Detecting Past, Present and Future Land Use Changes and Their Impacts on Ecosystem Services: Remote Sensing, GIS and Modelling Approaches in the Borana Pastoral Areas of Southern Ethiopia

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Abstract

In this study, detailed investigations of changes in ecosystem service values in response to past, present and future changes in land use and land cover (LULC) were undertaken for the first time in the Borana areas of southern Ethiopia. LULC of 2034 was simulated based on LULC maps of 1986, 2002 and 2018 using integrated Cellular Automata-Markov Chain (CA-Markov) modelling. Socio-economic and biophysical factors of land use change were used to derive LULC suitability maps in Multi-Criteria Evaluation (MCE) procedure using Remote Sensing and Geographical Information System (GIS). The model performed very well in its overall ability to predict LULC change of 2018. Results from CA–Markov model indicated that bush encroachment would continue to increase at the expense of grassland in the next 16 years unless corrective measures would be taken to reduce the encroachment. The results of this study also revealed that LULC dynamics between 1986 and 2018 in the studied landscape, had resulted in a loss of ecosystem services of about USD 185 million. If not abetted, this loss will increase to 195 million US$ by 2034. Outputs of this study can be used as an early warning information for understanding the future effects of LULC changes on ecosystem services in the Borana pastoral areas of southern Ethiopia.

Keywords: Land use and land cover, CA-Markov model, Remote Sensing, GIS, Borana, Pastoral area, Ecosystem service

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1. Introduction

The Borana pastoral area of Southern Ethiopia is well known to have had one of the most sustainable cattle production systems in East Africa until the 1980s due to its relatively huge livestock resources and the existence of a traditional system of range management (Cossins and Upton 1987). However, today the Borana rangeland is experiencing undesirable changes in land use and land cover (LULC). The most recent LULC changes include the transformation of former communal grazing lands to farmlands and bush encroached area (Homann 2004; Angassa and Oba 2008). Bush encroachment significantly reduces pasture quality and seriously affects the sustainability of Borana rangelands as well as soil nutrients (Oba *et al.* 2000; Angassa *et al.* 2012). Studies reported that the Borana rangeland conditions had been on a decline since the early 1990s (e.g. Oba and Kotile 2001; Oba *et al*. 2000).

The loss and degradation of rangeland significantly affects its ability to continuously supply the flow of ecosystem services for present and future generations (Angell and McClaran 2001; Wen *et al.* 2013). Ecosystem service can be defined as the direct and indirect contributions of ecosystems to human wellbeing and survival (MEA, 2005; Costanza *et al.* 2014). Ecosystem services are classified as provisioning services (food and timber production), regulating services (climate regulation, gas regulation, noise regulation, and hydrological regulation), supporting services (raw material and ecological production) and cultural services (tourism, recreation, heritage, and aesthetic values) (MEA 2005).

Several studies highlighted that LULC change was a widespread phenomenon in the Borana pastoral areas of southern Ethiopia (Angassa and Oba 2008; Tache and Oba 2010; Abate and Angassa 2016). In contrast to LULC studies, research on changes in ecosystem services resulting from LULC changes has not received much attention in the pastoral areas of Ethiopia. Thus, we aim at filling the gaps of the previous LULC change studies in pastoral areas of Ethiopia by computing changes in the ecosystem service value (ESV) in response to past, present, and future LULC changes in the Borana pastoral areas. There are few studies of LULC change and its associated consequences on ecosystem services in the highland part of Ethiopia (Kindu *et al.* 2016; Tolessa *et al.* 2017). To establish sustainable rangeland management options, policymakers and rangeland managers often require information on the value of ecosystem services. Assessment of ecosystem service is the backbone of the science of sustainability since it shows the interaction between nature and society (Clark and Dickson 2003). Consequently, several studies have used the concept of ecosystem service to support land use planning (MEA 2005; Carpenter *et al.* 2009; Tallis and Polasky 2009). Thus, rangeland management planning should consider land use options that may affect the distribution and quality of a wide range of ecosystem services (e.g. food provision, soil erosion control, water provision, climate regulation and genetic diversity). Moreover, ecosystem service-inclusive rangeland management could help ensure the sustainable use of land resources (Tarrason *et al*. 2016; Jacobs *et al*. 2016).

The effect of LULC changes on ESV can be highlighted using land cover types as proxies for ecosystems and by matching the land cover types to ESV (Costanza et al. 1997; de Groot *et al*. 2012). For the first time, Costanza *et al.* (1997) provided a method by which ecosystem service values are estimated for 16 types of ecosystems and 17 types of service functions using the benefits transfer method (BTM). Afterward, the estimation of global ecosystems was updated by de Groot *et al*. (2012) and Costanza *et al*. (2014) based on a larger database. Among the various approaches of ecosystem service valuation, BTM is widely used due to its simplicity and feasibility (e.g., Costanza *et al.* 1997, 2014). In this method, existing estimates of ESV from the original study site are used to estimate ESV of other similar location in the absence of site-specific valuation method. There are several studies that have used a similar approach to study the ESV changes resulting from LULC (e.g., Hu *et al*. 2008; Li *et al*. 2007; Kindu *et al.* 2016; Tolessa *et al*. 2017).

Besides monitoring ecosystem service changes in response to the present LULC change, prediction of future ecosystem services is needed to make sure that the future ecosystem service provision is adequate. Modelling of future LULC changes has rarely been studied in the Borana rangelands of southern Ethiopia. Numerous LULC models, such as statistical models (e.g., Teferi *et al*. 2013), Cellular Automata (CA) models (e.g., White and Engelen 1994), Markov chain model (e.g., Weng 2002), multi-agent models (Ralha *et al*. 2013), and a hybrid Markov chain and Cellular Automata (CA-Markov) model (Subedi *et al*. 2013) have been developed. The CA-Markov model is a robust approach for predicting land use change because it outperforms other methods (Behera *et al.* 2012; Guan *et al*. 2011). This study develops a geospatial technique towards LULC modelling of Dirre rangeland based on the simulation capability of integrated CA-Markov and multi-criteria evaluation (MCE) techniques. The objective of this paper was, therefore, to use historical LULC changes and identify the factors for LULC change to simulate future LULC changes. Knowing the future state of ESVs in response to the future LULC (2034) of the Dirre rangeland area will facilitate ESV-inclusive land use planning, which will ultimately generate information on the availability of grassland in the future. The study attempted to test the hypothesis that changes in LULC alter key ecosystem functions for pastoral communities. Thus, such a study has practical relevance for devising strategies and policies for sustainable rangeland management in pastoral areas of Southern Ethiopia.

2. Materials and Methods

2.1 Study Area Description

The study was carried out in Dirre grazing unit of Borana zone in Southern Ethiopia. The area extends from 3º20′ to 4°40′N latitude and 38º to 39°E longitude (Fig. 1). The Dirre rangeland unit is one of the five communal rangelands in the Borana areas of southern Ethiopia. The Dirre rangeland has an area of 753,160 and most of this land is found within two Woredas (i.e. Dirre and Miyo) but also extends into Arero and Dhas. The main source of livelihood in the Borana rangelands is livestock production, primarily cattle (Borana breed) along with goats, sheep, camels and equines (Helland 1997). The Dirre rangeland unit is characterized by its homogenous topography. It lies between an altitude of about 933 masl at the eastern boundary to 2485 masl at the north-western and western parts of the study area (Fig. 1). It is generally composed of flat to sloping topography, with the exception of few areas around Mega town, which have slopes of 8-30%. The mean annual temperature in the Borana rangelands varies from 19°C to

24°C. The Borana rangelands exhibit a bimodal pattern of rainfall (i.e. March to May and September to November). The annual rainfall of the Borana area ranges from 238 mm to 896 mm (Fig. 2). Moreover, the erratic nature of the rainfall makes the Borana ecosystem vulnerable to climate induced shocks.

