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Multitemporal remote sensing of landscape dynamics and pattern change in Dire district, southern Ethiopia

Berhanu Keno and K. V. Suryabhagavan*
*School of Earth Sciences, Addis Ababa University, Addis Ababa, P.O. Box 1176, Ethiopia
*Email: drsuryabhagavan@gmail.com

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Abstract: Improper land-use results in land degradation and decline in agricultural productivity. In order to get maximum benefits out of land, proper utilization of its resources is inevitable. The present study was aimed to identify land-cover changes in the study area during a period of 25 years (1986-2011) and to determine the extent and direction where changes occurred. The study made use of Landsat TM remote sensing satellite images of 1986 and 2011 to determine the extent and pattern of rangeland changes. Results of the land-use/land-cover changes revealed that grass land and open shrub land resource decreased significantly at a rate of 17.1 km^2/year and 12 km^2/year, respectively. On the other hand dense bush land, open bush land, dense shrub land and cultivated land have shown increase in the extent at a rate of 10.18 km^2/year, 13.53 km^2/year, 6.3 km^2/year and 0.2 km^2/year, respectively within 25 years. The expansion of unpalatable woody species reduced significantly the rangeland size and availability of grasses. The consequence of the decrease in herbaceous biomass production might result in the high risk of food insecurity in the area unless proper interventions are made in time.

Keywords: Dire district, Landsat TM, Land-use/land-cover, Multitemporal, Remote sensing.

1. Introduction

Human interventions in natural habitats are facilitating ecosystem changes as a whole and land-cover changes (LCC) in particular at a faster rate. In particular, land-cover change is a dynamic phenomenon occurring within the interface between human, agricultural and ecological systems (Manson, 2005). Detection of changes of habitats is an important application of Remote Sensing, providing information to make decisions regarding resource management, and prediction of future environmental conditions (Steve et al., 2008). It involves remotely sensed multi-temporal data sets to discriminate areas of land-cover changes between different periods of imagining (Misrak et al., 2012; Lillesand et al., 2004). According to Geist (2006), it is the process of extracting the type, amount, location and configuration of changes on land-cover pattern with respect to time. Similarly, digital change detection is a method of identifying and quantifying differences in the state of an object or phenomenon from multi-date imagery (Singh, 1989). In general, changes in vegetation are the most direct indicator of land degradation (Yang et al., 2005). One of the primary applications of remote sensing in the rangelands is prediction of production potential of the branch (Palmer and Fortescue, 2003). Using different imageries that have varying spatial and temporal resolution, it is possible to estimate vegetation biomass. Integration with geographical information system provides spatial and temporal information, which is valuable for inventory. Furthermore, range conditions can be handled with relative ease due to low cost and effort. Using these modern techniques, the overall changes in grass cover of larger extents of areas, and related changes in biomass and other land-use pattern changes can be estimated.

Borana rangeland of southern Ethiopia is considered to be one of the best grazing lands in East Africa (Coppock, 1994). Since the early 1980s, the rangeland system in the Borana rangeland is experiencing a decline in productivity, associated with periodic losses in cattle populations (Ayana, 2007). This was probably related to extreme climate change and variability, changes in land-use, bush encroachment, and suppression of fire that resulted in the proliferation of bush encroachment leading to a general decline in forage production (Ayana and Oba, 2007). Due to this fact, Borana rangelands have faced many problems in the past three decades (UN-OCHA, 2008), which necessitates interventions based on land-use/land-cover evaluation. The Dire district is in the Borena zone, situated in arid and semi-arid lands, experiences low and erratic rainfall and high temperature that hinder crop production. The expansion of unpalatable woody species significantly reduced the rangeland size and availability of grasses in the area. In addition, bushes prohibit access of livestock to the underlying grass and as the canopy closes, the grasses and herbs disappear letting the ground susceptible to water erosion. Rapidity of bush encroachment and expansion of cultivation are also threats for livestock production in the area.

While the focus of many change detection studies is on the areal extent of landscape disturbance terrestrial ecosystems are inherently heterogeneous, and thus maintaining the existing mosaic in the size, shape, and distribution of patches within a landscape has important ecological implications (Riiters et al., 2000). This variability is considered a critical element which drives the flow of species and materials within a landscape. Thus, in addition to calculating the amount of land cover change over time, it becomes important to quantify changes in landscape spatial pattern.

