LAND COVER DYNAMICS AS A RESULT OF CHARCOAL PRODUCTION: USE OF REMOTE SENSING AND GIS

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ABSTRACT

Charcoal is the most important energy source for middle and low-income people in many African cities. Its consumption shows no sign of decrease for the reasons of cost, convenience and availability. The use of charcoal, however, has been blamed for deforestation and degradation of natural forests and woodlands. To increase the understanding of the effects of charcoal use in three countries in Southern Africa: Tanzania, Zambia, and Mozambique, a collaborative project, CHAPOSA (Charcoal Potential in Southern Africa), was conducted. One of the project objectives was to assess the extent of environmental degradation due to charcoal production and to identify indicators that can quantify and locate such degradation. To meet this objective, an integration of remote sensing, using Landsat Thematic Mapper (TM) data, and Geographical Information System (GIS) tools was used to quantify and locate land cover changes, particularly degradation and regeneration of woodlands that had occurred in the study area between 1991 and 1998. The results reveal that, in the study period, much of the closed woodland has been converted to either open woodland or other cover types including agricultural farms. However, in some locations regeneration of woodlands has been observed. This precludes the presumption that cutting down trees for charcoal production must result in irreversible degradation. Given the fact that charcoal is and will remain, at least in a foreseeable future, the main domestic energy source, sustainable use of the woodland coupled with more use of other energy sources seems to be our best strategy if we want to sustain the remaining woodland.

Key words: Charcoal – CHAPOSA – woodlands – Southern Africa

INTRODUCTION

In Tanzania, forests and woodlands occupy about 50% of the total land (MoTNR 1994). The resources have unique environmental and biodiversity values, and make available a wide range of products for subsistence use. The most predominant use being in the form of firewood and charcoal by the majority of households in both rural and urban areas.

Fuelwood and charcoal are the cheapest available fuels, and are used extensively to provide energy for cooking, heating and lighting. It is estimated that fuelwood and charcoal constitute 92% of the primary energy consumed, while petroleum and electricity account only for 7% and 1% respectively (MoTNR 2001). Fuelwood and charcoal are also used as energy sources in small-scale industries such as, food processing, brewing, fish smoking, salt production, baking, tobacco curing, tea drying and bricks burning.

The extensive use of fuelwood and charcoal contributes significantly to the depletion of natural woodlands. According to Agrar-und Hydrotechnik GmbH (1987), about 55,300 hectares of miombo woodland would be needed for tobacco curing in Iringa district in 1983/84 alone. The figure does not include the woodland cleared during land preparation. In most tobacco-producing areas no fuelwood plantations for tobacco curing purposes are established as a result, the natural woodlands near the tobacco fields have been almost completely depleted.

Intense woodcutting has serious, though localized, effects on dry-land degradation by increasing further soil erosion. And if the soil erosion process is active long enough, gullies or deflated areas without any fertile soil may eventually appear. The effects of woodcutting include also fuelwood scarcity and ever-longer journeys and man-hours spent on search for fuelwood supplies. It is estimated that women and children are forced to walk distances more than 5 km searching for fuelwood (Malende 1997).

To lessen the dependence on fuelwood and charcoal as energy sources, the national environmental policy of 1997 stresses on development and use of indigenous energy sources such as bio-energy, coal, natural gas and hydropower (URT 1997). However, less than 2% of energy development budget is allocated to wood energy programs, and fuelwood is still regarded as a minor forest product with little market value (NFP 2001). Yet still, the majority of fuelwood and charcoal consumers cannot afford the high investment costs associated with alternative commercial energy sources (Moyo *et al.* 1993). Availability, reliability of supply, and cheaper prices renders fuelwood and charcoal more preferable than alternative sources of energy.

Looking at the present economic forces, the majority of population in Tanzania will continue to depend on fuelwood and charcoal for long time to come (Moyo *et al.* 1993). Furthermore due to the anticipated steady increase in population (at an annual growth rate of 2.8%) it is expected that actual consumption of firewood and charcoal will continue to rise to a greater extent. This will put strains on the remaining natural forests and woodlands from where charcoal is obtained, possibly resulting in degradation of the ecosystems.

Little is known on the dynamics of charcoal production in terms of ecological and socio-economic aspects. The CHAPOSA project aimed at increasing the understanding of the effects of charcoal use in three countries in southern Africa: Tanzania, Mozambique, and Zambia. One of the project objectives was to assess the extent of environmental degradation due to charcoal production, and to identify indicators that could locate and quantify such degradation.

The study assessed temporal-spatial dynamics of woodlands between 1991 and 1998 using remote sensing and GIS in the eastern part of Tanzania. Due to its synoptic, repetitive and uniform capabilities, remote sensing provided an essential input to the monitoring of degradation and regeneration of woodlands. Landsat TM data was used to gather spatial and temporal information as a means of monitoring these processes. In this study, reliable information extraction required analysis technique that could take advantage of both visual and digital image interpretation processes, as well as be able to combine temporal information, i.e. change detection, for that purpose GIS was an important tool.

