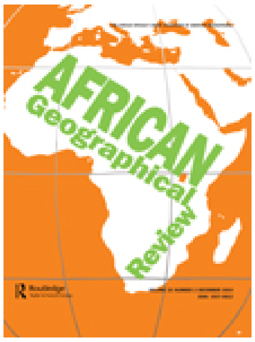

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RESEARCH ARTICLE

An Intensity Analysis of land-use and land-cover change in Karatu District, Tanzania: community perceptions and coping strategies

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Land-use and land-cover changes (LULCCs) are the result of complex interactions between the human (cultural, socio-economic and political) and the biophysical environment at different spatial scales. The present study assessed the spatial distribution of LULC (1976–2008) in the high and low altitude zones in the northern highlands of Karatu, Tanzania, using both qualitative (in-depth interviews and focus group discussions) and quantitative techniques (Intensity Analysis). The qualitative approach was used to elicit information on the coping strategies adopted by land users as transitions occurred with time and the Intensity Analysis was used to assess the systematic land losses, gains and persistence of the various land categories with time. The results of the Intensity Analysis show that overall land transformation is decelerating in both agro-ecological zones across the two time intervals. In the low altitude zone, woodland, settlements and bushland are active categories unlike cultivated and grassland, which are dormant. In the low altitude zone, grassland systematically loses to cultivated areas during both time intervals. However, in the high altitude zone, forest systematically loses to woodland during both time intervals. In both agro-ecological zones, land change was rapid during the first interval and slowed during the second. We suggest that the fast change in land during the first interval may be attributed to the villagization policy in the 1970s that sought to drive the population towards rural settlements.

Keywords: LULCC; complexity; Intensity Analysis; perceptions; Ayalabe; Upper-Kitete; Tanzania

Introduction

Both natural and anthropogenic factors account for the complex phenomenon of land-use and land-cover change (LULCC); however, human modification in LULCC across the globe has, in recent times, appeared as unprecedented, intensely affecting the earth's ecological systems (Lambin & Geist, 2005; Lambin et al., 2001; Steffen, Grinevald, Crutzen, & McNeill, 2011). This phenomenon is, on the whole, escalating in developing countries, where widespread land-use/cover change driven by socio-economic development leads to pervasive environmental degradation, particularly landscape fragmentation (Grimm et al., 2008). The East African rift valley epitomizes this phenomenon. East Africa is a mosaic of diverse landscapes and habitats, each of

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which is associated with an array of different values and perceptions by different users and observers. This presupposes that there is no unified account on the environmental history of East Africa. Previous work in the region range from various natural indexes such as biodiversity, vegetation type, soil quality or agro-ecological zones (e.g. Emerton, 1996; McClanahan & Young, 1996), through different assessments of economic value and/or agro-pastoral potential (e.g. Voortman, Sonneveld, & Keyzer, 2003) and notions of common property rights (e.g. Hanna, Folke, & Muler, 1996), to ideas concerning the cultural, historical or sacred significance of these landscapes to local, regional and international constituencies (e.g. Luig & von Oppen, 1997; Wagner, 1996). According to Roe (1991), twentieth-century polices directed toward the management, protection, enhancement and/or restoration of East Africa's landscapes and their associated habitats were driven by a restricted set of environmental narratives. First, there was a tendency to regard indigenous agriculture, pastoralism and hunting as wasteful practices and the associated land management regimes as having, over time, led to overall environmental degradation that continues to this day. Second, that surviving areas of high biodiversity and/or dense concentrations of wildlife were believed to represent the remnants of pristine environments barely touched by human activities and from which humans had to be excluded if their long-term survival was to be ensured. And finally, that throughout the pre-colonial era, East Africa's populations comprised a series of bounded social groups with fixed ethnic identities, whose spatial distributions were constantly changing as a consequence of recurrent population migration. In contrast, more recent studies conducted from the perspective of historical and political ecology both within the region (e.g. Anderson, 2002; Håkansson, 2004; Mackenzie, 2003; Steinhart, 2000) and elsewhere (e.g. Head, 2000; Kirch, 2005) have highlighted the complex and context-specific interplay between natural and anthropogenic forces in the shaping of landscapes, and the values attributed to them by different interest groups and communities. It is also now widely recognized that the earlier narratives and policies of environmental conservation, far from being value free, frequently served the interests of the colonial state and European settler communities (Beinart, 2000; Neumann, 1998).

Parallel studies have indicated that the fluid nature of many ethnic identities in the past facilitated population movement, particularly during periods of environmental stress, but that this coping system broke down following the colonial creation of tribal boundaries (e.g. Willis, 1992). These developments have in turn encouraged a shift in management strategies toward protected areas (Brockington, 2002; Lovett, Midgley, & Barnard, 2005), with new emphasis being placed on the importance of community-based conservation, pro-poor tourism and the significance of indigenous knowledge systems (e.g. Berkes, 1999; Bollig & Schulte, 1999), as well as on the need to link biodiversity conservation more overtly with poverty reduction (Adams et al., 2004).

Although such shifts in thinking have been fundamental, many questions still remain, not only as to what community-based conservation entails in reality or whether it achieves its conservation goals (e.g. Barrow & Fabricus, 2002; Logan & Mosely, 2002) but also how the landscape aesthetics of local populations and the cultural and historical values they attach to such places diverge from those that continue to be imposed by national governments and international conservation bodies. Moreover, while it is undeniable that human impacts on the environment have intensified over the last few centuries, as have certain natural processes, it is often difficult to assess claims about the current health of a particular ecosystem, its relative resilience, evidence for degradation or, more generally, its quality, since the relevant observational data on which such statements are based are either lacking, insufficiently detailed, or of insufficient time depth to allow accurate assessment. It is against this background that this study was carried out.

The primary goal of this paper is to analyse maps of land categories for three time points using Intensity Analysis (Aldwaik & Pontius, 2012). A comprehensive exposition on Intensity Analysis is given by Huang, Pontius, Li, and Zhang (2012) and Pontius et al. (2013). This method, which is accumulating a large body of literature across the globe (Pontius et al., 2013), accounts for the intensity of land transitions at the same time as answering the following three interrelated questions (Braimoh, 2006). (1) In which time interval is the annual rates of overall change relatively slow vs. fast as revealed by our interval Intensity Analysis? (2) Given the answer to question 1, which land categories are relatively dormant vs. active in a given time, and is this pattern stable across time intervals? (3) Given the answers to questions 1 and 2, which transitions are intensively avoided vs. targeted by a given land category in a given time interval, and is this pattern stable across time? Furthermore, we examined community perspectives on land-use and land-cover change in the study area, and tested the hypothesis that population increase has culminated in deforestation (loss in area of forest cover) in the high altitude zone. In the rest of the paper, we discuss the theoretical framework of the study. This is followed by a description of the specific steps used in Intensity Analysis and in eliciting community perspectives on LULCC. The study results are then presented, which is followed by a discussion of the findings.

Theoretical approach to land-use change

We situate this study within the nature–society theorization tradition. We embed the analysis of land-use change within the broader discourse on environmental change at various spatial scales. The principal, deeper question this theoretical view addresses is 'how man relates to nature' which translates into the more common and popular question of 'man's role in causing or shaping environmental change' or 'the human causes of global environmental change' (Briassoulis, 2000, p. 5). In this context, we consider the totality of the interactions between nature (or environment), economy, society (including politics and institutions) and culture (see Figure 1).

