Ethiop. J. Biol. Sci. 18(2): 123–143, 2019
 ISSN: 1819-8678

RESEARCH ARTICLE

TEMPORAL VEGETATION COVER DYNAMICS IN NORTHWESTERN ETHIOPIA: STATUS AND TRENDS

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ABSTRACT: The vegetation cover change of northwestern Ethiopia's high forests has not been investigated and no information is available on temporal changes in particular with vegetation cover dynamics. Thus, our study explores the trend of vegetation cover changes of the study area in the last 42 years. Landsat satellite images of the years 1973, 1987, 2001 and 2014 were acquired from the Earth Explorer website. Preprocessing of images, image classification, accuracy assessment, post classification image processing and change detection were carried out. The overall classification accuracy and Kappa coefficient were found to be above 85% and 0.8, respectively, for all study years. Four land use/cover classes were identified for the supervised classification. In 1973, the largest proportion (40%) was covered by primary forest, followed by agriculture (39%), grassland (12%) and secondary forest (9%). In 2014, agriculture covered the largest proportion (45%), followed by secondary forest (29%), grassland (17%) and primary forest (9%). The rate of conversion of the primary forest cover to other land use types was found to be above the national average conversion rate; which is highly alarming. Thus, introducing appropriate management options is urgently needed to halt those conversions.

Key words/phrases: Awi Zone, Classification, High forest, Landsat, Land use/cover, Primary forest.

INTRODUCTION

The greatest threat to the remaining natural vegetation in Ethiopia is man-made clearing for expansion of agricultural and grazing lands and uncontrolled exploitation of timber and fuel wood (Tamrat Bekele, 1993; Edwards and Ensermu Kelbessa, 1999; Friis *et al*., 2010). Rapid population growth has been regarded as the major cause of deforestation as high population demands more land and fuel, which are both directly or

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indirectly obtained at the expense of forest destruction and unsustainable utilization (Edwards and Ensermu Kelbessa, 1999; Tamrat Bekele *et al*., 1999; Alemnew Alelign *et al*., 2007). This has also been a major cause for land use/cover changes particularly vegetation cover changes in Ethiopia. The problem of deforestation and over-exploitation of forests is nationally recognized as one of the worst threats to the remaining plant biodiversity of the country. High forests of Ethiopia were lost in the past and the trend continues unabated. Particularly, the Afromontane forests of Ethiopia have been subject to agricultural and settlement activities as these areas are more suitable for living (Tamrat Bekele *et al*., 1999). To prevent such destruction, National Forest Priority Areas (NFPAs) have been considered as options in selected areas of the country and a number of NFPAs were established (Reusing, 1998).

The primary forest cover of Ethiopia was reduced to 16% in the 1950s and 3.6% in the 1980s from the original 35% cover before the 1950s (Reusing, 1998; Tamrat Bekele *et al*., 1999). The destruction was mainly caused by land use/cover changes for agriculture, settlement and grazing (Bedru Sherefa, 2006; Alemu Mekonnen and Bluffstone, 2007; Eyayu Molla *et al*., 2010; Binyam Alemu *et al*., 2015; Solomon Melaku, 2016). Consequently, about 150,000–200,000 ha of forest cover is believed to disappear annually as a result of anthropogenic influences, and the northern part of Ethiopia is the most affected (EFAP, 1994; Reusing, 1998). This has resulted in fragmentation of natural forest habitats in Ethiopia and elsewhere (Forman, 1995; Edwards and Ensermu Kelbessa, 1999; Martínez-Garza and Howe, 2003; Lunt and Spooner, 2005).

Studies on the temporal and spatial dynamics of land use/cover changes play critical roles in selecting and designing conservation sites as well as introducing appropriate management interventions. Land cover is the biological and physical cover of the surface/land, while land use refers to the total of arrangements, activities and inputs that people undertake in a certain land cover type (Anderson *et al*., 1976). To date no study is available on land use/cover changes of the study area (Guangua-Illala and Khatasa forests); except a study on small area in Banja district, northern part of the study area (Abyot Yismaw *et al*., 2014). We hypothesized that the northwestern forests particularly forests of Awi Zone (Guangua Illala and Khatasa forests) are better protected as these forests are included in the National Forest Priority Areas. Consequently, the results of this study will identify the major temporal land use/cover changes in the study area and assist land use planners, policy makers and conservationists to design effective land use and forest conservation plans in the study area.

MATERIALS AND METHODS

Description of the study area

The study area is located between longitudes 36° 28′ E to 36° 50′ E and latitudes 10° 42′ N to 11° 04′ N with total area coverage of 83,160 ha in Awi Zone, northwestern Ethiopia (Fig. 1). The study area is part of the Gojam Floristic Region (west Gojam), western Ethiopian highlands (Friis *et al.*, 2010). The study area consists of two National Forest Priority Areas (NFPAs) known as Guangua-Illala forest, which includes most forest patches, and Khatasa forest.