MATERIAL AND METHODS

Study Site

The study area is located in the eastern part of Tanzania covering the City of Dar es Salaam, part of Coast, Morogoro and Tanga regions. It is covered by one Landsat TM scene, extending from Mligaji River in the North to Dar es Salaam in the South, Indian Ocean in the East, and to Chalinze town in the West.

Dar es Salaam, the largest city in the country and main business centre with population of around 3 million, was considered to be the main consumer of charcoal and the surrounding areas as production sites. It was, therefore, anticipated that the greatest impact of charcoal dynamics would be realized in Dar es Salaam and its surrounding ecosystems.

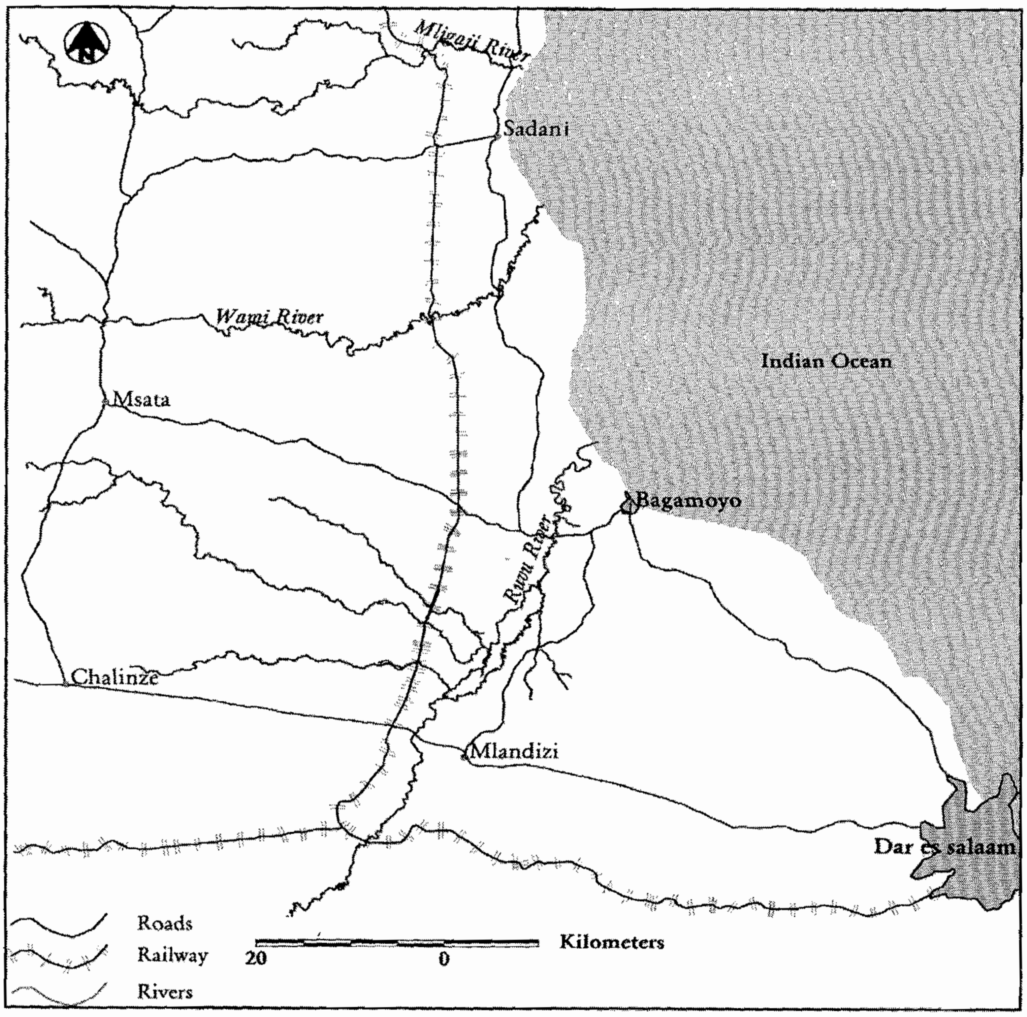


Figure 1: Location of the study area

Vegetation, Land use and Economy

Miombo woodland, with re-growth of mainly *Julbernadia spp*, *Brachystegia spp*, *Pterocarpus rotundifolia*, *Diplorhynchus candylocarpon*, *Combretum zeyheri* and *Acacia,* is the predominant vegetation in the study area. The woodlands are important sources of income for many households. According to surveys conducted in other CHAPOSA studies, more than 50% of the households derive their cash incomes from sale of forest products such as charcoal, honey, wild fruits, and firewood.

