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Land Use Land Cover Changes and Its drivers in Gojeb River Catchment, Omo Gibe Basin, Ethiopia

MELKU DAGNACHEW[1,2*], ASFAW KEBEDE[2], AWDENEGEST MOGES[3], ADANE ABEBE[4]

[1]*Natural Resources Management, Wolaita Sodo University, Wolaita Sodo, Ethiopia.*

[2]*Haramaya Institute of Technology, Haramaya University, Dire Dawa, Ethiopia.*

[3]*School of Biosystems and Environmental Engineering, Hawassa University, Hawassa, Ethiopia.*

[4]*Arba Minchi Institute of Technology, Arba Minchi University, Arba Minchi, Ethiopia.*

**Correspondence details:* melku1980@gmail.com.

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Abstract: Land use land cover (LULC) changes are inherently spatial and dynamic with high spatiotemporal variability resulted from complex human-environmental interactions. Current extents, rates and intensities of LULC changes are driving unprecedented changes in ecosystems functions and environmental processes at local, regional and global scales. The study was conducted to assess LULC changes and its drivers using remote sensing (RS) and geographic information system (GIS) in Gojeb River Catchment, Ethiopia. The satellite images at different reference years (1978, 1987, 2001 and 2015) were obtained from Landsat images. Supervised classification with maximum likelihood algorithm was applied for image processing and change analysis. The LULC classes identified were cropland, forestland, shrubland, swamp, and woodland. The study found that the catchment has undergone significant LULC changes. The major changes were expansion of cropland at the expense of other LULC classes at the rate of 29.56% in 1978, 38.91% in 1987, 46.62% in 2001 and 52.74% in 2015. It has gained about 160,736.08 ha with an annual average increment of 4,344.22 ha. Conversely, forestland has undergone reductions at an annual rate of 9,030.0 ha between 1978 and 1987. The conversions of other classes to cropland are mainly associated with more demand for crop production. On the other hand, the conversion of relevant part of forest land to other classes could be due to vegetation degradation. Hence, the conversion of forestland to other land use classes could be attributed to the highly demand of agricultural land, firewood, charcoal, timbers and housing materials. The major driving forces which should be considered in sustainable watershed management were population growth and government induced settlements. Provision of modern alternative sources of energy, agricultural inputs and promoting non-agricultural sectors are also other considerations for the community sustainable livelihood. It is critical to follow holistic view and management of the catchment for successful integrated watershed management endeavours.

Keywords: Land use land cover; GIS; Remote Sensing; Gojeb River Catchment; Ethiopia

Introduction

Land is the vital natural resource available to humankind. Land use land cover (LULC) changes have been considered as one of the factor of global environmental changes (Erdogan *et al.* 2015; Pandey *et al.*, 2019). Land cover (LC) and Land use (LU) are distinctive and closely associated characteristics of the Earth's surface (Melese 2016; Lambin *et al.*, 2003) and prominently derived by human activities (Teixeira *et al.*, 2014; Mifta *et al.*, 2017; Betru *et al.*, 2019). Land cover demonstrates the terrain features on the Earth surface while land use reflects the utilization of available land by the human beings i.e. built environment and/or human use of landscapes (Hansen and Loveland, 2012; Pandey *et al.*, 2019). The LC is directly observable in the field and by remote sensing images. It is the attributes of the earth's land surface including biota, vegetation, soil, topography, surface and groundwater, and human structures (Lambin *et al.*, 2003). LU, mainly driven by social, economic, political, technological, and cultural factors*;* signify how humans exploit the LC (Lambin *et al.*, 2003; Etter and McAlpine, 2008). LU is spatio-temporally constrained by biophysical factors such as climate, soil type, water availability, accessibility, and biological resources (Forkuor and Cofie, 2011; Etter and McAlpine, 2008). Hence, accurate knowledge of LULC provides critical information for integrated landscape planning and management (Pandey *et al.*, 2019).

The LULC changes are inherently spatial and dynamic with high spatiotemporal variability resulted from complex interaction of behavioural and structural factors having enormous importance in natural resource studies (Lambin and Meyfroidt, 2011; Sinha, Sharma, and Nathawat, 2015). Current rates, extents and intensities of change are driving unprecedented changes in the structure, function, and dynamics of ecosystems and environmental processes at local, regional and global scales (Lambin *et al*., 2003). LULC changes, including the expansion of agriculture, land degradation, deforestation, climate change, hydrology and human structures, are occurring at an unprecedented pace across the world (Pham *et al*., 2015). All these have direct impacts on livelihoods of local communities and multifaceted environmental impacts that can immensely affect food security and sustainable development (Lambin and Geist, 2006; Bewket and Abebe, 2013). Currently, LULC changes have arisen as a fundamental component of global environmental changes and sustainability issues that has received much attention (Geist and Lambin, 2001; Rawat and Kumar, 2015; Sinha *et al*., 2015). The driving forces governing LULC changes could be either proximate or underlying driver. The former are biophysical factors and unsustainable land management practices; while the latter are social, economic and institutional factors that lead to unsustainable land management practices (Lambin *et al*., 2003). The proximate (direct) drivers are agricultural expansion, infrastructure extension and urban expansion, logging, uncontrolled fires, livestock grazing in forests, forest wood and non-wood product extraction and fuel wood and charcoal collection (Lambin *et al.*, 2003; Lambin and Geist, 2006; Hosonuma *et al*., 2012). The (underlying) indirect drivers are fundamental forces that underpin the more proximate situations and formed by a complex of social, political, economic, demographic, technological, cultural and biophysical variables (Geist and Lambin, 2001; Lambin and Geist, 2006; Hosonuma *et al*., 2012).