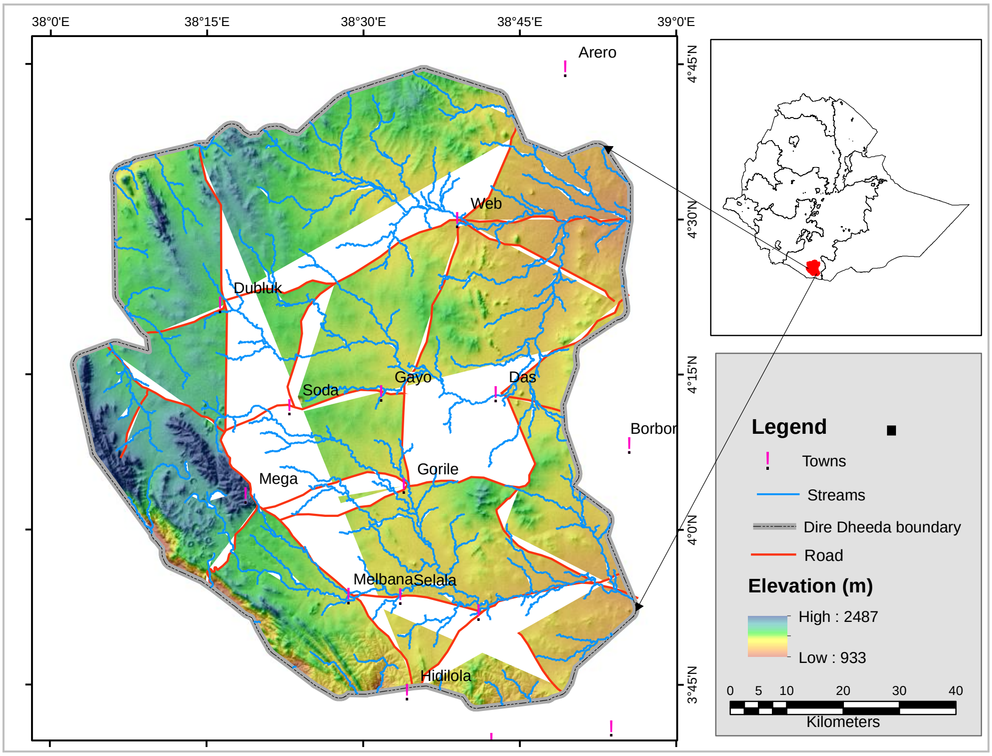

Figure 2. Location map of the Dirre rangeland unit

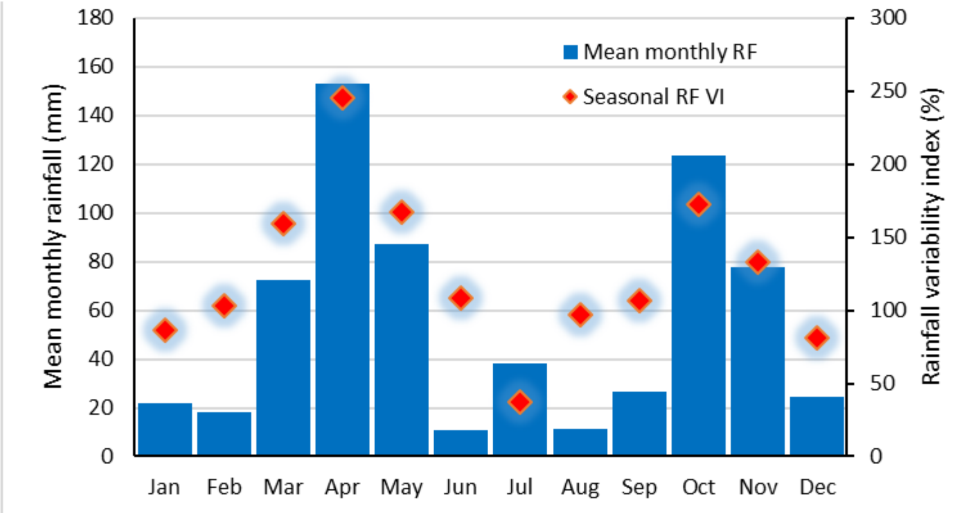

Figure 3. Mean monthly rainfall and seasonal rainfall variability index for Yabello

2.2 Data Sources

On-demand Landsat images were used for the years 1986, 2002 and 2018 from Landsat 5 Thematic Mapper (TM) sensor, Landsat 7 Enhanced Thematic Mapper Plus, and Landsat 8 Operational Land Imager (OLI) sensor, respectively, for land cover classification (Table 1). All Landsat images were accessed free of charge from the US Geological Survey (USGS) Center for Earth Resources Observation and Science (EROS) via Earth Explorer. Essential pre-processing operations such as radiometric and atmospheric corrections were performed by the data providers.

Elevation data (Digital Elevation Model (SRTM-30 m), slope data, river data and road data were used to obtain the required classification accuracy level of the classification and to facilitate the interpretation of land cover change. DEM of SRTMGL1 (NASA Shuttle Radar Topography Mission Global 1 arc second (~30 m) V003) was obtained from http://e4ftl01.cr.usgs.gov/SRTM/SRTMGL1.003/. Topographic maps of the study area at a scale of 1:50,000 were purchased from Ethiopian Mapping Agency (EMA) and vector overlays such as roads, and rivers were also obtained from topographic maps.

Table 3. Description of the satellite images used in the study (Path/row: 168/057)

	1986	**2002**	**2018**
Satellite	Landsat 5	Landsat 7	Landsat 8
Sensor	TM	ETM+	OLI/TIRS
Spatial resolution	30m	30m	30m
Acquisition date	25/01/1986	25/11/2002	13/01/2018
Atmospheric correction applied	Solar Spectrum (6S) radiative transfer models	Solar Spectrum (6S) radiative transfer models	Internal method
Version	Collection 1 Level 2 on-demand	Collection 1 Level 2 on-demand	Collection 1 Level 2 on-demand

2.3 Image Classification and Accuracy Assessment

All the scenes obtained from the Earth Explorer (https://earthexplorer.usgs.gov/) were already georeferenced to the Universal Transverse Mercator (UTM) map projection (Zone 37), WGS 84 datum and ellipsoid. Re-projection to the local projection system was made (UTM, map projection; Clarke 1880, Spheroid; and Adindan Datum). Image pre-processing operations were implemented before the classification and the change detection. These include image registration, radiometric correction, layer stacking and image sub-setting.

We implemented an integrated supervised/unsupervised classification approach together with successive geospatial operations to classify the Landsat imageries. First, unsupervised classification approach was performed to determine the spectral classes using Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm using ArcGIS software. Second, ground truth data were collected from field using Global Positioning System (GPS) to label the spectral classes. Ground truth data (reference data) were collected during field visit of accessible areas to assess the accuracy of derived thematic information. The number of samples required for each class was adjusted based on the proportion of the class and inherent variability within each category. Third, training areas were created from the field observation points collected to derive a signature for each class. Finally, images were classified using Maximum Likelihood Algorithm based on the training samples developed in the previous step.

A hierarchical land use classification was derived from the authors' prior knowledge of the study area and based on the most popular scheme of the U.S. Geological Survey Land Use/Cover System devised by Anderson *et al.* (1976). Table 2 contains a list of all land cover types present in the study area that could be clearly identified from the satellite images.

Table 2. Description of land use land cover classes identified in this study

Land use land cover class	**Description**
Cropland	Rain-fed/irrigated areas covered with annual/perineal crops
Grassland	Landscapes that have a ground story in which grasses are the dominant vegetation forms
Shrub and bush	A category which includes low woody plants, generally less than three meters in height, usually multiple stems growing vertically
Woodland	A continuous strand of single-story trees with a crown density of 20-80%.
Forest	A category which includes riverine forest, plantation forest, and natural forest
Others	Barren land, urban areas, water bodies and other unidentified features.

The classification accuracy was assessed before using the maps for subsequent land use change analysis and future prediction. To assess the accuracy of classified images, 327 ground truth data (i.e. training and validation) were gathered based on field observation using GPS and Google Earth images (http://earth.google.com). Key Informant interviews and old topo-sheets were used to obtain information about the historical land cover status of every sample points. According to the confusion matrix report (Table 3), overall accuracy and a Kappa Coefficient (Khat) value 93.58% overall accuracy and a Khat value of 0.89 were attained for the 2018 classified map.

