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Evaluation and prediction of land use/land cover changes in the Andassa watershed, Blue Nile Basin, Ethiopia

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Abstract

Background: Land use/land cover (LU/LC) change is the challenging and continuous drivers of environment change. Understanding the rate and process of change is, therefore, basic for managing the environment. This study was intended to analyze the LU/LC changes from 1985 to 2015 periods, and predict the situation to 2030 and 2045 in the Andassa watershed of Blue Nile basin, Ethiopia. The hybrid classification technique for extracting thematic information from satellite images and CA-Markov model for prediction of LU/LC were employed.

Results: Cultivated land was expanding from 62.7% in 1985 to 73.1% in 2000 and to 76.8% in 2015. The area of built-up also slightly increased (0.1–1.1%) between 1985 and 2015 periods. In contrast, forest, shrubland and grassland were reduced from 3.5 to 1.9%, 26.2 to 15.3% and 7.6 to 4.9% in 1985 and 2015 periods, respectively. The increase of cultivated land and built-up area, and the withdrawing of forest, shrubland and grassland were further continued in 2030 and 2045 periods.

Conclusion: Significant amount of LU/LC conversions had occurred in the watershed from 1985 to 2015 periods, and expected to continue in 2030 and 2045 periods. Thus, appropriate interventions to revert the trends are very much critical.

Keywords: Land use/land cover, Change detection, Prediction, CA-Markov

Background

Our planet earth is endowed with plenty of natural resources which sustain life for millennia. However, land use/land cover (LU/LC) changes are major environmental challenges in various parts of the world. Globally, there had been an increase of cropland and pastureland during 1970–1990 and 1700–1990 periods, respectively. Within these periods, Lambin et al. (2003) indicated that cropland and pastureland globally increased approximately five and six fold, respectively. The increase was at the expense of forest, natural grassland and savannas. Nevertheless, the direction of LU/LC change was not uniform in all parts of the world. In temperate forest, the increment was by almost $3*10^6$ ha/year, while the tropical forest decreased by $12*10^6$ ha/year (MEA 2005).

LU/LC changes are also common phenomena in Ethiopia. There was a rapid expansion of cultivated land at the expense of vegetative land cover types in various parts of the country. For example, Gete and Hurni (2001) study in Dembecha area of northwestern Ethiopia showed an increase of cultivated land from 39% in 1957 to 77% in 1995 while natural forest declined from 27 to 0.3%. The decline of forest cover from 50.9 to 16.7% was also observed in Upper Gilgel Abbay catchment of Blue Nile basin between 1973 and 2001 periods, basically due to the expansion of agricultural land (Rientjes et al. 2011). Gessesse and Kleman (2007) study in the South Central Rift Valley Region of Ethiopia also showed the reduction of natural forest cover from 16% in 1972 to 2.8% in 2000, which amounts to a total natural forest loss of 40,324 ha.

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In the entire area of Blue Nile basin also there had been a shrinking of wooded grassland, wood land, shrubs and bushes, natural forest and afro-alpine vegetation between 1973 and 2000 periods while rain fed cropland, grassland, water body and barren land had increased. The increase of water body is due to the construction of different dams in the basin (Gebremicael et al. 2013). Belay (2002) study in Derekolli catchment of the South Wello Zone also reported the decline of scrubland at the rate of 1.6 and 0.31% per year between 1957–1986 and 1986–2000, respectively. In contrast, cropland had increased from 65.1% in 1957 to 70.6% in 2000. In Northern Afar rangelands also a rapid reduction in woodland cover (97%) and grassland cover (88%) from 1972 to 2007 were reported, and in contrary bush land cover and cultivated land increased more than three and eightfold, respectively (Diress et al. 2010). A decrease in coverage of scrublands, riverine vegetation and forests, and an increase in open areas, settlements, floodplains, and water body were also observed in Kalu District of Southern Wello between 1958 and 1986 periods (Kebrom and Hedlund 2000). While, some studies conducted in the previously degraded parts of northern Ethiopia, revealed improvement of vegetation cover due to community afforestation and land rehabilitation activity (Amare (2007) and Amare et al. (2011) in Eastern Escarpment of Wello, Ethiopia; Muluneh (2003) in west Gurage land and Munro et al. (2008) in Tigray highlands). The increase of forest cover was also reported in Chemoga watershed from 1957–1998 periods (Woldeamlak 2002).

LU/LC change is increasingly recognized as an important driver of environmental change on all spatial and temporal scales. LU/LC change contributes significantly to earth atmosphere interactions, forest fragmentation, and biodiversity loss (Fu et al. 2000). In addition, it is also one of the factors for local environment disturbance by influencing runoff, soil loss and stream flow (Woldeamlak 2002). Due to these, modeling the dynamics of LU/LC is crucially important for managing the environment. The study area, Andassa watershed, is known to be the productive area in the country, and the head stream of Blue Nile River. Hence, identifying the rate and process of LU/LC changes is fundamental, which have national and international significance. However, the watershed LU/LC change is not well investigated. Thus, this study was aimed to analyze the LU/LC changes from 1985 to 2015 periods and predict the situation to 2030 and 2045 periods.

Methods

Study site

Andassa watershed is within the Blue Nile basin of Ethiopia (Fig. 1). It is situated approximately 560 km northwest of Addis Ababa (the capital city of Ethiopia) and in a close proximity to the capital city of the Amhara regional state (Bahir Dar). Geographically, the watershed extends between 11°08′N–11°32′N latitude and 37°16′E–37°32′E longitudes. The watershed covers a surface area of 58,760 ha belonging to three Administrative Districts (*Woredas*), which are Bahir Dar Zuria, Mecha and Yilmana Densa. The topography is hilly and elevation ranges from 1701 m to 3216 m a.s.l. Its agro-climate is remarkably dominated by sub-tropical climate (85.2%) with a small segment of temperate climate (14.8%). According to the data obtained from the GIS department of Ministry of Water and Energy, the major soil types in the studied watershed include Haplic Alisols, Eutric Leptosols, Chromic Luvisols, Haplic Nitisols and Eutric Vertisols. Its geology is also characterized by Alluvium, Ashangi basalts, basalts related to volcanic center and Termaber basalts. Andassa River is the major river of the studied watershed, which is also among the tributaries of Blue Nile River. Agriculture is the foremost economic activity and the main sources of livelihood for the population

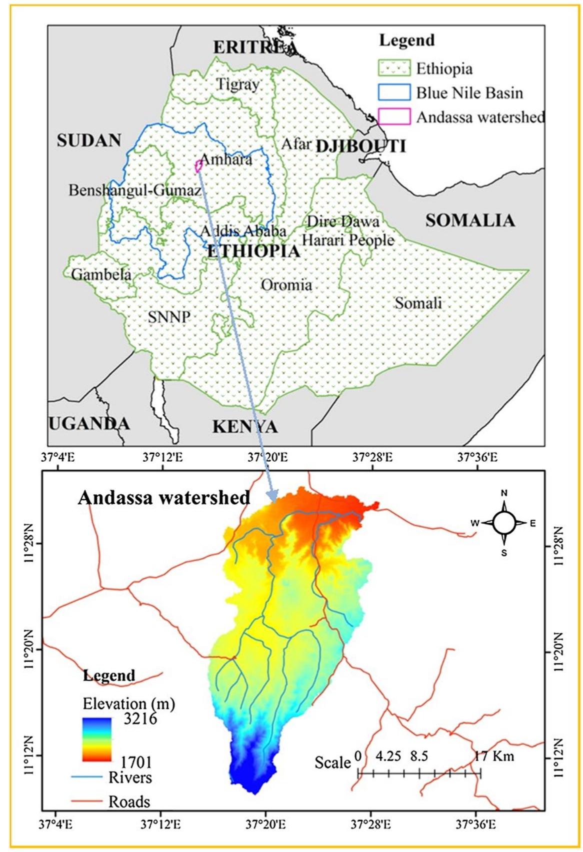

Fig. 1 Location map of the Andassa watershed in the Blue Nile basin from Ethiopia

and rainfall is bimodal which include spring and summer rainfall.