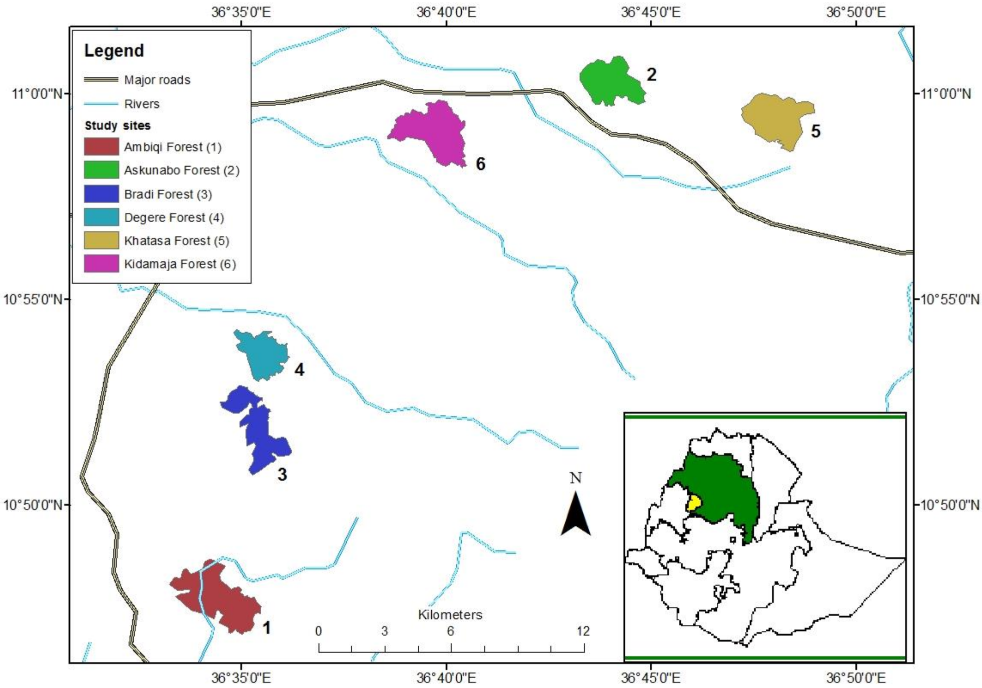
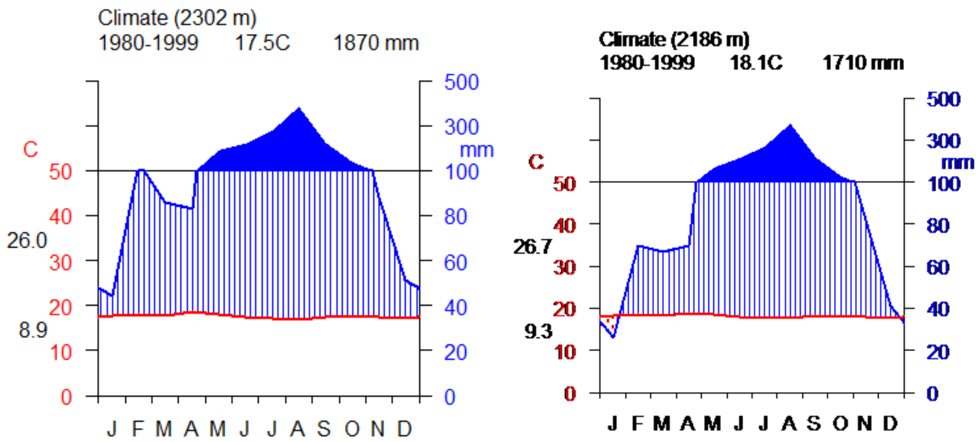


Fig. 1. Map of forest patches in Awi Zone, Amhara National Regional State (ANRS).

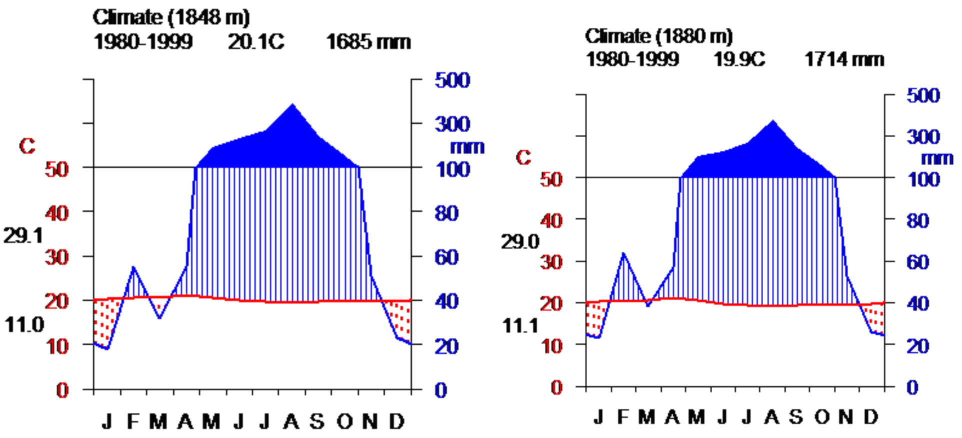
The topography of the study area consists of areas with gentle to steep slopes. The landscape is composed of agricultural and grazing areas, settlements, rivers valleys, hills and small to medium sized mountains (at the northern side of the study area). The slope of the largest part of the study area (69%) ranges from 0 to 25% and the remaining has slopes above 25%. Flat land and steep slopes each account to about 7% of the study area. Flat land and gentle slopes are mostly utilized for agriculture, settlement and grazing lands; whereas moderate and steep slopes above 25% slope gradient usually consists of primary/high forests, although in some areas the steep slopes are utilized for growing crops and settlement. A number of perennial rivers and small streams cross the study area.

The study area has been recognized as Important Bird and Biodiversity Area (EWNHS, 2010; Birdlife International, 2016). Assessment of bird species that are found in different habitats of Awi Zone indicated the existence of 214 bird species, of which 28 species belonged to the Afrotropical highland biome (EWNHS, 1996). Two globally threatened bird species are known to exist in the area, the Ethiopian and Eritrean endemic – Rouget's rail (*Rougetius rougetii*) and the Ethiopian endemic – Abyssinian long claw (*Macronyx flavicollis*). Mammals such as bush pig, leopard, hyena, Anubis Baboon, Colobus monkey, common Duiker, serval cat and common bush buck are also found in the forests (Agriculture and Natural Resources Office, unpublished data).