Up-to-date global land-cover data sets are necessary for studies on climate change, biodiversity conservation, ecosystem assessment and environmental modeling (Giri et al., 2005). As Land cover shows the actual distribution of physical and biological features of the land surface, up-to-date information on the status of the land surface is crucial for environmental planning and management activities (Melesse, 2004). For sustainable management and decision making processes related to natural resources, knowledge about the ecosystem on both the temporal and the spatial scale is required (Burnnett et al., 2003). Managerial decisions on resources have to be based on change analysis, which is a comparison of the current status with the past events. Acquiring of rangeland information can help in understanding historical variations of land resources, and thereby contribute to its management. In fact, vegetation types form one of the main resources of pastoral areas. Sound decisions on range management depend upon reliable information of the past and present vegetation resource. Hence, the present study was aimed to determine the temporal changes of land-use/land-cover dynamics and to quantify the rate and direction of the changes in the study area.

2. Study area

The present study area, the Borana rangelands is bounded by latitude 4° 37' 0"−4° 37' 10"N and longitude 37° 56' 0"−38° 31' 0" E in the Borana Zone, Oromia Regional State, Ethiopia, and covers a total area of 3921 km^2 (Figure 1). Altitude of the area ranges from 750 to 1870 m above sea level and the topography consists of isolated mountains, valleys and depressions. This area is considered as a good representative of the Borana rangelands.

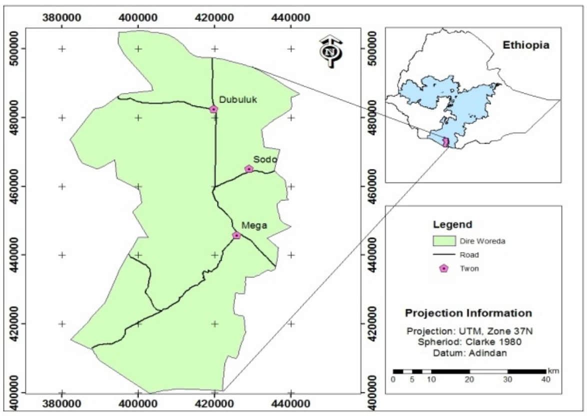

Figure 1: Location map of the study area

The rainfall of the study area ranges between 300-900 mm with bi-modal type, where 60 % of the annual precipitation occurs during March to May and 40% between September and November (Borana Low Land Pastoralist Development Program - BLPDP, 2004). The period from June to September is characterized by heavy cloud cover, mist and occasionally short showers, while the main dry season is from November to March with high evaporation (BLPDP, 2004). The overall average temperature ranges from an annual mean minimum of 13.3°C to annual mean maximum of 29.5°C.

The general vegetation type of the study area is Acacia savannah, the major trees being Acacia drepanolobium in black cotton soil, and Acacia brevispica and Acacia horrida on the slopes. According to Gemedo et al., 2005, Commbertum terminalia and Acacia commiphora woodlands characterize the lowlands of Borana zone. Bushlands and thickets, which cover major parts of the lowlands are dominated by Acacia and Commiphora species. Besides, species of the genera Boscia, Maerua, Lannea, Balanites, Boswellia and Aloe are common in the study area (Gemedo et al., 2006).

3. Methods

Digital change detection is a method of identifying and quantifying differences in the state of an object or phenomenon from multidate imageries (Singh, 1989), typically acquired from multispectral remote sensing platforms. To make multi-temporal analysis and land-use/land-cover types at various times, cloud free Landsat TM imageries (path 168 and row 057) during one dry season each were acquired in January 1986 and 2011. Geometric correction and image enhancement were conducted using ERDAS Imagine 9.2. Unsupervised classification of the study area was performed prior to field visits and representative points thought to represent various land-cover classes were marked using GARMIN GPS during field visits. Using ERDAS Imagine 9.2 software, 24 *in-situ* data points were selected from each classified group to be checked in the field. Later, some points were added in the field for class identification of images. For the year 1986, false colour composite was prepared using the order of 4, 3, 2 band sequence and then different enhancements were made to increase the visual interpretation of the image. Based on the field check points, supervised classification approach with the maximum likelihood classifier system was applied to improve the accuracy of the land-use classification of the images for 1986 and 2011. Post-classification comparison was carried out for two independent images (thematic maps). Differences or change information were generated by comparing image values of one data set (TM 1986) with those of the corresponding layer of the second data set (TM 2011). Confusion matrix between TM 1986 *vs* TM 2011 was compiled in the form of a contingency table. This confusion matrix was used to quantify land-cover change in terms of pixel values, km^2 or percentage of area coverage. The rate of land-use/land-cover change for each class was calculated as follows:

Rate of change (km/year) = (A-B)/C

where, A= recent land-use/land area in km^2 (2011), B= previous area of land-use/land-cover in km^2 (1986), C= interval between A and B in years (25).