Data types and sources

Three satellite images (Landsat-5 TM 1985, Landsat-7 ETM$^+$ 2000 and Landsat-8 OLI–TIRS 2015) with 30 m spatial resolution were used for the LU/LC change analysis of the studied watershed. Details of the images characteristics are tabulated in Table 1. The data required for the study were collected from various sources. Landsat data were downloaded free of charge from U.S Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) (https://earthexplorer.usgs.gov/). ASTER GDEM with 30 m cell size was obtained from Aster Global Digital Elevation Map (http://gdex.cr.usgs.gov/gdex/), and river and road data were collected from the GIS department of Ministry of Water and Energy (Ethiopia). Population data of 1994 and 2007 at the smallest administrative unit (*Kebele*) were also obtained from the Ethiopian Central Statistics Agency. In addition to these secondary data, primary data were also obtained through extensive field works and in-depth focus group discussions with agricultural development agents and local elders.

Image classification

Image classifications were carried out to extract useful thematic information (Boakye et al. 2008; Al-sharif and Pradhan 2013) from the three Landsat images (Table 1). Preprocessing tasks such as geometric and radiometric corrections (Giriraj et al. 2008; Schulz et al. 2010; Teferi et al. 2010; Mosammam et al. 2016; Temesgen et al. 2017) were applied before classifying the images. Image classifications were undertaken using the hybrid classification technique, which combines both unsupervised and supervised classification techniques (Teferi et al. 2010; Solomon et al. 2014). The hybrid classification technique improves the classification accuracy better than using either unsupervised or supervised classification techniques alone (Lillesand and Kiefer 2000). Primarily, unsupervised classification using Iterative Self-Organizing Data Analysis (ISODATA) clustering (Boakye et al. 2008; Teferi et al. 2010) method was undertaken as a baseline for collecting ground truth points. Using signature editor of unsupervised classes, a pixel based supervised classification with Maximum Likelihood Classification (MLC) algorism (Solomon et al. 2014; Temesgen et al. 2014a) was undertaken using the ground truth points collected from each LU/LC category. A total of 450 GPS points (75 GPS points in each LU/LC), which were collected between 9:00 a.m. and 5:00 p.m., were undertaken for supervised classification. The LU/LC classes together with their descriptions are presented in Table 2. In classifying the 1985 and 2000 images, reference data from Google earth images from the corresponding time periods were collected. Furthermore, geo-linking techniques and in-depth focus group discussions with local elders were also undertaken. ERDAS Imagine 2014 and ArcGIS 10.3 software were used for image classification and mapping purposes, respectively.

Accuracy assessment

Accuracy assessment was done to understand the representation of the classified images on the ground (Congalton 1991; Congalton and Green 1999; Congalton 2005; Temesgen et al. 2014a; Mosammam et al. 2016). Any

Table 1 Satellite images used for LU/LC change analysis and their characteristics

Satellite image	Path/row	Sensor	Resolution/scale (m)	No. of bands	Date of acquisition	Cloud cover
Landsat-5	170/52	TM	30	7	1985-02-17	0
Landsat-7	170/52	ETM$^+$	30	8	2000-02-03	0
Landsat-8	170/52	OLI–TIRS	30	11	2015-02-20	0

Table 2 Land use/land cover types in the Andassa watershed and their descriptions

Land use/land cover classes	Description
Cultivated land	Include areas used for perennial and annual crops, irrigated areas and the scattered rural settlements.
Forest	Areas covered with dense trees, which include both *eucalyptus* and coniferous trees.
Shrubland	Areas covered with small trees, bushes and shrubs. In some areas, grasses are found within them. These are areas less dense than forests
Grassland	Areas covered by grasses usually used for grazing and those remains some months in a year
Built-up area	Areas used for construction sites and towns

classified image without accuracy assessment limits the confidence of the result (Congalton 1991; Congalton and Green 1999). Accuracy assessment is commonly done with reference to other images (Congalton 1991; Congalton and Green 1999; Foody 2002; Congalton 2005; Mekuria 2005; Gessesse and Kleman 2007; Schulz et al. 2010; Teferi et al. 2010). To do accuracy assessment for the classified images, 480 random sample points in ArcGIS 10.3 was created. Reference points were collected for the 1985, 2000 and 2015 classified images from the corresponding Google Earth images (i.e. 05 February, 1985; 21 February, 2000 and 28 February, 2015, respectively). A similar procedure was followed by Abineh and Bogale (2015) and Temesgen et al. (2017). Then, the classified images were compared with the reference images by means of error matrix (Foody 2002; Schulz et al. 2010; Rientjes et al. 2011; Ariti et al. 2015). Various measures of accuracy assessment such as producer accuracy, user accuracy (Congalton 1991), overall accuracy and Kappa coefficient were done. Overall accuracy (Congalton 1991; Foody 2002; Congalton 2005) was calculated as Eq. 1 while Kappa coefficient (Congalton 1991) was calculated using Eq. 2.

$$OA = \left(\frac{X}{y}\right) * 100 \quad (1)$$

where, OA is overall accuracy, X is number of correct values in the diagonals of the matrix, and Y is total number of values taken as a reference point.

$$K = \frac{N \sum_{i=1}^{r} xii - \sum_{i=1}^{r} (xi+ * x + i)}{N^2 - \sum_{i=1}^{r} (xi+ * x + i)} \quad (2)$$

where, K is Kappa coefficient, r is the number of rows in the matrix, xii is the number of observations in row i and column i, $xi+$ are the marginal totals of row i, $x + i$ are the marginal totals column i, and N is the total number of observations.

The accuracy report of the 1985, 2000 and 2015 classified images are presented in Table 3. An overall accuracy of 86.9, 85.8 and 88.8% were attained for the 1985, 2000 and 2015 classified images, respectively. A kappa coefficient of 0.83, 0.81 and 0.85, respectively, were also obtained for 1985, 2000 and 2015 LU/LC maps. According to Monserud (1990), a Kappa values between 0.70 and 0.85 are generally rated as very good indicators of the classified image in representing the ground truths. Hence, the validation data set indicated a very good agreement of the classified image with the ground truths. The details of the accuracy assessment reports of the classified images are found in the Additional file 1: Appendix.

Land use/land cover prediction

Prediction of LU/LC conditions for the 2030 and 2045 periods were undertaken with Cellular Automata-Markov (CA-Markov) model. CA-Markov predicts not only the trend but also the spatial structure of different LU/LC categories (Arsanjani et al. 2011; Wang et al. 2012; Li et al. 2015). The model is widely applied in LU/LC change modeling elsewhere (Kamusoko et al. (2009) in Zimbabwe; Arsanjani et al. (2011) in Iran; Sang et al. (2011) in China; Al-sharif and Pradhan (2013) in Libya; Adhikari and Southworth (2012) and Singh et al. (2015) in India among others). Predictions were undertaken in IDRISI; Geospatial software for monitoring and modeling the Earth system; version 17.0 using the 2015 classified image as a basis LU/LC image and by considering factors and constraints (Clark Labs 2012; Eastman 2012; Omar et al. 2014; Singh et al. 2015). At first, however, transitions between 2000 and 2015 periods (with the proportion error of 0.15) were undertaken using Markov transition estimator in the IDRISI module. Factors are criterions that indicate the relative suitability of areas under consideration (Clark Labs 2012; Eastman 2012), and they are mapped in a continuous scale. Constraints are criterions which limits the alternatives under consideration (Clark Labs 2012; Eastman 2012), and they are mapped as Boolean image. In the Boolean images of each class, a value of either 1 or

Table 3 Accuracy assessment of the 1985, 2000 and 2015 classified images

Land use/land cover	1985		2000		2015	
	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy
Cultivated land	87.4	89.9	86.8	86.3	89.3	92.6
Forest	86.2	91	87	90.5	96.4	91.5
Shrubland	90.7	85.8	86.4	87.3	92.6	85.3
Grassland	82.9	76.8	82.4	81.3	82.2	80
Built-up area	82.8	88.9	84.1	80.4	81.7	90.7
Over all accuracy (%)	86.9		85.8		88.8	
Kappa coefficient	0.83		0.81		0.85	

