present and future; and their focus is how real-world attributes interact in space and time (Fisher & Unwin, 2005). Others have tried to formalize a conjecture of spatio-temporal thinking working from a theoretical construct (Qian *et al.,* 1997; Claramunt *et al.,* 1997), while Worboys (1998) uses a predicament directed approach. It is important that anyone who is involved in attempting to develop and environmental education programme towards sustainable management be *au fait* with such techniques and the data that are generated and are readily available from such approaches.

1.1 GIS, Remote Sensing and Spatial Temporal Changes

Geographic Information System (GIS) is computer-based software, hardware and systems designed to allow users to assemble, administer, scrutinize and envisage spatially referenced data and associated qualities (Cowen, 1998). A blend of GIS and Remote Sensing methods enhances the pace at which immense amounts of spatial and temporal data are analysed and broken down for faster and informed making of decisions.

Vogt *et al.,* (1997), asserts that the extensive use of Geographic Information System (GIS) and Remote Sensing mechanics has permitted researchers and managers to take a wider view of ecological processes and patterns. The techniques of remote-sensing have been applied successfully for forest monitoring and mapping and have made it possible to cover great areas consistently and cheaply (Coppin *et al.,* 2004). The ever varying composition and structure of landscape can be easily substantiated by using GIS together with remotely sensed data. When these tools for spatial information are put together with statistical models, planners and managers have a means for investigating the impacts of different management practices on trend and process (Vogt *et al.,* 1997).

Latest technologies in the remote sensing field address procedural challenges such as the parameter structure, height, density and make-up of forests. Airborne radiance detection and changes using lasers can evince highly precise approximations of tree cover and also height; it can even evaluate the outline of individual trees. Ranging

Space-borne radar has brilliant ways to arrive at approximates of biomass and stand volume and can go through clouds, defeating some of the demerits of ocular satellite sensors. Latest spectral sensing systems can compute a wide selection of land and vegetation distinctiveness, making it probable to evaluate a range of forest features – helping to improve mapping of forest cover, pests and diseases (Hestira, *et al.,* 2008).

GIS offers a tool for bringing together distinct themes of information and showing the physical, social and biological dimensions to describe and map ecosystems. Fresh progress in GIS technology comprises the capability to amass and manage bulky data sets and to execute spatial and statistical analyses. GIS can provide contribution to both stationary and dynamic ecological models. For instance, a fixed replica may be used to make erosion approximations based on soil category and topography characteristics, whereas a complex GIS model could be used to symbolize a spatial landscape at varying time durations (Stow, 1993).

At the global stage, GIS and global navigation satellite systems gives forest managers increasingly defined information on the character and the situation of forest resources, which can be processed rapidly. Fresh modelling and image software linking GIS and remote sensing provides high-class digital models of future forest landscapes to depict changes that might be as a result of natural mechanisms, such as climate variations, or human involvement, such as thinning, planting, and harvesting. Such creations make possible the engagement of communities in forest resource management and decision making (Sheppard & Meitner, 2005). Baltzer et al., (2007) point out that, further than forest management functions, remote sensing methods have the potential to provide data to the scientific society about forest conditions, central to the comprehension of sustainable land use.

Change evaluation is the practice of spotting out discrepancies in the nature of an object or event by studying it at different moments (Singh, 1989). Detection of Change is an important process in managing resources and development of urban areas since it offers a quantitative study of the distribution of spatial structures and the population in interest. The following are aspects of detecting change which are vital in natural resources monitoring (Macleod & Congation, 1998): Detecting if change has happened, Identification of the nature of change, Measuring the extent of change and Assessing the nature and pattern of the change.

The base-point of using remote sensing information for detecting change is that land cover leads to changes in values of radiance that can be remotely sensed (Turker, 2000). Methods of performing change detection with satellite data have become ubiquitous as a result of increased flexibility in manipulating data and the increasing power of computers and a large range of digital change detection methods have been developed over the last few decades. Singh (1989) summarizes eleven different change detection formulas that were found to be stored in the literature by the year 1995. These include:

i. Temporal change delineation.
ii. Post classification and delta comparisons.
iii. Multidimensional feature space analysis.
iv. Composite scrutiny.
v. Differencing of images.
vi. Linear data transformation.
vii. Vector change analysis.
viii. Regression of imagery.
ix. Temporal biomass index
x. Subtraction of background
xi. Rationing of images

In some cases, land cover change may result to socio-economic and environmental impacts (Bradley, & Mustard, 2005). Hence data on spatial temporal changes are of significance to planners in investigating the results of land use variations on any particular area. Such data are of benefit in administration of resources and to agencies that prepare and assess land use trends in modelling and forecasting future changes.

A number of studies have shown that LANDSAT Mapper has been sufficient for general synoptic coverage of huge areas, which decreases the need for costly and intense land surface surveys carried out for confirmation of data (Lulla, 1983). Satellite imagery can also offer more regular data collection than aerial photographs which, however, may present more geometrically precise maps (Paulsson, 1992).