Kappa: Estimated as (Ǩ). It reflects the difference between actual agreement and the agreement expected by chance.

Kappa of 0.84 means there is 84% better agreement than by chance alone.

$$\textbf{Kappa} = \frac{\text{observed accuracy} - \text{chance agreement}}{1-\text{Chance agreement}}$$

- Observed accuracy determined by diagonal in error matrix.
- Chance agreement incorporates off-diagonal.

In what follows, definition and description of land-use/land-cover types present in the study area is given.

Forest: It refers to an area naturally covered by closed stands of large trees of indigenous species like Juniperous procera, Olea european sub-spp. cuspidata and Podocarpus falcatus with more or less a continuous canopy cover and 7 to 30m height (Zemenu, 2009).

Bush land: It refers to open to closed stands of mainly Acacia trees 2 to 5m tall and canopy cover greater than 20%. This land-cover class dominantly refers to those species identified by the local people as invasive and mostly unpalatable to livestock. Most of them are thorny Acacia species forming a patch that prohibits human and livestock movement. Dominant species belonging to this category are A. brevispica (Hammaresa), A. bussie (Hallo), A. drepanolobium (Fillensa), A.melifera (Saphansa), A. reficiens (Sigirsa), A. seyal (Wachu) and Commiphora africana (hammessa) (Zemenu, 2009).

Grassland: It is an area dominated by local or introduced grasses and forbs species, including grass-like plants such as sedges and rushes, and small flowering and non-flowering plants or herbal vegetation with trees found scattered along the landscape is included in this category (Zemenu, 2009).

Cropland: It refers to agricultural lands that are seasonally cultivated by the local people for the production of mainly grains like wheat, sorghum, maize and teff. This category mainly includes fragmented or scattered areas that are cultivated mainly for subsistence. Perennial crops and irrigated lands are not significant and thus were not included in this category (Zemenu, 2009).

Shrub land: It refers to scrub vegetation dominated by shrubs greater than 0.5 meters and typically less than 4 to 5 meters in height. It can be dense or open, depending on the canopy cover of the vegetation (Zemenu, 2009).

Bare land: These categories include non-forested, non–vegetated, non-agricultural land that has less than 60 % herbaceous cover. Lands were formally agricultural, but now due to erosion and overuse became worthless or also classified under this category. In the image they were easily identified due to their high reflectance value appear whiter than the surrounding areas.

4. Results

The land-use/land-cover units of the study area were classified in the following eight types: forest, open bush land, dense bush land open shrub land, dense shrub land, grassland, farmland and bare land. The major portion of the land-use/land-cover was dominated by grassland and open shrub land in 1986, but in 2011, it was dominated by open and dense bush land (Table 1, Figure 2). The result of classification accuracy assessment is shown in Table 2. The overall accuracy and the Kappa value of field data *vs* automated classification results were 85.71% and 0.84, respectively. The accuracy level of each true land cover category is indicated in Table 2.

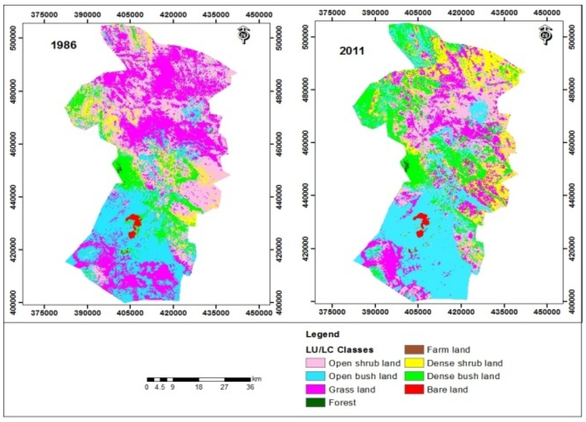

Figure 2: Land-use/land-cover maps of the study area (1986–2011).

The results of land-use/land-cover map showed that the area of grassland and open shrub land and bare land has declined (Figure 2). The rate of change was greater in the grassland and shrub land than in the bare land. Areas of open bush, dense bush and dense shrub land have increased rapidly while farmland and forest showed a general trend of increase in area coverage.