0 was assigned for non constraint and constraint criterions, respectively. The factors and constraints considered were distance to river, distance to town, distance to road, proximate to developed area, suitable areas for conversion to each class, elevation and slope. Suitable areas for conversion to each class were assigned by giving the value for the five classes from 0 (no probability for conversion) to 1 (high probability for conversion). It was done through in-depth focus group discussions with agricultural development agents. Slope was considered as a common constraint for cultivated and built-up area categories since increasing slope gradient inhabits both cultivation and built-up purposes. However, slope was not considered as a constraint for forest, shrubland and grassland uses. Table 4 presents the details of factors and constraint considered for each LU/LC class with their weights. In-depth focus group discussions with agricultural development agents and local elders were held to assign a set of relative weights for a group of factors, and a very good acceptable consistence ratio (Clark Labs 2012) for the group of factors considered were obtained for each class as shown in Table 4. The factors and constraint were integrated using a Multi-Criteria Evaluation (MCE) decision support system with Weighted Liner Combination (WLE) fuzzy membership function to produce a single suitability map for each class. To do so, factors were first changed to binary format from 0 to 255; in which 255 is high suitable and 0 is none suitable. The factors and constraint maps considered for each LU/LC class can be found from the Additional file 1: Appendix where the suitability maps for each LU/LC class are shown in Fig. 2.

Table 4 Factors and constraints considered and their weights for predicting LU/LC conditions in the Andassa watershed

LU/LC Class	Factors	Factor weight	Consistency ratio	Constraint and classes considered
Cultivated land	Suitable areas for conversion to cultivated land	0.5544	0.02	Slope (>15°–58°)
	Proximity to developed land	0.2835		
	Distance to rivers	0.1112		
	Elevation	0.0509		
Forest	Suitable areas for conversion to forest	0.6942	0.01	Slope (None)
	Proximate to developed land	0.2103		
	Elevation	0.0955		
Shrubland	Suitable areas for conversion to shrubland	0.5396	0.01	Slope (None)
	Proximate to developed land	0.2970		
	Elevation	0.1634		
Grassland	Suitable areas for conversion to grassland	0.6370	0.03	Slope (None)
	Proximate to developed land	0.2583		
	Elevation	0.1047		
Built-up area	Suitable areas for conversion to built-up area	0.4312	0.04	Slope (>13°–58°)
	Proximate to developed land	0.2703		
	Distance to towns	0.1724		
	Distance to roads	0.0794		
	Elevation	0.0467		

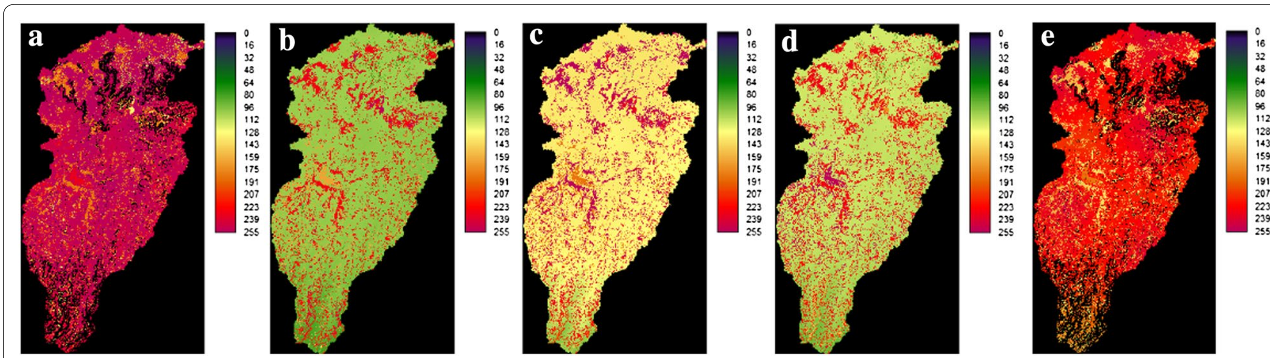

Fig. 2 Suitability map of cultivated land (**a**), forest (**b**), shrubland (**c**), grassland (**d**) and built-up area (**e**) in the Andassa watershed

Model validation

Model validation is a fundamental component in any modeling activity (Pontius and Schneider 2001; Al-sharif and Pradhan 2013; Singh et al. 2015; Mosammam et al. 2016). To check the quality of CA-Markov model in simulating future LU/LC conditions, the model was validated (Giriraj et al. 2008; Adhikari and Southworth 2012; Al-sharif and Pradhan 2013; Omar et al. 2014) after simulating the 2015 LU/LC conditions using the 1985 and 2000 classified images. Then, the simulated and the actual 2015 LU/LC maps were compared using the "Relative Operating Characteristic (ROC)" (Pontius and Schneider 2001) tool accessible in the IDRISI module. Furthermore, Kappa indexes (Mosammam et al. 2016) such as Kappa for no information (*K*no), Kappa for location (*K*location), Kappa for stratum-level location (*K*locationStrata) and Kappa for standard (*K*standard) (Clark Labs 2012; Omar et al. 2014; Mosammam et al. 2016) were also used to compare the agreements of the two maps. In addition, comparisons of the simulated and the actual area of each LU/LC class were also done.

Land use/land cover change

Change analysis is usually done to demonstrate the patterns of changes and to make useful decisions. After classification of images and projection of the 2030 and 2045 conditions, comparisons (Gete and Hurni 2001; Belay 2002; Schulz et al. 2010; Abate 2011; Rawat and Kumar 2015; Mosammam et al. 2016) between the subsequent periods were made to illustrate the changes between the periods. Conversion matrix (Mekuria 2005; Giriraj et al. 2008; Diress et al. 2010; Teferi et al. 2010; Abate 2011; Rientjes et al. 2011) between 1985 and 2000, 2000 and 2015, 2015 and 2030, and 2030 and 2045 periods were also done to distinguish the changes of each category at the expense of others. In addition, percent of change (Ebrahim and Mohamed 2017) and rate of change (Abate 2011; Temesgen et al. 2014a) was also computed to demonstrate the magnitude of the changes experienced between the periods using Eqs. 3 and 4, respectively.

$$Percent\ of\ change = \left(\frac{X - Y}{Y}\right) * 100 \quad (3)$$

$$Rate\ of\ change (ha/year) = \left(\frac{X - Y}{Z}\right) \quad (4)$$

where, X is area of LU/LC (ha) in time 2, Y is area of LU/LC (ha) in time 1, Z is Time interval between X and Y in years.

Furthermore, trends of LU/LC changes from 1985 to 2045 periods were also illustrated.

Methods of exploring the drivers of land use/land cover changes

It is generally apparent that LU/LC changes are driven by the interaction of natural and human forces (Meyer and Turner 1994; Belay 2002). The natural drivers such as climate change are felt after extended periods of time (Woldeamlak 2002; Ebrahim and Mohamed 2017). However, human drivers are immediate and often radical (Woldeamlak 2002). Whatever their speed and magnitude, most LU/LC changes have occurred due to human drivers (Gete and Hurni 2001). Hence, exploring the trend of population growth and its association with the observed LU/LC changes is very much crucial.

Thus, to appreciate the trend of population growth and its association with the observed LU/LC in the studied watershed, population data of the 1994 and 2007 census reports (CSA 1994, 2007) were used. As it is true in most of the time, obtaining population data of the entire studied watershed was indisputably difficult (Woldeamlak 2002; Ebrahim and Mohamed 2017). Due to this, the smallest administrative units called *Kebeles* whose entire areas are within the studied watershed were used for this purpose. Accordingly, ten *Kebeles* from the three administrative Districts (Bahir Dar Zuria, Mecha and Yilmana Densa) were purposefully selected. Using the data, various statistics such as growth between 1994 and 2007, rate of growth (%) and doubling time in years were computed, and associated with the observed LU/LC changes. Rate of growth (%) and doubling time in years was calculated using Eqs. 5 and 6 (Woldeamlak 2002; Abate 2011), respectively.

$$r = \frac{1}{n} \ln\left(\frac{Pt2}{Pt1}\right) * 100 \quad (5)$$

$$DT = 70/r \quad (6)$$

where, r is growth rate in percent, $Pt2$ is the population at time 2, $Pt1$ is the population at time 1, n is the number of years between time 1 and time 2, and DT is doubling time in year.