Daniel Gemechu (1977) classified the rainfall pattern of the study area as unimodal (Fig. 2). Most of the study area gets rain at least nine months with variable intensity. The annual precipitation ranges from 1,685 to 1,870 mm. The highest precipitation of the wettest month (August) is 388 mm; while the driest month (January) is 18 mm. The wettest months are May to October with high peaks in August; whereas the driest months are December to February. The annual mean temperature of the study area ranges between 17ºC and 22ºC.



a) Khatasa (10.98375 N; 36.8062 E) b) Askunabo (11.00299 N; 36.7307 E)



c) Kidamaja (10.98662 N; 36.65749 E) d) Ambiqi (10.79456 N; 36.5794 E)

Fig. 2. Climatic diagram of meteorological stations in the study area.

Data collection

Landsat images of the years 1973, 1987, 2001 and 2014 were acquired from the Earth Explorer website (http://earthexplorer.usgs.gov/) (Table 1). The images with better quality and minimum or no cloud cover were selected from a number of images for each year. The images taken in January and February were found to have no cloud cover and these months were preferred for all years. For identification of major land use types in the study area, field visits were carried out in December 2014. Accordingly, four major land use/cover classes were identified in this study: primary forest (high forest), secondary forest/scrub/plantation, grazing land/grassland and agriculture. Primary forest or high forest in this study includes large and old trees with closed canopies having several layers/storeys. Secondary forest/scrub/plantation indicates a change in land use from primary forest, agriculture or grazing land to secondary growth of scrub/bushland; as well as plantations, such as introduced species. Grazing land/grassland is a land usually utilized for grazing domestic animals that has sparsely scattered trees/shrubs; grass/herbs being the dominant cover. Agricultural land (agriculture) in this study is defined as a land that is utilized for production of crops and settlement. Point location data was collected using Garmin GPS with 5 to 10 metres accuracy (most of the time).

Table 1. List of satellite images used for the land use/cover change analysis.

Year	Resolution	Sensor	Path	Row	Band	Acquisition date
1973	57 m	Landsat 1 MSS	170	52/53	4	01/15/1973
1987	30 m	Landsat TM	170	52/53	6	01/13/1987
2001	30 m	Landsat 7 ETM+	170	52/53	7	02/05/2001
2014	28.5 m	Landsat 7 ETM+	170	52/53	7	02/01/2014

Primary forest or high forest in this study includes large and old trees with closed canopies having several layers/storeys. Secondary forest/scrub/plantation indicates a change in land use/cover from primary forest, agriculture or grazing land to secondary growth of scrub/bushland; as well as plantations, such as introduced species. Secondary forests and plantations are usually found mixed in areas where plantation and area closure activities were carried out. Grazing land/grassland is a land usually utilized for grazing domestic animals that has sparsely scattered trees/shrubs; grass/herbs being the dominant cover. Agricultural land (agriculture) in this study is defined as land that is utilized for production of crops and settlement. At least 40 reference data (coordinates) were collected from each land use type using stratified random sampling procedure. Local people particularly elders were consulted about the age of the land use/cover type using open ended questionnaires, that is the periods in which that land use type remained in the same state.

Data analysis

Five major steps were followed for the analysis of temporal dynamics of land use/cover in the study area (Fig. 3). They are preprocessing of images, image classification, accuracy assessment, post classification image processing and change detection.

Image preprocessing techniques involved georeferencing, resampling and clipping. A polygon with an area of 831.6 km^2 (83,160 ha); which encompasses most of the forest patches and other nearby forest patches, was constructed using ArcMap 10.2 (ESRI, 2013). The polygon was digitized by using the 1973 image and saved as shapefile for later use for clipping the other raster images. The 1973 image was used on the assumption that the forest cover was in better conservation status compared to later years (Tamrat Bekele *et al*., 1999). The spatial references of all the raster images and the clipping polygon were projected to Adindan UTM Zone 37 N and each image was clipped by the polygon. The 1973 and 2014 raster images were resampled to a pixel size of 30 m x 30 m by the "nearest neighbour assignment" method. This method is primarily used for discrete data, such as a land use/cover classification, since it does not change the values of the cells (ESRI, 2013). Moreover, the pixel correction (resolution) is primarily useful for comparison purposes of the classified images.

