Landscape change dynamics in a semi-arid part of Baringo District, Kenya, based on Landsat-TM-Data and GIS analysis
Mwasi, B.

Citation for published version (APA):
Mwasi, B. (2004). Landscape change dynamics in a semi-arid part of Baringo District, Kenya, based on Landsat-TM-Data and GIS analysis Amsterdam: UvA
CHAPTER 8

FINAL SYNTHESIS

8.1 Introduction

The primary goal of this study was to establish the extent to which land cover patterns and their changes, in a semi-arid area within a developing tropical country, can be mapped from satellite data using a section of the greater Baringo district of Kenya as an example. A secondary goal, which follows from the first, was to use the land cover pattern information to understand the landscape change dynamics in the area. Understanding land cover change dynamics, i.e. the forces and processes that control land cover change patterns, provides an entry point for planning and managing land use. In pursuit of these goals, a) a method for mapping and monitoring changes in the structural and functional landscape characteristics was developed, b) the factors that induce and control landscape changes were identified, c) the interaction of these factors was modelled to simulate the change processes in order to predict future changes and, d) mechanisms were devised for making conflict-free multi-objective land use allocations. These objectives were addressed through five research questions, namely:

a) Which is the most accurate classification approach for delineating land cover details in an agricultural landscape within a semi arid area? (Chapter 3)
b) What land cover changes have taken place in the Lake Baringo area and how have they affected the quality of the landscape? (Chapter 4)
c) Which are the most important biophysical and socio-economic factors that influence landscape change patterns in the study area? (Chapter 5)
d) Can future landscape patterns in the study area be predicted from biophysical characteristics and socio-economic trends? (Chapter 6)
e) How well are the land use types in the area placed in terms of land use conflicts avoidance? (Chapter 7)

The study assembled procedures for obtaining relevant data on landscape characteristics and methods for manipulating these data into desired information (Figure 8.1). Details of the processes summarised by this figure together with specific
findings from the study area are discussed in sections 8.2 to 8.6. Section 8.7 presents some general conclusions drawn from the study and recommendations for further, future research.

Figure 8.1 Schematic representation of the landscape dynamics analysis presented in the study

8.2 Accurate Classification Method

The complex nature of the study area, occasioned by the heterogeneity of both biophysical and socio-economic characteristics, makes it very difficult to accurately map this area from satellite data. While most of the required land cover details can be identified from enhanced images such as a false colour composite (FCC), it is extremely difficult to isolate and classify all these details due to the high spectral similarities between land cover classes that are functionally different.
To address this problem, a classification method that combines unsupervised and supervised classification to maximize the advantages inherent in the two approaches was developed. The unsupervised classifier is used to isolate as many spectral groups as possible on the basis of which relatively pure training statistics are derived through analyst intervention. These training statistics are then used with a supervised classifier to produce a land cover map. Unsupervised classification was found to be better in isolating land cover types that occupy large areas such as plantations but relatively poor in picking smaller scale land cover types such as subsistence agricultural settlements. With the hybrid approach developed in this study, higher accuracies obtained in mapping large size land cover types with unsupervised classification approaches can be retained while the smaller land cover types are classified with the more robust supervised classifier. Results of this study demonstrated that it was very difficult to separate some land cover classes using spectral characteristics alone. This problem was addressed by incorporating spatial characteristics of the land cover types into the classification scheme through spatial separation, done on the basis of ecological and socio-economic delineation.

The overall classification accuracy attained was still rather low (<60%). However, the individual accuracies for most land cover classes that were used in further analyses were higher than this. As explained in Chapter 3, the overall accuracy value is considered to be lower than the true classified image accuracy. A great portion of the error stated is associated with the method of accuracy assessment used. Overall, the method produced results consistent with our field observation based expectations.

8.3 Change Detection and Analysis

The results showed that land cover changes have taken place in the study area. These changes largely concern an increase in settlements and increase in landscape patchiness. Although alterations in natural vegetation characteristics are evident, the results do not show any conclusive evidence in reduction in total biomass. In some areas, natural vegetation has been converted into other land cover types while in others noticeable phyto-sociological transformations have occurred. This is consistent with the observations made in the field, i.e. there are new settlements and transformations of natural land cover conditions due to selective harvesting and overgrazing.
Although most of these changes could be identified from enhanced images, it was not possible to accurately delineate them through image classification due to limitations in isolating the spectrally close land cover types discussed in section 8.2. For example, it was difficult to fully separate some settlement types e.g. unplanted farms, roads and suburban centres, from bare and sparsely vegetated areas. Similarly, forests, permanent swamps and sisal plantations, where they existed together, were difficult to separate. The area estimates derived from the overlay procedures are thus not very accurate and hence the estimates of both spatial and temporal change patterns should be treated as indicative values only.