The knowledge and available data on LULC changes have paramount importance for many environmental planning and management activities to provide critical input to decision-making. It is very imperative to have good, accurate, continual, historical and up-to-date precise information on LULC changes for a better and efficient use of land resources (Reis, 2008; El-Kawy *et al.*, 2011) Remote sensing (RS) and geographic information systems (GIS) have proved to be useful tools for quantification, mapping and detection of the spatiotemporal dynamics of LULC (Hassan *et al*., 2016; Mifta *et al*., 2017). RS has emerged as very powerful technology providing accurate spatial information and LULC distribution in the temporal period (Gidey *et al.*, 2017; Rani *et al.*, 2018; Dagnachew *et al.*, 2020). Most studies conducted in Ethiopia indicated that LULC dynamics have resulted in undesirable biophysical and socioeconomic impacts. The LULC changes were mainly the conversion of natural vegetation (forest) to agricultural lands and grazing lands due to high demand for agricultural food production and livestock grazing lands in Ethiopia (Assen, 2011; Bewket and Abebe, 2013; Kibret *et al.*, 2016), while Moges and Holden, (2009) reported such changes leading to the development of gully erosion in the Southern Ethiopia. Conversely, forestland increment was observed in Chemoga, Gerado and Hirmi watershed of Ethiopia (Gebrelibanos and Assen, 2015). Moreover, studies (Kindu *et al.*, 2013; Yeshaneh *et al.*, 2013) showed that significant declines in natural vegetation cover as the expense of open grassland and cultivated lands which could exacerbate the problem of land degradation. These land degradations in turn threaten the environment, hydrology and the livelihoods of local communities, in particular.

Despite the presence of such studies in the other parts of Ethiopia, up to date and well documented scientific evidence about LULC dynamics is lacking in Gojeb River Catchment (GRC), one of the main contributor of Gibe III hydropower reservoir. In this catchment, the ecosystem is fragile and more susceptible, due to rugged topography and diverse climatic variability (Kochito, 2014), to negative impacts of LULC changes, which may result in wider ramification. Deforestation, unsustainable agricultural practices, population growth, unplanned rural settlements may have wide ranging effects in the catchment and changes occurred over long period of time. Therefore, river catchment-based spatial and temporal LULC changes monitoring is a pre-requisite for efficient use and long-term development of agriculture, water and the environment facets. Hence, understanding the nature of LULC dynamics through scientific evidences is unquestionably crucial for sustainable watershed management practices and to prevent the costly built reservoirs from sedimentation in the downstream of GRC. Therefore, the objective of this study was to assess and quantify LULC dynamics and its drivers using remote sensing and GIS in GRC, Omo-Gibe basin, Ethiopia.

Materials and Methods

Description of the study area

The study was conducted at the GRC, a part of the Omo-Gibe basin in Ethiopia (Figure 1). The Omo-Gibe basin, third largest perennial river in Ethiopia next to the Baro Akobo and Blue Nile rivers, lies between 5° 31′ to 10° 54′ N and 33° 0′ to 36° 17′ E and covers about 79,000 km^2 of land area in South and Southwest Ethiopia (Wolka *et al.*, 2018). The GRC is located between 7° 00´-7° 50´ N latitude and 35° 30´-37° 20´ E and covers a total area of 6932.345 km^2 with altitudinal ranges from 817 to 2500 m a.s.l.

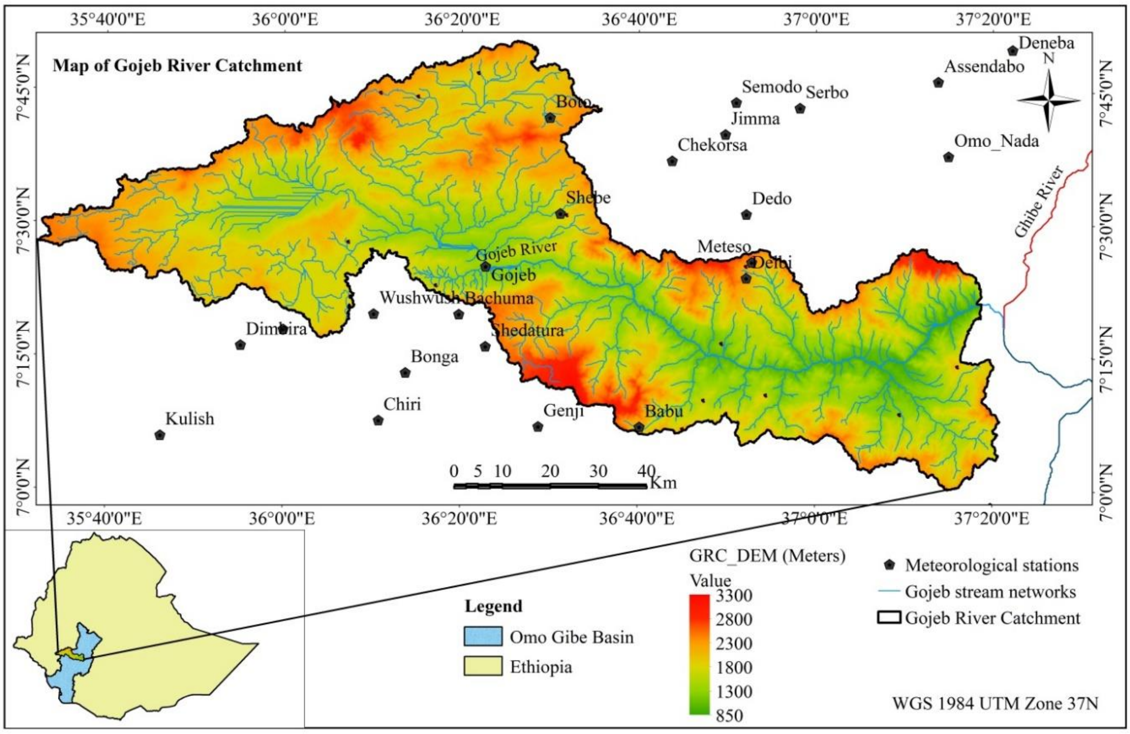

Figure 1 - Study map of Gojeb River Catchment, Omo-Gibe Basin, Ethiopia.