We consider population increase as the distal driver, and ecological, socio-economic and political factors as proximal drivers of LULCC. We show that feedback arrows link these drivers, LULCC and coping strategies at the individual and the rural community levels. In Figure 1, six feedback loops are discernible. One loop exists between population increase, ecological factors, and socio-economic and political factors. Another loop exists between population increase, ecological factors and coping strategies. A third loop exists between LULCC, ecological factors, and socio-economic and political factors; and the fourth exists between LULCC, ecological factors and coping strategies. The fifth loop exists between population increase, coping strategies, LULCC and ecological factors, whereas, the final loop exists between population increase, socio-economic and political factors, LULCC and ecological factors. The loops between each sub-system can either be reinforcing or balancing. For instance, out-migration reinforces (increases) the establishment of human settlement in destination communities whereas it balances (reduces) the establishment of such settlements in the original community. The arrows represent unidirectional, bidirectional, linear and non-linear causal relationships. In this context, we attempt to treat the environment, land and land use concretely and comprehensively – as material entities with characteristic properties and particular ways of relating to one another and to the socio-economic forces that impinge on them.

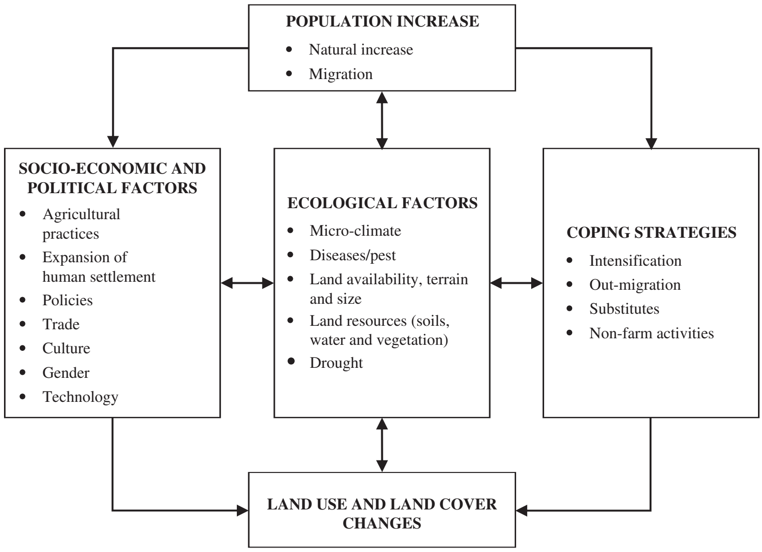

Figure 1. The relationship between socio-ecological system and LULCC (modified from UNFPA (1991, p. 17).

We take a more balanced view for the study of nature–society relationship by focusing specifically on 'cultural-human ecology' (Briassoulis, 2000, p. 73). In doing so, we draw upon ecology and systems theories to provide comprehensive descriptions of the complex interactions between people and their bio-physical environment (Butzer, 1990; Sack, 1990); and to study the adaptive processes by which human societies and cultures adjust through subsistence patterns to the specific parameters of their local habitat (Johnston, Gregory, & Smith, 1994, p. 111). As Sack (1990, p. 665) observes:

> the primary, though by no means only, device that ecologists employ to connect human and natural systems is, to put it positively, to focus on characteristics that both systems possess, or to put it slightly negatively, to reduce human actions to physical ones.

Butzer (1990), notes that cultural-human ecology has attracted contributions from sociologists, anthropologists and geographers that make it an interdisciplinary field of study of the nature–society relationship. Important in most studies is the concept of adaptation – an ongoing process of adjustment as people cope with internal and external impulses, in the short or long term (Davidson-Hunt & Berkes, 2003; Schutkowski, 2006). The basic function of adaptation is 'to maintain a balance between population, resources and productivity' (Butzer, 1990, p. 696). We recognize that our choice of this theoretical approach to explaining land-use change is not without its limitations. For instance, Merchant (1990) argues that cultural-human ecology does not adequately specify the processes of social change that lead to environmental impacts, and do not account for the power relations that both maintain class structures and lead to social struggles to break them. Also, it does not account for the inequalities created by class relations, inequalities that do not give all people within a system similar choice; including environmental ones. Further, it assumes the unity and structure of systems, perhaps not recognizing that, like the platonic form, a system is nothing more than a conceptual framework with which we interpret the world (Briassoulis, 2000). Moreover, a cultural-human ecology perspective is 'a historical and does not account for the fact that environmental transformations are the product of decisions made in specific social systems and locational settings' (Merchant, 1990, pp. 675–676). The foregoing theoretical conceptualization is used to explain the drivers of land-use change and community perceptions of land-use change in the study context.

Materials and methods

Study area

The Karatu District is one of six districts in the Arusha Region. The district is located South of the Equator between latitudes 3°10′S and 4°00′S and longitudes 34°47′E and 35°56′E. It covers an area of 24,536 km^2, with an estimated population of 228,929 in 2009 (Karatu District Council Report [KDCR], 2008). The northern highlands of Karatu District were selected because this setting epitomizes the LULCC to which we have alluded. The area is adjacent to the Ngorongoro Conservation Area (NCA) which is ecologically rich in biodiversity. Moreover, the villagization policy was implemented in the area in the 1970s and it is interesting to ascertain how this policy may have contributed to land transitions in the area from that era till now. The study was done in two villages: Upper-Kitete in the high altitude (1500–1800 masl) and Ayalabe in the low altitude (1200 m–1500 masl) zones, respectively (Figure 2). Dominant tribes in the area include the Iraqw and Barbaig. Other ethnic groups are Hadzabe who are hunters and gathers, and the Maasai, who are the pastoralists.

Data collection

Both qualitative and quantitative data were collected for this study. Qualitative data comprised in-depth interviews (IDIs), field observation and focus group discussions (FGDs) that elicited information on community perceptions and coping strategies in response to land transitions in the study areas. Quantitative data comprised community surveys and Intensity Analysis.

In-depth interviews (IDIs), focus group discussions (FGDs) and community surveys

IDIs, FGDs, surveys, and transect walk and observation were carried out in the two study areas in 2010. Interviews (n = 50) were conducted in 30 and 20 households in Ayalabe and Upper-Kitete communities, respectively. One hundred and five individuals were involved in FGDs of which 56 and 49 were residents of Ayalabe and Upper-Kitete, respectively. Eight and seven FGDs each were conducted in Ayalabe and Upper-Kitete. Each FGD comprised seven individuals: two village leaders (VEO and Village chairperson), two farmers (male and female), one extension officer and two experienced and influential people (male and female) in each community. Transcriptions of the interviews were analysed according to the principles of grounded theory described by Strauss and Corbin (1990), using open and axial coding. The process involved breaking down, examining, comparing, labelling and categorizing data, then putting data back together in new ways by making connections between categories according to a coding paradigm comprising conditions, context, interactional strategies and consequences. Analysis of and interpretation of interviews were facilitated by the software NVIVO 9. The technique was useful in bringing to the fore, the perceptions and lived experiences of community members regarding changing livelihoods and land-use/cover changes that