Rainfed agriculture is the dominant land-use system in the study area. The majority of farmers are subsistence, growing maize, sorghum, and millet, as major staple crop as well as important cash crops. Other crops grown in the area include rice, sweet potatoes, cassava, pineapples and cotton. Many farmers plant two or more crops in the same field (intercropping). For example, maize is planted together with either pineapples or cassava, or both. Tree crops, particularly, cashewnut, mango, and coconut, are very important cash crops in the area. They are mostly planted near to the settlements, mixed with other crops such as pineapples, maize, and cassava. Old cashewnut and mango trees are also used for charcoal production where preferred species are scarce or not available.

Charcoal production system

Charcoal production is usually a small-scale economic activity based on traditional methods. The activity is meant to provide household extra cash income. It is, however, now changing from meeting subsistence needs to commercial ambitions, as charcoal dealers from urban centres are directly engaged in the business. They provide needed capital and facilitate transportation of charcoal to a growing demand in urban centres where very little woodland is available for charcoal production because most of it has already been depleted (Dar es Salaam City Commission 1997). Thus, in the process, charcoal dealers are exporting woodland degradation to the nearby rural areas.

All the charcoal in the study area is made in traditional earth kilns built by covering a stack of logs with soil clumps dug around the kiln site. The process involves woodcutting, kiln preparation, carbonization and finally unloading charcoal from the kiln. Average wood to charcoal conversion efficiency is 19% (Malimbwi *et.al.* 2003). The inefficiency of traditional earth kilns contributes significantly to the depletion of woodlands.

Charcoal producers appear to practice selective cutting using size and tree species as criteria for selection. According to Monela *et al.* (2000), the producers prefer to use large trees (dbh of at least 10cm) from species such as Mkamba *(Acacia nigrescens)*; Mnhondolo/Mhangala (*Jurbernadia globiflora)*; Myombo (*Brachystegia boehmii)* and Mhungilo (*Lannea schimperi)*. But where preferred species and large stems are scarce or not available, other tree species and small stems are used. Thus in deforested areas, people have fewer options to be selective.

Tree removal intensity and purpose for tree harvesting

The harvesting intensity estimated by Luoga *et al* (2002) from new and old stumps revealed that there is more harvested wood in general land (19.6 + 2.6 m3/ha) than in the forest reserve (7.1 + 1.2 m3/ha) (Table 1). The largest amount of wood harvested in both general land and forest reserve is for charcoal (Table 2), followed by land preparation for agriculture in general land and firewood in the forest reserve. Nduwamungu (1996) estimated an average of 12 stems per ha with dbh greater than 20 cm of species suitable for charcoal removed annually in Miombo woodlands of Kitulangalo SUA Training Forest Reserve. Most of these trees cut were intended for charcoal production and were mainly from *Julbernardia*, *Combretum* and *Brachystegia* species. Zahabu (2001) observed that an average of 43 bags of charcoal was produced per month for each household in Gwata and Maseyu villages (located in the study area). No charcoal is produced intentionally for home use except that which is left after sale and usually it is very minimal.

Table 1 Harvesting intensity in the forest reserve and the general land

Removals	Parameters	Whole Kitulangalo Forest reserve (n=34)	General land (n= 30)
New	Stumps (Stems / ha)	5.00 + 3.18	47.00 + 17.58
	BA (m^2/ha)	0.14 + 0.54	1.38 + 0.54
	Volume (m^3/ha)	1.12 + 0.68	6.38 + 2.39
Old	Stumps (Stems / ha)	50.00 + 8.55	135.00 + 22.28
	BA (m^2/ha)	1.04 + 0.19	2.61 + 0.51
	Volume (m^3/ha)	5.98 + 0.86	13.24 + 2.18
All	Stumps (Stems / ha)	55.00 + 8.96	182.00 + 24.19
	BA (m^2/ha)	1.28 + 0.24	4.03 + 0.64
	Volume (m^3/ha)	7.11 + 1.18	19.62 + 2.58

Source: Luoga *et al.* (2002)

Table 2 Purposes of tree harvesting

Purposes	Kitulangalo forest reserve				Kitulangalo general land			
	Sampled stumps	% of all stumps	Stumps /ha	DBH (cm)	Sampled stumps	% of all stumps	Stumps /ha	DBH (cm)
Charcoal	101	54.6	30	14.6	309	56.4	103	14.2
Firewood	26	14	8	12.9	11	2.0	4	9.1
Natural mortality	17	9.2	5	6.9	28	5.1	9	8.2
Poles	16	9.0	5	10.5	55	10.0	18	9.0
Carving	10	2.2	1	20.2	3	0.5	1	17.2
Fires	10	5.4	3	8.2	16	2.9	5	4.1
Unknown	9	4.9	3	12.8	7	1.3	2	11.1
Ropes	1	0.5	0	20.0	9	1.6	3	6.4
Timber	1	0.5	0	44.2	2	0.4	1	26.4
Land preparation	0	0.0	0	-	99	18.1	33	10.9
Tracks	0	0.0	0	-	9	1.6	3	7.1
All	182	100	55	-	548	100	182	-

Source: Luoga *et al.* (2002)

Image Processing for Change Detection

Due to heterogeneity of land covers in the study area, the assessment of woodland dynamics needed a combination of digital and visual image interpretation techniques. This could be achieved by the use of GIS tools. Figure 2 summarizes the methodology.