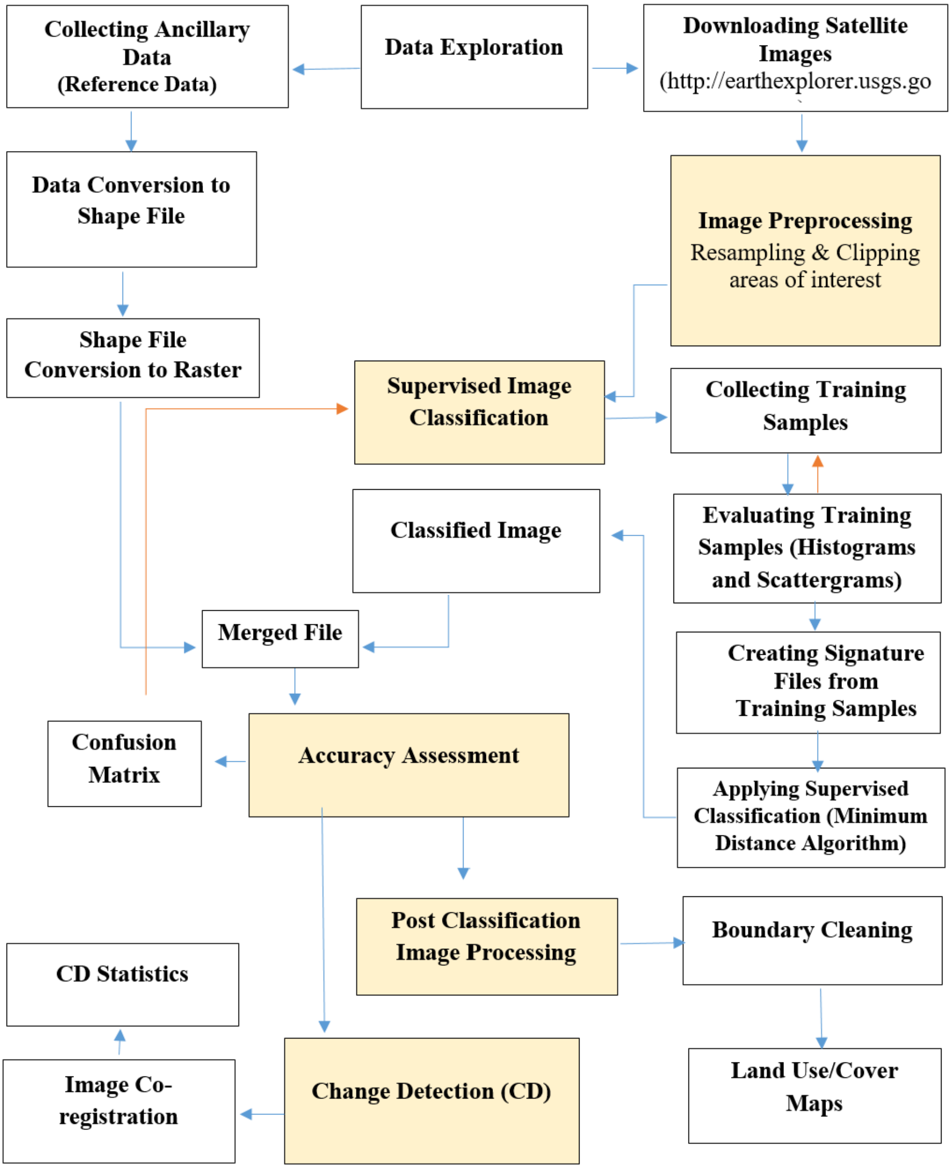


Fig. 3. Workflow of major activities in land use/cover classification and change detection in the study area.

The resampled images were enhanced and corrected using the image analysis tool in ArcMap for clear identification of the potential land use/cover classes. Image enhancement (contrast enhancement, spatial filtering, density slicing) is the procedure of improving the quality and information content of original data before processing; while image correction refers to mathematical operations that compensate for various sources of spectral distortion and positional errors in the data. Consequently, the images were exported as ENVI 5.0 file format for classification purposes. Unsupervised and supervised classification techniques were performed in ENVI 5.0. Unsupervised classification was carried out to see how distinct potential classes were. Then supervised classification was employed for final image classification purposes. The goal of supervised classification is to assign each cell in the study area to a known class/land use (Richards, 1999).

The analysis was carried out based on the following four major steps: a) the input bands of each raster image were identified; b) at least 30 training samples were produced for each class (120 samples per image/from each year) from known locations of desired classes (Primary forest, secondary forest/scrub, grazing land and agriculture); c) a signature file was developed from the training samples; and d) the minimum distance (MD) algorithm was employed to classify land uses for each period using raster images and signature files. The MD algorithm uses the mean vectors for each class and calculates the Euclidean distance from each unknown pixel to the mean vector for each class. Post classification image processing of the classified images was carried out in ArcMap. The Boundary Clean tool was primarily used to clean ragged edges between zones. Consequently, the land use/cover maps were produced using the mapping tools.

A thematic map derived from a classification may be considered accurate if it provides an unbiased representation of the land use/cover of the region it portrays (Congalton, 1991; Foody, 2002; Congalton and Green, 2009). Accordingly, accuracy assessment was carried out for each period to ensure that the land use/cover classes were properly classified. The reference data, which were collected from field for each land use type, were plotted and saved as point shapefile in ArcMap (Congalton, 1991; Powell *et al*., 2004; Congalton and Green, 2009). The shapefile was converted to raster and merged with the classified images. Consequently, an error or confusion matrix or contingency table was produced for each period and the producer’s and user’s accuracy as well as overall accuracy and Kappa coefficient were computed in ArcMap and spreadsheet programmes (Foody, 2002; Congalton and Green, 2009). According to Congalton and Green (2009), error matrices are very effective representations of map accuracy because the individual accuracies of each map category are plainly described along with both the errors of inclusion (commission errors) and errors of exclusion (omission errors) present in the map. Generally, the error matrix compares counts of agreement between reference data and classified image data by class (Powell *et al*., 2004). The Kappa (K') analysis is a discrete multivariate technique used in accuracy assessment to determine statistically if the Producer's accuracy is significantly different from the User's accuracy or if there is an agreement between the two (Congalton and Green, 2009). The value falls between 0 and 1 (inclusive), meaning no and perfect agreement, respectively.

Change detection analysis encompasses a broad range of methods used to identify, describe and quantify differences between images of the same scene at different times or under different conditions (Richards, 1999). The classified input images were co-registered before change detection analysis. Among the various tools in ENVI 5.0, change detection statistics, which compiles a detailed tabulation of changes between two classified images, was computed as it is a recommended approach. A matrix, where the columns holding the "initial state" classes and the rows representing "final state" classes, was produced in the form of area (ha) and percentage changes. To determine extent and rate of change of land use types per temporal scale, the following formula were employed following Richards (1999) and spreadsheet programme was used for the computation.

$$A_c = A_2 - A_1$$

$$E_c = A_c/A_1 \times 100 \text{ or } (A_2 - A_1)/A_1 \times 100$$

$$R_c = E^c/(t_2 - t_1) \text{ or } (A_2 - A_1)/A_1(t_2 - t_1) \times 100$$

whereas A_c is change area; A_1 and A_2 areas in time 1 and 2; E_c percent change extent; R_c rate of change; t_1 and t_2 are time 1 and time 2.