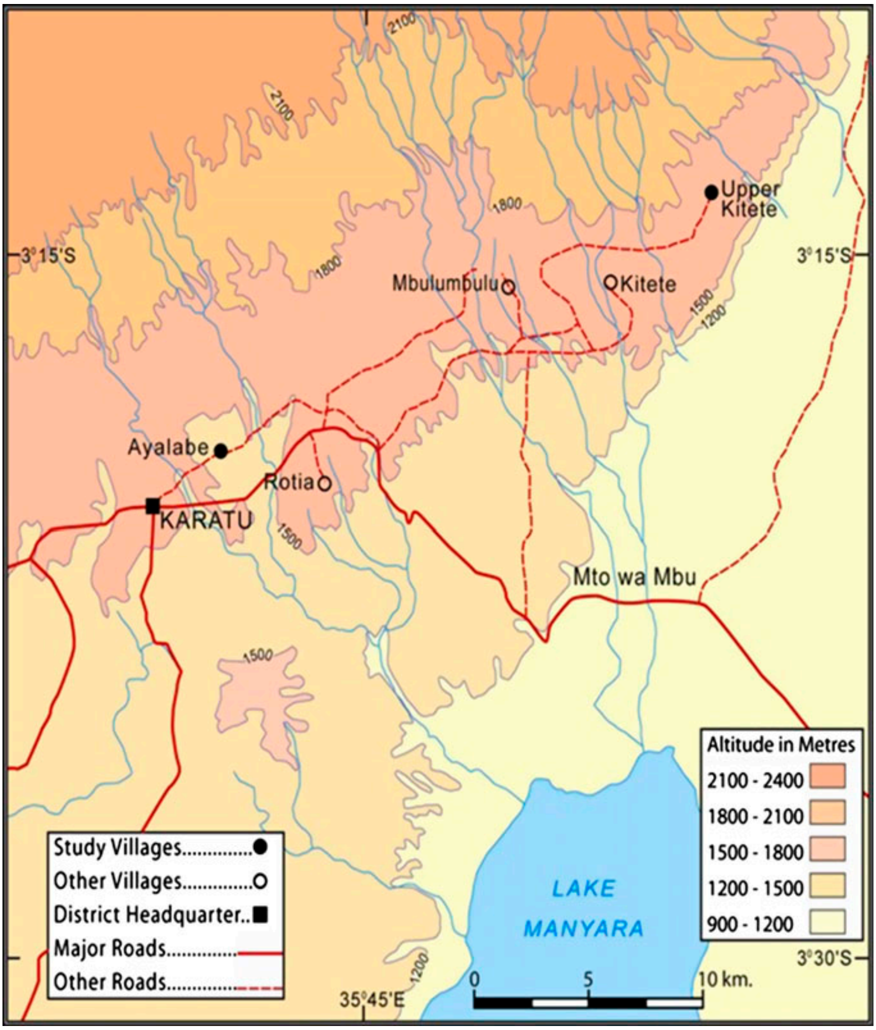

Figure 2. Map of the study area showing Upper-Kitete and Ayalabe communities, Tanzania.

were not articulated in the survey. The survey elicited household demographic and socio-economic information such as age, gender, occupation, educational level, marital status and land tenure: ownership, acquisition, size and control with time in relation to its use. Transect walk and observation involved taking photographs of the social, economic and agronomic activities, cultivation patterns, types of crops grown, grazing types and human impacts on land. This method was useful in providing pictorial evidence of land-use and land-cover changes in the study area in order to verify previous information obtained through the earlier mentioned techniques.

GIS and remote sensing techniques

Both primary and secondary data were collected using GIS and remote sensing techniques. Primary data included multi-year topography sheets for 1976, 1987 and 2008. Two field surveys were conducted in 2007 and 2008 in the study area to obtain ground truth data for 2008 land use/cover. An image from Google Earth and a false colour composite of IRS-LISS-III image (RGB 321) depicting different land cover types were printed on poster size papers and taken to the field. These colour hard copies were used to identify the existing land cover features and singular attention was paid to spectrally similar land covers on the IRS image. Thus, a ground truth map was prepared to locate the training pixels. Additionally, 200 reference points were recorded by a handheld GPS and put into a GIS for evaluating the accuracy of 2008 land-use/cover data.

Data processing and analysis

GIS database were constructed using ArcGIS 9.3 (ESRI, 2009). All images were pre-processed and underwent ortho-rectification and radiometric calibration to reduce atmospheric effects using ARCGIS 9.3. Image subsets were then made for the study area according to the limits of the Karatu District. Satellite data were processed by geometric correction, land-use/cover classification and accuracy assessment. Geometric rectification of the images was carried out using a master–slave approach (Jensen, 2005) since commercial satellite data contain errors that may inhibit efficient land-use/cover analysis. With the aid of a digital Landsat TM of 1997 as a reference, three satellite data (LANDSAT 1 MSS 1976, LANDSAT5 TM 1987, and LANDSAT 7 ETM+ 2008) were rectified to a common geometric system. A total of 61 ground control points was used in the rectification process. The root-mean-square error varied from .25 to .45 pixels. A first-order polynomial fit was applied and all the data were resampled to 30 m pixel size using the nearest neighbour method. Seven separable land-use/cover types were identified in this study as: water bodies, settlements, woodland, bushland, grassland, forest and open land (see Table 1). In all, five categories in the low altitude zones and the six categories in the high altitude zone were considered in this study. The classification scheme is coarse since detailed classes of some of the categories exist. For instance, woodland encompasses three detailed classes: open, closed and scattered with crops. However, the scheme suffices for our study since we were more interested in inter-category land transitions rather than intra-category land transitions.

In addition to ancillary information obtained from various sources, we also utilized documents on spatio-temporal characteristics of land use/cover. Prior to classification, all the images were studied thoroughly using the spectral and spatial profile tools available in ARCGIS 9.3 to ascertain the digital numbers of an image and their probable allocation into different land-use/cover categories. Then, a spectral signatures file was generated and used for each of three images: LANDSAT 1 MSS (1976), LANDSAT5 TM (1987) and LANDSAT 7 ETM+ (2008). Using information from the field, historical maps and high-resolution images, the known land-use/cover types were identified on the

Table 1. Land-use/cover change classification scheme.

Land-use/cover types	Description
Forest	Deciduous forest, mixed forest lands, palms, conifer and others
Woodland	Integral open space; tree cover of 10% or more
Bushland	Agricultural area, crop fields, fallow lands and vegetable fields
Grassland	Herbaceous shrub vegetation
Open land	Exposed soils, landfill sites and areas of active excavation
Water features	River, permanent open water, lakes, ponds and reservoirs
Built-up (settlement)	Residential, commercial and services, industrial, transportation, roads

image as class signature sample sites. It may be mentioned that the historical images were trained using the historical maps and topo-sheets. To determine the changes in land use/cover between image dates, a post-classification comparison of change detection was made. This technique is the most common approach to compare data from diverse sources and dates (Jensen, 2005). Using GIS overlay functions, a land-use transition matrix was computed and change statistics was calculated on a pixel-by-pixel basis. In order to assess the accuracy of land cover maps extracted from satellite data, stratified random sample strategy was employed, which is a measure of unbiased assessment (Jensen, 2005). A total of 200 pixels each was first generated for the 1976, 1987 and 2008 land cover data. A non-parametric Kappa test was used to measure the classification accuracy as it accounts for all the elements in the confusion matrix rather than the diagonal elements (Rosenfield & Fitzpatirck-Lins, 1986). The overall accuracy for land cover maps of 1976, 1987 and 2008 was 75.5, 78.6 and 80.5% with corresponding kappa statistics of .600, .625 and .639, respectively.

Transition matrix for each time interval

The first step in the quantitative analysis was to compute transition matrices in terms of the percentage of the study area for two time intervals: 1976–1987 and 1987–2008. The first two tables in the results section show the format of these matrices. The matrices give both the stocks and flows of the land categories. The stocks are numbers on the diagonal that indicate land persistence. The stocks also include the total column at the right and the total row at the bottom, which indicate the amount of each land class at the interval's initial and final times, respectively. The flows are the numbers off the diagonal that indicate land change. We extend the conventional matrix to include two additional types of flows: gross losses and gross gains. The gross losses are computed as the initial totals minus persistence, while the gross gains are computed as the final totals minus persistence. These matrices serve as the basis for the remainder of the analysis.

Land change summary for each time interval

Change in the percentage of landscape does not directly indicate the area of change per year because the number of years is different in each time interval (Huang et al., 2012). Therefore, we calculate the rate of change in terms of hectares per year. The total change for a category is the sum of its gross gain and its gross loss, as the first two tables in the results section demonstrate. The total change for a category can also be expressed as the sum of net change and swap change. The net change for a category is the absolute value of the difference between the category's gross gain and gross loss. Swap change is the total change minus the net change. The swap change for a category is a type of change whereby a category's gross gain at one place on the landscape occurs simultaneously with the category's gross loss at a different place on the landscape. The sum of the category totals double-counts the overall change because the loss of a category at the initial time is accompanied by the gain of a different category at the subsequent time. Thus, the overall total is one-half the sums of the category level totals (Huang et al., 2012). Similarly, the overall net is one-half the sum of the category level net, and the overall swap is one-half the sum of the category level swap (Pontius, Shusas, & McEachern, 2004). Tables representing the change in area per year are helpful; however, they do not show three important types of information. First, the tables do not show the interval's rate of change compared with the rate of change that would exist if the change were distributed uniformly from 1987 to 2008. Second, they do not show the amount of each category's gross gain and gross loss relative to the size of the category. Therefore, we cannot tell whether a gross gain or gross loss is large simply because the category accounts for a large portion of the landscape or because the category experiences change more intensively than the other categories. Third, the tables of gross gain, gross loss, net and swap do not show any specific transitions from one category to another category. For these three reasons, we perform three levels of Intensity Analysis, which are presented in the next subsection.