1.2 Land Use Change

The rate, extent and spatial attainment of human conversion and change of the earth's land surface can be exceptional (Lambin *et al.,* 2001), however, some regions around the world are presently undergoing speedy, wide-raging alterations in land cover (Mas, 2004; Coppin *et al.,* 2004). Land cover adjustment has been known as a vital driver of universal environmental change (Petit, 2001). According to Foody (2001), change in land cover is a chief component of global change with a superior effect than that of climate change. Causes of such fluxes are natural as well as anthropogenic or a combination of the two. Escalating land use changes at the price of rapid rates of deforestation in the tropics are leading to drastic alterations in the chemical, physical, and biological distinctiveness of ecosystems in the tropics. Land use changes lessen the magnitude of natural habitats for instance forests and their structural assortments resulting in manifold ecological impacts. The ecological impacts of large scale forest decrease include loss of biodiversity (Shukla, 1990), soil conditions degradation (Buschbacher, Hull & Serano, 1988) and balance changes of greenhouse gases within the biosphere, which may in turn accelerate climate change (Dale *et al.,* 2001).

As a result of increasing appreciation of the impacts of global land cover change, the presence of timely and consistent Land Use Land Cover (LULC) information is becoming much significant than ever in sustaining decision making mechanisms at different levels, both within and across countries (Foley *et al.,* 2005). Increasing global environmental change and an added prominence on sustainable development (Bradley, & Mustard, 2005; Leitao & Ahren, 2002) suggest that spatial data will play a principal role in altering existing environmental patterns through relevant policy formulation and implementation. Jansen and Gregorio (2002) submit that land cover data forms a central base for a number of applications; including rangeland and forest monitoring, figures for investment and planning, conservation of biodiversity, desertification monitoring and climate change assessment.

Although spatial data are significant in the process of managing resources and decision making, there is still no widespread land cover information at global and local scales (Chandra, 2005). The situation is graver in developing countries where there is inadequacy and unavailability of data due to the time consuming and costly nature of processing these data (Richard & Haack, 1996).

1.3 Land Use and Land Cover

Land use and land cover are routinely used interchangeably in many change detection studies (Seto *et al.,* 2002). Land use is used to refer to the human utilization of the land, or the instant actions modifying land cover (Bradley & Mustard, 2005; Meyer & Turner, 1992). Land use can consist of mixed land covers; and it is conceptual model constituting a merger of social, cultural, economic and strategy factors which have diminutive physical magnitude with the respect to reflectance asset, and hence has restricted relationship to remote sensing (Rogan & Treitz, 2004).

Ecosystems are continuously transforming; leading to adjustments in the surface constituent of vegetation cover and substantive spatial progress of a vegetation bodies over time (Coppin *et al*., 2004).

1.4 Sources and Effects of Change

The pace of change can either be remarkable as exemplified by fire; or ongoing, such as biomass amassing (Coppin *et al.,* 2004). Correspondingly, land cover changes are usually viewed as non-constant in space, leading to compound landscape mosaics and mixtures of cover modes (Mertens & Lambin, 2000). Land cover changes are so pervasive that, when collected globally, they extensively affect key structures of the Earth systems (Lambin *et al.,* 2001; Lambin *et al*., 2003). Land cover has a large influence on many crucial environmental processes and as a result any transformation in it can have marked effect on the environment at home to global scales. Anxiety about LULC change came up on research agenda on global environmental alteration several decades ago with the realization that land processes persuades climate. In the 1970s it was largely renowned that land cover change modifies facade albedo and thus causing surface-atmosphere vigor exchange; while in the 1980s, terrestrial ecosystems as sinks of carbon were highlighted (Lambin *et al*., 2001).

It is broadly recognized today that land cover transformation causes soil erosion and amplifies surface run off and flooding, climate change and carbon dioxide concentration (Lambin *et al*., 2003). Land cover variation contributes radically to earth-atmosphere exchanges and loss in biodiversity, it is a foremost factor in sustainable development and human reactions to global change, and its measurement is essential for incorporated modelling and measurement of environmental problems in general (Turner *et al*., 2004). Land cover changes have, for example, important influences on water and climatic systems that impact notably on global biogeochemical movements (Boyd, 2002) and biodiversity loss (Mas, 2004). LULC changes also establish, in part the susceptibility of places and people to economic, climatic or socio-political perturbations (Lambin *et al*., 2003).

1.5 Predicting Change

In order to comprehend and predict the change procedure, one needs to observe and characterize spatial trends of LULC transformations (Petit, 2001). While the study of land cover modification is inclusive of description and classification of land changes, observance of change, and mechanism of motivating forces, the definitive goal of scientists is to construct models that can be used to predict changes and their effects (Xu *et al.,* 2002). As noted before, an assortment of methods of LULC study have been generated and applied, such as remote sensing, GIS, and statistical schemes (Xu *et al.,* 2000).

1.6 Digital Change Detection

Digital change detection pertains to the systematic stages from acquiring images to pre-processing, then classification and finally, change detection. Conventionally, this type of remote sensing started in the early 1960s with feeble analysis of wide-spectral scanner data and digitized aerial images (Lillesand *et al.,* 2004), and since the introduction of Landsat-1 in 1972, image processing has seen remarkable growth to date. The whole development from acquiring data to the final obtaining of the intended information involves assorted steps and every juncture is important as it can have considerable impacts on the ultimate results. Successful carrying out of change detection analysis using the technology of remote sensing requires careful determination of the sensor, environmental attributes and image processing modes (Lu *et al.,* 2003); and a malfunctioning to understand the effects of these parameters can lead to erroneous results.