Field observations suggest that the study area is experiencing high rates of degradation (patches of cleared vegetation, presence of tree stumps, erosion features, etc.). Although it is difficult to quantify degradation from the change detection results, its presence could be inferred from some indirect indicators. For example, the shrinkage of Lake Baringo from almost 150 km$^2$ in 1984 to about 120 km$^2$ in 1995 (Chapter 4) and the apparently more visible suspended silt in the water can be used as confirmatory sign of increased degradation. However, lake level fluctuations can also be due to short-term climate changes, i.e. variation in precipitation at decennial scale and thus have to be interpreted with care. The results of Chapter 4 also indicate an apparent increase in fragmentation within the natural/semi-natural vegetation cover types in the later date images. Finally, the low organic matter content in cultivated areas, of which there is a higher percentage in 1995 than in 1984, is indicative of increased susceptibility to erosion. This was not detected on the satellite images, but from field sampling as explained in Chapter 4 (see data in Appendix 4).

8.4 Drivers of Landscape Changes

Results from this study suggest that the patterns of land use changes are more strongly related to socio-economic than biophysical characteristics. Image interpretation results show a positive correlation between the presence of roads and settlement patterns. Field observations and satellite interpretation together also indicate that there is a strong relationship between the presence of subsistence farms and distance to a perennial river. Land use patterns appear to be sensitive to the more physical (as opposed to chemical)
soil properties such as soil depth and surface stoniness as opposed to soil fertility. All these did not however come out clearly in the logistic regression model in Chapter 5.

The apparent weakness of the logistic model derived from the data used in this study can be explained by three factors. The first is the difficulty in separating farms/settlements from other land use types as discussed in Section 8.2. Second, the spatial resolution of some independent variables derived from secondary data was not compatible with the level of detail assumed in the analysis. Specifically, the model assumes the accuracy of discrete points while most of the variables are continuous surfaces averaged over large areas. For example, population density, soil properties, rainfall, etc. are all thematic type data. Third, the points used to develop the model were generated randomly from a population in which farms/settlements exist among non-farm (natural vegetation). Consequently, two points with practically similar characteristics could belong to farm or non-farm, which dilutes the predictive power of the model. The only way to deal with this problem is to manually select the points to include in the model using field coordinates. This would involve another fieldwork exercise, which was not practicable in the present study.

It will be interesting to investigate the behaviour of the model at finer and coarser spatial and temporal resolutions since it is known that the causal links between land use changes and different biophysical and socio-economic factors manifest themselves more clearly at different scales (Veldkamp and Fresco, 1997). By taking care of scale dependence, stronger relationships between variables and change may become apparent making the model more relevant for planning at specific scales (local, national, regional).

8.5 The Change Process

Modelling changes of complex processes such as land cover change patterns was found to be quite challenging for two reasons. Firstly, these changes lean more towards being probabilistic than mechanistic although they do indeed possess both characteristics (Chapter 6). Secondly, the factors associated with inducing and controlling these processes are in themselves complex as well as their interactions. It is thus not only difficult to identify all the factors but also to find a function that can link them.
The probabilistic model developed in this study using the discriminant analysis function seemed to be able to predict land cover change patterns with modest success. This implies that the model can be used for planning and managing changes. Different land cover change scenarios (using different growth trends) can be developed and evaluated on the basis of which the most desirable scenario is selected after which socio-economic developments can be tailored towards the attainment of the selected scenario.

8.6 Suitability of Current Land Use Allocation

From the land allocation results using the conflict resolution decision support system, it appears that the selection of land for settlement is quite systematic and strongly conforming to environmental suitability. However, field observations indicate that the selection of specific crops is far from optimal. For example, some land uses with potentially higher economic and calorific returns, such as sorghum, are not as extensive as expected while crops with lower returns and higher failure risks such as maize are allocated more area. This can be explained by socio-economic influences where maize is considered more important, probably due to its diversity of use and wider cross-cultural acceptance. It is considered worthwhile to promote the acceptance of such more suited crops by popularising them through research on their nutritive and other advantages. Further, improvement of marketing and processing infrastructure for high economic value products such as honey and groundnuts may facilitate the attainment of the largely unexploited potential capacity. Last, planting crops with a lesser likelihood of failing also enhances soil protection and thus minimises degradation.