Significant spatial expansion in open bush land, dense bush land and dense shrub land and the rapid decrease in grassland and open shrub land were observed in 2011. The major cover changes observed during this period had been the reduction in the area of grassland from 27.8 % (1090 km^2) in 1986 to 17 % (663.4 km^2) in 2011 with a rate of 17 km^2/year while open shrub land from 27 % (1068.8 km^2) in 1986 to 20% (770 km^2) with a rate change of 12 km^2/year. The area of open bush land, dense bush land and dense shrub land were showed increasing pattern in the study area over the period of analysis. Of the total land area, the land-cover by open bush land in Dire district was 24% (932 km^2) in 1986 which increased to 32% (1270 km^2) with a rate change of 13.53 km^2 /year throughout the analysis period while dense bush land increased from 11.7 % (459 km^2) to 17.5% (684.5 km^2) with a rate of 10.18 km^2 /year. Dense shrub land increased from 8.7 % (341.3 km^2) to 12.7% (498.8 km^2) with the rate of 6.3 km^2 /year. General patterns of land-use/land-cover identified in the two images were largely dominated by shrub land, bush land and grassland.

The classification of forest and farmland showed 100 % producer's accuracy, which means no pixel was incorrectly excluded from its category. However, dense bush land, dense shrub land, open bush land, open shrub land, grassland, and bare land showed omission of 22.22 %, 16.67 %, 25 %, 20 % and 14.29 %, respectively. Forest, dense bush land and bare land showed 100 % user's accuracy indicating accurately automated classification was of bush land, whereas open bush land and farmland were less accurately classified (75 %) in automated classification. Error matrix for each land-use/land-cover is shown in Table 3.

Table 1: Land-use/land-cover classes and changes during 1986–2011 in Dire district, of the Borana zone, Ethiopia.

Habitat class	Year1986		Year 2011		Change (km^2)	Change (%)	Rate of change in (km^2 /year)
	Area (km^2)	Area (%)	Area (km^2)	Area (%)			
Forest	3.4	0.1	4.16	0.11	0.76	0.01	0.03
Open bush land	931.67	23.76	1270	32.39	338.33	8.63	13.53
Dense bush land	459.1	11.7	684.52	17.46	254.42	5.76	10.18
Open shrub land	1068.8	27.26	769.87	19.63	-298.93	-7.63	-11.96
Dense shrub land	341.3	8.71	498.76	12.72	157.46	4.01	6.3
Grass land	1090.17	27.8	663.35	16.92	-426.82	-10.88	-17.1
Farm land	2.11	0.05	6.64	0.17	4.53	0.12	0.18
Bare land	24.45	0.62	23.7	0.6	-0.75	-0.02	-0.03
Total	3921	100	3921	100	-	-	-

Table 2: The accuracy level of each land-cover category Landsat TM 2011.

Habitat class	Reference total	Classified Total	No. of corrected	Producers Accuracy (%)	Users Accuracy (%)
Forest	2	2	2	100	100
Dense bush land	9	7	7	77.78	100
Open Shrubs land	5	7	5	100	71.43
Dense shrub land	6	7	5	83.33	71.43
Open bush land	4	3	3	75	100
Grass land	5	5	4	80	80
Farm land	4	5	4	100	80
Bare land	7	6	6	85.71	100
Total	42	42	36		
Over all accuracy (%)					85.71
Over all kappa value					0.84

Table 3. Error matrix of Landsat TM 2011 showing classification accuracy of the true land-cover.

Habitat class Classified data	Forest	Dense Bush land	Dense shrub land	Open bush land	Open shrubs land	Grass land	Farm land	Bare land	Total
Forest	2		-	-		-	-	-	2
Dense bush land	-	7	-	-		-	-	-	7
Dense shrub land		-	5	1		1			7
Open bush land	-	2	-	5		-	-	-	7
Open Shrubs land	-	-	-		3	-	-	-	3
Grass land	-	-	-	-	1	4	-	-	5
Farm land	-	-	-	-		-	4	1	5
Bare and	-	-	-	-		-	-	6	6
Total	2	9	5	6	4	5	4	7	42

5. Discussion

The problems of land-use practices so far identified in the Dire district, southern Oromia, Ethiopia can be summarized to be associated with poverty, inequity among stakeholders in the district, ineffectual institutions, institutions acting at cross-purposes, poor land management practices and a lack of extension support of farmers, and insufficient knowledge of resource dynamics and ecosystem needs. A wealth of information was retrieved on land-use/land-cover changes with the help of interpretation of satellite images of 1986 and 2011. Interpretation of images of these periods indicated the existence of considerable dynamics in the land-use/land- cover systems of the study areas. In both images (1986 and 2011), eight land-use classes were identified but most of the land-uses either increased or decreased in size at different change rates in 2011, as compared to 1986.