To asses other drivers of LU/LC changes, focus group discussions with local elders and agricultural development agents were also carried out.

Results and discussion

Land use/land cover change analysis

Analysis of LU/LC patterns in the studied watershed indicated the growth of cultivated land and built-up area at the expense of vegetative cover types over the last three decades (Table 5; Fig. 3). During these periods, cultivated land has expanded from 62.7% in 1985 to 73.1% in 2000, and again to 76.8% in 2015 (Table 5). Between 1985–2000

Table 5 Area of LU/LC class from 1985 to 2015 periods in the Andassa watershed

Land use/land cover	1985		2000		2015	
	Area (ha)	Percent (%)	Area (ha)	Percent (%)	Area (ha)	Percent (%)
Cultivated land	36,820	62.7	42,925	73.1	45,108	76.8
Forest	2068	3.5	1504	2.6	1138	1.9
Shrubland	15,377	26.2	10,447	17.8	8992	15.3
Grassland	4461	7.6	3783	6.4	2850	4.9
Built-up area	35	0.1	101	0.2	672	1.1
Total	58,760	100	58,760	100	58,760	100

and 2000–2015 periods, it was increased by 16.6 and 5.1%, respectively. The rate of increment during 1985–2000 and 2000–2015 periods were 407 and 145.5 ha/year, respectively (Table 6). Similarly, built-up area had also increased from 0.1 to 0.2% and to 1.1% in 1985, 2000 and 2015 periods, respectively (Table 5). During 1985–2000 and 2000–2015 periods, built-up area increased by 192.5 and 562.8%, respectively (Table 6). The rapid percent change taken place in built-up area during these periods is associated with the nearest location of Bahir Dar town to the study site as can be seen most of the increased in built-up area occurred in the north-eastern areas of the studied watershed. This reason was also mentioned during focus group discussions of agricultural development agents. In contrast, forest, shrubland and grasslands had decreased in the whole study periods. For example, forest coverage decreased from 3.5% in 1985 to 2.6% in 2000 and to 1.9% in 2015 (Table 5) with the annual diminishing rate of 37.6 and 24.4 ha/year between 1985–2000 and 2000–2015 periods, respectively (Table 6). Similarly, shrubland and grasslands also decreased at a rate of 328.7 and 97 ha/year, and 45.2 and 62.2 ha/year, respectively, between 1985–2000 and 2000–2015 periods. During 1985 to 2015 periods, forest, shrubland and grassland have shown a reduction in size (Table 6).

The finding of this research is consistent with other studies carried out by Gete and Hurni (2001) in Dembecha area of northwestern Ethiopia; Gessesse and Kleman (2007) in South Central Rift Valley Region of Ethiopia; Rientjes et al. (2011) in Upper Gilgel Abbay catchment of Blue Nile basin; Gebremicael et al. (2013) in Blue Nile basin; Temesgen et al. (2014a) in Dera District of northwestern Ethiopia; Solomon et al. (2014) in Birr and Upper-Didesa watersheds of Blue Nile basin, where the agricultural land increased significantly where forest land was shrinking. A study in Shomba and Michity catchments of Kefa zone (Mekuria 2005) also indicated the conversion of vegetative lands into non-vegetative lands between 1987 to 2001 periods mainly for the expansion of cultivated land and settlement. Studies by Ebrahim and Mohamed (2017) in Geleda catchment and Solomon et al. (2010) in Koga watershed also reported the growth of cultivated lands at the reduction of forest cover in the respective study periods.

Analysis of land use/land cover conversions

Conversions of LU/LC from one category to another are common phenomena in LU/LC studies (Belay 2002). The conversions of one LU/LC category to another between 1985–2000 and 2000–2015 periods are presented in Tables 7 and 8. The diagonals in the matrix from the tables are the persistence while the off-diagonals are the conversions from one category to the others. The change detection analysis indicated the significant conversions in LU/LC in both periods.

Conversions between 1985 and 2000

In these periods, 8216, 2230, 547 and 1 ha of cultivated land were converted from shrubland, grassland, forest and built-up area, respectively. While cultivated land gained from other LU/LC categories, a significant area of cultivated land were also reverted to shrubland, grassland, forest and built-up area (Table 7). During these time, some area of built-up were also converted from cultivated land (47 ha), grassland (26 ha) and shrubland (2 ha). Although it is a small proportion, 5, 3 and 1 ha of built-up area were also in reverse converted to grassland, shrubland and cultivated land, respectively. Gains and losses in forest, shrubland and grassland were also taken place during these periods (Table 7). For example, 8216 ha of cultivated land, 651 ha grassland, 408 ha of forest and 2 ha of built-up area were altered from shrubland. In reverse, a considerable area of shrubland were also reverted from cultivated land (3009 ha), grassland (794 ha), forest (542 ha) and built-up area (3 ha).

Conversions between 2000 and 2015

During these periods, 4598, 322, 207 and 148 ha of shrubland were converted to cultivated land, forest, grassland and built-up area, respectively. About 2484, 513, 110 and