Table 3. Classification accuracy assessment result

Land use/cover type	1986		2002		2018	
	Producer accuracy	User accuracy	Producer accuracy	User accuracy	Producer accuracy	User accuracy
Cropland	53.85	87.50	38.46	100	69.23	100.00
Grassland	84.21	80.00	89.47	77.27	89.47	85.00
Shrub and bush	94.30	94.79	95.90	96.89	96.92	96.43
Woodland	88.24	83.33	92.75	88.89	89.86	93.94
Forest	73.33	73.33	83.33	76.92	100.00	75.00
	Overall accuracy=89.29 Kappa= 0.82		Overall accuracy=91.74 Kappa= 0.86		Overall accuracy =93.58 Kappa= 0.89	

Applying the methods of Congalton and Green (2008), the above results represent strong agreement between the ground truth and the classified classes. Thus, the maps met the minimum accuracy requirements to be used for the subsequent post-classification operations such as change detection (Anderson *et al.*,1976). Overall accuracies for the LULC maps of 1986, 2002 and 2018 were 89.29, 91.74 and 93.58 %, respectively; thus, indicating the suitability of the LULC maps for further analysis such as ecosystem service analysis.

2.4. Predicting Land Use Change Based on CA-Markov

Several LULC models are available in the literature, developed for different objectives. Commonly used LULC models are statistical models (Teferi *et al.*, 2013), cellular automata (CA) models (e.g., White and Engelen, 1994), Markov chain model (e.g., Weng, 2002), multi-agent models (Ralha *et al.*, 2013), and a hybrid Markov chain and Cellular Automata (CA-Markov) model (Subedi *et al.*, 2013). The CA-Markov model is a combination of Markov-Chain (MC) and Cellular Automata (CA) models in which future LULC change in time and space is predicted based on current state and on ancillary information which may drive future land cover transitions. The MC component controls temporal dynamics among the LULC classes based on transition probabilities, while the spatial dynamics are controlled by local rules determined either by the CA spatial filter or transition potential maps.

Thus, use of the CA-Markov model in LULCC studies provides a powerful modelling framework in which the shortcomings of each are eliminated. Furthermore, its ability to simulate multiple land covers and complex patterns makes the CA-Markov model a robust approach for predicting land use change (Behera *et al.* 2012; Guan *et al.* 2011). However, in CA-Markov model, projection of the future LULC changes is determined based on LULC patterns that have been identified in the past. A coupled CA-Markov model was employed to predict future LULC change by pursuing the following steps:

First, transition area matrix was computed for the periods 1986–2002 and 2002–2018. Transition suitability images were created using Markov chain and multi-criteria evaluation (MCE) approaches (Fig. 3). The MCE employed in this study involves four main parts: factors selection (Table 4), suitability score assignment, weighting, and combination. The standardized suitability maps for each LULC class defines the suitability of each pixel to each of the LULC classes. Field survey, previous studies, and experts' knowledge of the study area were used to define transition rules and identify the factors and constraints for each LULC class. The Analytic Hierarchy Process (AHP) technique was employed to assign weights for the driving factors by means of pairwise assessments. The suitability map for each LULC class was prepared with different criteria and relative weights. According to the recommendation of Mondal *et al.* (2020) a contiguity filter of size 5x5 pixels was used to define the neighbourhood rules. The future assignment for each pixel to specific LULC class was based on how much suitable the pixel to this LULC category is and how near the pixel is to other pixels of the same class.

Based on the CA-Markov model LULC for the year 2018 was predicted using the transition probabilities from 1986 to 2002 with LULC base map from the year 2002. The predictive capability of the model was evaluated by comparing the actual map (2018) and projected map (2018). Two types of Kappa statistics were used for the performance evaluation: Kappa for location ($K_{location}$), and Kappa for quantity ($K_{quantity}$) (Pontius 2002). $K_{location}$ is a measure of validation of the simulations to predict location perfectly. $K_{quantity}$ is a measure of validation of the simulations to predict quantity perfectly. Finally, LULC for the year 2034 was predicted with the CA–Markov model using the transition probabilities from 2002 to 2018. Fig. 4 depicts the flowchart of implementing the CA-Markov model as it was implemented in IDRISI software.

Table 4. Factors of suitability

Type	Factors	Weights	CR	Constraints
Cropland suitability	Slope	0.0731	0.08	River
	Elevation	0.1553		Road
	Distance from road	0.0897		Water bodies
	Distance from stream	0.2464		
	Distance from towns	0.0229		Urban
	Conditional probability image of cropland	0.3679		
	Population density	0.0447		
Grassland suitability	Slope	0.1814	0.09	Urban
	Elevation	0.1085		River
	Distance from road	0.0563		
	Distance from towns	0.0293		
	Conditional probability image of grassland	0.3698		
	Livestock Population density	0.0727		
	Distance from watering points	0.1820		
Shrub and bush suitability	Population density	0.2855	0.06	River
	Road	0.0836		Road
	Distance from stream	0.0438		Urban
	Slope	0.0276		
	Distance from town	0.1528		
	Conditional probability image of shrub and bush	0.4067		
Woodland suitability	Population density	0.0366	0.07	River
	Distance from road	0.1314		Road
	Distance from stream	0.2651		Urban
	Distance from town	0.0647		
	Conditional probability image of woodland	0.5022		
Forest Suitability	Conditional probability image of woodland	0.6370	0.03	Road River
	Distance from road	0.1047		Urban
	Slope	0.2583		