In the Omo-Gibe River Basin, the climate varies from a hot arid climate in the southern part of the floodplain to a tropical humid in the highlands that include the extreme north and north western part of the basin (Wolka *et al.*, 2018). The rainfall varies from over 1900 mm per annum in the north central areas to less than 300 mm per annum in the south. Moreover, the rainfall regime is unimodal for the northern and central parts of the basin and bimodal for south. The mean annual temperature in Omo-Gibe basin varies from 16 °C in the highlands of the north to over 29 °C in the lowlands of the south (Kochito, 2014). In the GRC, the rainfall is unimodal and the amount increases with the increase in elevation. The mean annual rainfall of the catchment ranges from 1391 mm in downstream to 1884 mm in the upper stream. The mean monthly maximum and minimum temperature is 25.9 and 14.4 °C, respectively (Figure 2). The land use pattern is dominated by five land use categories namely: woodland, cropland/agricultural, swamp, forest and shrubland (Denboba, 2005). The total population of the catchment is about 2,637,351 of which 1,320,571 (50.07%) are men and 1,316,780 (49.93%) women and while only 9.2% are urban inhabitants (CSA, 2008).

Methods

Data Used

The satellite imagery used in this study to classify land cover changes were from the Landsat Multi-Spectral Scanner (MSS) of 1978, the Landsat Thematic Mapper (TM) of 1987, the Landsat Enhanced Thematic Mapper Plus (ETM+) of 2000 and the Landsat Operational Land Imager (OLI) of 2015. The used Landsat images were within reasonable time series and acquired on dates as close as possible. The images in dry season (January to March) were taken to reduce atmospheric and radiometric problems and possible cloud cover.

Accordingly, the 1978, 1987, 2001 and 2015 were obtained from www.earthexplorer.usgs.gov/ to come up with the LULC map and classification (Table 1).

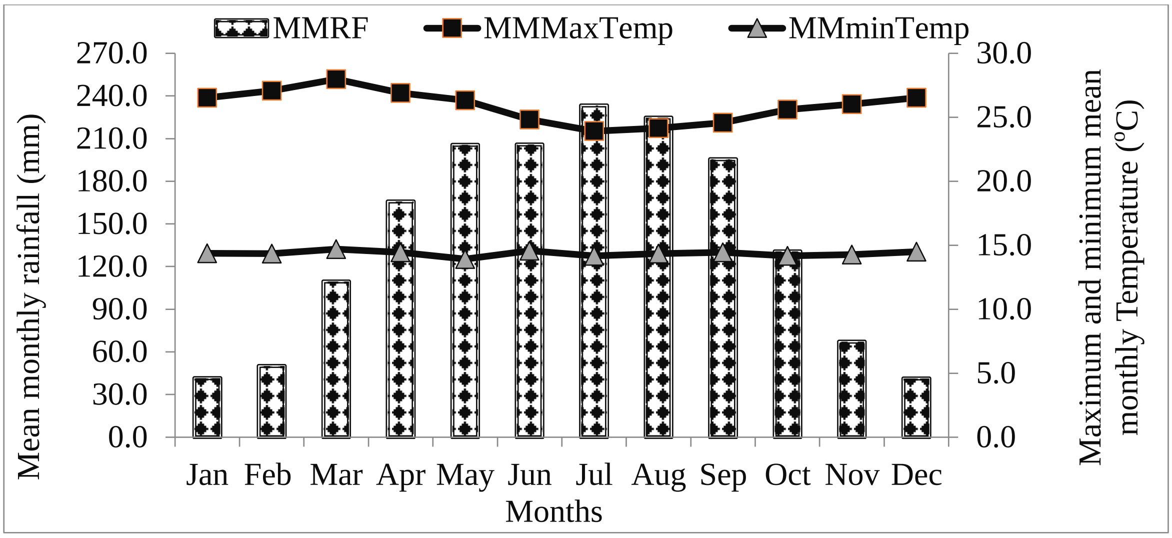

Figure 2 - Mean monthly rainfall (mm) and maximum and minimum temperature (°C) of GRC (1982-2015) (Sources: Dagnachew *et al*., 2020).

Table 1 - The characteristics of the image data in the Gojeb River Catchment.

No.	Data type	Sensor	Date of acquisition	Path/row
1	Landsat	MSS	11 and 12/03/1978	181, 182, 183/55
2	Landsat	TM	01/03/ & 02/02/1987	169, 170/55
3	Landsat	ETM+	09/03 & 06/03/2001	169, 170/55
4	Landsat	OLI 8	02/08 & 05/03/2015	169, 170/55

Note: MSS- Landsat Multi-Spectral Scanner, TM- Landsat Thematic Mapper, ETM+- Landsat Enhancement Thematic Mapper plus, OLI- Operational Land Imager.

Ancillary data were used to improve accuracy of the classification and interpretation of LULC changes. Ancillary data, such as ground truth data, topographic maps at a scale of 1:50,000 and aerial photographs were collected from Ethiopia mapping authority for verification. Additionally, Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM-30 m) and its derived data sets were obtained. Besides, vector layers, such as boundary of the study area, roads, administrative maps and rivers were obtained from the Ministry of water resource, irrigation and electric power of Ethiopia. Moreover, field survey, short interviews with key informants and focus group discussions with farming households (HHs), especially older ones who resided long years, were carried out in 2016 to understand their perception about the trends of LULC changes. Accordingly, a total of 45 key informants and participants to the focus group discussion were considered (15 individuals from each upper, middle and lower positions of the Catchment) in the GRC.

Information gathered from these interviews guided the authors in developing valid data for historic images.

Image pre-processing

Pre-processing of satellite images prior to image classification and change detection is essential. Pre-processing commonly comprises a series of sequential operations, including atmospheric correction or normalization, band ratio, layer stacking, image registration, geometric correction, image enhancement and masking (e.g., for clouds, water, irrelevant features) to correct the surface features reflectance characteristics (El-Kawy *et al.*, 2011; Muriithi, 2016; Kogo *et al.*, 2019; Langat *et al.*, 2019). First, radiometric corrections were carried out to remove the influence of the atmosphere, and then, all the images were converted from digital number values to top-of- atmospheric reflectance to make them comparable. Secondly, image registration was done using an image-to- image registration process. Landsat Operational Land Imager (OLI) images were used as base images and other images were employed as wrap images. Mosaic processing was applied to merge the image frames to cover the entire Gojeb River Catchment. Finally, the study catchment was masked from the mosaicked images and geo-referenced and subset on the basis of area of interest (AOI) and projected to WGS 1984, UTM Zone 37 N. The entire image processing tasks were carried out using ERDAS IMAGINE 2014 software, and ArcGIS 10.4.1 software was used for spatial data integration.