RESULTS

Land use/cover classification

The supervised classification clearly identified the four land use/cover classes in the study area (Fig. 4). In 1973, the primary forest and agriculture covered 40% and 39% of the study area, respectively. The largest proportion was covered by primary forest, followed by agriculture, grassland (12%) and secondary forest (9%). In 1987, the largest proportion of the study area was covered by agriculture (46%), followed by primary forest (29%), grassland (14%) and secondary forest (11%). In 2001, agriculture took the significant portion of the land use/cover (50%), followed by secondary forest (27%), primary forest (16%) and grassland (7%). In 2014, agriculture covered the largest proportion (45%), followed by secondary forest (29%), grassland (17%) and primary forest (9%). The most significant negative and positive changes were observed for primary forest and secondary forest, respectively in the whole study period.

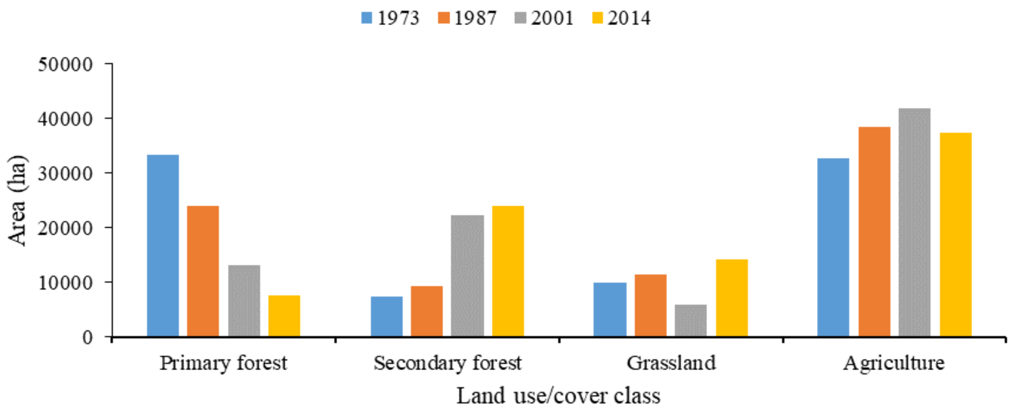


Fig. 4. Proportion of land use/cover classes (ha) in each study year in the study area.

Accuracy assessment

The overall accuracy level and Kappa coefficient were above 85% and 0.8, respectively for all study years. The lowest and highest accuracy and Kappa coefficient were obtained for 2001 and 1987 images, respectively. Consequently, the overall classification accuracy of the 1973, 1987, 2001 and 2014 images were 94, 96, 87 and 93%, respectively; while the Kappa coefficients were 0.92, 0.95, 0.83 and 0.88, respectively (Table 2). The producer's accuracy ranged between 87 and 97% for all study years. The highest accuracy was for the primary forest and the lowest was for secondary forest/scrub. The user's accuracy was generally above 91%, the lowest and the highest being for primary forest and agriculture, respectively.

The 1973 image was classified with the second highest accuracy among all years (Table 2). The user's accuracy was 95.5% for grassland, 92% for primary forest, 95.7% for agriculture and 93.6% for secondary forest/scrub.

The producer’s accuracy was 95.5% for grassland, 95.7% for agriculture, 97.1% for primary forest and 88% for secondary forest/scrub.

Table 2. Classification accuracy of the 1973 image in the study area.

	Land use/ cover type	Reference data					User’s accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified data	Primary forest	67	6	0	0	73	91.8
	Scrub	2	58	2	0	62	93.6
	Grassland	0	1	84	3	88	95.5
	Agriculture	0	1	2	66	69	95.7
Total		69	66	88	69	292	-
Producer’s accuracy		97.1	87.9	95.5	95.7	-	-
Overall accuracy		94.2	-	-	-	-	-
Kappa coefficient		0.92	-	-	-	-	-

The 1987 image was classified with the highest accuracy among all years, which is also true for the producer and user’s accuracies (Table 3). The user’s accuracy was 98% for grassland, 97.7% for primary forest, 97.6% for agriculture and 90.6% for secondary forest/scrub. The producer’s accuracy was 98% for grassland, 97.6% for agriculture, 94.4% for primary forest and 94% for secondary forest/scrub. The Kappa coefficient and overall accuracy were generally the highest for the 1987 image.

Table 3. Classification accuracy of the 1987 image in the study area.

	Land use/ cover type	Reference data					User’s accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified data	Primary forest	84	2	0	0	86	97.7
	Scrub	5	77	1	2	85	90.6
	Grassland	0	2	99	0	101	98.0
	Agriculture	0	1	1	82	84	97.6
Total		89	82	101	84	356	-
Producer’s accuracy		94.4	93.9	98.0	97.6	-	-
Overall accuracy		96.1	-	-	-	-	-
Kappa coefficient		0.95	-	-	-	-	-

The lowest classification accuracy among the years was for the 2001 image (Table 4). Accordingly, the user’s accuracy was 77% for secondary forest, 97.6% for grassland, 81.3 for agriculture and 100% for primary forest. The producer’s accuracy was 98.3% for secondary forest/scrub, 89% for primary forest, 84% for agriculture and 77% for grassland. The overall accuracy and Kappa coefficient were 87% and 0.83, respectively.