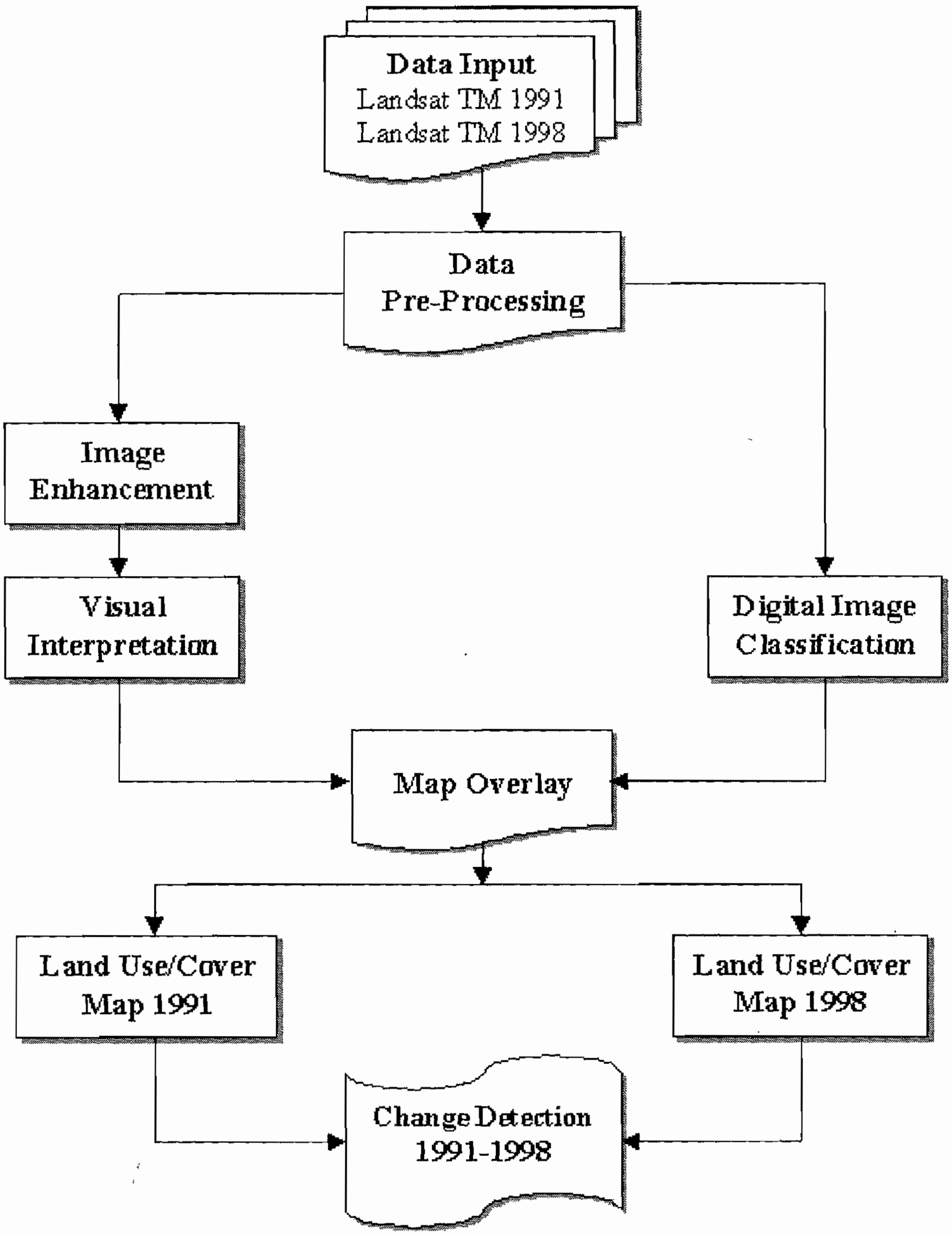


Figure 2. Methodology flowchart

Before starting image processing a field observation was conducted to establish different land-cover classes and their training fields. Image characteristics for the land covers were also identified on colour composite image (bands 4 5 3).

The following major classes were identified: closed woodland; open woodland; thicket; bushland; grassland; bushed grassland; mangrove forest; and cultivation, comprising mixed cultivation, annual cultivation, and fallow. Mixed cultivation comprises a mixture of settlements, tree crops, i.e. cashew nuts, mango and coconut, and other crops such as maize, pineapples, and cassava.