8.7 Final Conclusions and Recommendations

This study has shown that remotely sensed data and other spatially referenced data, with appropriate analytical tools i.e. GIS, multivariate statistics, and spatial models, can provide reliable information on landscape change dynamics. The medium resolution Landsat-TM images carry detailed information on land cover types and their change patterns. However, the image processing software used in this study could not fully isolate some of these land cover types and their change patterns. For example, roads, rain-fed agriculture farms and other human settlement centres could visually be identified.
by their spatial configuration in the three images but could not be separated on the basis of their spectral characteristics at pixel scale. To improve accuracy, the classification process should begin with an unsupervised classification isolating as many spectrally different classes as possible, followed by a comprehensive field campaign to identify and collect adequate representatives of each class from which to develop training statistics. Another possibility of increasing accuracy is modifying the hybrid method developed in this study into a multi-step approach, such that after the unsupervised classification the accurately identified classes, mainly the large-area features with known spatial locations, are masked out before the supervised classification is carried out.

Secondly, land cover changes, i.e. new settlements and developments or abandonment of other land uses (sisal plantations and irrigation fields), as well as changes in natural vegetation conditions, are clearly detectable through sequential image analysis. It can therefore be concluded that the detailed land cover information required for studying landscape change dynamics in a semi-arid subsistence agriculture landscape is available in Landsat-TM imagery. The problem is to consistently separate the data into relevant information classes. This requires a more powerful image processing software than what was available for this study. Alternatively, the required class separation could probably be better achieved through a combination of either higher resolution imagery or direct inclusion of spatial data in the classification. This would enable more accurate change detection in a complex environment such as the study area. It is also clear from this study that a combination of supervised and unsupervised techniques produces the best results under such circumstances. It was also observed in Chapter 4 that the identification of human settlements could best be done from images acquired during dry seasons rather than wet seasons.

From the results of chapters 5 and 6 it can be concluded that the methodologies developed in this study could be used to identify the important drivers of land use change and to model the change process. However, the models could not be assessed conclusively because of two limitations, both of which are related to the data used. Firstly, limitations in both available satellite data and image processing software rendered the image classification results relatively inaccurate. Consequently, the reliability of the change results is not high. Secondly, the spatial and thematic resolutions of the secondary data sets were not compatible with the detailed analyses demanded by the models. The overall results indicate
that if well selected remotely sensed data backed by adequate field data are available, together with the relevant and detailed secondary data, the methodologies developed in this study can produce accurate and detailed land cover information on past and present land cover patterns. Furthermore, this information will allow for the identification of trends, which can be used to predict the future.

Although the current study produced results that were far from optimal, it shows that further improved automatic processing of combined satellite based remotely sensed data with other biophysical and socio-economic data using GIS and spatial statistical tools provides a suitable methodology for managing land resources sustainably. This approach is particularly useful for the vast arid and semi-arid areas within the developing countries, which are experiencing rapid environmental degradation due to both global climatic changes and rapid population growths. Such a system will produce detailed inventories of existing resources for socio-economic exploitation, detect changes in both available resources quantity and quality timely and provide guidelines for appropriate remedial measures. One other useful application of the developed methodology is in degradation management. By identifying fragile ecosystems, it is possible, through this method to direct human settlements away from such areas or concentrate remedial development towards such areas.

With more detailed and more reliable data, this work can be continued further to be linked with the current Land-Use and Land-Cover Change (LUCC) project of the International Human Dimensions Programme on Global Environmental Change (IHDP) (Lambin et al., 1999), as a test case for a semi-arid subsistence agricultural area in East Africa. This requires the development of a more detailed (finer resolution) database for both biophysical (rainfall, soil properties, topography) and socio-economic parameters (population and infrastructure). The conflict-resolution land allocation model with the decision support system, produced in this study, provides an important tool for optimising land use planning and sustainable land use. However, it still needs to be tested for a whole administrative unit, such as a district using area-specific land use requirements, economic and calorific return estimates, with a group of stake-holders and experts identifying the objectives, their criteria and priorities.