Intensity Analysis

Intensity Analysis was conducted at the interval, category and transition levels. The interval level examines how the size and rate of change varies across time. For any particular time interval, the category level examines how the size and intensity of gross losses and gross gains in each category vary across categories. For any particular category, the transition level examines how the size and intensity of the category's transitions vary across the other categories that are available for that transition. At each level, the method tests for the stationarity of patterns across time intervals (Aldwaik & Pontius, 2012). For Intensity Analysis across time intervals, stationarity means that the pattern at one time interval is the same as the pattern at the other time intervals, where the pattern is defined with respect to uniform intensities, as we explain below.

The interval Intensity Analysis examines how the annual area of overall change varies across the three time intervals. Here, we computed the area of change per year for each time interval and compared it to a uniform rate of change that would exist if all the changes were distributed uniformly across the study's entire time extent. Huang et al. (2012) and Aldwaik and Pontius (2012) present a comprehensive account on the notation and equations for the Intensity Analysis. The category level of Intensity Analysis examines how the intensity of change varies among categories. The analysis computes the intensity of annual gross gains and annual gross losses for each category and then compares them with a uniform intensity of change that would exist if the overall change was distributed uniformly across the landscape. This assessment is performed for each time interval. It was also important to perform transition Intensity Analysis because we want to observe whether there is a systematic relationship between the two transitioning categories relative to the sizes of all categories (Huang et al., 2012). The transition Intensity Analysis consisted of two parts: (1) analysis of the gaining category and (2) analysis of the losing category. The transition level Intensity Analysis of the losing category explained the sizes of the transitions from the losing category relative to the stock of the other categories.

Systematic processes of land transitions

A transition is said to be uniform when a land-cover type gains from other categories in proportion to the availability of those other categories at time *t*1 or when a land-cover type loses to other categories in proportion to the sizes of those other categories at time *t*2. A transition is said to be systematic if the observed transition deviates from the uniform transition as computed by the Intensity Analysis (Aldwaik & Pontius, 2012; Alo & Pontius, 2008; Huang et al., 2012). If category A loses systematically to category B and category B gains systematically from category A, then it may be concluded that there is a systematic process of transition from A to B (Alo & Pontius, 2008).

Table 2. Net change and swap change of each category for two time intervals: 1976–1987 (in bold) and 1987–2008 (in italics) in both agro-ecological zones*.

		Final year of time interval				
		Gross losses	Gross gains	Net change	Total change	Swap change
Low altitude agro-ecological zone (five categories)						
	Woodland	**9346**	**11,386**	**2040**	**20,732**	**18,692**
		11,540	*8730*	*(2810)*	*20,270*	*23,080*
	Bushland	**14,709**	**12,404**	**(2305)**	**27,113**	**29,418**
Initial year of time interval		*12,680*	*13,605*	*925*	*26,285*	*25,360*
	Grassland	**30,772**	**16,327**	**(14,445)**	**47,099**	**61,544**
		19,898	*16,488*	*(3410)*	*36,386*	*39,796*
	Cultivated	**8816**	**23,286**	**14,470**	**32,102**	**17,632**
		19,543	*23,788*	*4245*	*43,331*	*39,086*
	Others	**9541**	**9781**	**240**	**19,322**	**19,082**
		9523	*10,573*	*1050*	*20,096*	*19,046*
High altitude agro-ecological zone (six categories)						
	Woodland	**74,065**	**79,957**	**5892**	**154,022**	**148,130**
		78,204	*82,830*	*4626*	*161,034*	*156,408*
	Bushland	**51,665**	**51,725**	**60**	**103,390**	**103,330**
		54,034	*40,120*	*(13,914)*	*94,154*	*108,068*
Initial year of time interval	Grassland	**78,416**	**52,562**	**(25,854)**	**130,978**	**156,832**
		58,524	*48,606*	*(9918)*	*107,130*	*117,048*
	Cultivated	**44,980**	**74,062**	**29,082**	**119,042**	**89,960**
		65,599	*87,295*	*21,696*	*152,894*	*131,198*
	Others	**38,277**	**38,193**	**(84)**	**76,470**	**76,554**
		38,360	*37,442*	*(918)*	*75,802*	*76,720*
	Forest	**83,507**	**74,411**	**(9096)**	**157,918**	**167,014**
		76,189	*74,617*	*(1572)*	*150,806*	*152,378*

*Net change in brackets indicates net loss.

Results

Gross patterns of land change in the two agro-ecological zones

Table 2 provides information about the annual area of gross gain, gross loss, net and swap for each category and overall in the low and high altitude zones.

In the low altitude zone, woodland shows a net gain in the first time interval and then shows a net loss in the subsequent time interval. Bushland first loses, then gains in the second interval. Grassland loses in both time intervals whereas cultivated and others gained in both time intervals. The swap change is larger than the net change for all five categories for both time intervals. In the high altitude zone, woodland shows a net gain in both time intervals likewise cultivated. However, grassland, others and forest showed net losses in both time intervals. Bushland showed a net gain in the first interval and a net loss in the second time interval. The swap change is larger than the net change for all six categories for both time intervals in the high altitude zone.

Land persistence

During the first interval in the low altitude zone, 812, 2939, 9601, 4602 and 342 ha of land persisted as woodland, bushland, grassland, cultivated and others, respectively (diagonals in Table 3). During the second interval in the same agro-ecological zone, 658, 2663, 6030, 8345 and 600 ha of land persisted as woodland, bushland, grassland, cultivated and others, respectively (diagonals in Table 3). During the first interval in the high altitude zone, 19,960, 7302, 14,199, 11,215, 572 and 20,934 ha of land persisted as woodland, bushland, grassland, cultivated, others and forest, respectively (diagonals in Table 3). During the second interval in the high altitude zone, 21,713, 4993, 8273, 19,678, 405 and 19,156 ha of land persisted as woodland, bushland, grassland, cultivated, others and forest, respectively (diagonals in Table 3).

Intensity Analysis (low altitude agro-ecological zone)

The extent of the various land-use/cover types between 1976 and 2008 in the low altitude zone (Ayalabe) is shown in Table 3 and their respective spatial distributions are shown in Figure 3.

Interval level

Generally, observed overall change during the first (1976–1987) and second (1987–2008) time intervals are relatively the same (80%). However, the change in the first interval was rapid unlike during the second interval.

Category level

During the first interval, annual gains were only observed in grassland whereas during the second interval, grassland and cultivated areas gained. In terms of gain intensities during the first interval, all categories were relatively active compared to uniform except grassland, which was relatively dormant compared to uniform. During the second interval, grassland and cultivated were dormant compared to uniform while the other categories were active compared to uniform. Cultivated had the largest size in terms of gross gains during the first and second intervals. During both intervals, annual losses were observed in both grassland and cultivated. The intensity of the both losses was dormant compared to uniform. Grassland had the largest size in terms of annual losses during both intervals and these have also slowed.

Table 3. Pixel counts of persistence on the main diagonal (underlined) and change off the main diagonal for two time intervals: 1976–1987 (in bold) and 1987–2008 (in italics) in both altitude zones.