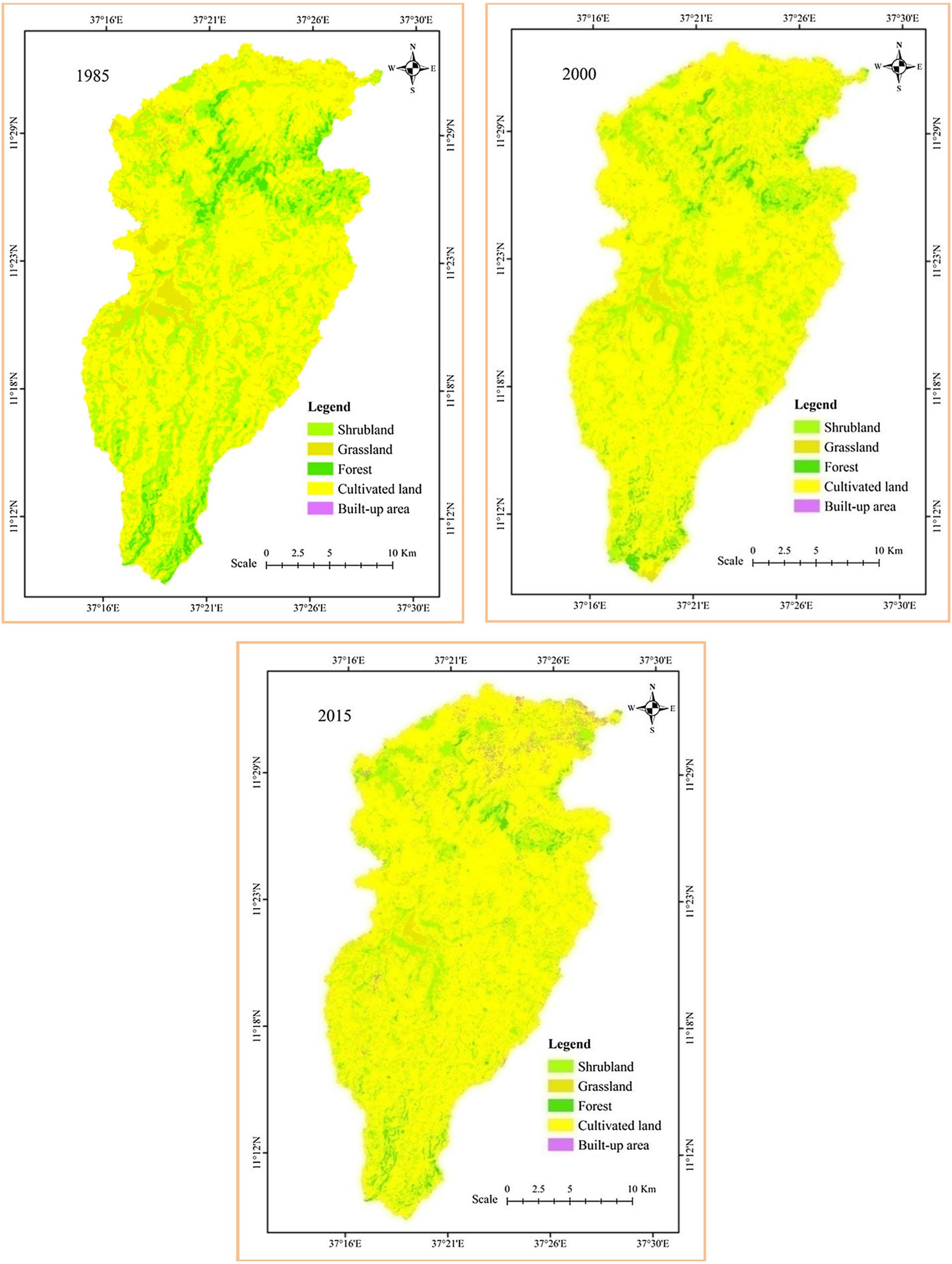

Fig. 3 Land use/cover of 1985, 2000 and 2015 of the Andassa watershed

Table 6 Percent and rate of changes occurred in the Andassa watershed from 1985 to 2015 periods

Land use/land cover	Percent change			Rate of change (ha/year)		
	1985–2000	2000–2015	1985–2015	1985–2000	2000–2015	1985–2015
Cultivated land	+16.6	+5.1	+22.5	+407	+145.5	+276.3
Forest	−27.3	−24.3	−45	−37.6	−24.4	−31
Shrubland	−32.1	−13.9	−41.5	−328.7	−97	−212.8
Grassland	−15.2	−24.7	−36.1	−45.2	−62.2	−53.7
Built-up area	+192.5	+562.8	+1838.4	+4.4	+38	+21.2

Table 7 Transition area matrix (ha) between 1985 and 2000 periods in the Andassa watershed

1985	2000					
	Cultivated land	Forest	Shrubland	Grassland	Built-up area	Total
Cultivated land	31,930	119	3009	1715	47	36,820
Forest	547	948	542	30	0	2068
Shrubland	8216	408	6099	651	2	15,377
Grassland	2230	29	794	1382	26	4461
Built-up area	1	0	3	5	26	35
Total	42,925	1504	10,447	3783	101	58,760

Table 8 Transition area matrix (ha) for the period 2000 and 2015

2000	2015					
	Cultivated land	Forest	Shrubland	Grassland	Built-up area	Total
Cultivated land	37,721	180	2724	1969	331	42,925
Forest	297	619	575	12	0	1504
Shrubland	4598	322	5171	207	148	10,447
Grassland	2484	16	513	660	110	3783
Built-up area	9	0	9	2	82	101
Total	45,108	1138	8992	2850	672	58,760

16 ha of grassland were also reverted to cultivated land, shrubland, built-up area and forest, respectively. An estimated 575, 297, 12 ha of forest were also converted to shrubland, cultivated land and grassland, respectively. Similarly, shrubland, grassland and forest were also gained from other LU/LC categories (Table 8). In these periods, a significant area of cultivated land were converted from shrubland (4598 ha), grassland (2484 ha), forest (297 ha) and built-up area (9 ha). In reverse, there was also a considerable conversion of cultivated land to other categories. A significant amount of gains and losses in built-up area was also occurred in these periods (Table 8).

Generally, during the two periods the conversion of cultivated land from shrubland is higher than any other category of conversions. Studies conducted in various parts of the country also reported the conversions of one category to others. For instance, a study in northern Afar rangelands (Diress et al. 2010) reported the conversions of scrubland, bushy grassland, and grassland to cultivated land between 1972 and 2007 periods. Woodlands were converted to bushland, scrubland and bushy grassland. Similarly, a study in Upper Gilgel Abbay catchment of Blue Nile basin between 1973 and 2001 periods (Rientjes et al. 2011) also reported the conversions of one category to the other and the gains and losses between each category. During 1973 to 1986 and 1986 to 2001 periods, the greatest conversions taken place were the conversions of shrubland, forest and grassland into cultivated lands.

Drivers of land use/land cover changes

It is quite observed that, population has grown in the studied watershed through 1994 to 2007 periods. The increase of population between these periods varied from 11% in Wetet Ber *Kebele* to 51% in Kimbaba *Kebele* (Table 9). Population growth increases demands of more cultivated land, fuel wood, charcoal and infrastructural development; which leads to vegetative cover losses. Hence, the increased of population number is certainly the primary driver of LU/LC changes in the studied watershed as observed in the sample *Kebeles* (Table 9), which was manifested largely through the expansion of cultivated lands at the expense of vegetative land covers (Table 4). A result from focus group discussions has also confirmed that the reduction of land productivity, which leads the intension of the people for getting new fertile cultivable lands, is the other important driver to these changes.

Similar with the conclusion drawn above, population growth was also the most important factor for the LU/LC dynamics in the Chemoga watershed of northwestern highland of Ethiopia (Woldeamlak 2002); Dendi District, Ethiopia (Berhan 2010); Dera District of northwestern Ethiopian highlands (Temesgen et al. 2014b) and Geleda catchment of northwestern highlands (Ebrahim and Mohamed 2017) to mention among others. Similarly, Hurni et al. (2005) also noted that population increment from the mid to the turn of the twentieth century at the country level (Ethiopia) accelerated deforestation and intensified cultivation.

Future land use/land cover change

CA-Markov model validation

Visual comparison of the 2015 simulated and actual maps (Fig. 4a, b) are reasonably similar. The area extent of the two maps (Table 10) also illustrates the acceptable range of decisions, in which agriculture accounts 77.1 and 76.8% in the simulated and actual maps, respectively. In addition, there are also approximately equal proportions of forest, shrubland and grasslands between the simulated and the actual maps. The less effective projected LU/LC category is built-up area. This is due to models' less ability in capturing the randomly new developed areas. Validations through different statistics have been also done, and ROC value of 89.5% was achieved. All the kappa statistics such as *K*no (87.7%), *K*location (82.2%), *K*locationStrata (82.2%) and *K*standard (81.6%) were also above 80% (Table 10), which indicates the good performance of the model in simulating future LU/LC conditions (Singh et al. 2015; Mosammam et al. 2016).

The predicted land use/land cover

The projected 2030 and 2045 LU/LC conditions using CA-Markov model are indicated in Fig. 5a, b while their area coverage is presented in Table 11. According to the resulted maps, the area of cultivated land has grown from 76.8% in 2015 to 83.3% in 2030 and to 85.8% in 2045. A continuous increase of built-up area have been also observed from 2015 (1.1%) to 2030 (2%) and to 2045 (5.9%) periods. In contrast, a diminishing of forest cover from 1.9 to 1.5% and to 1.3%; shrubland from 15.3 to 9.2% and to 4.7% and grassland from 4.9 to 4% and to 2.3% were observed through 2015, 2030 and 2045 periods, respectively. In general, the increased of cultivated land and built-up area at the cost of vegetative LU/LC classes will be observed through 2015, 2030 and 2045 periods.