1.7 Change Detection Methods

Digital adjustment detection involves the quantification of temporal events from multi-date imagery that is commonly acquired by satellite multi-spectral sensors and detectors (Coppin *et al*., 2004). In general, change detection pertains to the appliance of multi-temporal data information to substantially analyse the temporal impacts of the events (Lu *et al*., 2003).

Preceding literature has revealed that image variation, major component analysis and classification relations are the most widespread methods used for terrestrial change detection. Change detection modes have been classified generally into image geometric, alteration and classification. The algebra class includes differencing of images, image waning, image rotating, plant life index differencing, transformation vector analysis and backdrop subtraction. These methods involve calculation of two or more images of about similar radiometric characteristics; where subtraction led to both positive and negative standards in areas of change and absolute values in areas of no little variation (Green *et al.,* 1998).

The change detection methods have been outlined as:

1.7.1 Image Differencing

In this technique, spatially referenced images obtained at varying times are subtracted to create a lasting image which stands for the change between dates (Mas, 2004).

1.7.2 Vegetation Index Differencing

This technique involves eliminating parts of images which have been transformed to the various vegetation indices for varying dates in the study.

1.7.3 Principal Components Analysis (PCA)

PCA comprises of two referenced images to form a new multiband image consisting of bands from date to date (Lillesand *et al*., 2004).

1.7.4 Post-Classification Comparison

Post-categorization analysis is common of these techniques and it comprises of autonomously produced spectral results from various ends of time intervals, followed by a segment by segment relation to detect land cover change (Coppin et al., 2004).

1.8 Global Trends

Humans have transformed massive parcels of the Earth's surface: 10 to 15% presently is conquered by urban-industrial and agriculture areas (Vitousek *et al.,* 1997).

Climate inconsistencies have transformed land use practices in different parts of the world, highlighting differences in societal susceptibility and pliability. Research on land use and climate change requires the development of new models connecting the geophysics of climate with the socioeconomic drivers of land use (IPCC, 2007). Given a scientific understanding of the progression of land use change, the impacts of different land use decisions, and how they will be convoluted by a changing climate and increasing climate variability becomes an area of concern for research (IPCC, 2000).

Other than anthropogenic factors, natural phenomena also affect or alter land cover. Natural events such as weather and climatic fluctuations, epitomized in flooding, wild fires and ecosystem changes, may also pioneer adjustments on land cover (Honnay *et al.,* 2002). Globally, however, land cover is altered primarily via anthropogenic uses such as: suburban construction and development, agriculture and livestock raising, forest resources harvesting and management.

1.8.1 Conditions and Trends in Kenya

The area of land in Kenya is about 582,646 km^2 with roughly 80% being semi-arid and arid lands. These areas receive less than 700 mm of rain each year. The country is further ramified into agro-climatic zones by the use of a humidity indicator (Sombroek *et al.,* 1982). This index utilized is rainfall done annually expressed as a percentage of possible evaporation. Some areas with less than 50% index have a high agricultural prospective and are classified into three zones. These are about 12% of Kenya's terrestrial area. Partially-humid to dry regions have humidity index of less than fifty per cent. These are grouped into zones of 1 to 4. They are commonly known as savannah lands and are about 88% of the land area of Kenya (de Leeuw *et al*., 1991).

Approximately eighty percent of Kenya's (about 40 million) population is therefore saturated in only (10%) ten per cent of the land that is moderate and high-productive agricultural land surface (Rutten, 1992). Kenya's economy is mainly agricultural driven and over 70% of Kenyans are involved in some subsistence and/or profit-making agricultural practices. Hence, a good amount of the country's land is being used for agricultural activity relative to other countries. The quantity and quality of land at hand for rain-based agriculture is quite low. And the allocation of land between land owners is highly tampered with (Emerton *et al.,* 2001).

1.9 Land Use Change and Spatial Temporal Variations in Kenya

In Kenya, land has varied meanings according to diverse people: To pastoralists and farmers land is property to be owned and a basis of livelihood and accessing it is a major concern (Orodho, 1997). The influential deem land as a marketable item from which to make profits via market conjecture mechanisms (Ojani & Ogendo, 1973). Often administrators and politicians view land as a valuable entity whose boundaries echo a social, political and cultural identity (Ntsebeza, 2005). To agencies involved in development land offers goods and services needed for people's wellbeing and opulence. These views roughly decode into different, and habitually competing, land needs in Kenya. No sole definition can sufficiently reflect the differing perceptions.

The areas under forests in Kenya are about 2.3 million hectares of which 1.60 million hectares are gazetted. The non-gazetted land area which is about 0.76 million hectares is ramified into about three hundred units of forests. Forty percent of the units lie on about 100 hectares. The tight canopy of native and alien forest species lies on approximately 1.20 million hectares; plantations stretch to about 0.16 million hectares (Government of Kenya, 1999a). Congested canopy forests without the gazetted forest reserves extends to about 0.18 million hectares. The Kenyan government has anticipated a further 0.5 million hectares through gazettement and afforestation.