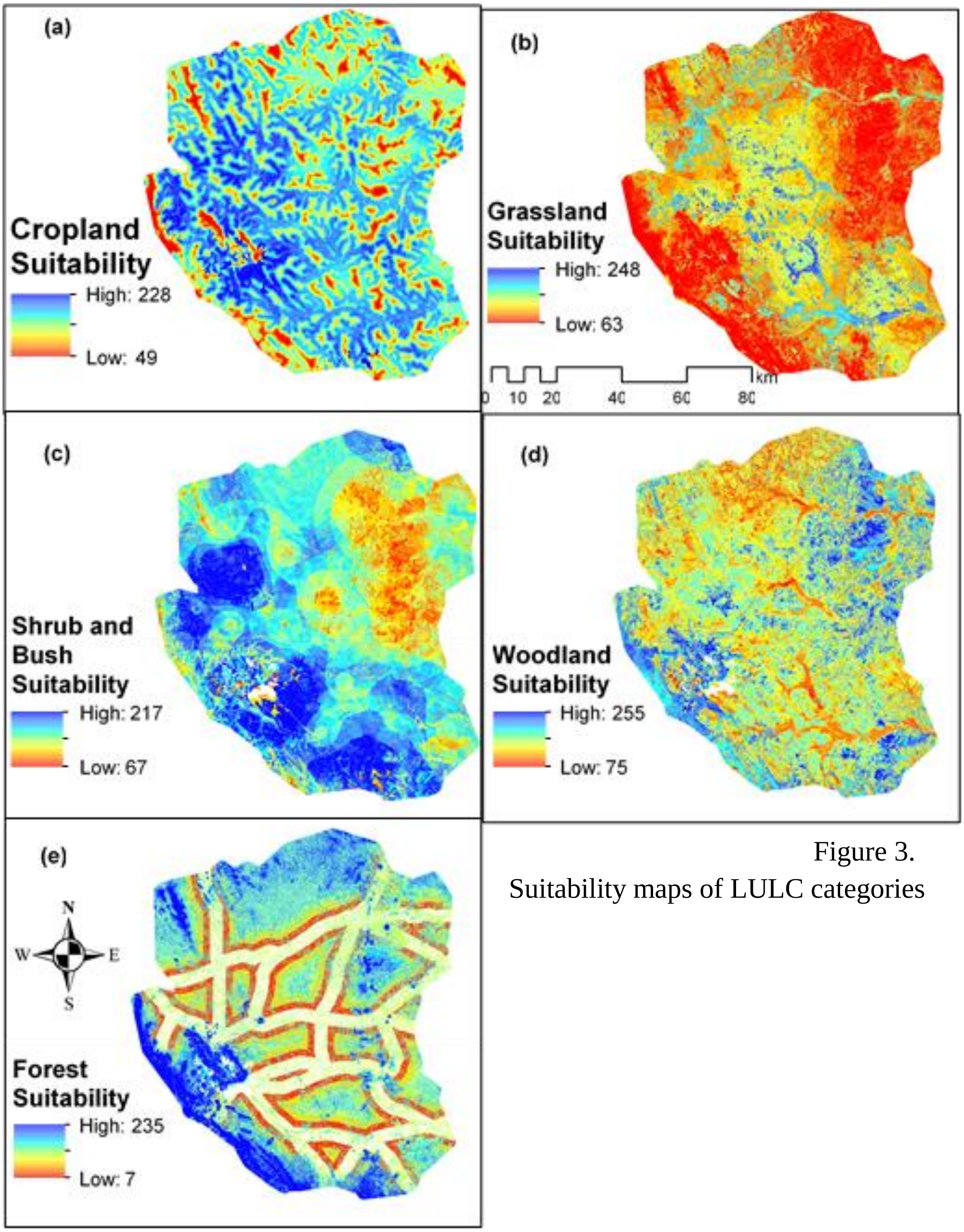

Figure 3.
Suitability maps of LULC categories

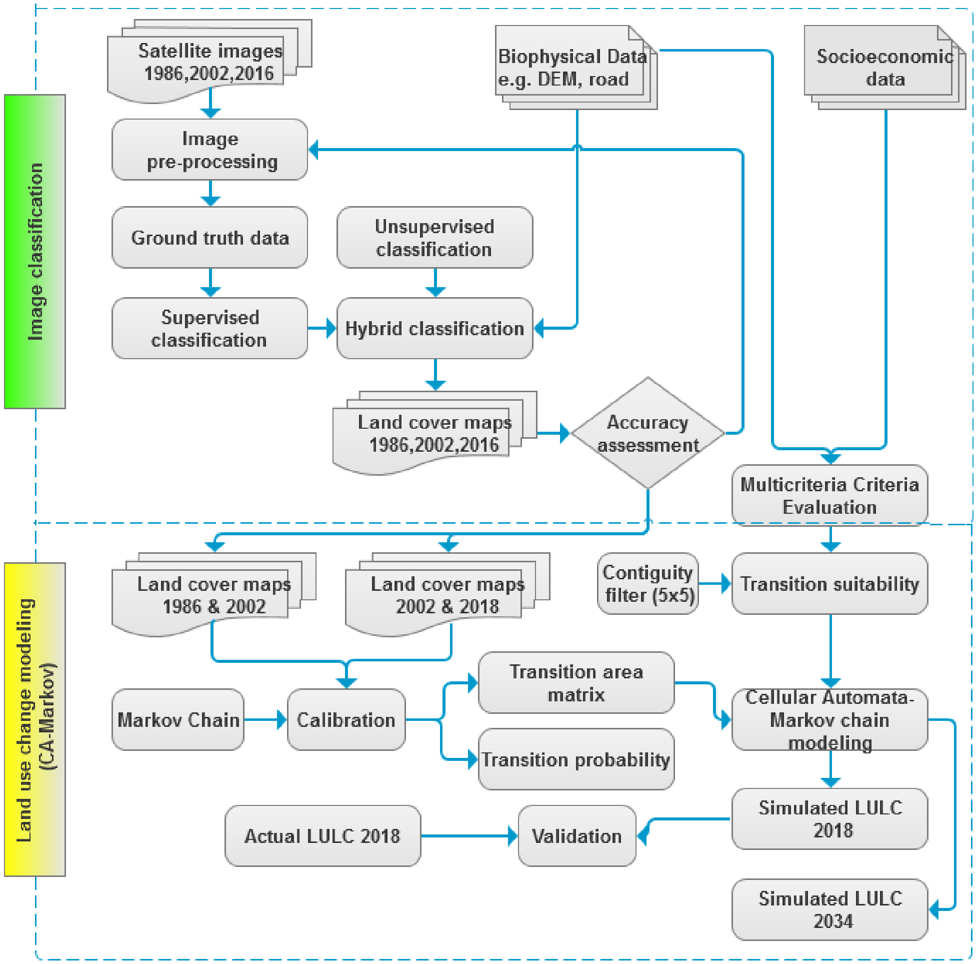

Figure 4. Schematic presentation of Cellular Automata (CA)-Markov Land Use Change Model

2.5. Changes in ESVs in Response to Changes in LULC

Equation1, Equation 2, and Equation 3 were used to determine ecosystem service value for each LULC type (ESV_k), for each service function (ESV_f), and for the total ESV, respectively:

$$ESV_k = A_k * VC_k \text{..........} \quad \text{Eq.1}$$

$$ESV_f = \sum(A_k * VC_{fk}) \text{..........} \quad \text{Eq.2}$$

$$ESV = \sum(A_k * VC_k), \text{..........} \quad \text{Eq. 3}$$

Where A_k is the area (ha) and VC_k is the value coefficient (US \$ ha^{-1} yr^{-1}) for LULC category *k; ESV_f* is the estimated ecosystem service value of function *f*; A_k is the area (ha); and VC_{fk} is the value coefficient of function *f* (US \$ ha^{-1} yr^{-1}) for LULC category *k*.

Due to the large uncertainty involved in the assignment of value coefficients, the Coefficient of Sensitivity (CS) was computed for analysing coefficients' sensitivity and robustness (Kreuter *et al.*, 2001). The CS was calculated using the following equation (Equation 4).

$$CS = \frac{(ESV_j - ESV_i)/ESV_i}{(VC_{jk} - VC_{ik})/VC_{ik}}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq.4$$

Where *ESV* is the ecosystem service value, *VC* is the value coefficient (Table 5); *i* and *j* are the initial and adjusted values (i.e., ±50%), respectively. If $CS < 1$, then the results of the ESV estimations is reliable. If CS > 1, then it indicates that it is crucial to accurately assign the VC.

Table 5. Ecosystem Service coefficient for each LULC in USD million /year based on 2007 price levels

Ecosystem service functions	Cropland	Grassland	Shrub and bush	Woodland	Forest
Provisioning services	**125.2**	**1305**	**254**	**254**	**1828**
Food	125.2	1192	52	52	200
Water		60			27
Raw material		53	170	170	84
Genetic resources					13
Medical services					1504
Ornamental resources			32	32	
Regulating services	**27**	**159**	**20**	**20**	**2496**
Air quality regulation					12
Climate regulation		40	7	7	2044
Disturbance moderation					66
Water regulation					342
Waste treatment		75			6
Biological control	27				11
Erosion prevention		44	13	13	15
Supporting services	**17**	**1214**	**1307**	**1307**	**72**
Nutrient cycling					3
Pollination	17		31	31	30
Nursery service			1273	1273	16
Genetic diversity		1214	3	3	23
Cultural services		**193**	**7**	**7**	**867**
Aesthetic information		167			
Recreation		26	7	7	867
Total ESV	169.2	2871	1588	1588	5263

Source: (de Groot *et al.* 2012; Temesgen *et al.* 2018)

3. Results and Discussion

3.1 Historical LULC Change Analysis

Table 6 depicts the area of LULC class that made a transition from one class to another for each of the study periods. The general tendencies of the changes in LULC depict that shrub and bush land cover type was the dominant LULC category, accounting for 49.15%, 57.50%, and 65.09% of the total landscape in 1986, 2002, and 2018, respectively (Table 6). The diagonal elements in Table 6 show the unchanged landscape. About 61% and 68% of the landscape persisted or 39% and 32% of the landscape had changed during the period 1986-2002, and 2002-2018, respectively, indicating that persistence dominated in the two periods. In both periods (1986-2002 & 2002-2018) grassland experienced the largest loss, whereas shrub and bushes experienced the largest gain. The relative decrease in grassland cover observed during the period 2002-2018 (-45%) is higher as compared to its relative decrease during 1986-2002 (-27%). This is likely because of cropland expansion, or perhaps there is a lack of strict local government rules and regulations on the control of bush encroachment at the expense of grassland. Fig. 5 shows the spatial pattern of land cover types in the Dirre rangeland unit in 1986, 2002, and 2018.