Image pre-processing

Accurate identification of temporal changes requires geometrical precision. Two Landsat scenes, from 1991 and 1998, were thus registered to a map co-ordinate system, i.e. UTM zone 37 South, Datum Arc 1960, prior to change detection analysis. The 1st order Polynomial transformation and nearest-neighbourhood interpolation were considered for image rectification.

Visual interpretation

As described earlier, cultivation pattern in the study area is very heterogeneous, characterized by a non-uniform mixture of crops and field sizes. This makes discrimination of the cover using digital image classification very unreliable, resulting into mixed pixels. Thus, due to spectral and spatial heterogeneity of the cover, visual interpretation was considered to be more reliable technique to extract the cover.

Visual interpretation involved use of image characteristics such as pattern, texture, and colours to translate image data into land cover. In order to reinforce the visual interpretability, a 3 x 3 edge-enhancement filter was applied to the Landsat TM images. The resulting images were then visually interpreted on a computer screen. Technically, an edge enhancement algorithm consists of a window that is systematically moved through the image, centred successively on each pixel. At each position, a new digital value is calculated using the original value and the local average of adjacent pixels. The effect of this procedure is to increase the brightness of pixels that are already brighter than the local average and to decrease the brightness of pixels that are already darker than the local average (Campbell 1987). As a result, edge enhancement makes spatial details comprising the image more conspicuous and easier to interpret.

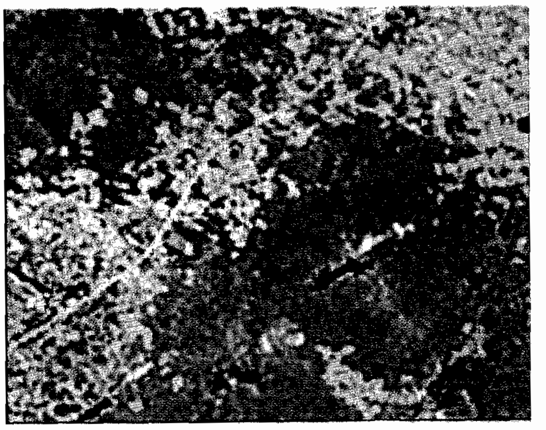


Figure 3 Enhanced colour composite (bands 4 5 3) for visual identification of a land cover mixed cultivation (greenish and yellowish pixels). Reddish colour represents closed woodlands.

Digital image classification

Digital image classification refers to a computer-based assignment of image pixels to information classes. In this study a supervised image classification using the Maximum Likelihood Classifier was performed in ERDAS imagine software. Training fields were identified in the field and by inspecting enhanced colour composite (bands 4 5 3). Training was an iterative process, whereby the selected training pixels were evaluated by performing an estimated classification (ALARM command). Based on the inspection of alarm results, training samples or critical spectral distance were refined until a satisfactory result was obtained. The maximum likelihood classification was then performed to the Landsat TM images.

The results from visual interpretation and digital image classification were later combined using overlay function resulting into 1991 and 1998 land cover/use maps.

Change detection analysis

Change detection analysis entails finding the type, amount and location of land use changes that are taking place (Yeh *et. al.*, 1996). Various algorithms are available for change detection analysis. They can be grouped into two categories:

Pixel-to-pixel comparison of multi-temporal images before image classification.

Muti-date images are placed in a single dataset. To extract change information, the composite dataset can then be analyzed in a number of ways such as: unsupervised clustering, image differencing, image ratioing, and principal component analysis.

Although the methodology is sensitive in detecting pixels that have changed, it is very difficult to construct a land use conversion matrix from it. Also since the methodology is based upon the fundamental assumption that a change in the use of a particular parcel of land will accordingly lead to a change in the spectral response of that parcel, change in brightness values influenced by factors other than changes in land use are mis-classified.

Post-classification comparison

The approach identifies changes by comparing independently classified multi-date images pixel-by-pixel basis using a change detection matrix. The matrix analysis produces a thematic layer that contains a separate class for every coincidence of classes in multi-date dataset. Although, the use of a change detection matrix provides a detailed from-to information, i.e. the nature of change, mis-classification and mis-registration that may be present in each classification affect the accuracy of the results. In this study post-classification comparison was used to assess land use changes that had occurred between 1991 and 1998.

RESULTS AND DISCUSSION

Results of change detection analysis are shown in table 3, table 4, figure 5 and figure 6. The focus of the analysis was to quantify and locate degradation and regeneration of woodlands that had occurred in the studied period. In the context of this study, woodland degradation refers to the conversion of closed and open woodland to other land covers. The conversion from closed to open woodland is also regarded as woodland degradation. Woodland regeneration refers to conversion from other land covers to closed and open woodland. The conversion from open to closed woodland is also referred as woodland regeneration.