The cover of Kenyan forests has differed across space and time. In 1897 the only officially recognised forest area was the 'Wood Strip of the Akamba' that extends about 2 miles on every side of the railway line in Uganda. The strip was founded on the umbrella of the 'Akamba Forests and Woods Regulations'. By 1932, forty-two different forests had been allocated as government areas of forests which went up to about 1.05 million hectares later in 1940 (IUCN, 1998). During the time of independence documented forests were about 1.8 million hectares that represents 3.5% of the overall area of land. A survey done aerially in the year 2000 evinces that these group of forests have reduced considerably (Kenya Forest Working Group/East African Wildlife Society, 2001). A number of native and exotic forests exist in the highlands of Central Kenya where there is high rainfall, fertile soils and limited human settlements. In the arid and semi-arid regions (ASALs), forests exist in isolated mountain ranges and in thin bands adjacent to rivers.

2 Materials and Methods

The study employed a mixed methodological design which incorporated both qualitative and quantitative methodologies. The sample frame of the study is for persons above 18 years in Nandi County and there was heterogeneity in the population in the sample frame due to variety of issues such as: spacio-topographical exposure to the forests, urbanization, intermarriages, migration, education levels and even economic statuses

To alleviate some of these causes of heterogeneity to the closest achievable extent, the sampling units were hence delimitated based on the administrative boundaries (largely per district and finely per division). All the districts (4 districts) in the Nandi County were sampled. Relevant stakeholders (in the management of the Nandi Forests) other than the mainstream local community were also purposively sampled to obtain data. The desired sample size of households for simple random sampling was obtained from a formula as used by Fisher *et al* (1998) which yielded a sample size of 306 respondents. Oral interview schedules, questionnaires, Digital cameras and review of documented literature were used in data collection.

3 Results

3.1 The Extent of Spatiotemporal Variation in the Study Area from 1994 To 2008

The area under forest decreased between 1994 and 1999 by 8.5149 km^2. However, there were notable gains in forest cover (21.1113 km^2 between 1999 and 2003). The results of this variation are shown in Figure 1 below. The fluctuation in forest cover area denotes spatio-temporal variability in forest cover as a land use.

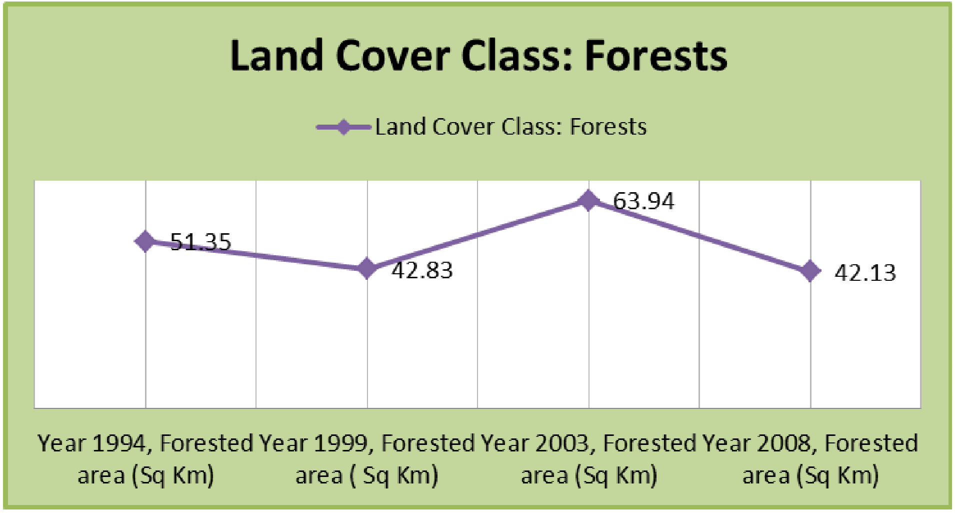

Figure 1: Forest Cover Class Changes

Variations were also noted on shrubs as a land cover. In 1994 for instance, land cover under shrubs was 26.21 km^2 while in 1999 a shrub cover of 37.06 km^2 was registered. This was a variation of 10.8504 km^2 between these years; 1994 and 1999 (see Figure 2).

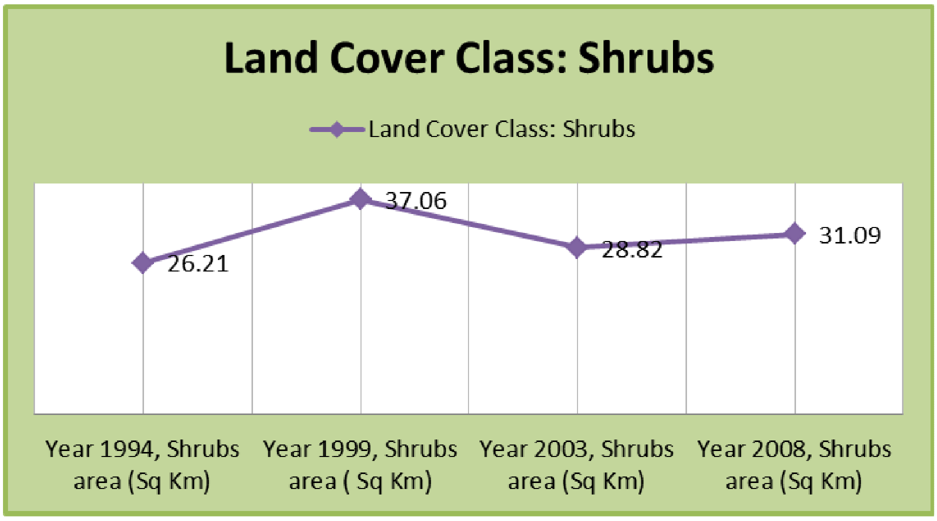

Figure 2: Shrubs Cover Class Changes

Tea farming as a land use registered an upward fluctuation of about 17.05 km^2 between 1994 and 1999. However there was a decrease in tea cover between 1999 and 2003 as shown in figure 4. The subsequent years (2003 and 2004) on the other hand registered a near constant tea cover as shown in Figure 3 below.