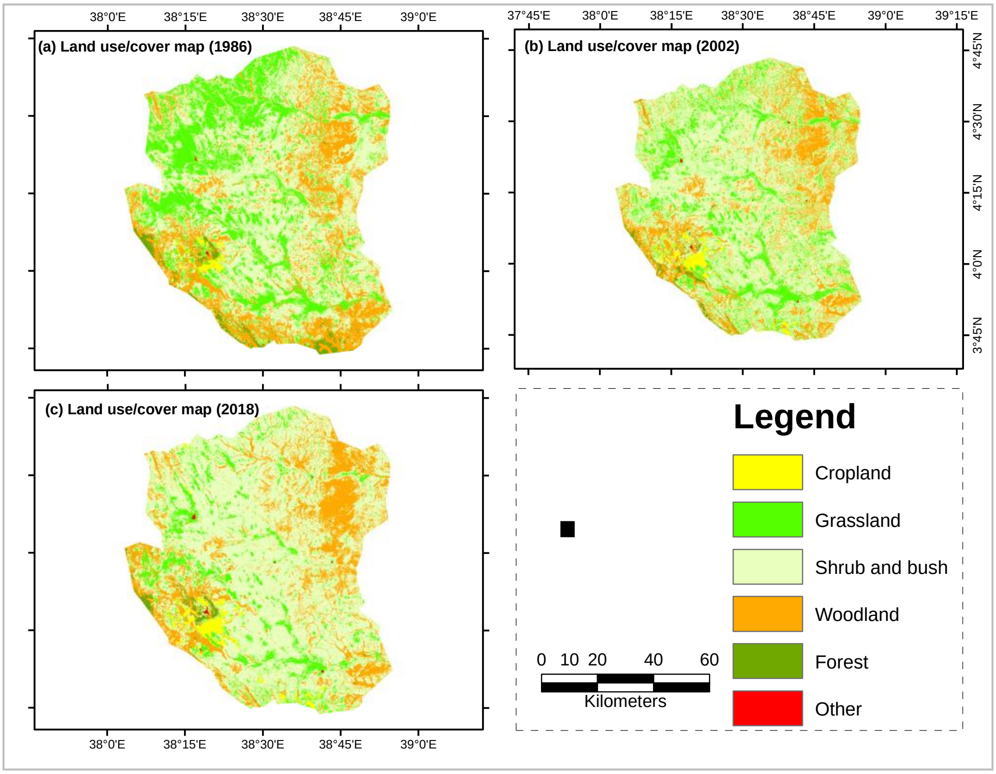

Figure 5: Land use and land cover maps for 1986, 2002, and 2018

Table 6. Transition area (1000 ha) matrix for each land use and land cover classes for the periods 1986-2002, 2002-2018, and 1986-2018

	2002									
1986	CL	GL	SHB	WL	F	O	Row total	loss	Gain	Net
Cropland	4.30	0.08	0.12	0.04	0.00	0.00	4.53	0.23	5.43	5.20
Grassland	1.60	88.72	98.17	4.07	0.02	0.13	192.71	103.99	52.85	-51.13
Shrub and bush	2.43	43.01	267.07	57.48	0.15	0.05	370.18	103.11	165.99	62.88
Woodland	1.33	9.37	63.47	93.84	3.45	0.07	171.53	77.69	67.08	-10.61
Forest	0.08	0.39	4.22	5.48	3.85	0.00	14.02	10.17	3.62	-6.55
Other	0.00	0.01	0.01	0.01	0.00	0.16	0.19	0.03	0.25	0.22
Column total	9.73	141.58	433.06	160.92	7.46	0.41	753.16			
	2018									
2002	CL	GL	SHB	WL	F	O	Row total	loss	Gain	Net
Cropland	9.48	0.07	0.13	0.05	0.00	0.00	9.73	0.25	3.91	3.66
Grassland	1.00	50.69	83.73	5.89	0.08	0.19	141.58	90.89	27.15	-63.74
Shrub and bush	2.09	24.53	349.11	55.50	1.67	0.15	433.06	83.95	141.11	57.17
Woodland	0.81	2.43	56.64	97.23	3.73	0.09	160.92	63.70	66.42	2.73
Forest	0.01	0.02	0.60	4.95	1.88	0.01	7.46	5.58	5.48	-0.10
Other	0.00	0.10	0.02	0.03	0.00	0.26	0.41	0.15	0.45	0.30
Column total	13.39	77.83	490.22	163.65	7.36	0.71	753.16	0.00	0.00	0.00
	2018									
1986	CL	GL	SHB	WL	F	O	Row total	loss	Gain	Net
Cropland	4.42	0.04	0.06	0.01	0.00	0.00	4.53	0.12	8.97	8.85
Grassland	2.53	57.19	128.00	4.60	0.06	0.34	192.71	135.52	20.65	-114.88
Shrub and bush	4.18	15.73	288.78	60.80	0.54	0.15	370.18	81.40	201.44	120.05
Woodland	2.17	4.29	69.14	93.20	2.66	0.07	171.53	78.34	70.45	-7.89
Forest	0.09	0.56	4.23	5.04	4.10	0.00	14.02	9.92	3.27	-6.65
Other	0.00	0.03	0.01	0.01	0.00	0.15	0.19	0.04	0.56	0.51
Column total	13.39	77.83	490.22	163.65	7.36	0.71	753.16	0.00	0.00	0.00

Loss of grassland, cropland expansion and loss of forest are the three most important LULC change types that merit discussion. During the historical period 1986–2018, the highest loss (135,520 ha) and the highest gain (201,442 ha) occurred in grassland and shrub/bush, respectively (Table 6). The results of this finding revealed that grasslands had lost a greater percentage of area to shrub and bush when compared with any other class. Degradation and loss of grassland has become a profound concern because undesirable thorny shrub and bush cover is replacing highly desirable grass species. During our fieldwork, we observed some of the undesirable plant species, including *Acacia mellifera* and *Acacia drepanolobium*. The observed increase in shrub and bush cover at the expense of grassland is consistent with previous findings conducted in Borana area (Dalle *et al.* 2006; Haile *et al*. 2010; Mesele *et al.* 2006; Abate and Angassa 2016). In contrast, Elias *et al.* (2015) reported an increase in grassland and a decline in bushland in their study conducted in Borana Zone between 1985 and 2011. Even though grasslands are the source of feed for the Borana breed cattle, they are endangered resources.

The possible causes of the observed bush encroachment in the Dirre rangeland are the presence of heavy grazing and a ban on fire. Burning is a traditional method of rangeland management used to control the expansion of undesirable plant species and to improve the nutritional quality and accessibility of the grasses (Coppock and Delting 1986). Despite the benefits of burning, government policy restricted the use of fire in the Borana area. Consequently, fire suppression allowed woody plants such as *Acacia drepanolobium* and *Acacia seyal* to invade a considerable portion of the rangeland (Woldu and Nemomissa 1998). Bush encroachment is affecting livestock production and challenging the sustainability of the pastoral system in the Borana lowlands. Figure 6 shows a significantly decreasing trend in cattle population in Borana zone according to the data from Central statistical Agency (CSA). Information on the size of livestock populations was obtained from the CSA annual report series, the agricultural sample survey and agricultural census (http://www.csa.gov.et/). The pattern of keeping cattle and goats followed the pattern of rangeland degradation resulting from bush encroachment (Solomon *et al.* 2007).