Table 4. Classification accuracy of the 2001 image in the study area.

	Land use/ cover types	Reference data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified data	Primary forest	56	0	0	0	56	100.0
	Scrub	7	59	0	10	76	77.6
	Grassland	0	1	40	0	41	97.6
	Agriculture	0	0	12	52	64	81.3
Total		63	60	52	62	237	-
Producer's accuracy		89.0	98.3	77.0	84.0	-	-
Overall accuracy		87.3	-	-	-	-	-
Kappa coefficient		0.83	-	-	-	-	-

The 2014 image was classified with high accuracy except some overlaps between agriculture and grassland, and primary forest and secondary forest (Table 5). The user's accuracy was 89% for agriculture, 93% for primary forest, 94% for secondary forest and 100% for grassland. The producer's accuracy was 87% for grassland, 90% for secondary forest, 96% for primary forest and 97% for agriculture. The overall accuracy was one of the highest (93%) with high Kappa coefficient (0.88).

Table 5. Classification accuracy of the 2014 image in the study area.

	Land use/ cover types	Reference data					User's accuracy
		Primary forest	Scrub	Grassland	Agriculture	Total	
Classified data	Primary forest	49	4	0	0	53	92.5
	Scrub	2	64	0	2	68	94.1
	Grassland	0	0	35	0	35	100.0
	Agriculture	0	3	5	66	74	89.2
Total		51	71	40	68	230	-
Producer's accuracy		96.1	90.1	87.5	97.1	-	-
Overall accuracy		93.0	-	-	-	-	-
Kappa coefficient		0.88	-	-	-	-	-

Change detection and extent and rate of changes

The land use pattern showed a marked variation from 1973 to 2014. The primary forest cover declined from 40% in 1973 to only 9% in 2014; whereas secondary forest or scrub, grassland/grazing land and agriculture increased from 9, 12 and 39% to 29, 17 and 45%, respectively (Table 6).

Table 6. Land use/cover changes (ha) from 1973 to 2014 in the study area.

Land use/cover class		Initial state (1973)				Class total [2]
		Primary forest	**Scrub**	**Grassland**	**Agriculture**	
Final state (2014)	Primary forest	6165.7	1063.1	54.3	405.8	7689
	Scrub	12041.1	3478.5	1506.0	6900.1	23926
	Grassland	2864.3	773.5	3418.9	7185.9	14243
	Agriculture	12301.4	2162.8	4825.2	18012.2	37302
	Class total [1]	33373	7478	9804	32504	-
	Class changes [3]	27206.8	3999.4	6385.5	14491.8	-
	Difference [4]	−25684.0	+16448.0	+4438.0	+4798.0	-

Note: [1]total area in each initial state class (1973); [2]total area in each final state class (2014); [3]total area of initial state pixels that changed classes; [4]the difference in the total area of equivalently classed pixels in the two states (2014 and 1973) (Row class total - Column class total).

Most land use/cover changes, except the primary forest, were positive that is it increased in extent from 1973 to 2014, although grassland and agriculture showed a decrease in some of the periods. The primary forest cover change was consistently negative throughout the four study years. The changes were mainly from primary forest to secondary forest/scrub and to agricultural land as well as grassland to agricultural land. For example, the primary forest cover was converted to agriculture (37%), secondary forest (36%) and grassland (9%) in 42 years. A significant proportion of grassland (49%) was also converted to agricultural land in similar years.

Moreover, a portion of the secondary forest/scrub cover was converted to agriculture (29%) and grassland (10%). On the other hand, only a small proportion of the primary forest cover (18%) remained in its initial state; whereas a significant share of other land use types i.e., agriculture (57%), secondary forest (47%) and grassland (35%) remained in similar state. Extent and rate of changes in land use/cover were variable for the classes considered in the whole study period. The primary forest has gone through consistent negative changes, at a rate of −1.8% in the whole study period (Table 7); that is, 490 ha of primary forest has been converted to other land use types annually.

Table 7. Land use/cover changes (ha), extent and rate of change (%) from 1973 to 2014.

Land use/cover class	1973–2014		
	Change	**Extent**	**Rate**
Primary forest	−25684.0	−77.0	−1.8
Scrub	+16448.0	220.0	+5.2
Grassland	+4438.0	45.0	+1.1
Agriculture	+4798.0	15.0	+0.4

The highest destruction occurred in the second study period at a rate of −3.8%. The change had been slow in the first study period with minimum rate of −1.9% compared to the other periods. Generally, the highest destruction took place in the second study period, followed by the third and first study periods (Table 8). The extent of secondary forest cover was more than double at the end of the whole study period, the highest increasing rate being in the second study period. Consequently, the rate of secondary forest cover change was 5.2% in the whole study period. That is 208 ha of land was converted into secondary forest each year in the study area. On the other hand, grassland cover showed a wave-like pattern, increasing in the first study period, decreasing in the second study period and finally increasing in the third study period. Consequently, at the end of the study period the area covered by grassland increased by 45%.

Table 8. Land use/cover changes (ha), extent and rate of change (%) in the three periods.