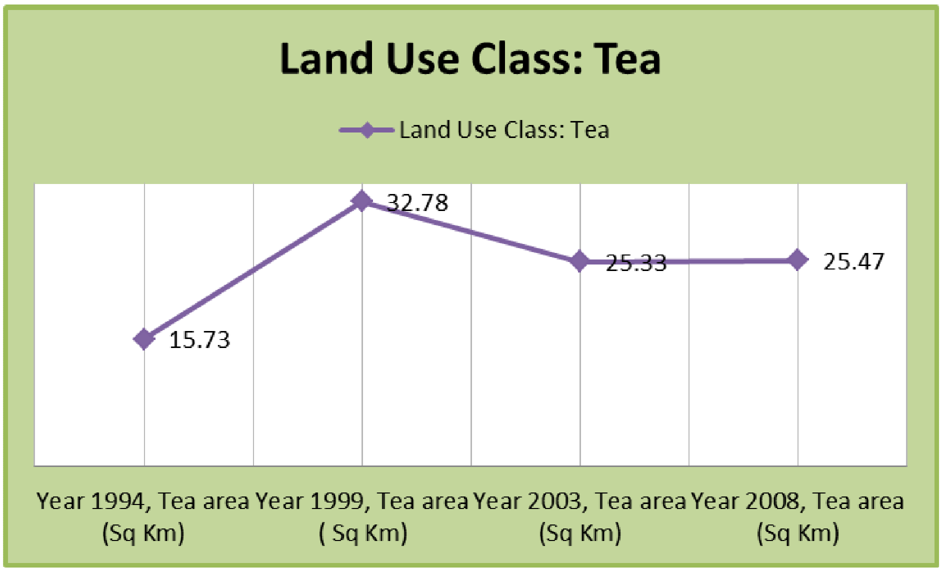

Figure 3: Tea Cover Class Changes

The area under grassland cover showed a near constant area of about 23 km^2 between 1994 and 1999. A decrease of about 6 km^2 was however registered between 1999 and 2003 while an increase of 12.56 km^2 between 2003 was witnessed (see Figure 4).

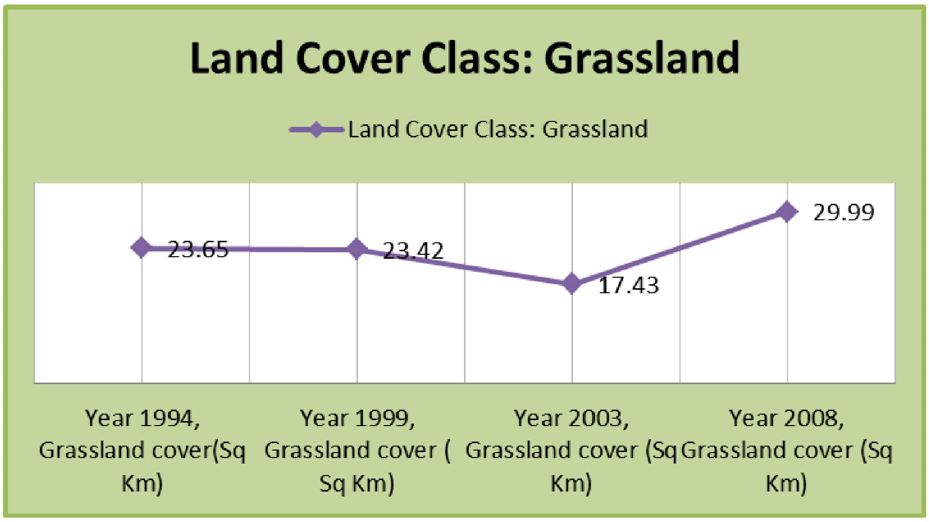

Figure 4: Grassland cover class changes

Bare ground as a land cover class registered 31.16 km^2 in 1994, 12.00 km^2 in 1999, 12.57 km^2 in 2003 and 19.41 km^2 in 2009 (see Figure 5 below).