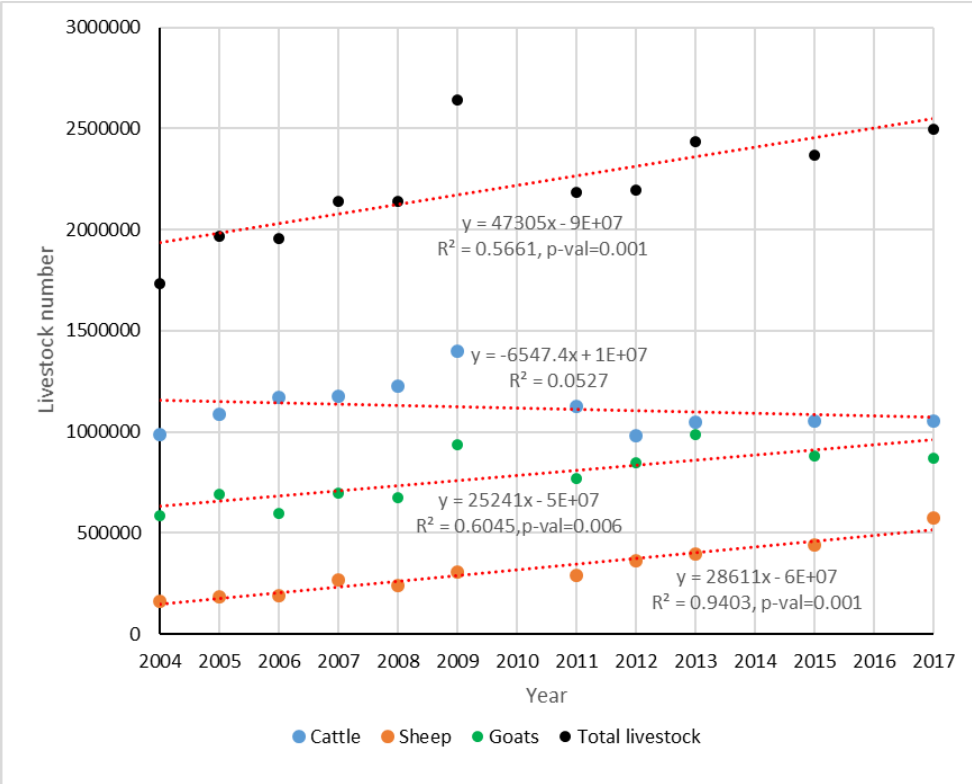

Figure 6. Statistical trend of livestock population from 2004 to 2017

Loss of forest (deforestation) is another major LULC change occurring in the Dirre communal rangeland unit. Forest area decreased from 14,014 ha in 1986 to 7,363 ha in 2018 and 36% of the original forest went to woodland (Table 6). The forest landscape is mainly located around Mega town and on steep slope areas of the rangeland units (Fig. 5). About 56% of the initial forest persisted during the period 1986-2018. The loss of forest could be attributed to the rise in demand for charcoal and construction wood by the growing population.

Cropland expansion is another emerging LULC change type in the Dirre rangeland. Cropland increased from 4,533 ha in 1986 to 13,386 ha in 2018 (Table 6). About 31%, 19%, and 16% of the cropland in 2018 were gained from shrub/bush, grassland and woodland, respectively. Cultivated land showed a tendency to gain suggesting extensive cultivation was expanding in the rangeland unit. This indicates the conversion of a livestock-based livelihood system to the emerging crop-based farming system. The possible explanations for the beginning of cropland expansion in pastoral areas of Borana are government's attention to irrigated farming and absence of communal land use certification. Thus, Ethiopia's policy statement on pastoral development gives much attention to transformation strategies that are highly related to non-pastoral livelihood options such as irrigated farming (Fratkin 2014).

Consequently, pastoral land losses have occurred mainly due to expansion of irrigated agriculture promoted by the government, and agricultural encroachment both by former pastoralists themselves and by neighbouring non-pastoralists (Little et al. 2010; Fratkin 2014). Rather than abandoning pastoralism, the recovery of traditional practices of rangeland management in the Borana area is vital to secure sustainable livelihoods of pastoralists.

3.2 Analysis of Transition Probability of LULC Change

Table 7 depicts the transition probability of different LULC classes and shows that the probability of change of grassland to shrub/bush from 1986 to 2002 was 57.7%. This probability of change increased to 64% in 2018 (Table 7). The probability of cropland to remain as cropland was 83% and it had 17% probability to change into other classes during the period 1986-2018. The probability of grassland to remain as grassland was 25.22% and it showed a 70.63% probability of change into shrub and bush category during the period 1986-2018. This result clearly shows that only small portion of grassland remains unchanged and grassland is more vulnerable to change into shrub and bush because of bush encroachment.

The probability of change of grassland to other classes increased from 0.61 during the period 1986-2002 to 0.70 during the period 2002-2018. This indicates that the conversion of grassland was massive during the period 2002-2018. Shrub/bush class had 66.31% probability to remain as shrub and bush cover and it had 25.16% probability to change into woodland. This means that if the shrub and bush could change its state to other LULC categories, there was a probability of 25.16% that it would change to woodland during the period 1986-2018.

Table 7. Transitional probability matrix showing the probability that each land cover category will change to every other category

	2002					
1986	Cropland	Grassland	Shrub and bush	Woodland	Forest	Other
Cropland	0.8064	0.0636	0.0966	0.032	0.0014	0.000
Grassland	0.0094	0.3913	0.5746	0.0238	0.0001	0.0008
Shrub and bush	0.0091	0.1613	0.6132	0.2156	0.0005	0.0002
Woodland	0.0091	0.0646	0.4371	0.465	0.0238	0.0005
Forest	0.0058	0.0292	0.3183	0.4135	0.2332	0
Other	0.000	0.1061	0.0763	0.0789	0.0132	0.7254
	2018					
2002	Cropland	Grassland	Shrub and bush	Woodland	Forest	Other
Cropland	0.828	0.0486	0.0855	0.0366	0.0014	0
Grassland	0.0076	0.3043	0.6409	0.0451	0.0006	0.0015
Shrub and bush	0.0079	0.092	0.6852	0.2081	0.0063	0.0006
Woodland	0.0062	0.0185	0.4326	0.5136	0.0285	0.0007
Forest	0.0014	0.0021	0.084	0.6964	0.2143	0.0019
Other	0	0.3067	0.0575	0.0988	0	0.5369
	2018					
1986	Cropland	Grassland	Shrub and bush	Woodland	Forest	Other
Cropland	0.8279	0.0612	0.0936	0.0162	0.0011	0
Grassland	0.0139	0.2522	0.7063	0.0254	0.0003	0.0019
Shrub and bush	0.0173	0.0651	0.6631	0.2516	0.0023	0.0006
Woodland	0.0149	0.0294	0.475	0.4618	0.0183	0.0005
Forest	0.0071	0.0422	0.3204	0.3818	0.2484	0.0001
Other	0	0.2298	0.0535	0.0557	0	0.661

3.3 LULC Change Modelling and Validation

Evaluation of the model was carried out by comparing the simulated map of 2018 with the actual land cover map of 2018 based on Kappa statistics. The observed and simulated LULC classes for the year 2018 are shown in Fig. 7. The overall ability of the model to predict LULC change of 2018 was very good (K_{no} = 0.7388), and the $K_{location}$ value of 0.7442 indicates that the model provides a very good spatial representation. According to the classification provided by Monserud and Leemans (1992), different ranges of Kappa values are characterized. Kappa values < 0.40 are characterized as poor, 0.40 - 0.55 as fair, 0.55 – 0.70 as good, 0.70 – 0.85 as very good, and >0.85 as excellent. According to this classification, the Kappa values of the CA-Markov model in this research lies in a very good category. Therefore, the CA–Markov model can be used to predict the state of future LULC in the Borana area. After the successful simulation of LULC classes in 2018, the future LULC classes for the year 2034 were predicted by using a LULC base map for 2018, the transition matrix for 2002 to 2012, and a potential transition map for 2018.