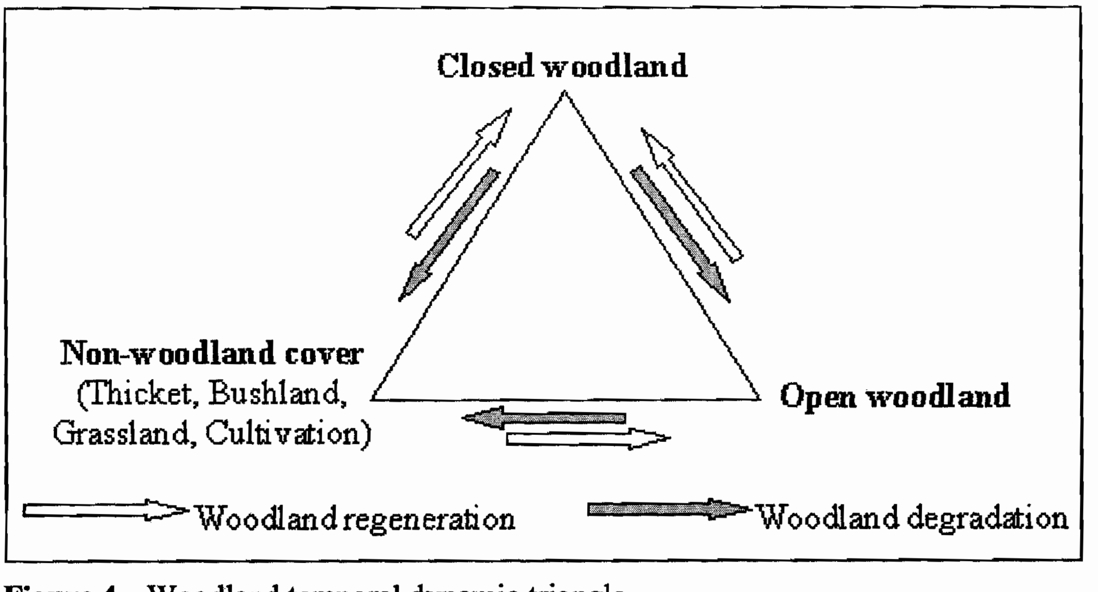
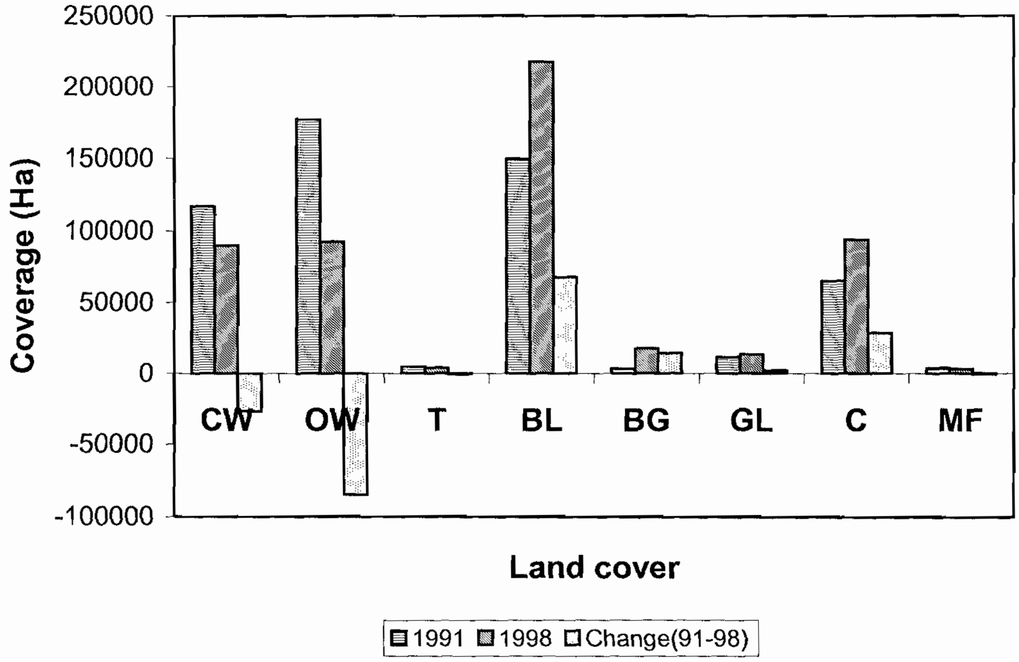


Figure 4 Woodland temporal dynamic triangle

Based on the statistics presented in table 3, table 4, figure 5 and figure 6, the results reveal that between 1991 and 1998 much of the closed woodland has been converted to either open woodland or other cover types, including cultivation. However, in some locations regeneration of woodlands has been observed.



CW = closed woodland, OW = open woodland, T = thicket, BL = bushland, BG = bushed grassland, GL = grassland, C = cultivation and MF = mangrove forest.