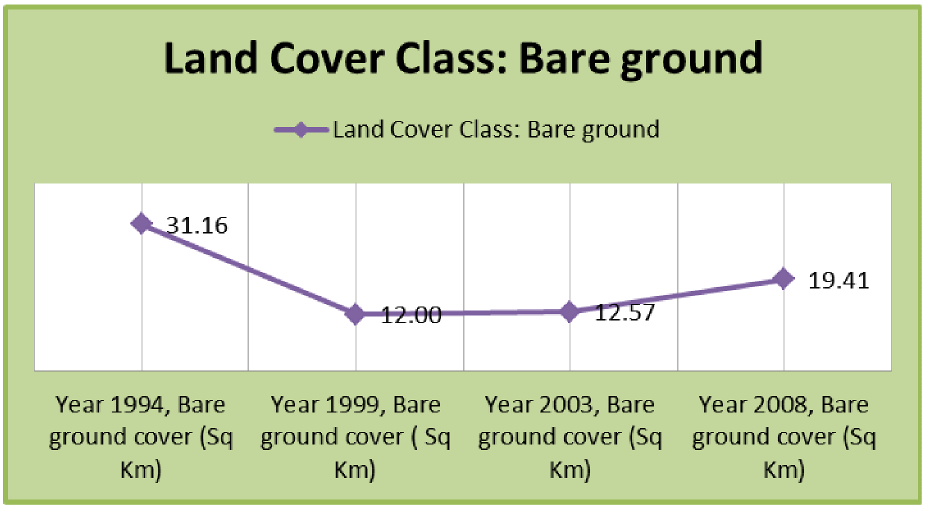

Figure 5: Forest Change 1994 and 2008

4 Discussion

4.1 Extent of Spatiotemporal Variation in Land Use in the Nandi District and the Impact of the Changes

The findings on spatial temporal variations in land use in the forest and the forest catchment areas of the Nandi district as evidenced by Geographic Information Systems (GIS) and Remote Sensing (RS) observations, photography, and a ground truthing survey are discussed here: A comprehensive GIS database for the Nandi District has been generated in this study. This database comprises of the following GIS layers:

- Landsat images of 1994, 1999, 2003 and 2008
- Thematic layers clipped from the Kenya and Nandi District map that include forests, and vegetation.
- Administrative boundary of the Nandi District
- Field photographs

The extent of spatiotemporal variation in land use empirically obtained through triangulation of Remote Sensing (RS), Geographic Information Systems (GIS) data generated from Landsat maps change computations, and observation and ground truth survey of the study area, revealed a number of spatiotemporal variations in land use and land cover over the period considered.

To further understand the extent of spatiotemporal variation in land use, an unsupervised classification of RS data was undertaken. The results indicated the variation that occurred in land cover types such as shrubs, tea and grasslands were positive while there was a reduction in forest cover and bare ground cover, which suggests that there might be serious implications for forests in the Nandi district. On aggregate land areas under shrubs, tea and grasslands areas increased between 1994 and 2008. The nature of the changes in land uses/cover types seem to be in consonance with as the case in other parts of the globe (Geist & Lambin, 2001), but the data indicates that the spatiotemporal variations are a consequence loss of forest cover and conversion of bare ground to agriculture, and human settlement influx in areas not suitable for agriculture.

One cover type, tea increased by 61.95% between 1994 and 2008. The greatest registered upward fluctuation of about 17.05 km^2 was noted between 1994 and 1999. However there was a decrease in tea cover between 1999 and 2003. The change in tea cover levels are believed to have come from the prevailing fall in tea prices in the global market as at that time. Shrubs increased by 18.62% between 1994 and 2008. In 1994 for instance, land cover under shrubs was 21.21 km^2 while in 1999 a shrub cover of 37.06 km^2 was registered. This was a variation of 10.8504 Km^2 between these years. Increases in shrubs as a land cover suggests either a continuous loss of forest cover or encroachment of aridity from loss of forests. The area under grassland cover showed a near constant area of about 23 km^2 between 1994 and 1999. A decrease of about 6 km^2 was however registered between 1999 and 2003 while an increase of 12.56 km^2 between 2003 and 2008 just like shrubs basically exhibiting similar trends.

5 Conclusion

Results from the GIS data indicated a decrease in forest cover of 9.219 km^2 (17.95%). This is an implication of changing land use practices from forests to human settlements and agriculture as emergent land uses/land practices. The fluctuations in forest cover area denote spatiotemporal variability in forest cover as a land use and the data, based on the predetermined classes, clearly showed variations in land use and land cover over time and that the forest cover in Nandi Forests is under considerable threat.

6 Recommendation

In order to address the complex issues of climate change in the Nandi County, a detailed study on climate change adaptation-mitigation synergies ought to be undertaken. The GIS files generated in this study are flexible and can always be updated as a way of checking future state of land use and land cover in the area as well as the future trend of land use and land cover changes. Therefore further studies should be undertaken with an aim of frequently updating the LULC change and disseminating the change detection patterns to the local community.

References

Balzter, H., Luckman A, Skinner, I., Rowland, C., & Dawson, T. (2007). Observations of Forest Stand Top Height and Mean Height from Interferometric S.A.R. and LiDAR over a conifer plantation at Thetford Forest, UK. *International Journal of Remote Sensing*, *28*(6), 1173–1197.

Boyd, D. S., Foody, G. M., & Ripple, W. J. (2002). Evaluation of approaches for forest cover estimation in Pacific Northwest, USA, using remote sensing. *Applied Geography*, *22*, 375-392.

Bradley, A. B., & Mustard, J. F. (2005). Identifying land cover variability distinct from land cover change: Cheatgrass in the great basin. *Remote Sensing of Environment*, *94*, 200-213.