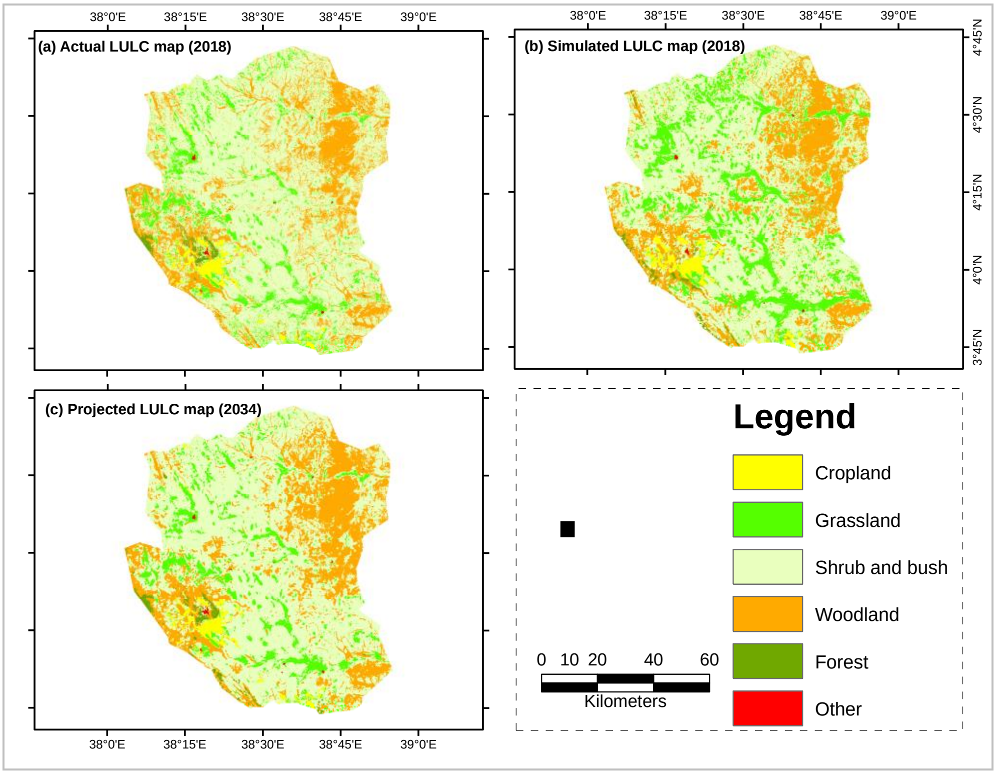

Figure 7. Actual, Simulated and Projected LULC Maps

3.4 Projected LULC of 2034

Fig. 8c depicts the projected LULC for the year 2034. Visual interpretation LULC of 2034 shows the great efficiency of the model in terms of the location of most land cover classes. Some discrepancies observed between the actual and simulated land cover maps can be attributed to the inadequacy of the spatial drivers used for modelling the phenomenon. Table 8 shows the probability of transition that is expected to occur from 2018 to 2034. Results from CA–Markov models indicate that grassland is expected to decline from 77,834 ha in 2018 to 72,775 ha in 2034. If grassland could change its state to other LULC classes in the next 16 years, there is a probability of 37% that it will change to shrub and bush. This suggests that the bush encroachment will continue in the next 16 years unless measures are taken to reduce the encroachment. Shrub/bush class has 71.97% probability to remain as shrub/bush land and it has 21.02% probability to change into woodland. Rangeland ecologists suggest different strategies. Bush clearing (Angassa, 2002), re-utilization of fire (Dalle *et al.*, 2006) and herd diversification (Megersa *et al.* 2014) are mentioned as potential options to reduce bush encroachment, thereby increasing grass available for livestock.

Table 8. Transition area matrix and transition probability matrix during the period 2018-2034

(A) Transition area matrix, 1000 ha										
2018	2034									
	CL	GL	SHB	WL	F	O	Row total	loss	Gain	Net
Cropland	13.09	0.28	0.00	0.01	0.00	0.00	13.39	0.30	2.44	2.15
Grassland	0.27	55.50	20.60	1.37	0.04	0.05	77.83	22.34	17.28	-5.06
Shrub and bush land	1.62	15.48	420.85	50.82	1.45	0.02	490.22	69.38	48.71	-20.67
Woodland	0.54	1.39	27.69	132.42	1.57	0.03	163.65	31.22	54.98	23.76
Forest	0.01	0.00	0.37	2.71	4.27	0.00	7.36	3.10	3.07	-0.02
Other	0.00	0.13	0.04	0.07	0.00	0.46	0.71	0.25	0.10	-0.15
Column total	15.53	72.78	469.55	187.41	7.34	0.56	753.16			

(B) Transition probabilities						
2018	2034					
	CL	GL	SHB	WL	F	O
Cropland	0.83	0.17	0.00	0.00	0.00	0.00
Grassland	0.00	0.60	0.37	0.03	0.00	0.00
Shrub and bush land	0.00	0.06	0.72	0.21	0.01	0.00
Woodland	0.00	0.01	0.26	0.69	0.03	0.00
Forest	0.00	0.00	0.05	0.43	0.53	0.00
Other	0.00	0.27	0.07	0.11	0.00	0.55

The probability of cropland to remain as cropland is 83% and it has 17% probability to change into grassland (Table 8). One of the most important driving factors for grassland to convert into cropland is absence of certification of communal grazing land. Land certification appears to be enhancing pastoralists' confidence and security of tenure. However, these land certification operations do not include communal land holdings such as communal grazing land. Absence of land certification for common grazing lands thus contributes to the conversion of grazing land to cropland, and degradation of land. Having recognized this problem, USAID's Land Administration to Nurture Development (LAND) project has been working on pastoral communal land use rights in close collaboration with the Ethiopian government in Borana Zone (https://www.land-links.org/project/land-administration-to-nurture-development-ethiopia/). Currently, the certification of Dirre rangeland unit has been completed. It is believed that this certification will stop or reduce the further expansion of cropland at the expense of grassland.

3.5 Changes in Ecosystem Service and LULC Change

The ESVs for each LULC category from 1986 to 2034 were computed using the ESV coefficients for the corresponding biome and the area of each LULC type. The ESVs notably differed among the LULC classes. The total ESVs of the Dirre rangeland unit were about USD 1488 million in 1986, USD 1391 million in 2002, USD 1302.82 million 2018, and USD 1293.44 million in 2034 (Table 9). Overall, during the entire period (1986 - 2034) the total ESVs of the Dirre rangeland decreases from USD 1488 million in 1986 to USD 1293 million in 2034, that is a total loss of USD 194.6 million. This loss occurred due to the extensive expansion of shrub and bush with a low ESV at the expense of mainly grassland with a high ESV.

The ESV of grassland will decrease steadily from USD 553 million in 1986 to USD 209 million in 2034 and showed a total loss of USD 344 million (Table 9). Even though the Dirre rangeland area is known as a cattle production area, the current LULC change, particularly the conversion of grassland with high ESV into shrub and bushland with low ESV (Table 9) has led to a reduction in the ES provisioning of the Borana area. Similarly, the ESV of forest will decease form USD 74 million in 1986 to USD 38 million in 2034, showing a total loss of about 48% from its initial state (i.e. 1986). Continuous use of the forest for various purposes in the area has caused a reduction in forest coverage, consequently reducing its ESV. Forests play a significant role in ecosystem service provision and the decline in forest area could bring an aggregate reduction of ecosystem services. The cropland and shrubland categories, by contrast, have been increasing substantially during the three periods. The ESV of cropland, which is assumed to provide food for local people, will increase from USD 770 thousand in 1986 to USD 2.63 million in 2034. In the past decades, local people increased the area of cropland by destroying forest and grassland driven by different factors. The increase in human population of Borana is the most important force as it leads to increasing demand for food to its growing population.

As shown in Table 9, the contribution of individual ecosystem functions to the total ESV in each year were ranked based on ESV_f in 1986; 2002; 2018; and 2034. Nursery service, food provision, genetic diversity, raw material provision, and climate regulation contributed more than 89% to the total ecosystem service value. The contribution of other ecosystem functions (i.e. erosion prevention, water regulation, waste treatment) was minimal.