Image classification

The satellite image processing and land cover classification was carried out using the widely-used supervised maximum likelihood classification algorithm (MLC) (Rawat and Kumar, 2015; Tran *et al.*, 2015; Muriithi, 2016; Mubako *et al.*, 2018), one of the most well-known parametric classifiers used for supervised classification and post-classification change detection analysis method (Langat *et al.,* 2019). The standard implementation of supervised maximum likelihood classification requires training samples representing the feature types (Tran *et al*., 2015). The supervised classification allowed us to define AOIs that identify and recognize features on the image. The classification was performed through identification of features and selection of training areas, evaluation and analysis of training signature statistics and spectral patterns, and classification of the images. The collection of number of training samples and their highly representativeness is a critical task for image classification of the LULC (Lu and Weng, 2007). For training and validation sampling, Google Earth image and published topographic maps were applied. The AOIs (training samples) were collected for the various LULC categories, based on a) prior knowledge of the area, and b) uniformity in appearance. The AOIs were used to create a signature file for each Landsat scene. The signatures were evaluated using histograms, band by band scatter plots and a separability analysis to obtain the expected error, covariance between bands in the classification for various feature combinations (Muriithi, 2016). The quality of the AOIs was analyzed using histograms, band scatter plots, and statistics reports derived from the training sample evaluation tool. Therefore, five main LULC categories, swamp area, forest land, cropland, woodland and shrubland were classified and mapped (Table 2). Furthermore, detail descriptions of the definitions of the various LULC types we used are available in Wassie (2017) and Mengist (2019).

Table 2 - The LULC classes for the classification of all observed images and periods.

No.	LULC Class	Descriptions
1.	Cropland	Arable and fallow land that grows annually, perennial crops and permanent fruit trees on the small or commercial level and also includes rural settlements residential.
2.	Forestland	Natural and/or plantation vegetated land composed of either or mixed of evergreen, deciduous, semi deciduous, with an area that exceeds 0.5 ha, height ≥ 2 m and canopy cover ≥ 20%.
3.	Shrubland	Land with shrubs/bushes canopy cover ≥ 10% or combined cover of bush, shrubs and trees ≥ 10%.
4.	Swamp	Those areas dominated by wetland herbaceous vegetation where the water table is at, near, or above the land surface.
5.	Woodland	Area ≥ 0.5 ha; tree canopy cover 5-10% with trees > 5 m at maturity in situ or shrubs/bushes canopy cover ≥ 20%. Woodland (75-150 trees/ha) and grassland areas with moderate to dense scattered trees (10-75 trees/ha).

A blend of steps and procedures was developed to interpret, analyze, map, and quantify the available data sets (Figure 3). Training data or spectral signatures were established from the previous knowledge of the area, and with the help of other supporting data sources, such as aerial photographs, topographic maps, GPS data, Google Earth online and interviews with elderly people of the study area. Moreover, local knowledge, reference data, as well as visual analysis, considerably improved the results obtained using the supervised algorithm.

Accuracy Assessment

In remote sensing, accuracy assessment is mandatory in providing information about the quality of the produced classification (El-Kawy *et al.*, 2011). It is essential for individual image classification generated from any remote sensing data (Congalton and Green, 2009). Error (confusion) matrix is the most frequently used methods and standard form of reporting site-specific classification errors (El-Kawy *et al.*, 2011). The accuracy assessment was performed on the resulting classified images by generating a set of points and comparing them with actual points on the ground truth. The LULC classification assigned to each pixel was compared with the same location on the reference sources to check whether the classification result is accurate or not. Therefore, for efficient classification accuracy assessment, a minimum of about 50 random points were required (Congalton and Green, 2009) to represent the different classes of the area. Thus, in the study catchment, a total 256 random points (pixels) were generated using stratified random sampling method from each of the five LULC classes. Moreover, Kappa statistic was performed to measure the extent of classification accuracy (Rosenfield and Fitzpatrick-Lins, 1986). A confusion matrix was created to drive overall, user and producer's accuracies, and the Kappa statistic using the observed and classified LULC classes of each pixel of the GCPs.

Land use Land cover change detection and analysis

In the study catchment, post-classification change detection technique was applied to compare and analyze the LULC maps resulting from the integration of the results of visual interpretation and supervised classification (Hassan *et al.*, 2016). Images of different