Buschbacher, R., Hull, C., & Serrano, E. A. (1988). Abandoned pastures in eastern Amazonia: Nutrient stocks in the soil and vegetation. *Journal of Ecology, 76*, 682–699.

Chandra, G., Zhilang, Z., & Reed, B. (2005). A comparative Analysis of the global land cover 2000 and MODIS land cover data sets. *Remote Sensing of Environment, 94*, 123-132.

Claramunt, C., Parent, C., & Theriault, M. (1997). Design Patterns for Spatio-temporal Processes. In Searching for Semantics : Data Mining, Reverse Engineering, S. Spaccapietra and F, Maryanski (eds), Chapman & Hall, pp 415-428.

Coppin, P. I., Jonckheere, K., & Nackers, B. M. (2004). Digital change detection in ecosystem monitoring: A review. *International Journal of Remote Sensing*, *25*(9), 1565-1596.

Dale, V. H., Joyce, L. A., Mcnulty, S., Neilson, R. P., Ayres, M.P., Flannigan, M. D., Hanson, P. J., Irland, L.C., Lugo, A. E., Peterson, C. J., Simberloff, D., Swanson, F. J., Stocks, B. J., & Wotton, B. M. (2001). Climate change and forest disturbances. *Bioscience, 51*, 723–734.

De-Leeuw, P. N., Grandin, B. E., & Bekure, S. (1991). Introduction to the Kenyan rangelands and Kajiado District. In Bekure, S., De-Leeuw P. N., Grandin, B. E., & Neate, P. J. (Eds.), *Maasai Herding: An analysis of the livestock production system of Maasai pastoralists in eastern Kajiado District, Kenya.* ILCA System study 4 (pp. 7- 19). Addis Ababa, Ethiopia: International Livestock Centre for A frica (ILCA).

Emerton, L., & Karanja, F. (2001). *Valuation of forest resources in East Africa*. Nairobi, Kenya: African Centre for Technology Studies (ACTS) and World Conservation Union (IUCN) Eastern Africa Regional Office (EARO).

Fisher, P. F., & Unwin, D. J. (Eds.). (2005). *Re-presenting GIS.* West Sussex: John Wiley & Sons Ltd.

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., Chapin, F. S., Coe, M. T., Daily, G. C., Gibbs, H. K., Helkowski, J. H., Holloway, T., Howard, E. A., Kucharik, C. J., Monfreda, C., Patz, J. A., Prentice, I. C., Ramankutty, N., & Snyder, P. K. (2005). Global consequences of land use. *Science, 309,* 570-574.

Foody, G. M. (2001). Monitoring the magnitude of land cover change around the southern limits of Sahara. *Photogrammetric Engineering & remote sensing, 67*(7), 841-847.

Geist, H. J., & Lambin, E. F. (2001). *What drives tropical deforestation?* LUCC Report Series (No. 4). CIACO: Louvain-la-Neuve.

Government of Kenya (1999a): *The Forestry Master Plan for Kenya. Ministry of Environment and Natural Resources.* Nairobi: Government Printer.

Green, E., Clark, C. D., Mumby, P. J., Edwards, A. J., & Ellis, A. C. (1998). Remote sensing techniques for mangrove mapping. *International journal of remote sensing, 19*(5), 935-956.

Halls, P. M. (1995). *Moving GIS into the fourth dimension: Or the case of todes.* Proceedings of the GIS Research UK 1995 Conference. Newcastle upon Tyne, pp 41-43.

Hestira, E. L., Khannaa, S., Andrewa, M. E., Santosa, M. J., Viersb, J. H., Greenberga, J. A., et al. (2008). Identification of invasive vegetation using hyperspectral remote sensing in the California Delta ecosystem. *Remote Sensing of Environment , 112*(11), 4034-4047.

Honnay, O., Verheyen, K., Butaye, J., Jacquemyn, H., Bossuyt, B., and Hermy, M. (2002). Possible effects of habitat fragmentation and climate change on the range of forest plant species. *Ecology Letter, 5,* 525–530.

Jansen, L. J., & Gregorio, A. (2002). Parametric land cover and land-use classifications as tools for environmental change detection. *Agriculture, Ecosystems and Environment, 91*, 89-100.

Lambin, E. F., Tuner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, T. O., Dirzo, R., Ficher, G., Folke, C., George, P. S., Homewood, I. J., Leemans, R., Li, X., Moran, E. F., Mortimore, M., Ramakrishan, P. S., Richards, J. F., Skanes, H., Stone, G. D., Svedin, U., Veldkamp, T. A., Coleen, V., & Xu, J. (2001). The causes of land-use and land-cover change: moving beyond the myths. *Global environmental change, 11*, 261-269.

Lambin, E. F., Geist, J. H., & Lepers, E. (2003). Dynamics of land-use and land-cover change in tropical regions. *Annual review of environmental resources, 28*, 205-241.

Leitao, A. B., & Ahern, J. (2002). Applying Landscape ecological concepts and metrics in sustainable landscape planning. *Landscape and urban Planning, 59*, 65-93.

Lillesand, T. M., Kiefer, R., & Chipman, J. W. (2004). *Remote sensing and image interpretation.* (5th ed.). New York: John Wiley & sons, Inc.