		Final year of time interval						
		Woodland	Bushland	Grassland	Cultivated	Others	Initial total	Gross losses
Low altitude agro-ecological zone (five categories)								
	Woodland	**812**	**1441**	**3558**	**3950**	**397**	**10,158**	**9346**
Initial year of time interval		*658*	*2034*	*3284*	*5207*	*1015*	*12,198*	*11,540*
	Bushland	**2310**	**2939**	**5056**	**5448**	**1895**	**17,648**	**14,709**
		1287	*2663*	*3913*	*5836*	*1644*	*15,343*	*12,680*
	Grassland	**6855**	**7484**	**9601**	**9993**	**6440**	**40,373**	**30,772**
		3404	*4780*	*6030*	*7953*	*3761*	*25,928*	*19,898*
	Cultivated	**1464**	**2093**	**4210**	**4602**	**1049**	**13,418**	**8816**
		3796	*5172*	*6422*	*8345*	*4153*	*27,888*	*19,543*
	Others	**757**	**1386**	**3503**	**3895**	**342**	**9883**	**9541**
		243	*1619*	*2869*	*4792*	*600*	*10,123*	*9523*
Final total		**12,198**	**15,343**	**25,928**	**27,888**	**10,123**	**91,480**	**73,184**
		9388	*16,268*	*22,518*	*32,133*	*11,173*	*91,480*	*73,184*
Gross gains		**11,386**	**12,404**	**16,327**	**23,286**	**9781**	**73,184**	
		8730	*13,605*	*16,488*	*23,788*	*10,573*	*73,184*	

High altitude agro-ecological zone (six categories)		Woodland	Bushland	Grassland	Cultivated	Others	Forest	Initial total	Gross total
Initial year of time interval	Woodland	**19,960**	**13,145**	**14,434**	**17,520**	**9768**	**19,198**	**94,025**	**74,065**
		21,713	*11,808*	*13,763*	*22,118*	*10,597*	*19,918*	*99,917*	*78,204*
	Bushland	**14,117**	**7302**	**8591**	**11,677**	**3925**	**13,355**	**58,967**	**51,665**
		14,898	*4993*	*6948*	*15,303*	*3782*	*13,103*	*59,027*	*54,034*
	Grassland	**19,725**	**12,910**	**14,199**	**17,285**	**9533**	**18,963**	**92,615**	**78,416**
		16,187	*6282*	*8237*	*16,592*	*5071*	*14,392*	*66,761*	*58,524*
	Cultivated	**13,655**	**6840**	**8129**	**11,215**	**3463**	**12,893**	**56,195**	**44,980**
		19,273	*9368*	*11,323*	*19,678*	*8157*	*17,478*	*85,277*	*65,599*
	Others	**10,764**	**3949**	**5238**	**8324**	**572**	**10,002**	**38,849**	**38,277**
		11,521	*1616*	*3571*	*11,926*	*405*	*9726*	*38,765*	*38,360*
	Forest	**21,696**	**14,881**	**16,170**	**19,256**	**11,504**	**20,934**	**104,441**	**83,507**
		20,951	*11,046*	*13,001*	*21,356*	*9835*	*19,156*	*95,345*	*76,189*
Final total		**99,917**	**59,027**	**66,761**	**85,277**	**38,765**	**95,345**	**445,092**	**370,910**
		104,543	*45,113*	*56,843*	*106,973*	*37,847*	*93,773*	*445,092*	*370,910*
Gross gains		**79,957**	**51,725**	**52,562**	**74,062**	**38,193**	**74,411**	**370,910**	
		82,830	*40,120*	*48,606*	*87,295*	*37,442*	*74,617*	*370,910*	

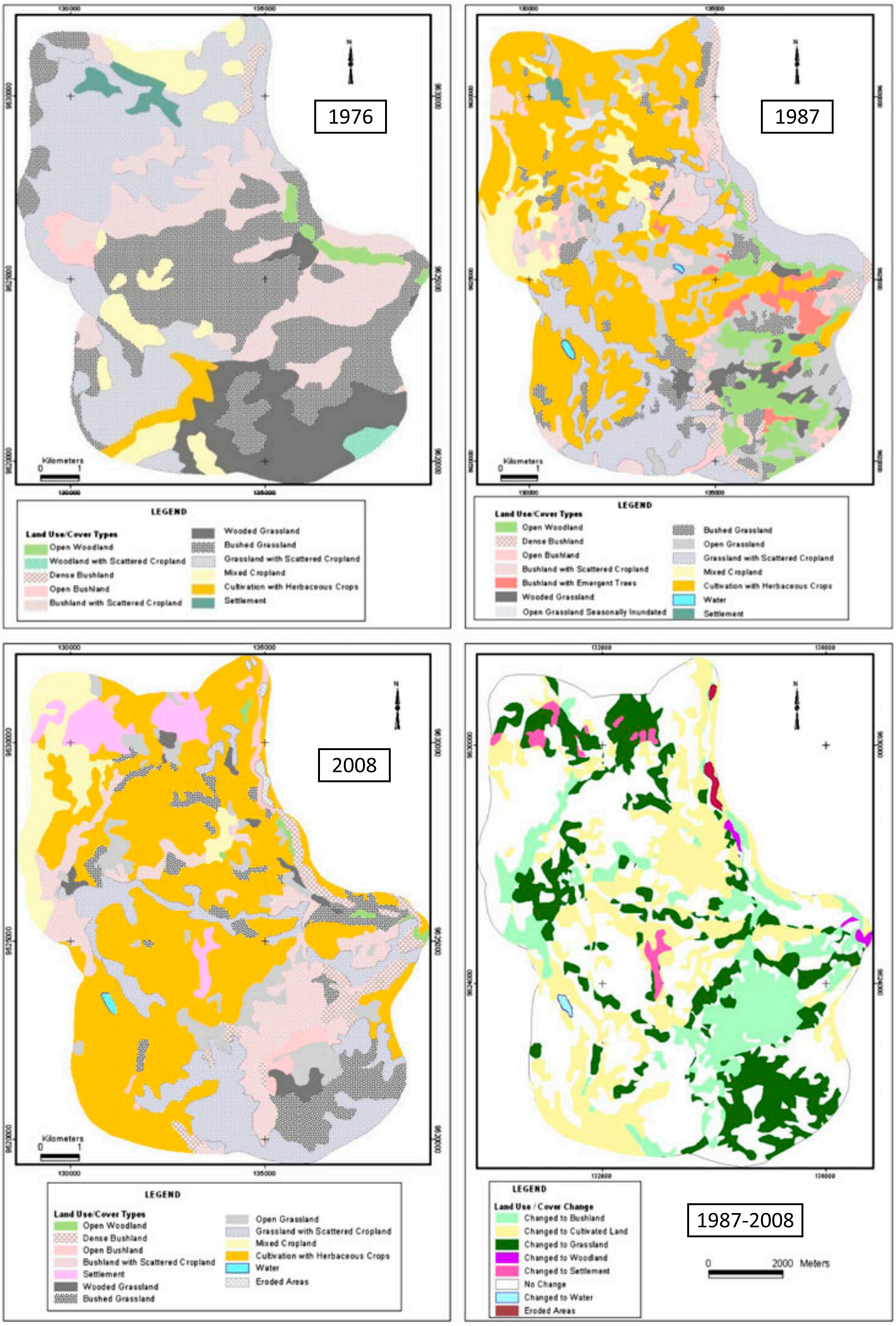

Figure 3. Land-use/cover types and changes between 1976 and 2008 in the low altitude zone.

Transition level

During the first interval, all categories except grassland make transitions to woodland. The intensities of these transitions are dormant compared to uniform. Similarly, all categories except grassland make transitions to bushland and the intensities are dormant compared to uniform. Also, bushland and cultivated make transitions to grassland during the first interval and the intensities are dormant compared to uniform. Only grassland makes transitions to cultivated areas during the first interval. All categories except grassland make transitions to other (e.g. settlement). During the second interval, other and bushland make transitions to woodland unlike the remaining categories. Similarly, woodland and others make transitions to bushland. During the same period, only cultivated make transitions to grassland.