The decrease in grass cover could be associated with a steady increase in the other land-use/cover patterns such as bush and shrub cover land. As a result, an increase in bush and shrub cover has been reported elsewhere in response to heavy grazing in rangelands (Coppock, 1994). This will have a significant effect on ecology and socio-economic condition of the area and the consequences of the trends in land use/cover are far reaching. Grasslands have been the main source of feed for livestock especially cattle in the area. The progressive reduction of grass cover may put serious constraints on animal feed and their productivity. Therefore, the relative increase in cultivated land could be a response to this problem in order to secure the required food demand of the society. This in turn could result in severe soil degradation, as has been shown in the expansion of bare lands of the present study areas.

In general, the overall increase in land covered by bush and dense shrub land might be attributed to a number of factors like overgrazing, drought, and ban on the use of fire (Ayana, 2007). The major land-use/land-cover changes within the Dire District were the results of the dynamic nature of bush encroachment, which is critically expanding and an issue of concern for the local communities. Bush encroachment has an adverse effect on the ecosystem and the environment. Herbaceous biomass production and bush encroachment are negatively correlated (Gemedo et al., 2006). The expansion of unpalatable woody species significantly reduced the rangeland size and availability of grasses. The consequence of the decrease in herbaceous biomass production might result in high risk of food insecurity in the area. In addition, the bush prohibits access of livestock to the underlying grasses and as the canopy closes the grasses and herbs disappear letting the ground susceptible to water erosion. Furthermore, Gemedo et al. (2006) recommended re-introduction of fire as a rangeland management tool, and selective clearing of encroaching woody plants could help reclaim degraded rangelands of Borana.

The current study has also revealed an increase in the spatial extent of farmland from 0.05% (2.11 km^2) in 1986 to 0.2% (6.6 km^2) in 2011, in order to meet the increasing demands caused by human population growth. Areas under forest and bare land remain more or less stable and not showing remarkable change during the study period. Forest showed slight increase from 3.4 km^2 to 4.2 km^2, while bare land areas decreased from 24.5 km^2 to 23.7 km^2, which might be related to the increasing pattern of land covered bush and shrubs that hide the visibility of the land from the air.

The result of the present study is similar in the direction of change with Borghesio and Gainnetti (2005) in which the study undertaken on Bush crow (Zavattariornis stresemanni) in Yabello Sanctuary and its immediate surroundings, south of Mega, showed 8 % increase in dense bush cover between 1986 and 2002. The result is also in agreement with the study reported by Sintayehu (2007) in Yabello district, which revealed the grassland cover declined by about 149 km^2 over 30 years, while that of bush land, bushed grasslands, and croplands (maize) increased.

Dire rangelands had faced a significant decrease in grassland and open shrub land-cover since 1986s: associated with a significant increase in all the other recognized land-use/land-cover systems. This might have generally resulted in the deterioration of the ecosystem such as increasing the area prone to soil erosion and destruction of original grasses. On the other hand, it was not only the coverage of grassland that decreased but also desirable vegetations species types might have been destroyed (e.g. increase in bush encroachment). This directly decreased the productivity and carrying capacity of the area and negatively affected the yield of grasses, which in turn suppressed the productivity of livestock particularly sheep and cattle as they do not prefer bush grazing. As a result, local communities shifted to a changed land-use pattern (e.g. expansion of cultivated land and/or rearing more drought resistance animals). Such activities could further drive ecological disturbances to irreversible conditions that might result in high risk of food insecurity in the area unless proper interventions are made in time.

6. Conclusion

Results of the land-use/land-cover changes revealed that grass land and open shrub land resource decreased significantly at a rate of 17.1 km^2/year and 12 km^2/year, respectively. On the other hand dense bush land, open bush land, dense shrub land and cultivated land have shown increase in the extent at a rate of 10.18 km^2/year, 13.53 km^2/year, 6.3 km^2/year and 0.2 km^2/year, respectively within 25 years. The expansion of unpalatable woody species reduced significantly the rangeland size and availability of grasses. The consequence of the decrease in herbaceous biomass production might result in the high risk of food insecurity in the area unless proper interventions are made in time.

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