Lu, D., Mausel, P., Brondizio, E., & Moran, E. (2003). Change detection techniques. *International Journal of Remote Sensing*, *25*(12), 2365-2407.

Macleod, R. D., & Congalton, R. G., (1998). A quantitative comparison of change detection algorithms for monitoring eelgrass from remotely sensed data. *Photogrammetric Engineering and Remote Sensing, 64*(3), 207-216.

Mas, J. F. (2004). Mapping land use/cover in a tropical coastal area using satellite data, GIS and artificial neural networks. *Estuarine, coastal and Shelf Science, 59,* 219-230.

Mertens, B., & Lambin, E. F. (2000). Land cover change trajectories in southern Cameroon. *Annals of Association of American Geographers*, *90* (3), 467-494.

Meyer, W. B., & Turner, B. L. (1992). Human population growth and global land use/cover change. *Annual Review of Ecology and Systematics*, *23,* 39-61.

Meyer, W. B., & Turner, B. L. (1994). *Changes in land use and land cover: A global perspective*. Cambridge, UK and New York, USA: Cambridge University Press.

Ntsebeza, L. (2005). *Democracy Compromised: Chiefs and the Politics of the Land in South Africa*. Leiden and Boston: Brill Academic Publishers.

Ojani, F. F., & Ogendo, R. B. (1973). *A Study in Physical and Human Geography*. Nairobi: Longman Kenya.

Orodho, A. B. (1997). *Country Pasture/Forage Resource Profiles: Kenya.* Retrieved May 11, 2011, from http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Kenya.htm

Paulsson, B. (1992). *Urban Applications of Satellite Remote Sensing and GIS Analysis.* Washington: World Bank.

Petit, C., Scudder, T., & Lambin, E. (2001). Quantifying processes of land-cover change by remote sensing: Resettlement and rapid land-cover changes in south-east Zambia. *International Journal of Remote Sensing, 22*(17), 3435-3456.

Qian, L., Wachowicz, M., Peuquet, D. & MacEachren, A. (1997). Delineating Operations for Visualisation and Analysis of Space-Time Data in GIS. GIS/LIS'97, Cincinatti. Richard, E., & Haack, B. (1996). National land cover mapping by remote sensing. *World Development, 24,* (5), 845-855.

Treitz, P., and Rogan, J., 2004, Remote sensing for mapping and monitoring land-cover and land-use change – an introduction. *Progress in Planning*, 61, 269-279.

Rutten, M. M. (1992). *Selling wealth to buy poverty: The process of the individualization of landownership among the Maasai pastoralists of Kajiado District, Kenya, 1890-1990.* Saarbrucken, Germany: Verlag Breitenbach Publishers.

Sheppard, S. R., & Meitner, M. (2005). Using multi-criteria analysis and visualization for sustainable forest management planning with stakeholder groups. *Forest Ecology and Management, 207*(1-2), pp 171-187.

Shukla, J., Nobre, C., Sellers, P. (1990). Amazon deforestation and climate change. *Science, 247,* 1322–1325.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. *International Journal of Remote Sensing, 10,* 989-1003.

Sombroek, W. C., Braun, H. M., & Van-der-Pouw, B. J. (1982). *Explanatory soil map and agro-climatic zone map of Kenya. Report E1.* Nairobi: National Agricultural Laboratories, Soil Survey Unit.

Stow, D. A. (1993). The role of geographical information systems for landscape ecological studies. In R. Haines-Young, D. R. Green, & S. Cousins (Eds.), *Landscape Ecology and GIS.* (pp. 11-21). London: Taylor and Francis.

Turker, M. (2000). Change detection using the integration of remote sensing and GIS: A polygon based approach. *International Archives of Photogrammetry and Remote Sensing , 33*, 560-564.

Turner II, B. L., Clark, W. C,. Kates, R. W. Richards,J. F. Mathews, J. T. & Meyer, W. B. (1990). *The Earth as Transformed by Human Action: Global and Regional Changes in the Biosphere over the Past 300 Years*. Cambridge and New York: Cambridge University Press with Clark University.

Vitousek, P. M., Aber, J. D., Howarth, R. W., Likens, G. E., Matson, P. A., Schindler, D. W., Schlesinger, W. H., & Tilman, D. G. (1997). Human alteration of the global nitrogen cycle: Sources and consequences. *Ecological Application, 7,* 737–750.

Vogt, K. A., Gordon, J. C., Wargo, J. P., Vogt, D. J., Asbjornsen, H., Palmiotto, P. A., Clark, H. J., O'Hara, J. L., Keeton, W. S., Patel-Weynand, T., & Witten, E. (1997). *Ecosystems: Balancing Science with Management.* New York: Springer.

Wade, T.G., et al. (2003). Distribution and causes of global forest fragmentation. Conservation Ecology 7(2): 7

Worboys, M. F. (1998). Modeling changes and events in dynamic spatial systems with reference to socio-economic units. In the proceedings of the ESF GISDATA Conference on Modeling Change in Socio-Economic Units, Napthlion, Greece.

Xu, X., Guo, H., Chen, X., Lin, H., & Du, Q. (2002). A multi-scale study on land use and land cover quality change: The case of the Yellow River Delta in China. *Geojournal*, *56*, 177-183.