Intensity Analysis (high altitude agro-ecological zone)

The extent of the various land-use/cover types between 1976 and 2008 in the high altitude zone (Upper-Kitete) is shown in Table 3 and their respective spatial distributions are shown in Figure 4.

Interval level

Observed annual change in each of the time intervals is 83.3%. The change in the first interval was fast unlike in the second interval. Systematic change occurred in the second interval. The patterns of change during the two time intervals (1976–1987 and 1987–2008) were stationary for both agro-ecological zones.

Category level

During the first interval, annual gains were made by woodland, grassland and forest. The intensities of the gains were dormant compared to uniform. During the second interval, cultivated gained in addition to woodland and forest. Woodland had the largest size in terms of gross gains during the first interval unlike in the second interval during which cultivated had the largest size. Forest had the largest size of gross losses during the first interval. However, woodland had the largest size of gross losses during the second interval. We argue that during the first interval, the population encroached on forest but programmes (e.g. afforestation) were initiated during the second interval to reverse this trend.

Transition level

During the first interval, grassland and forest made transitions to woodland and the intensities were dormant compared to uniform. Cultivated and others made transitions to bushland. Similarly, cultivated, others and bushland made transitions to grassland. During this same period, bushland and cultivated also made transitions to others (e.g. settlement). During the second interval, cultivated and forest made transitions to bushland. Wood land and cultivated made transitions to forest; this is indicative of the afforestation programmes that were initiated during this era).

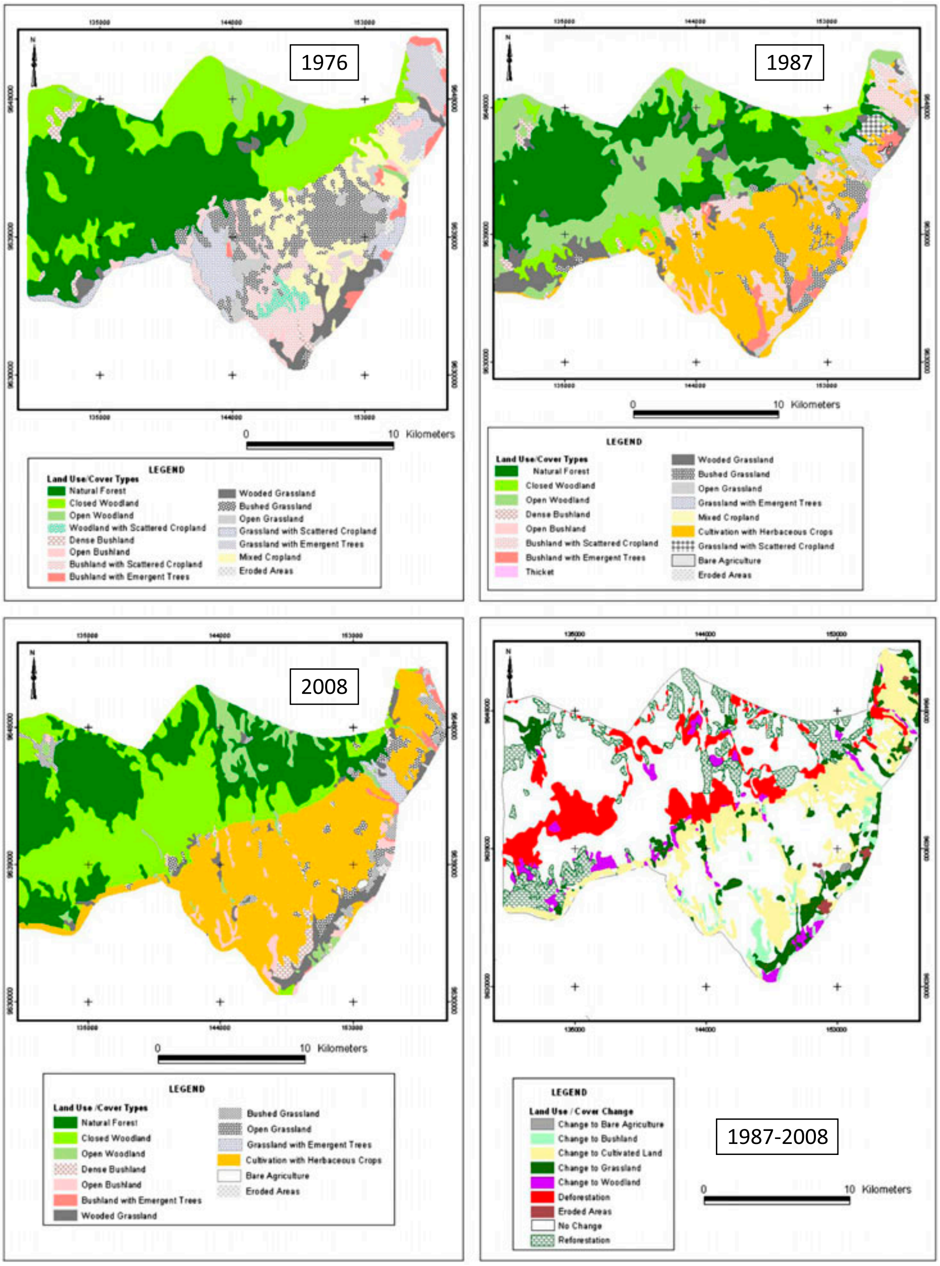

Figure 4. Land-use/cover types and changes between 1976 and 2008 in the high altitude zone.

Perceptions of communities, livelihoods and coping strategies in response to land-use change

Demographic characteristics of participants

Table 4 shows the age composition of respondents by gender, education levels, occupation type, household size and reasons for migration in Ayalabe and Upper-Kitete communities.

Table 4. Community demographics and sample characteristics in Ayalabe and Upper-Kitete.

Socio-demographic variables	Ayalabe, *N* (%)	Upper-Kitete, *N* (%)
Males – Age		
≤17	1054 (26.2)	1227 (26.8)
18–35	346 (8.6)	374 (8.1)
36–45	219 (5.4)	279 (6.1)
46–64	221 (5.5)	257 (5.6)
65+	76 (1.9)	93 (2.0)
Females – Age		
≤17	1130 (28.2)	1235 (27.0)
18–35	365 (9.1)	383 (8.4)
36–45	256 (6.4)	342 (7.5)
46–64	249 (6.2)	278 (6.1)
65+	96 (2.4)	109 (2.4)
Education		
No education	7 (10.0)	11 (18.0)
Primary	34 (48.0)	26 (44.0)
Secondary	14 (20.0)	10 (16.0)
Certificate	4 (6.0)	4 (6.0)
Diploma	3 (4.0)	2 (4.0)
Adult education	8 (12.0)	7 (12.0)
Occupation		
Peasant	56 (80)	46 (76.0)
Formally employed	8 (12)	4 (6.0)
Business	4 (5)	8 (14.0)
Others	2 (3)	2 (4.0)
Household size		
1–3	12 (17.0)	8 (13.0)
4–6	30 (43.0)	40 (67.0)
7–9	16 (23.0)	9 (15.0)
10+	12 (17.0)	3 (5.0)
Reasons for migration		
Villagization	15 (21.0)	35 (57.0)
Scarcity of agric land	17 (24.0)	11 (18.0)
Plantation economy	16 (23.0)	4 (7)
Search for grazing land	5 (7.0)	4 (7)
Joining the family	8 (11.0)	4 (7)
Drought in area of origin	6 (9)	1 (2)
Security/insecurity	3 (5)	1 (2)

Perceptions and coping strategies to land-use change at the household level in Ayalabe and Upper-Kitete

There was a general consensus that natural forest has declined significantly between 1976 and 2008. A 68-year old man in the FGDs commented that:

> … the decline in forest cover was mainly due to population increase which has resulted into the high demand of forest products such as timber and building poles.