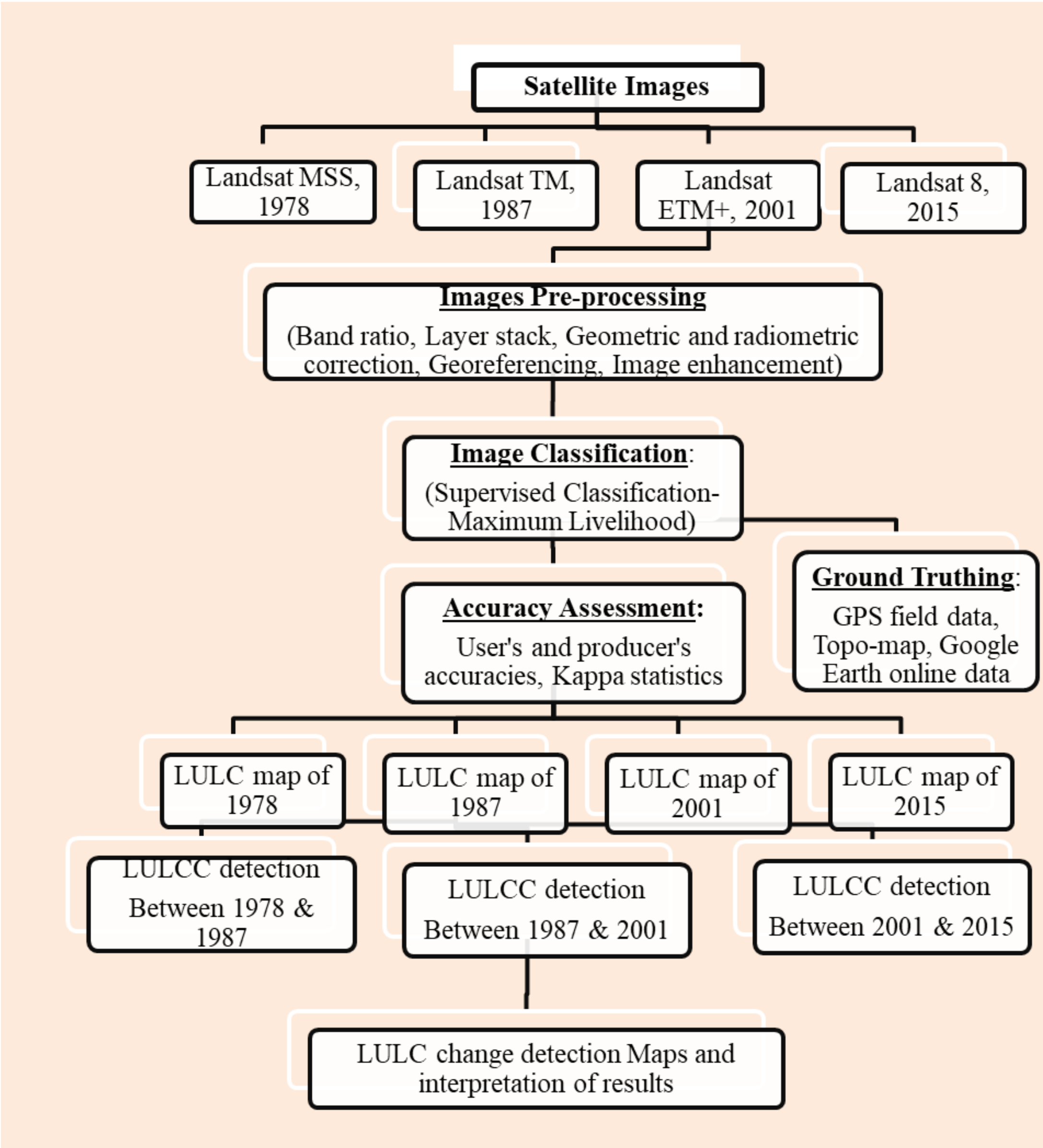

Figure 3 - Flow chart of LULC image classification and analysis.

reference years were first independently classified and then the classified images were compared in three periods (1978-1987, 1987-2001, and 2001-2015) to detect the differences between each pair of LULC maps. Moreover, overlay procedure and a two-way cross-matrix were used to describe the key change types. Cross tabulation analysis was conducted in order to determine the quantitative conversions from a particular LULC class to another and their corresponding area over the evaluated period on pixel to pixel basis. Thus, a new thematic layer was produced from the two five-class maps, containing different combinations of ‘‘from-to’’ change classes. Accordingly, three change maps were produced to display the specific nature of the changes between the classified images. The rate of change was calculated for each LULC classes using the formula used by Shiferaw, 2011 and Gashaw *et al*., 2014. The LULC conversion matrix between 1978 and 1987; 1987 and 2001; 2001 and 2015 was generated and compiled in a matrix table by comparing image values of one data set with the corresponding value of the second data set in each period.

Results

Accuracy Assessment

In GRC, the details on the accuracy assessment results and Kappa statistics of LULC classes were provided in table 3 (a - d).

Table 3 - Confusion (Error) matrix of LULC classification accuracies for the reference years (a) 1978, (b) 1987, (c) 2001 and (d) 2015.

Classified data, 1978	a) Reference Data										
	CL	FL	SHL	SW	WdL	Row total	PA (%)	UA (%)	OCA (%)	Kappa statistics	Overall Kappa
Cropland	**74**	0	7	1	2	84	97.37	88.10		0.83	
Forest	0	**32**	1	0	3	36	94.12	88.89		0.87	
Shrubland	2	2	**61**	0	5	70	83.56	87.14	89.45	0.82	0.86
Swamp	0	0	0	**4**	0	4	80.00	100.00		1.00	
Woodland	0	0	4	0	**58**	62	85.29	93.55		0.91	
Col. Total	76	34	73	5	68	**256**					
1987	b) Reference Data										
Cropland	**89**	0	8	0	1	98	98.89	90.82		0.86	
Forest	0	**12**	0	0	0	12	75.00	100.00		1.00	
Shrubland	1	4	**104**	0	9	118	91.23	88.14	90.23	0.79	0.85
Swamp	0	0	0	**2**	0	2	100.00	100.00		1.00	
Woodland	0	0	2	0	**24**	26	70.59	92.31		0.91	
Col. Total	90	16	114	2	34	**256**					
2001	c) Reference Data										
Cropland	**119**	0	7	0	1	127	100.00	93.70		0.88	
Forest	0	**21**	2	0	0	23	84.00	91.30		0.90	
Shrubland	0	3	**75**	0	5	83	87.21	90.36	91.80	0.85	0.87
Swamp	0	0	0	**5**	0	5	100.00	100.00		1.00	
Woodland	0	1	2	0	**15**	18	71.43	83.33		0.82	
Col. Total	119	25	86	5	21	**256**					
2015	d) Reference Data										
Cropland	**133**	0	6	0	3	142	100.0	93.66		0.87	
Forest	0	**24**	1	0	0	25	96.0	96.00		0.96	
Shrub land	0	1	**41**	0	5	47	82.0	87.23	92.97	0.84	0.89
Swamp	0	0	0	**5**		5	100.0	100.00		1.00	
Woodland	0	0	2	0	**35**	37	81.4	94.59		0.94	
Col. Total	133	25	50	5	43	**256**					

Where CL = Cropland, FL = Forestland, SHL = Shrubland, SW= Swamp, Woodland, UA = user's accuracy, PA = producer's accuracy and OCA = Overall classification Accuracy. The columns represent actual location of samples on the ground, while rows display classified data showing location of samples in the classified images. Diagonal numbers showed in bold are the correct classifications. The off diagonal numbers in rows and columns are misclassifications or errors.