Land use/ cover class	**1973–1987**			**1987–2001**			**2001–2014**		
	Change	**Extent**	**Rate**	**Change**	**Extent**	**Rate**	**Change**	**Extent**	**Rate**
Primary forest	−9330.7	−28.0	−1.9	−16965.0	−56.4	−3.8	−5666.6	−42.6	−3.0
Scrub	1783.9	23.9	1.6	12994.2	140.4	9.4	1673.6	7.5	0.5
Grassland	1712.1	17.5	1.2	−5132.7	−46.3	−3.1	8320.6	140.3	10.0
Agriculture	5834.7	18.0	1.2	9103.5	27.8	1.9	−4327.6	−10.4	−0.7

DISCUSSION

Land use/cover classification and change detection

The primary forest cover of the study area has been severely affected by conversion to secondary forests, agricultural lands and grazing lands in the past four decades (Fig. 5). In similar periods, the number of domestic animals and the human population gradually increased which exerted huge pressure on primary forests, secondary forests and grasslands (CSA, 2013a; b). The highest proportion of land cover at the beginning of the study period was shared by primary forest (40%), which was eventually converted to other land use types. There are various justifications for the forest destruction; the most important being population growth, which requires space for settlement and agricultural and grazing lands (Alemu Mekonnen and Bluffstone, 2007; Sisay Nune, 2007; Abyot Yismaw *et al*., 2014). Policy, though it does not contribute directly, is believed to influence land use/cover changes in rural areas (Samuel Gebreselassie, 2006), as for example, the enforced displacement of farmers from their agricultural fields (steep slopes and hillsides) for afforestation purposes in the 1980s disputed afforestation programmes and protection of forests in later years (Sisay Nune, 2007). Thus, the most significant decrease in primary forest cover and grassland cover in the second study period (1987–2001) was mainly attributed to government change that led to the illegal destruction and proprietorship of protected forests and grasslands for agriculture by farmers (Abiyot Berhanu *et al*., 2017).

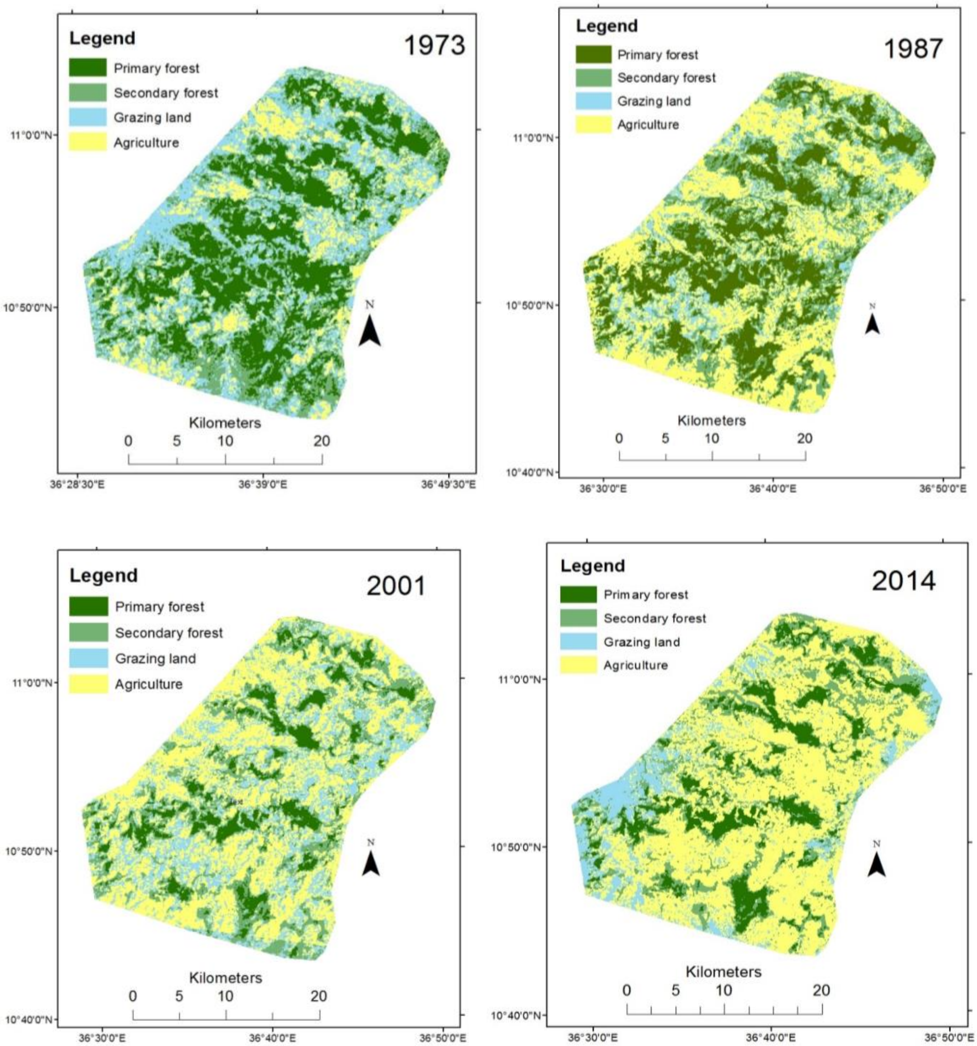


Fig. 5. Land use/cover classification map of the study area in each study year.

The rate of forest cover conversion to other land use types (−3.8%) in the second study period was one of the highest in the country (Belay Tegene, 2002; Eyayu Molla *et al*., 2010; Abiy Wogderes, 2014). Particularly, the highest destruction of forest resources occurred between 1991 and 1997. Consequently, the overall forest conversion rate in the study area was higher than the national average rate of forest destruction in the country; which was about −1% per annum nationally in similar period (Tigabu Dinkayoh, 2016). Elsewhere in Ethiopia, similar trends were revealed in that the primary forest cover and woodlands were converted to mainly agricultural lands (Efrem Garedew, 2010; Eyayu Molla *et al*., 2010; Mengistie Kindu *et al*., 2013). Similarly, the conversion of forests to agricultural lands and settlements was reported elsewhere in the world (Critchley and Bruijnzeel, 1996; Houghton and Goodale, 2004; Dittrich *et al*., 2010). In 1997, land was legally redistributed to farmers in the study area, which also contributed to the decrease in grasslands. The decrease in primary forest cover was accompanied by an increase in secondary forest cover in the study area. The most significant increase in the extent of secondary forest cover (220%) was mainly caused by various factors; revision and enforcement of forest laws and area closure being the most important. Forest laws were revised and reinforced which prohibited illegal forest destruction and introduced penalties on the wrong doers (Alemu Mekonnen and Bluffstone, 2007; Sisay Nune, 2007). Consequently, the farmlands that were illegally owned by clearing the primary forest were abandoned and allowed to regenerate, which eventually developed to grasslands and subsequently to secondary forest/scrub.