Farmers in both communities have devised several strategies to cope with the effects of land-use changes. These include crops diversification, intensive farming practices and introduction of improved livestock breeds, non-agrarian activities and out-migration (Table 5). The diversification of agriculture is more evident in the low altitude zone (Ayalabe village) than in Upper-Kitete. About 18 and 17% of residents from Ayalabe

Table 5. Summary of responses from FGDs and IDIs in both Ayalabe and Upper-Kitete.

Response	Number of mentions (number of participants)	
	FGD (n = 105)	IDI (n = 50)*
Perceptions and understandings of land-use change		
Have no idea what LULCC is	56 (12)	–
It is driven by population increase	287 (93)	50 (14)
It is driven by overgrazing	167 (80)	18 (4)
It caused by dysfunctional policy	49 (15)	13 (7)
It is through abandonment/conservation	186 (76)	5 (2)
LULCC has caused emergence of new diseases	51 (10)	56 (13)
LULCC is complex and multi-faceted	13 (4)	41 (13)
Little knowledge of LULCC at local level	57 (10)	18 (7)
Growing problem	134 (25)	61 (14)
LULCC is driven by existing land tenure system	35 (6)	15 (5)
Linkage of LULCC and livelihoods		
Intensification has positively affected my livelihood	79 (35)	23 (7)
Intensification has negatively affected my livelihood	56 (28)	17 (10)
Migration has positively affected my livelihood	101 (45)	49 (25)
Migration has negatively affected my livelihood	75 (30)	23 (11)
Diversification has positively affected my livelihood	132 (70)	45 (12)
Diversification has negatively affected my livelihood	56 (34)	24 (9)
Use of substitutes has positively affected my livelihood	50 (15)	12 (4)
Use of substitutes has negatively affected my livelihood	12 (7)	4 (2)
Non-agrarian activities have positively affected my livelihood	70 (23)	16 (7)
Non-agrarian activities have negatively affected my livelihood	24 (15)	7 (3)
Reasons for migrating		
Villagization	185 (76)	33 (14)
Lack of agricultural land	175 (70)	92 (43)
Plantation economy	41 (13)	59 (13)
Reunion with family	19 (4)	21 (14)
Drought in area of origin	163 (77)	173 (41)
Security/insecurity	49 (38)	26 (8)
Political neglect of the region	89 (35)	36 (11)
Lack of policy awareness and interest by government	15 (3)	23 (13)
Strategies to increase public awareness and reduce LULCC		
Robust land-use management strategies	78 (33)	54 (14)
Equitable and locally appropriate land tenure regimes	69 (27)	29 (13)
Advocacy (intense and sustained broadcast through radio)	65 (37)	36 (11)
Credible stakeholder engagement process	47 (29)	28 (13)
Effective governance and policy action	43 (22)	21 (11)
Regional planning and landscape management systems	39 (21)	19 (13)

*The numbers reflect the different issues that were talked about by the local residents and key informants.

village and Upper-Kitete community, respectively, had diversified livelihoods in terms of types of crop cultivated and livestock keeping. Before the introduction of wheat, the dominant crops were maize, beans and millet. Other crops that have been introduced recently are pigeon peas, sorghum and sunflower as they are resistant to drought. Based on informal observation made by village leaders, farmers in the low altitude zone have few numbers of cattle and goats despite the fact that milk, meat and manure are still some of the most needed resources for food and fertilizers. The study revealed that 12% of the respondents in the low altitude zone (Ayalabe community) have an average of two to three dairy cattle, which was introduced in the late 1980s to replace the African

Zebu cattle as grazing land became scarce in the area. The respondents added that they prefer improved cattle breeding because recently, veterinary services in the village have been made available with support from Ngorongoro Conservation Authority (NCA) under subsidized costs to farmers. However, in the highland zone, the majority of livestock holders (58%) still keep indigenous cattle. They argued that despite the continuous decline in grazing land, they prefer indigenous cattle, as they are more resistant to diseases and drought which hit the area periodically.

Regarding preference of indigenous cattle, a 67-year old female in Upper-Kitete community had this to say:

> … I prefer indigenous cattle to exotic ones, as they are resistant to diseases and drought. My family, also, is not able to meet the cost of keeping improved cattle, especially, the high initial costs in establishing stall structures and difficulties in acquiring fodder in this situation of dynamic weather in our village nowadays …

About 11 and 8% of respondents from Ayalabe village and Upper-Kitete village, respectively, reported that they have undertaken intensified farming systems, in response to the problem of land scarcity and increased population requirements. Modern and better equipment like tractors, combine harvesters and oxen were used in both study areas. Manure and chemical fertilizers were also applied to relatively fertile soil to support sustained cultivation.

About 9 and 6% of respondents in Ayalabe village and Upper-Kitete villages, respectively, used substitute building materials to cope with deforestation. The decline in woodland and bushland in both communities, due to agricultural activities, has forced people to seek for alternative building materials. The communities engaged in making burnt bricks to supplement household income as well as wood building materials. A large number of burnt brick houses were mainly observed in Ayalabe village, where there is declined forest/woodland cover near the village compared to Upper-Kitete village in the high altitude zone. The households also use crop residues such as maize and pigeon peas to substitute firewood and charcoal fuels. These coping mechanisms have provided alternative ways of forest/woodland land-use/cover conversion.

About 31% of the respondents in both villages reported that some members in their household have migrated to towns (Karatu and Arusha) to seek employment. They, further, explained that others have migrated to Tanga and Morogoro rural areas where there is sufficient land for cultivation and for grazing. Agriculture was the dominant activity in the area. Diversification in the sense of changing activities from farming is limited in the study areas. Most respondents (49%) engaged in petty business including 20% that were engaged in brick making. About 16% of the respondents engaged in masonry and carpentry activities to supplement household income. Fifteen per cent were employed as security guards in Karatu town and private companies. All individuals currently engaged in non-agrarian livelihoods were originally farmers.

Generally, it was observed that, most of the respondents engage in non-agrarian activities to supplement household incomes that have deteriorated due to crop production decline and price fluctuations. Although people engaged in off-farm activities, they were still tied to farming activities. A 60-year old woman in Ayalabe community said that:

> … farming is all that I know how to do. My people have always been farmers. I don't know how I can earn a living outside farming …

This statement reflects a cultural attachment to livelihoods. The explanation given by a female farmer in Ayalabe village aged 65 regarding the fall in prices of agricultural products is that:

> … I have engaged in non-agricultural activities (Petty business) since the 1990s due to decline in agricultural production resulting from periodic droughts and anticipated market prices to supplement household income. The decline in agricultural production is also due to the decreased land under cultivation owned by households as it was fragmented to small portions to meet the needs of increased number of males …

During the FGD, one male member of Ayalabe village aged 70 commented that:

> the decline in hectares converted to cultivation and grassland can be explained by the fact that between 1980s and 1990s, the people were more settled and had established permanent settlements (sedentary community), compared to the period between 1960s and 1970s when people were still in-migrating to the area and opening new farms as well as grazing land …

Some changes in land use have resulted in improvement on vegetation cover. One male interviewee in Ayalabe village aged 65 said that:

> … This abandonment was reinforced by villagization policy which initially forced people to move to 'Ujamaa villages' and left their family land but later on in 1980s, people claimed to return to land originally owned by their ancestors due to the policy failure. This has created land conflicts among the villagers who wanted to reclaim their former land. Even now some villagers are not sure of the ownership of their land as they are waiting for court judgment …

Two major reasons were assigned for land conversion, that is, in-migration into the area resulting from the villagization scheme of 1963 and secondly, the provision of free farming inputs by the government to the farmers. A female interviewee aged 58 from Upper-Kitete village alleged that:

> … The introduction of farm inputs subsidies in 1963 like fertilizer, pesticides and seeds encouraged the farmers to engage in farming activities which led to the vegetation clearance in this area. On the other hand, the Rift Valley Co-operative Union (RIVACU), the only place we sold our crops, has been able to offer reasonable prices …

Many people from different areas were attracted into the study areas resulting in an annual population growth rate of 6.7% (1978–1988) which is higher than the district annual increase of 3.3%.This implies that, farmers benefited from the increased acreages under cultivation, which stimulated the vegetation clearance.