In the GRC, the overall accuracies of LULC classification for the four reference years (1978, 1987, 2001 and 2015) were 89.45, 90.23, 91.80 and 92.97 % respectively (Table 3 a - d). The accuracy assessment revealed that overall accuracy and a Kappa statistics were greater than 85% and 0.85 which is higher than the Anderson's standard 85% accepted overall accuracy level for LULC classification (Anderson *et al*., 1976). The user's, producer's and overall accuracies were found to be very good for almost all the land use classes. Since, the overall and per-class accuracies obtained from all types of images were higher than the 85% and 70% minimum threshold, respectively, the accuracy assessment result of the LULC classification in the GRC is acceptable (Anderson *et al*., 1976; Thomlinson *et al*., 1999). Moreover, the overall classification accuracy of the satellite images yielded a Kappa statistics of 0.86, 0.85, 0.87 and 0.89 for the 1978, 1987, 2001 and 2015 images, respectively (Table 3a-d). The value of Kappa statistics for each of the four classified images was greater than 0.80 (80%) confirming a strong level of agreement classification accuracy (Appiah *et al*., 2015; Congalton and Green, 2009; Reis, 2008; Congalton, 2004).

Land Use Land Cover Dynamics in the Gojeb River Catchment

Figure 4 and table 4 depict the LULC maps and areas under the five extracted LULC classes during the reference periods (1978, 1987, 2001 and 2015) for GRC. In 1978, the dominant LULC classes were cropland followed by shrubland, woodland, forestland and swamp of the study catchment. In 1987, shrubland constituted for the largest part, while cropland and woodland accounted the second and third dominant classes, respectively followed by forestland, and swamp. In 2001 and 2015, cropland is the dominant LULC classes and occupied the largest proportion, followed by shrubland, woodlands, forestland and swamp. However, the forestland and swamp occupied the smallest proportion.

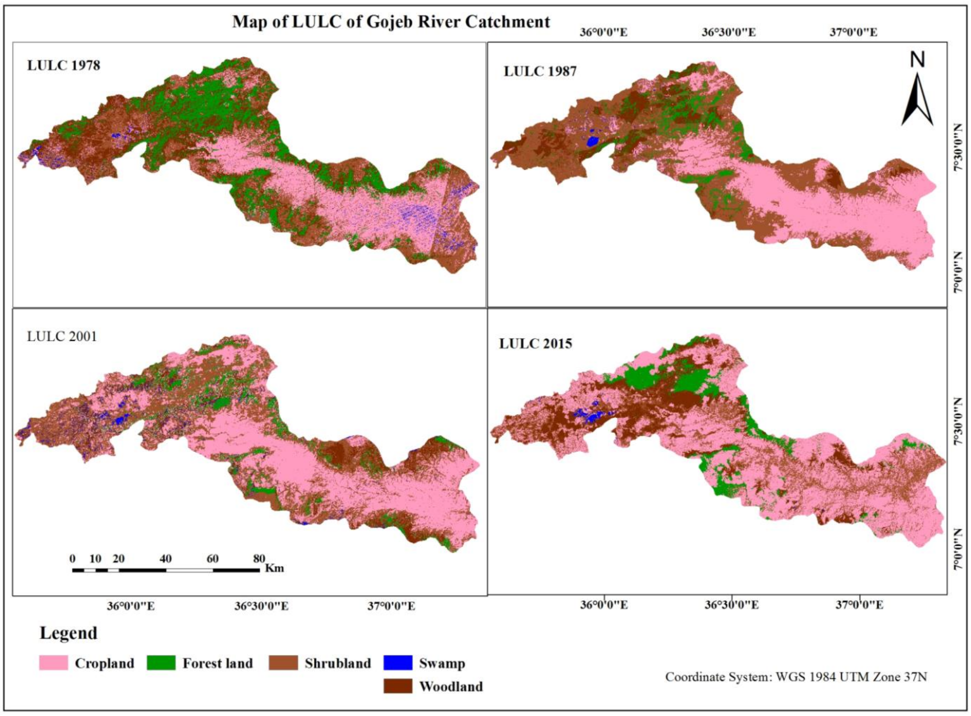

Figure 4 - The LULC map of Gojeb River Catchment, 1978, 1987, 2001 and 2015.

Table 4 - Area in ha and proportion of classified LULC classes in Gojeb River Catchment.

LULC CLASSES	1978		1987		2001		2015	
	AREA (ha)	(%)	AREA (ha)	(%)	AREA (ha)	(%)	AREA (ha)	(%)
Cropland	204910.3	29.56	269752.7	38.9	323199.4	46.6	365646.4	52.7
Forestland	128942.1	18.60	47671.9	6.90	47077.0	6.79	60842.1	8.78
Shrubland	175234.6	25.28	298172.6	43.0	250601.7	36.2	161536.0	23.3
Swamp	10700.0	1.54	4347.2	0.63	13239.2	1.91	3767.0	0.54
Woodland	173447.5	25.02	73290.1	10.6	59117.3	8.53	101443.0	14.6
TOTAL AREA	693234.5	100	693234.5	100	693234.5	100	693234.5	100

In the GRC, the trend of cropland increased throughout the study periods (1978-2015). On the contrary, forest land has undergone reductions, except slight increases during 2015 which might be attributed to reforestations and prevention of existing land cover following establishment of protected forests. Particularly, during 1978-1987, forestland has reduced from 128,942.05 ha to 47,671.91 ha. The woodland cover reduced during the study periods, 1978 to 2015 except slight increment in 2015.