Future land use/land cover conversions

The LU/LC conversions occurred between 2015–2030 and 2030–2045 periods (Tables 12 and 13) are presented below:

Table 9 Population number and growth rate in the sample *Kebeles* of the Andassa watershed

Name of *Kebele*	District	1994	2007	Growth between 1994 and 2007	Change between 1994 and 2007 (%)	Growth rate (%) between 1994 and 2007	Doubling time in years (after 2007)
Sebatamit	Bahir Dar Zuria	5624	6281	657	12	0.85	82
Wenedata	Bahir Dar Zuria	2965	3588	623	21	1.47	48
Kimbaba	Bahir Dar Zuria	6182	9309	3127	51	3.15	22
Alahayi	Bahir Dar Zuria	4209	5123	914	22	1.51	46
Feres Woga	Bahir Dar Zuria	4933	5786	853	17	1.23	57
Genebe Sosetu	Bahir Dar Zuria	5050	5867	817	16	1.15	61
Wetet Ber	Mecha	5223	5802	579	11	0.81	87
Braqet	Mecha	6282	7719	1437	23	1.58	44
Felege Berhan	Mecha	5343	6409	1066	20	1.40	50
Abeyot Fere	Yilmana Densa	5726	7135	1409	25	1.69	41

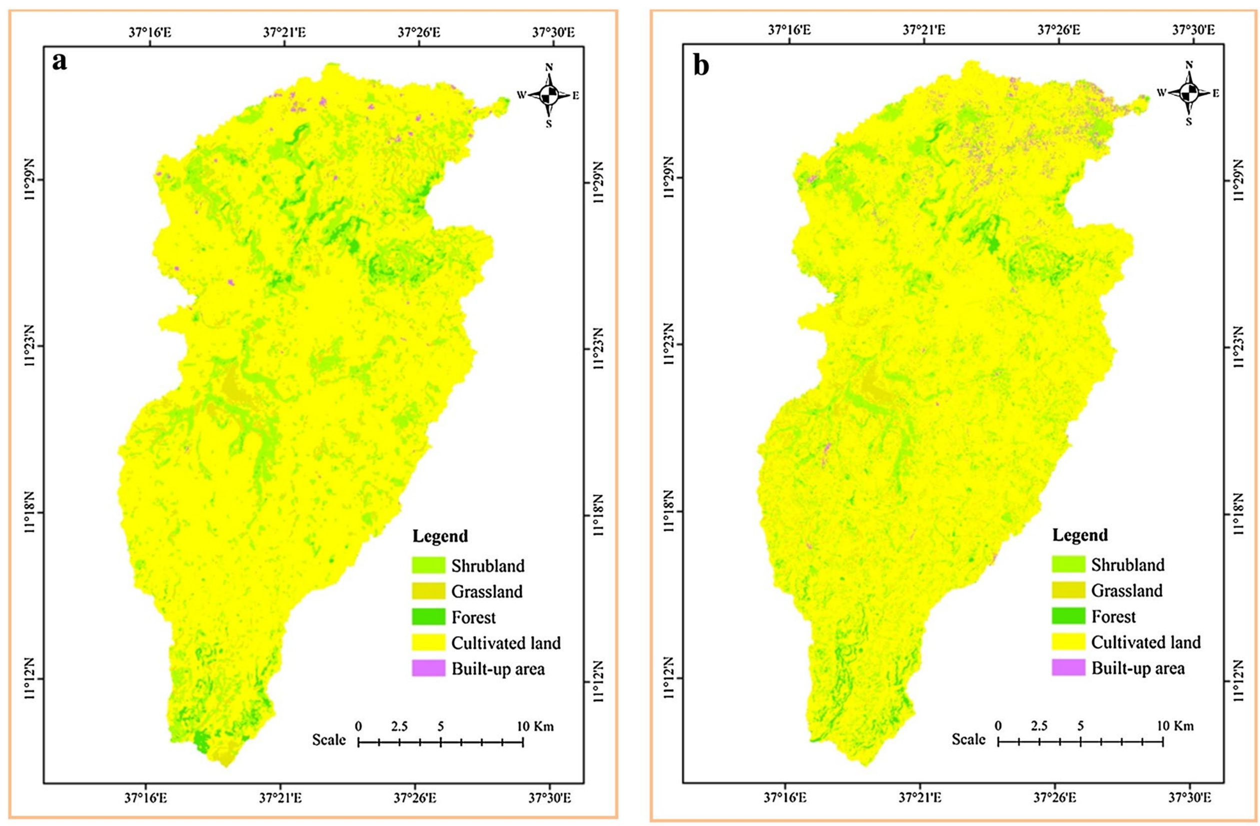

Fig. 4 The simulated (**a**) and the actual (**b**) land use/land cover of the Andassa watershed in 2015

Conversions between 2015 and 2030

Within these periods, 3890, 1218, 113 and 36 ha of cultivated land were gained from shrubland, grassland, forest and built-up area, respectively. About 389, 135 and 39 ha of built-up area were also reverted from cultivated land, shrubland and grassland, respectively. Although cultivated and built-up area gained from other categories, there was also a significant loss of cultivated and built-up area to other categories (Table 12). Between these periods, there was a huge loss of forest, shrubland and grassland to other categories. For example, about 3890, 135, 69 and 4 ha of shrubland were converted to cultivated land, built-up area, grassland and forest, respectively. About 141, 113 and 5 ha of forest were also converted to shrubland, cultivated land and grassland, respectively. The grassland converted to cultivated land, built-up area, shrubland and forest were 1218, 39, 11 and 1 ha, respectively. In contrast, forest, shrubland and grassland were also gained from other categories (Table 12).

Conversions between 2030 and 2045

A significant conversion of LU/LC categories has been also taken place between these periods (Table 13). For example, 2466, 1083, 103 and 20 ha of cultivated land were reverted from shrubland, grassland, forest and built-up area, respectively. A considerable area of cultivated land (2115 ha), shrubland (117 ha) and grassland (41 ha) were also converted to built-up area. A substantial area of cultivated land and built-up area were also reversed to other categories. In contrast, there was also a huge conversion of forest, shrubland and grassland to other categories. For instance, 103, 34 and 2 ha of forest were converted to cultivated land, shrubland and grassland, respectively. An estimated 2466, 117, 80 and 2 ha of

Table 10 The simulated and the actual land use/land cover area (ha) of the Andassa watershed in 2015

Land use/land cover	Simulated		Actual	
	Area (ha)	Percent (%)	Area (ha)	Percent (%)
Cultivated land	45,313	77.1	45,108	76.8
Forest	1167	2.0	1138	1.9
Shrubland	9149	15.6	8992	15.3
Grassland	2917	5.0	2850	4.9
Built-up area	214	0.4	672	1.1
Total	58,760	100	58,760	100