Moreover, area closures were introduced in some areas to enhance the recovery of abandoned fields and steep slopes (BoA, 2012; Amogne Asfaw, 2014). Nevertheless, coupled with agricultural expansion, this resulted in the scarcity of grazing areas, construction materials and firewood that inflicted heavy pressure on secondary forests and edges of primary forests. Thus, selective cutting of woody plants (Abiyot Berhanu *et al*., 2017) and illegal conversion of secondary forests to grasslands was a common phenomenon in similar periods. Although insignificant, the hillsides and steep slopes which were previously used for agricultural activities were also planted with introduced species such as *Eucalyptus* sp., *Acacia* sp. and *Sesbania sesban* (Sisay Nune, 2007; BoA, 2012; Amogne Asfaw, 2014). This was highly practical starting in the 1980s and onwards (Amogne Asfaw, 2014).

The change from grassland into secondary forest/scrub is predictable as pioneer species and some native nitrogen fixing woody plants such as *Acacia* species establish themselves following disturbance, overgrazing and abandonment (Brown and Archer, 1989; Polley *et al*., 2002; Myster, 2012; Liu *et al*., 2013). Generally, the land use/cover changes during the whole study period and the three study periods (1973–1987, 1987–2001 and 2001–2014) were multidirectional. That is one land use type (e.g. secondary forest) was converted or developed into another land use type (e.g. grassland, agricultural land, etc.) and *vice versa*. Those changes were highly noticeable except that of the changes from grassland and agriculture into primary forest; which were nonexistent for the three periods. The most visible changes in the whole study periods were from grassland to agriculture (49%), followed by primary forest to agriculture (37%) and primary forest to secondary forest (36%).

An insignificant portion of agricultural (1.2%) and grazing lands (0.6%) developed into primary forest in the whole study period (42 years); probably because of subsequent changes through development of agriculture and grassland to secondary forest and finally to primary forest (Mengistie Kindu *et al.*, 2013; Adedeji *et al.*, 2015). According to Cole *et al.* (2014), tropical forests disturbed by anthropogenic impact such as logging and burning for agriculture recover very slowly depending on management activities. This may most likely be due to lack of seed sources such as soil seed banks, which are sources for woody species regeneration, as they are usually depleted in the course of time. For example, Mulugeta Lemenih and Demel Teketay (2006) found out that there was a general tendency of disappearance of native woody species from the soil seed banks with increasing period of soil cultivation.

On the other hand, a portion of secondary forest (14%) developed into primary forest. This was highly visible in the first study period (1973–1987) when deforestation was relatively less practical in the study area.

Accuracy assessment

It is impossible to produce a land use/cover map that is completely accurate and satisfies the needs of all (Brown *et al.*, 1999; Strahler *et al.*, 2006). Moreover, there is no one universal “best” method of accuracy assessment, but rather a suite of methods of varying value and applicability for any given map and purpose (Strahler *et al.*, 2006). Hence, although there is no set standard, it is recommended that the minimum level of interpretation accuracy in the identification of land use/cover categories from remote sensor data be at least 80–85 percent (Anderson *et al.*, 1976; Foody, 2002; Olson, 2008). This has also been employed in the study of land use/cover changes in Ethiopia and elsewhere (Addis Getnet, 2009; Mengistie Kindu *et al.*, 2013). In view of that, the producer and user’s accuracies, overall accuracy as well as the Kappa coefficient of this study were above the recommended level. Nevertheless, some confusion was detected in the classification results, which was mainly caused by the misclassification of some pixels of primary forest and secondary forest as well as grassland and agriculture. The primary forest and secondary forest are usually found side by side or in close proximity and sometimes mixed in areas of major disturbance such as forest clearing and selective logging in the study area. However, both errors were insignificant and it was generally concluded that the classification results were accurate and acceptable.

CONCLUSION AND RECOMMENDATIONS

Land use/cover changes induced by humans are detrimental to vegetation cover. A significant conversion of high/primary forest to other land use types such as secondary forests, agriculture and grazing land occurred in the study area and this is an evidence for the decline of forest patches. Consequently, our hypothesis that "the forests of the study area are better protected as they are included in the NFPAs" was rejected. The rate of conversion of the primary forest cover to other land use types is highly alarming. The overall forest conversion rate in the study area was higher than the national average rate of forest destruction in the country. Consequently, the most visible changes in the whole study periods were from grassland to agriculture (49%), followed by primary forest to agriculture (37%) and primary forest to secondary forest (36%). If this trend continues, it will not be far before all the primary forests are gone. Thus, it is recommended to halt/reverse these changes by introducing appropriate land use planning.

ACKNOWLEDGEMENTS

We would like to acknowledge local people and administrative staff of Agricultural and Natural Resources offices in the study area for their kind collaboration during field activities. The field expense of the first author was fully covered by the Ethiopian Biodiversity Institute, Addis Ababa, Ethiopia.

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