The percentages and rates of Land Use and Land Cover changes in GRC

Table 5 showed the description of the percentage changes (ha, %) and the rate of LULC changes (ha, ha/year) for the study catchment. In the first period (1978-1987), a considerable reduction of woodland, forestland and swamp was revealed. Conversely, cropland and shrubland were increased by 64,842.3 ha and 122,938.0 ha, respectively. The cropland gained throughout the study periods with annual increment of 7,204.70 ha. During the same period, forestland cover loss was 81,270.1 ha at a rate of 9,030.02 ha per annum. In the second period (1987-2001), shrubland, forestland and woodland showed considerable reduction. The cropland revealed a significant increment with annual increment of about 3,817.6 ha; while other LULC classes showed reductions throughout the study period. In the same period, the extent of forestland reduced at annual rate of 42.5 ha. In the third period (2001-2015), except shrubland and swamp which showed a considerable reduction, other classes showed an increment. Besides, between 2001 and 2015, the average cropland gained was 3,031.93 ha annually; while, the gain of forestland was 983.2 ha annually (Table 5). In the GRC, the cropland has shown remarkable increment during the first, second and third periods, respectively. For the entire study periods, the cropland gained about 160,736.1 ha with an annual average increment of 4,344.2 ha. Conversely, the forestland was reduced during the first and second period, with very slight increase for the third period. For the entire study periods, forestland has lost an area of 68,099.9 ha with an annual loss of 1840.5 ha. The shrubland showed increment and gained an estimated of 122,938.0 ha (13,659.8 ha per annum), during the first period, while it has been declined in the second and third periods. The annual rate of decrement of shrublands between 1987 - 2001, 2001 - 2015, and 1978 - 2015 were 3,397.9, 6,361.8 and 370.2 ha, respectively. The woodland showed reductions between 1978-1987, 1987-2001 and 1978-2015 in favour of shrubland; whereas, for the period between 2001 and 2015, it gained an estimated annual rate of 3,023.27 ha. The swamp area also showed a reduction at an estimated rate of about 705.87, 676.59 and 187.38 ha per year, respectively (Table 5), which might be attributed to its dependence on the seasonal variations of rainfall. Generally, over 37-years, cropland showed increment at the expense of other LULC classes

Table 5 - Results in percentage (ha, %) and rate (ha, ha/year) of changes in LULC from 1978 - 1987, 1987- 2001, 2001 - 2015 and 1978 - 2015 time periods in the Gojeb River Catchment.

LULC CLASSES	PERCENTAGE AND RATE OF CHANGES IN LULC BETWEEN 1978 TO 2015											
	1978 - 1987			1987 - 2001			2001 - 2015			1978 - 2015		
	AREA (ha)	%	ha/yr	AREA (ha)	%	ha/yr	AREA (ha)	%	ha/yr	AREA (ha)	%	ha/yr
Cropland	64842.3	31.6	7204.7	53446.7	19.8	3817.6	42447.0	13.1	3031.9	160736.1	78.4	4344.2
Forestland	81270.1	-63.0	-9030.0	595.0	-1.3	-42.5	13765.2	29.2	983.2	68099.9	-52.8	-1840.5
Shrubland	122938.0	70.2	13659.8	47570.9	-16.0	-3397.9	89065.8	35.5	6361.8	13698.7	-7.8	-370.2
Swamp	6352.8	-59.4	-705.9	8892.0	204.6	635.1	9472.2	71.6	676.6	6933.0	-64.8	-187.4
Woodland	100157.4	-57.8	-11128.6	14172.9	-19.3	-1012.4	42325.8	71.6	3023.3	72004.5	-41.5	-1946.1

over the study periods; while the remaining classes declined in their cover. There has been negligible net gain from other LULC classes changing into the forest lands.

The Land Use and Land Cover change matrix in Gojeb River Catchment

Table 6 - 7 and figure 5 showed the LULC change matrices for GRC from 1978-1987, 1987-2001 and 2001-2015. The analysis has shown that the land within the study catchment underwent LULC changes in one or another way in the 37-year study periods. The level of changes differed among the LULC classes and study periods. Most of the lost area from forestland, woodland and shrubland was converted to cropland. In the first period (1978-1987), the LULC change matrix results revealed that about 54% of the study area experienced alterations, while 46% of the catchment area remained unchanged. In the same period, 3.36, 42.86, 73.37 and 10.89 % of forestland, shrubland, swamp and woodland were converted to cropland, respectively (Table 6).

Moreover, the majority of forestland converted into shrubland and woodland and 28.01% of its cover remained unaltered. On the contrary, very small proportion of cropland, shrubland and woodland were converted to forestland from 1978 to 1987. Similarly, about 49.33% of shrubland remained unaltered, while about 5.63% of its cover was converted to woodland in the same period. Inversely, 64.68 % of woodland was converted to shrubland, while about 18.85% of its cover remained unchanged (Table 6).

In the second period (1987-2001), around 58.25% of the land cover remained unchanged, while 41.75% of the classes converted into any of the other LULC classes. The change matrix results of the same period revealed that 80.7, 39.88, 51.02, 20.29, 19.34% of cropland, forestland, shrubland, swamp and woodland remained unaltered. In the same period, 16.91, 27.41, 41.96 and 19.09% of forestland, shrubland, swamp and woodland were converted to cropland, implying expansion of agricultural land as the expense of other LULC classes. For instance, the remaining 38.78 and 4.09% of forestland were converted to shrubland and woodland, respectively, which implied loss of vegetation due to deforestation. Moreover, out of 73,290.16 ha of woodland in 1987, about 34,411.46 ha, were converted to shrubland in 2001 (Table 6).

In the third period (2001-2015), almost half of the catchment area remained unchanged, while the remaining, almost the other half of the area of the catchment, undergone alteration. In the same period, 70.60, 41.59, 31.64, 13.26 and 31.77% of cropland, forestland, shrubland, swamp and woodland remained unaltered. For instance, 20.28, 40.64, 28.33, and 37.74% of forestland, shrubland, swamp and woodland were converted to cropland, respectively, implied intensification of agricultural activities for crop production. On the contrary, out of 29.40% of the altered cropland, 2.95, 21.50, 0.05 and 4.89% of cropland were converted to forest land, shrubland, swamp and woodland in the same periods, respectively. Moreover, 6.93 and 31.20% of forestland were converted to shrubland and woodland, respectively during the third period. In opposite trend, 8.16 and 17.61% of shrubland and woodland were converted to forestland, respectively (Table 7).

Table 6 - Land use land cover change matrix of the GRC (1978-1987, 1987-2001).