Figure 5 Land cover change between 1991 and 1998

Table 3 Change detection matrix

Cover in 1991 (Ha)	Cover in 1998 (Ha)								
	CW	OW	T	BL	BG	GL	C	MF	Total
CW	54729	29268	1988	23308	1481	10	6019	0	116803
OW	23475	43600	582	87113	5649	300	16383	0	177102
T	641	511	842	2505	107	0	61	0	4667
BL	10937	18909	486	102493	6244	387	9939	366	149761
BG	0	12	0	120	3050	0	0	161	3343
GL	99	163	0	1210	857	8707	552	0	11588
C	1	40	0	67	35	4237	61095	0	65475
MF	0	0	0	752	420	2	6	2573	3753
Total	89882	92503	3898	217568	17843	13643	94055	3100	532492

Note: CW = closed woodland, OW = open woodland, T = thicket, BL = bushland, BG = bushed grassland, GL = grassland, C = cultivation and MF = mangrove forest.

Table 4 Woodland temporal dynamics

Unchanged Woodland		
Cover	Acreage (Ha)	% of the cover in 1991
CW	54729	47
OW	43600	24
Woodland Degradation		
Change	Acreage (Ha)	% of the cover in 1991
CW - OW	29268	25
CW - T, BL, BG, GL	26787	23
CW - C	6019	5
OW - T, BL, BG, GL	93644	53
OW - C	16383	9
Woodland Regeneration		
Change	Acreage (Ha)	% of the cover in 1998
OW-CW	23475	26
T, BL, BG - CW	11677	13
T, BL, BG - OW	19595	21

Note: CW = closed woodland, OW = open woodland, T = thicket, BL = bushland, BG = bushed grassland, GL = grassland and C = cultivation.

Table 3 and 4 reveal that, out of the original 116803 hectares of closed woodland in 1991, less than half (47%) has remained unchanged by 1998. 25% had been degraded to open woodland; 23% to thicket, bushland, bushed grassland, and grassland; 5.0% had been converted to cultivation. A similar trend had been observed in open woodland where, out of 177102 hectares present in 1991, only 24% of the cover remained unchanged by 1998; 53% were degraded to thicket, bushland, bushed grassland, and grassland; and 9% had been converted to cultivation. The results imply that cultivation, in the study area, had little contribution to the degradation of woodlands. Most of the degradation has been due to tree cutting for charcoal production, fuelwood and other products such as timber.

Similar observation was reported by Luoga *et. al.* (2002) in Kitulangalo public land, whereby 56.4% of the sampled stumps were for charcoal production compared to 18.1% for land preparation (Table 2). According to Monela *et.al.* (2001), degradation of woodlands could be due to population growth, increased demand for forest products, rigid paramilitary orientation of forest services in Tanzania which employs a restrictive and punitive approach in managing government forest reserves. It was also observed that the vast forested areas fall under public lands which are *de facto* open access. The forests being open access means that there is no security of tenure or formal user rights and there is no incentive for systematic and sustainable forest management. Continued harvesting of a forest, without taking into account its capacity to replace the volume which has been harvested, i.e. sustainable harvesting, will lead to the depletion of the forest, and with time the forest might disappear completely. As mentioned earlier, selective cutting is the predominant form of harvesting trees for charcoal production in the study area, sometimes only a small proportion of the biomass is removed and therefore canopy cover might not be significantly reduced to be detected by the Landsat TM. This implies that the actual amount of woodland degradation might be higher than what has been depicted.

Furthermore, the results revealed that the regeneration potential of the woodlands in the study area is substantial. 26% of the closed woodland in 1998 was a result of regeneration of open woodland; and 13% had resulted from regeneration of thicket, bushland, and bushed grassland. 21% of open woodland in 1998 was due to regeneration of bushland and bushed grassland. The observation precludes the presumption that cutting down trees for charcoal production must result in irreversible degradation. The observed woodland regeneration is, however, comparatively small to the removal rate. The same was observed by Monela *et.al.* (2001) in the Kitulangalo general land with estimated annual removal of 6.38 m3/ha/year compared to the estimated mean annual increment (MAI) of 2.3 m3/ha/year. Thus interventions are needed if sustainability of forest product supply from woodland is to be achieved. The challenge to the managers of the woodlands, including local communities is on how to develop and promote conservation and management strategies that could promote woodland regeneration. Such strategies might include empowerment of local people to control and manage their woodlands, development or improvement of existing institutional arrangements and use of local management options in conjunction with technical options.