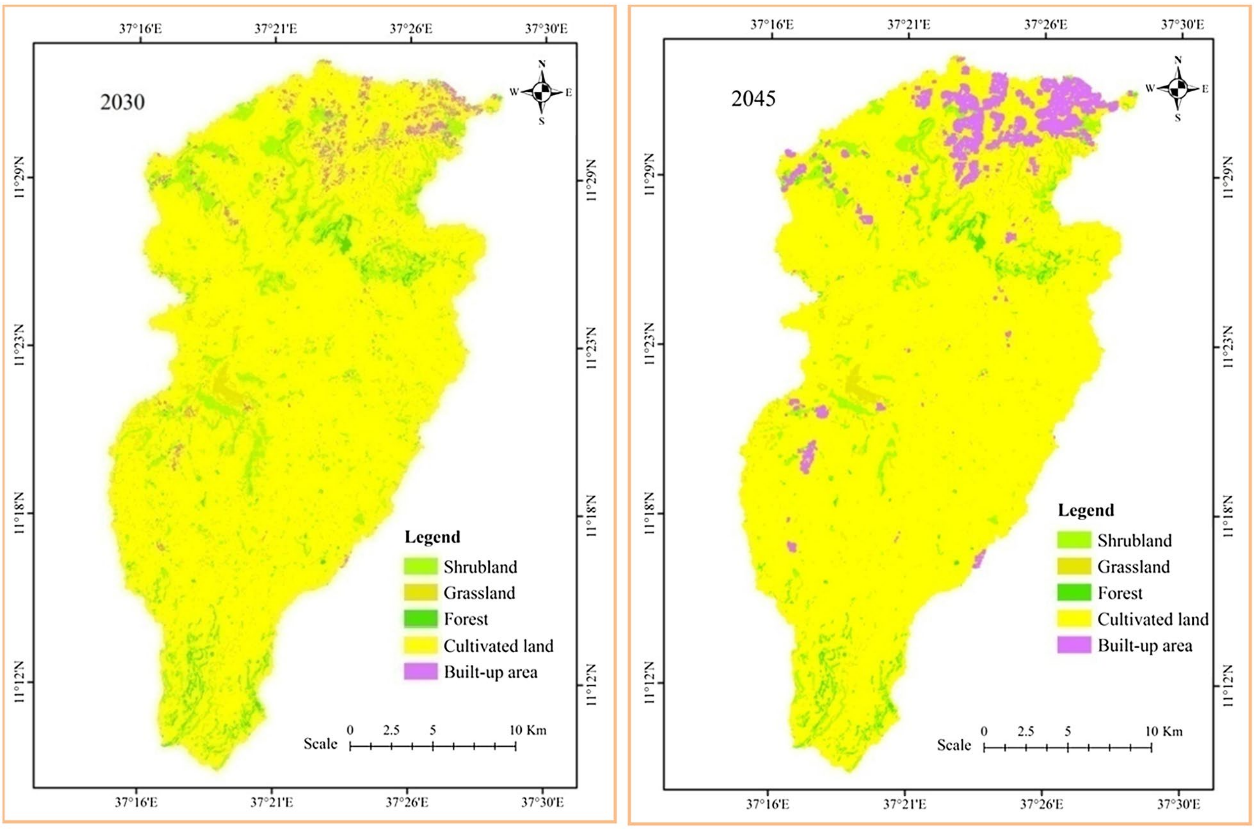

Fig. 5 The 2030 and 2045 land use/land cover of the Andassa watershed

Table 11 The projected LU/LC area in 2030 and 2045 in the Andassa watershed

Land use/land cover	2030		2045		2030–2045	
	Area (ha)	Percent (%)	Area (ha)	Percent (%)	Percent change	Rate of change (ha/year)
Cultivated land	48,932	83.3	50,425	85.8	+3	+99.5
Forest	898	1.5	763	1.3	−15	−9
Shrubland	5391	9.2	2780	4.7	−48.4	−174
Grassland	2342	4.0	1344	2.3	−42.6	−66.5
Built-up area	1197	2.0	3448	5.9	+188	+150
Total	58,760	100	58,760	100		

Table 12 Land use/land cover conversion matrix (ha) for the period 2015 and 2030

2015	2030					
	Cultivated land	Forest	Shrubland	Grassland	Built-up area	Total
Cultivated land	43,676	15	343	685	389	45,108
Forest	113	879	141	5	0	1138
Shrubland	3890	4	4895	69	135	8992
Grassland	1218	1	11	1582	39	2850
Built-up area	36	0	0	0	635	672
Total	48,932	898	5391	2342	1197	58,760

Table 13 Land use/land cover conversion matrix (ha) for the period 2030 and 2045

2030	2045					
	Cultivated land	Forest	Shrubland	Grassland	Built-up area	Total
Cultivated land	46,753	3	17	45	2115	48,932
Forest	103	758	34	2	0	898
Shrubland	2466	2	2727	80	117	5391
Grassland	1083	0	2	1215	41	2342
Built-up area	20	0	0	2	1175	1197
Total	50,425	763	2780	1344	3448	58,760

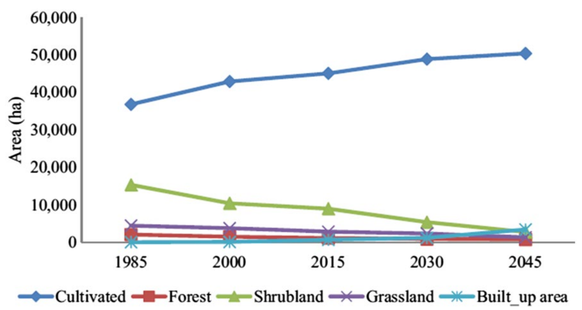

Fig. 6 Trends of land use/land cover changes from 1985 to 2045 in the Andassa watershed

shrubland were also converted to cultivated land, built-up area, grassland and forest, respectively. The grassland reverted to cultivated land, built-up area and shrubland were 1083, 41 and 2 ha, respectively. Even though, forest, shrubland and grasslands experienced a significant losses (Table 13), there was also a gain of forest, shrubland and grassland from other categories.

Generally, cultivated land and built-up area have shown an increasing trend from 1985 to 2045 periods. In contrast, vegetative land cover types such as forest, shrubland and grasslands are in a decreasing trend (Fig. 6).

Conclusion

Significant amount of LU/LC conversions had occurred from 1985 to 2015 periods in the Andassa watershed. Cultivated land and built-up area had increased in the period of 1985 to 2015. In contrast, forest, shrubland and grassland have decreased in coverage. The trend of increasing in cultivated land and built-up area and decreasing in forest, shrubland and grassland LU/LC categories are expected continued in 2030 and 2045 periods. Population growth and reduction of land productivity are the drivers of such changes. If the trends of LU/LC changes continued, it will have implications on increasing soil loss and impacting the hydrology of the studied watershed in particular and the Blue Nile basin in general. Hence, reversing the projected conditions is very much important for maintaining the productivity of the studied watershed.

Recommendations

It is recommended that experts of environment, conservation, resource management and sustainability, ecology, biodiversity and eco-system are required to develop a plan for sustainable use of the site to ensure its functions for the next generations.

Additional file

Additional file 1. Appendix.

Abbreviations

CSA: Central Statistics Agency; CA-Markov: Cellular Automata-Markov; DEM: Digital Elevation Model; ETM^{+}: Enhanced Thematic Mapper; GIS: Geographic Information System; GPS: Global Positioning System; MCE: Multi-Criteria Evaluation; MLC: Maximum Likelihood Classification; OLI–TIRS: Operational Land Imager–Thermal Infrared Sensor; ROC: Relative Operating Characteristic; TM: Thematic Mapper; ISODATA: Iterative Self-Organizing Data Analysis; WLE: Weighted Liner Combination.

Authors' contributions

TG carried out designing the research idea, method design, field data collection, data analysis and interpretation, prepare draft of the manuscript, and structuring the report; TT, MA and AW participated in method design, data analysis and interpretation, and structuring the report. All authors read and approved the final manuscript.

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Competing interests
The authors declare that they have no competing interests.

Availability of data and materials
The three landsat images were downloaded from U.S Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS). ASTER GDEM was obtained from Aster Global Digital Elevation Map, and river and road data were collected from Ministry of Water and Energy. In addition, primary data were also obtained through extensive field works and in-depth focus group discussions with agricultural development agents and local elders.