Table 9. Estimated services of individual ecosystem functions and their changes (ESV_f in US $ million per year)

Ecosystem function	1986			2002			2018			2034		
	ESV_f	%	Rank	ESV_f	%	Rank	ESV_f	%	Rank	ESV_f	%	Rank
Nursery service	689.82	46.36	1	756.25	54.38	1	832.5	63.9	1	836.42	64.67	1
Food	261.25	17.56	2	202.36	14.55	2	129.93	9.97	2	124.32	9.61	2
Genetic diversity	235.9	15.85	3	173.83	12.5	3	96.62	7.42	4	90.49	7	4
Raw material	103.48	6.95	4	109.11	7.85	4	115.9	8.9	3	116.16	8.98	3
Climate regulation	40.15	2.7	5	25.08	1.8	5	22.74	1.75	5	22.51	1.74	5
Aesthetic information	32.18	2.16	6	23.64	1.7	6	13	1	8	12.15	0.94	9
Medical services	21.08	1.42	7	11.22	0.81	11	11.07	0.85	11	11.04	0.85	11
Recreation	20.96	1.41	8	14.31	1.03	9	12.98	1	8	12.85	0.99	8
Ornamental resources	17.33	1.16	9	19.01	1.37	7	20.92	1.61	6	21.02	1.63	6
Pollination	17.29	1.16	9	18.8	1.35	8	20.72	1.59	7	20.85	1.61	7
Erosion prevention	15.73	1.06	11	14.06	1.01	10	12.04	0.92	10	11.85	0.92	10
Waste treatment	14.54	0.98	12	10.66	0.77	12	5.88	0.45	12	5.5	0.43	12
Water	11.94	0.8	13	8.7	0.63	13	4.87	0.37	13	4.56	0.35	13
Water regulation	4.79	0.32	14	2.55	0.18	14	2.52	0.19	14	2.51	0.19	14
Disturbance moderation	0.93	0.06	15	0.49	0.04	15	0.49	0.04	15	0.48	0.04	15
Biological control	0.28	0.02	16	0.34	0.02	16	0.44	0.03	16	0.5	0.04	15
Genetic resources	0.18	0.01	17	0.1	0.01	17	0.1	0.01	17	0.1	0.01	17
Air quality regulation	0.17	0.01	17	0.09	0.01	18	0.09	0.01	17	0.09	0.01	17
Nutrient cycling	0.04	0	19	0.02	0	19	0.02	0	19	0.02	0	19
Total	1488.04	100		1390.63	100		1302.82	100		1293.44	100	

The contribution of food production to total ecosystem service values will decline from 17.56% in 1986 to 9.61% in 2034 (Table 9 and Fig. 8). The degradation of food production could be attributed to the decline of ecosystem services that underpin food production (e.g., genetic diversity and climate regulation).

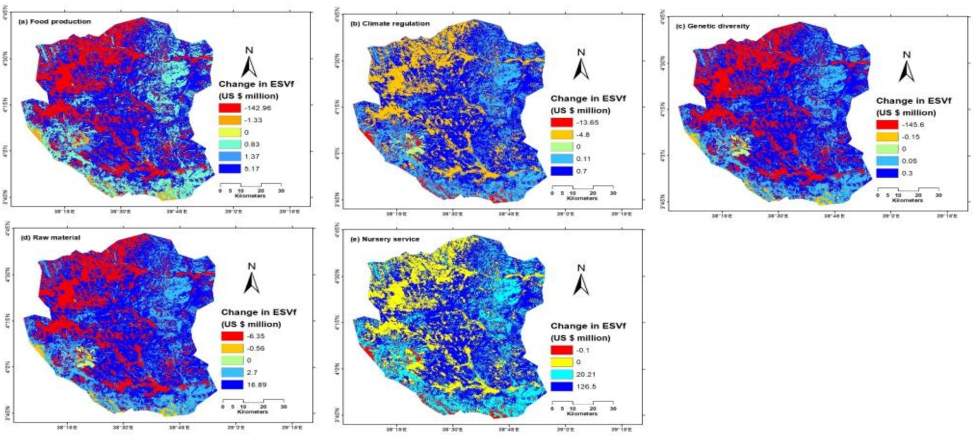

Figure 9. Overall changes (1986-2034) in services of top 5 ecosystem functions (ESV_f in US $ million per year); (a) Food production, (b) Climate regulation, (c) Genetic diversity, (d) Raw material, and (e) Nursery sites

The contribution of genetic diversity to total ecosystem service values will decline from 15.85% in 1986 to 7% in 2034. This suggests that ecosystem restoration will significantly be hampered from obtaining transplants or seeds in an area with low genetic diversity (Raynolds *et al.* 2012). The contribution of climate regulation to total ecosystem service values will decline from 2.7% in 1986 to 1.74% in 2034. The reduction of climate regulation function has important implication on other ecosystem services such as food production (Bangash *et al.* 2013). For example, food production can be affected by climate change (precipitation, temperature and extremes) (Muller 2014). Thus, there is an urgent need to find ways to produce more food without undesirable ecosystem trade-offs. During the period 1986–2034, among the five top-ranked ecosystem functions, the contribution of food provision, genetic diversity, and climate regulation will decrease; while the contribution of nursery service and raw materials will increase.

3.6 Analysis of Coefficient of Sensitivity (CS)

Uncertainty of the results of this study may arise from two known sources. First, the error encountered during the classification of satellite images to generate LULC classes can be considered as a source of uncertainty. However, the classification accuracies of LULC classification was found to be with in the acceptable limit (greater than 85% overall accuracy). Secondly, the error might have been introduced through using Value Coefficients (VCs) that were generated elsewhere by previous studies (Costanza *et al.*,1997; de Groot *et al.* 2012; Temesgen *et al*. 2018*).* The Coefficient of Sensitivity (CS) was computed in order to test if the VCs used in our study were inelastic (i.e. CS <1) after adjusting the VCs by ±50%. The CS values are presented in Table 10. CS values were less than one for all LULC classes suggesting the low sensitivity of the estimated ecosystem service values in the Borana area with respect to the adjusted VCs. The very low CS values were observed for cropland ranging from 0.001 to 0.002. This indicates that adjustment to the VCs for cropland, has very little effect on the estimated ESV. In contrast, relatively high CS values were observed for shrub/bush class (0.4-0.6). Overall, the CS values presented in Table 10 indicated that the ESV estimations for all classes were robust despite the uncertainties on the VCs.

Table 10: The coefficient of sensitivity (CS)

Change in valuation coefficient (VC)	1986		2002		2018		2034	
	%	CS	%	CS	%	CS	%	CS
Cropland VC ±50%	0.03	0.001	0.06	0.001	0.09	0.002	0.1	0.002
Grassland VC ±50%	18.59	0.37	14.61	0.29	8.58	0.17	0.08	0.16
Shrub and bush VC ±50%	19.75	0.4	24.73	0.49	29.88	0.6	28.82	0.57
Woodland VC ±50%	9.15	0.18	9.19	0.18	9.97	0.2	11.5	0.23
Forest VC ±50%	2.48	0.05	1.41	0.03	1.49	0.03	1.49	0.03

4. Conclusions

This study integrated socio-economic data with biophysical data of the Dirre rangeland to simulate LULC of 2034 based on LULC of 1986 and 2002 using multi-criteria evaluation technique and Cellular Automata-Markov Chain (CA-Markov) modelling. The CA-Markov model was reasonably accurate for projecting future LULC, since it produced the overall accuracy of 73.88%. Thus, it is possible to draw the conclusion that the combination of Markov and a simple CA filter integrated with MCE was effective for predicting future LULC classes. The simulated future LULC map can be used as an early warning information for understanding the future effects of LULC changes such as bush encroachment at the expense of grassland.

The ESVs notably differed among the LULC classes. The ESV of grassland is decreasing steadily from USD 553 million in 1986 to USD 209 million in 2034 and shows a total loss of USD 344 million. Even though the Dirre rangeland area is known as a cattle production area, the current LULC change, particularly the conversion of grassland with high ESV into shrub and bushland with low ESV has led to a decline in providing the ecosystem services that are important to pastoralists in the Borana area. The total ESVs of the Dirre rangeland is decreasing from USD 1,488 million in 1986 to USD 1,293 million in 2034, amounting to a total loss of USD 194.6 million. This loss is because of the extensive expansion of shrub and bush with a low ESV at the expense of mainly grassland with a high ESV. Significant changes have occurred in ecosystem service functions with highest contributors of the total ESVs. Nursery service, food provision, genetic diversity, raw material provision, and climate regulation contributed more than 89% to the total ecosystem service value. The contribution of other ecosystem functions (i.e. erosion prevention, water regulation, and waste treatment) was minimal. Therefore, it is critical to distinguish invaluable ecosystems that deliver high economic value and contribute to increased cumulative ESV. In conclusion, these notable findings can also serve as a strategic guide to land use planning and help natural resources managers to better understand a complex LULC system in arid and semi-arid regions of Ethiopia.

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