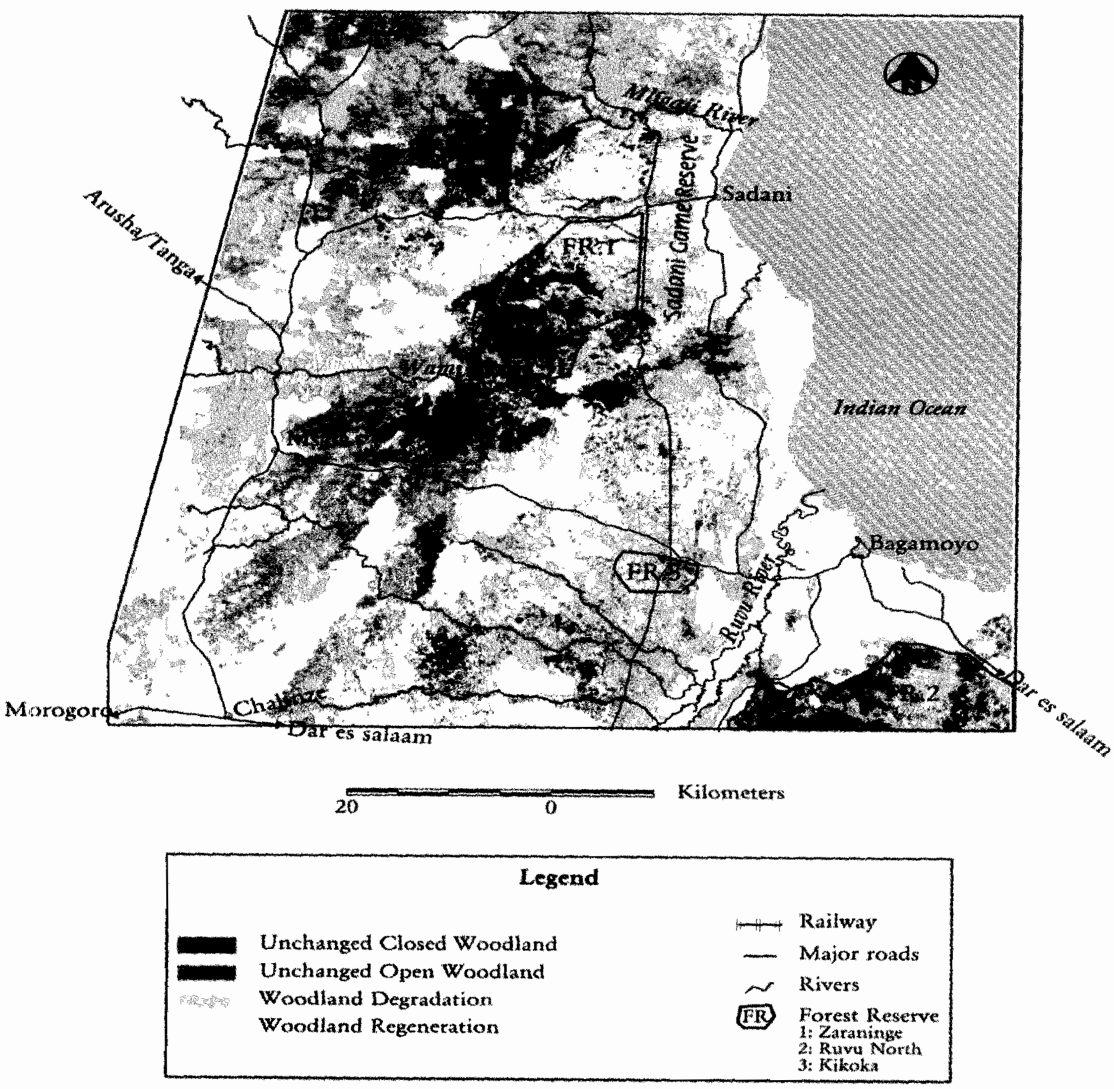


Figure 6 Woodland change detection map between 1991 and 1998

CONCLUSIONS

Remote sensing and GIS were found to be very useful tools for quantifying and locating degradation and regeneration of woodlands in the study area. The findings could be very useful information to guide decision marking on questions such as where, how much, and which intervention strategies could be appropriate.

It was also found that integration of visual and digital image interpretation is an important technique for classifying images from areas of heterogeneous land covers. While visual interpretation was more capable of identifying spatial information described in the form of pattern and texture, digital image classification had a higher spectral discrimination capability. The two could therefore complement each other. GIS provided capabilities for integrating the two image interpretation processes, as well as for change detection analysis.

Change detection analysis revealed that charcoal production in areas surrounding the city of Dar es Salaam had a substantial impact on the natural woodlands. Much of the woodlands have been degraded to other cover types as a result of the activity. Between 1991 and 1998, 53% of closed woodland was degraded to either open woodland or other land covers and 76% of open woodland was degraded to other land cover. However, in some locations regeneration of woodlands has been observed. This precludes the presumption that cutting down trees for charcoal production must result in irreversible degradation.

Given the fact that charcoal is and will remain, at least in a foreseeable future, the main domestic energy source, sustainable use of the woodland coupled with more use of other energy sources seems to be our best strategy if we want to sustain the remaining woodland.

Joint management of woodland resources between the government and communities and other local bodies which in most cases have a stake in the resource is recommended.

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