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References

Abate S (2011) Evaluating the land use and land cover dynamics in Borena Woreda of South Wollo highlands, Ethiopia. J Sustain Dev Afr 13(1):87–105
Abineh T, Bogale T (2015) Accuracy assessment of land use land cover classification using google earth. AJEP 4(4):193–198
Adhikari S, Southworth J (2012) Simulating forest cover changes of Bannerghatta National Park based on a CA-Markov model: a remote sensing approach. Remote Sens 4:3215–3243
Al-sharif AA, Pradhan B (2013) Monitoring and predicting land use change in Tripoli Metropolitan City using an integrated Markov chain and cellular automata models in GIS. Arab J Geosci 7:4291–4301
Amare B (2007) Landscape transformation and opportunities for sustainable land management along the Escarpment of Wello, Ethiopia. Ph.D. Thesis, Bern University, Bern
Amare B, Hurni H, Gete Z (2011) Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. Nor J Geogr 65:42–53
Ariti AT, Vliet JV, Verburg PH (2015) Land-use and land-cover changes in the Central Rift Valley of Ethiopia: assessment of perception and adaptation of stakeholders. Appl Geogr 65:28–37
Arsanjani JJ, Kainz W, Mousivand AJ (2011) Tracking dynamic land-use change using spatially explicit Markov Chain based on cellular automata: the case of Tehran. Int J Image Data Fusion. doi:10.1080/19479832.2011.605397
Belay T (2002) Land-cover/land-use changes in the Derekolli catchment of the South Welo Zone of Amhara Region, Ethiopia. EASSRR 18(1):1–20
Berhan G (2010) The role of geo-information technology for predicting and mapping of forest cover spatio-temporal variability: Dendi district case study, Ethiopia. J Sustain Dev Afr 12(6):9–33
Boakye E, Odai SN, Adjei KA, Annor FO (2008) Landsat images for assessment of the impact of land use and land cover changes on the Barekese Catchment in Ghana. Eur J Sci Res 22(2):269–278
Congalton R (1991) A review of assessing the accuracy of classifications of remotely sensed data. Remote Sens Environ 37:35–46
Congalton RG (2005) Thematic and positional accuracy assessment of digital remotely sensed data. Proceedings of the seventh annual forest inventory and analysis symposium. pp 149–154
Congalton RG, Green K (1999) Assessing the accuracy of remotely sensed data: principles and practices. Lewis Publishers, Boca Raton, p 137
CSA (Central Statistics Authority) (1994) The 1994 population and housing census of Ethiopia: results for Amhara region. Volume I, Part I. Statistical report on population size and characteristics. Central Statistics Authority, Addis Ababa
CSA (Central Statistics Authority) (2007) Report of the 2007 population and housing census of Ethiopia. Central Statistics Authority, Addis Ababa
Diress T, Moe SR, Vedeld P, Ermias A (2010) Land-use/cover dynamics in northern Afar rangelands, Ethiopia. Agric Ecosyst Environ 139:174–180
Eastman J (2012) IDRISI Selva manual, version 17. Clark University, Worcester
Ebrahim EA, Mohamed A (2017) Land use/cover dynamics and its drivers in Gelda catchment, Lake Tana watershed, Ethiopia. Environ Syst Res 6(4):1–13
Foody GM (2002) Status of land cover classification accuracy assessment. Remote Sens Environ 80:185–201
Fu B, Chen L, Ma K, Zhou H, Wang J (2000) The relationships between land use and soil conditions in the hilly area of the Loess Plateau in northern Shaanxi, China. CATENA 36:69–78
Gebremicael TG, Mohamed YA, Betrie GD, van der Zaag P, Teferi E (2013) Trend analysis of runoff and sediment fluxes in the Upper Blue Nile basin: a combined analysis of statistical tests, physically-based models and land use maps. J Hydrol 482:57–68
Gessesse D, Kleman J (2007) Pattern and magnitude of deforestation in the South Central Rift Valley Region of Ethiopia. Mt Res Dev 27:162–168
Gete Z, Hurni H (2001) Implications of land use and land cover dynamics for mountain resource degradation in the northwestern Ethiopian Highlands. Mt Res Dev 21(2):184–191
Giriraj A, Irfan-Ullah M, Murthy MS, Beierkuhnlein C (2008) Modeling spatial and temporal forest cover change patterns (1973–2020): a case study from South Western Ghats (India). Sensors 8:6132–6153
Hurni H, Kebede T, Gete Z (2005) The implications of changes in population, land use, and land management for surface runoff in the Upper Nile Basin area of Ethiopia. Mt Res Dev 25(2):147–154
Kamusoko C, Aniya M, Adi B, Manjoro M (2009) Rural sustainability under threat in Zimbabwe–simulation of future land use/cover changes in the Bindura district based on the Markov-cellular automata model. Appl Geogr 29:435–447
Kebrom T, Hedlund L (2000) Land cover changes between 1958 and 1986 in Kalu District, Southern Wello, Ethiopia. Mt Res Dev 20(1):42–51
Labs Clark (2012) Idrisi Selva help system. Clark University, Worcester
Lambin E, Geist H, Lepers E (2003) Dynamics of land use and land cover change in tropical regions. Annu Rev Environ Resour 28:206–232
Li S, Jin B, Wei X, Jiang Y, Wang J (2015) Using CA-Markov model to model the spatiotemporal change of land use/cover in Fuxian Lake for decision support. International workshop on spatiotemporal computing, 13–15 July 2015, Fairfax, Virginia, USA
Lillesand T, Kiefer R (2000) Remote sensing and image interpretation, 4th edn. Wiley, New York
MEA (Millennium Ecosystem Assessment) (2005) Ecosystems and human well-being: Synthesis. Island Press, Washington, DC
Mekuria A (2005) Forest conversion-soil degradation-farmers' perception nexus implications for sustainable land use in the southwest of Ethiopia. In: Vlek P, Denich M, Martius C, Rodgers C and Giesen N (ed) Ecology and development series no. 26, p 161
Meyer WB, Turner BL (eds) (1994) Changes in land use and land cover: a global perspective. Cambridge University Press, Cambridge

Monserud RA (1990) Methods for comparing global vegetation maps, Report WP-90-40. IIASA, Laxenburg
Mosammam H, Nia J, Khani H, Teymouri A, Kazem M (2016) Monitoring land use change and measuring urban sprawl based on its spatial forms: the case of Qom city. Egypt J Remote Sens Space Sci. doi:10.1016/j.ejrs.2016.08.002
Muluneh W (2003) Population growth and environmental recovery: more people, more trees; lesson learned from western Gurageland. Ethiop J Soc Sci Humanit 1(1):1–33
Munro R, Deckers J, Mitiku H, Grove A, Poesen J, Nyssen J (2008) Soil landscapes, land cover change and erosion features of the Central Plateau region of Tigrai, Ethiopia: photo-monitoring with an interval of 30 years. CATENA 75:55–64
Omar NQ, Ahamad MS, Hussin WM, Samat N, Ahmad SZ (2014) Markov CA, multi regression, and multiple decision making for modeling historical changes in Kirkuk City, Iraq. J Indian Soc Remote Sens 42(1):165–178
Pontius RG, Schneider LC (2001) Land-cover change model validation by an ROC method for the Ipswich watershed, Massachusetts, USA. Agric Ecosyst Environ 85:239–248
Rawat JS, Kumar M (2015) Monitoring land use/cover change using remote sensing and GIS techniques: a case study of Hawalbagh block, district Almora, Uttarakhand, India. Egypt J Remote Sens Space Sci 18:77–84
Rientjes TH, Haile AT, Kebede E, Mannaerts CM, Habib E, Steenhuis TS (2011) Changes in land cover, rainfall and stream flow in Upper Gilgel Abbay catchment, Blue Nile basin-Ethiopia. Hydrol Earth Syst Sci 15:1979–1989
Sang L, Zhang C, Yang J, Zhu D, Yun W (2011) Simulation of land use spatial pattern of towns and villages based on CA–Markov model. Math Comput Model 54:938–943
Schulz JJ, Cayuela L, Echeverria C, Salas J, Rey Benayas JM (2010) Monitoring land cover change of the dryland forest landscape of Central Chile (1975–2008). Appl Geogr 30:436–447
Singh SK, Sk Mustak, Srivastava PK, Szabó S, Islam T (2015) Predicting spatial and decadal LULC changes through Cellular Automata Markov Chain models using earth observation datasets and geo-information. Environ Process 2:61–78
Solomon G, Ayele T, Bishop K (2010) Forest cover and stream flow in a headwater of the Blue Nile: complementing observational data analysis with community perception. Ambio 39(4):284–294
Solomon G, Woldeamlak B, Ga¨rdena¨s AI, Bishop K (2014) Forest cover change over four decades in the Blue Nile Basin, Ethiopia: comparison of three watersheds. Reg Environ Change 14:253–266
Teferi E, Uhlenbrook S, Bewket W, Wenninger J, Simane B (2010) The use of remote sensing to quantify wetland loss in the Choke Mountain range, Upper Blue Nile basin, Ethiopia. Hydrol Earth Syst Sci 14:2415–2428
Temesgen G, Amare B, Abraham M (2014a) Evaluation of land use/land cover changes and land degradation in Dera District, Ethiopia: GIS and remote sensing based analysis. Int J Sci Res Environ Sci 2(6):199–208
Temesgen G, Amare B, Abraham M (2014b) Population dynamics and land use/land cover changes in Dera District, Ethiopia. GJBAHS 3(1):137–140
Temesgen G, Taffa T, Mekuria A (2017) Erosion risk assessment for prioritization of conservation measures in Geleda watershed, Blue Nile basin, Ethiopia. Environ Syst Res 6(1):1–14
Wang SQ, Zheng XQ, Zang XB (2012) Accuracy assessments of land use change simulation based on Markov-cellular automata model. Procedia Environ Sci 13:1238–1245
Woldeamlak B (2002) Land cover dynamics since the 1950s in Chemoga watershed, Blue Nile basin, Ethiopia. Mt Res Dev 22(3):263–269