In explaining the change of bushland and woodland to grassland, a 79-year old male pastoralist observed that:

> … when we arrived here in the early 1970s, we cleared the forest land, woodland and bush land to eradicate tsetsefly, a threat to our livestock …

The village leaders further added that, farmers and pastoralist used the bushland, woodland and forest as sources of firewood/charcoal and building materials during villagization. This, also, contributed to deforestation in the area.

Discussion and conclusions

Intensity Analysis

This is one of the first studies to use Intensity Analysis to determine the nature and extent of LULCC in the Karatu Highlands of Tanzania. In both agro-ecological zones, land change was rapid during the first interval and slowed during the second. The swap change is larger than the net change for all five categories in the low altitude zone and the six categories in the high altitude zone for both time intervals. This result indicates that most of the land change in all five categories in the low altitude zones and the six categories in the high altitude zone is attributable to spatial reallocation rather than net quantity change (Huang et al., 2012). Aggregation of detailed classes of woodland (open, closed and scattered with crops) and detailed classes of bushland (dense, open, scattered with crops) works well as it simplifies the swap change and still keeps the important transitions to other categories. This aggregation works well since we wanted to focus only on the overall category but not detailed classes of each category. Nevertheless, if researchers are interested in studying how different types of bushland or woodland were replacing each other or how developed land with different levels of intensity interacts with each other, the aggregation is not recommended.

Intensity Analysis showed that in the low altitude zone, woodland, others and bushland were active compared to uniform. We suggest that the fast change in land during the first interval may be attributed to the villagization policy in the 1970s that sought drive the population towards rural settlements. This suggestion is consistent with Kabanza et al. (2013) who argued that rural development and land-use policies are a local driver of LULCC in Tanzania. The 'villagization' policy affected the distribution of people and land-use/cover with, as a first obvious consequence, the creation of large, semi-urban villages. This policy also affected land tenure, whereby people claiming descendance from first settlers have the strongest control over access to land (Kabanza et al., 2013).

Also, tsetsefly infestation in the 1950s forced people in the Mbulu highlands to migrate to the Karatu highlands. In the second interval, there was economic decline in Tanzania that culminated in the introduction of structural adjustment programmes (SAPs). SAPs stimulated two simultaneous processes (diversification and intensification). People were assisted to engage in alternative livelihoods thereby reducing the pressure on the land. At the same time, people were assisted to increase agricultural productivity with minimum input. Additionally, it was during this era that people started migrating to cities in search of alternative livelihoods. It is, therefore, unsurprising that population density in the low altitude zone is 15–30 persons/km^2. The population density (3–6 persons/km^2) in high altitude agro-ecological zone is even much lower than in the low altitude zone.

Winter and Molyneaux (1963) estimated that the population growth in Karatu has been as high as 2.4% for at least 100 years. This is a quite remarkable growth rate, even within the African context. Yet, when we want to explain local changes in agricultural practices, the growth rate in itself plays but a minor role. Indeed, we found no significant correlations between population increase and forest cover ($r = .074$, $p > .05$) in the high altitude zone. It is true that population pressure in Karatu led to the development of a much intensified agriculture, where soil conservation played an important role. However, the decisive factor in this process seems not to be the growth rate, but the ecological and political factors that constrained their migration out of Karatu.

Rohde and Hilhorst (2001) argue that the increase in the hectares under cultivation in Karatu highlands was the result of economic liberization under SAPs of the early 1980s. The same observation was made by Borjeson (2004), to the effect that features of SAPs such as market liberation, price and institutional reforms have contributed to the change in land use from grassland and bushland to permanent cultivation as farmers need to produce more to get more outputs to sell. This situation enhances the occupation of marginal areas as farmers need to compensate for the land under conflict to meet food demand for the returned population. There were no significant changes in areas under woodland as they were maintained and conserved under NCA soon after independence in 1961 (Borjeson, 2004). Generally, farmers have maintained their household land uses between 1987 and 2008 compared to the period 1976–1987. This is, probably, due to coping mechanisms adopted by community members in response to land-use/ cover changes.

Community perceptions and responses to land-use change

The introduction of wheat in both communities reflects diversification from traditional crops. Its adoption was quick since it promotes household income (KDCR, 2008). Meindertsma and Kessler (1997) noted that improved cattle were introduced in the study areas so as to control animal numbers and their mobility. Population increase has not only resulted in the deterioration of agro-ecosystems but also the decline of the agro-ecosystems' capacity to support livestock numbers (Hyden, Kates, & Turner, 1993). Related to the dairy cattle is the introduction of new types of grass such as elephant (*Pennisetum purpureum*) and Guatemala grasses (*Tripsacum fasciculatum*) used for feeding cattle. However, rainfall fluctuation in the area has limited fodder production, which was supplemented by brewing residues, maize stove, wheat stocks, beans and cowpeas residues (KDCR, 2008). The application of soil-water conservation in the area has contributed to the healing of eroded areas to cultivation. However, Kikula (1996) associated healing of eroded areas with the out-migration of pastoralists and introduction of zero grazing in the area. This study shows that healing of eroded areas has increased by 43 ha between 1976 and 1987 and by 126 ha between 1987 and 2008. These findings imply that the changes in land-use/cover types are more evident in the period between 1976 and 1987 than in the period between 1987 and 2008 due to the established settlement schemes and ecological factors.

Apart from intensive farming, improved soil management techniques such as grassed contour, sisal and euphorbia fences around cropland, bench terraces and diversion canals were also adopted (Meindertsma & Kessler, 1997). As observed by Kweka (2004), changes from extensive traditional farming to intensive farming were an effort towards combating land degradation and food insecurity caused by population pressure on land resources. However, intensive agriculture in the study areas appears to be ineffective due to the ongoing land degradation emanating from poor and mismanaged new technologies introduced. The main reasons for out-migration were the periodic droughts, and population increase that has resulted in land scarcity in the area. Mbonile, Missana, and Sokoni (2003) observed that the increase of absentees due to out-migration of labour power in the rural areas has led to poor farm management and abandonment of farms, and thus, land-use/land cover change. However, some households interviewed indicated that out-migration was the last option after failure of other coping mechanisms.

The overall amount of land change has been decelerating, which reflects a successful land-use policy and diversification from agriculture. Population densities in both agro-ecological zones were relatively very low, hence, the lack of relationship between population increase and forest cover decline in the high altitude agro-ecological zone. In the low altitude zone during the first interval, grassland (68%) and bushland (19%) were the two largest categories in the landscape while cultivated area was only 9% initially but increased to 40% of the landscape by the end of the interval. During the second interval, cultivated increased to about 50% of the landscape by gaining from grassland. Our study shows that the transition from grassland to cultivated is a systematic transition in which the gaining category targets the losing category and the losing category is targeted by the gaining category. This systematic transition from grassland to cultivated can be partially explained by examining the spatial distribution of the categories. Cultivated areas are typically surrounded by grassland in the study area and thus, if cultivated expands spatially, then it is likely to take over grassland. Similarly, in the high altitude zone during the first interval, cultivated to a large extent, systematically, gained from grassland and gained to a lesser extent from bushland. During the second interval, forest remained virtually stable.

The patterns of change during the two time intervals (1976–1987 and 1987–2008) were stationary for both agro-ecological zones. Based on the findings, we suggest that government and other stakeholders should identify land-use options that can better achieve human development and sustainable goals; better understand the trade-offs involved in environment-related decisions, and align land-use change response options at all scales, from the local to the national, where they can be most effective.

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