From / To	LULC classes	LULC 1978					
		Cropland	Forestland	Shrubland	Swamp	Woodland	1987 Total
LULC 1987	Cropland (ha, %)	**163571.2**	4331.5	75111.1	7850.9	18887.9	269752.7
		79.83	3.36	42.86	73.37	10.89	38.91
	Forest land (ha, %)	1222.01	**36115.2**	1111.2	11.69	9211.9	47671.9
		0.60	**28.0**	0.63	0.11	5.31	6.88
	Shrubland (ha, %)	35856.4	60954.3	**86445.8**	2726.9	112189.2	298172.6
		17.50	47.3	**49.33**	25.49	64.68	43.01
	Swamp (ha, %)	1100.7	47.8	2700.6	**33.06**	464.95	4347.18
		0.54	0.04	1.54	**0.31**	0.27	0.63
	Woodland (ha, %)	3160.0	27493.3	9865.9	77.33	**32693.7**	73290.2
		1.54	21.32	5.63	0.72	**18.85**	10.57
	1978 Total (ha, %)	204910.3	128942.1	175234.6	10700.0	173447.5	**693234.5**
		100.00	100.00	100.00	100.00	100.00	**100.00**
From/To		LULC 1987					2001 Total
LULC 2001	Cropland (ha, %)	**217581.3**	8062.9	81742.7	1823.9	13988.6	323199.4
		80.7	16.91	27.41	41.96	19.09	46.62
	Forest land (ha, %)	1959.0	**19010.4**	18132.1	37.6	7937.8	47077.0
		0.73	**39.88**	6.08	0.87	10.83	6.79
	Shrubland (ha, %)	44072.1	18488.5	**152137.5**	1492.2	34411.5	250601.7
		16.34	38.78	**51.02**	34.33	46.95	36.15
	Swamp (ha, %)	729.4	161.9	8688.9	**881.9**	2777.1	13239.2
		0.27	0.34	2.91	**20.29**	3.79	1.91
	Woodland (ha, %)	5410.9	1948.2	37471.4	111.5	**14175.2**	59117.3
		2.01	4.09	12.57	2.57	**19.34**	8.53
	1987 Total (ha, %)	269752.7	47671.9	298172.6	4347.2	73290.2	**693234.5**
		100.00	100.00	100.00	100.00	100.00	**100.00**

N.B. Entries on the cell of the matrix along the diagonal in bold and underlined indicated no change was observed in LULC classes, i.e., no loss or no gain.

Discussion

Land Use Land Cover Dynamics in the Gojeb River Catchment (1978-2015)

LULC dynamics, as the expansion of one land use type at the expense of others, are complex and interrelated (Lambin and Geist, 2006). The GRC has experienced a substantial and increasing rate of LULC changes over the past 37 years between 1978 and 2015. Both cultivated land and shrubland were the major LULC classes throughout the study period. In the GRC, except in 1987, LULC changes have been dominated by cultivation lands.

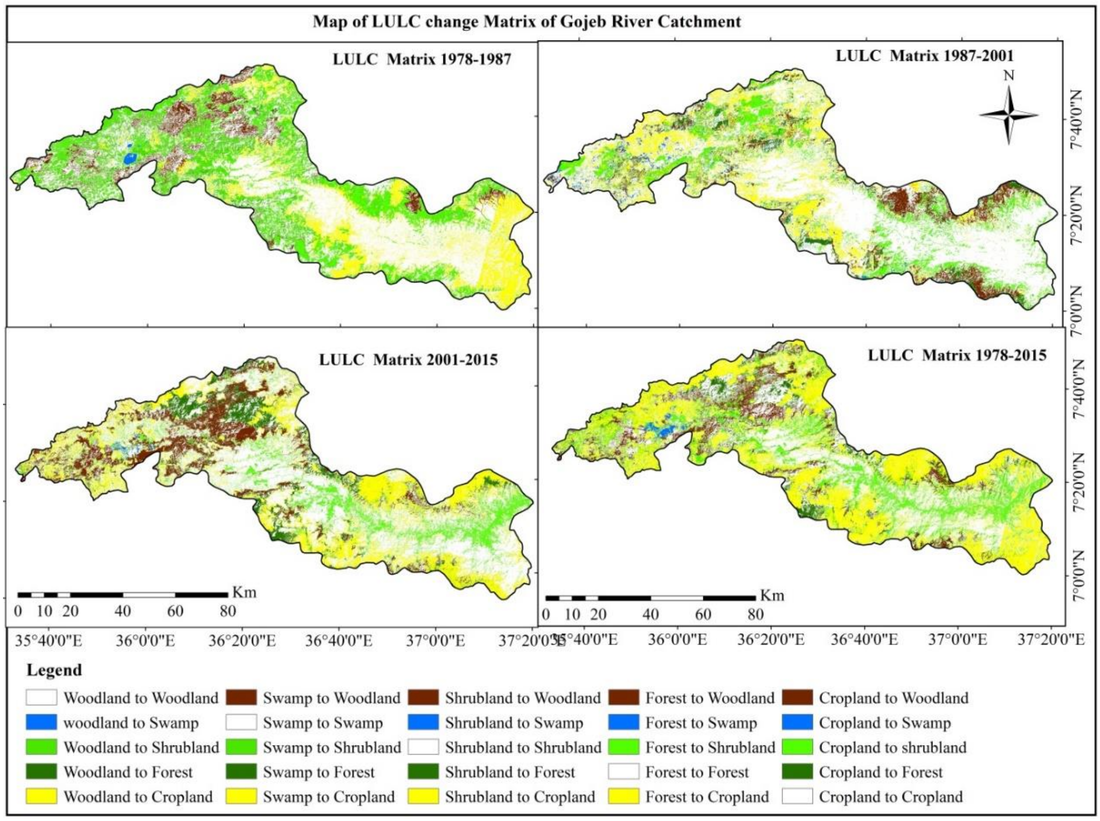

Figure 5 - The map of LULC change matrix GRC from 1978 -1987, 1987-2001, 2001-2015 and 1978-2015 in the GRC.

Table 7 - Land use land cover change matrix of the Gojeb River Catchment (2001-2015).

FROM	LULC CLASSES	LULC 2001					
TO		CROPLAND	FORESTLAND	SHRUBLAND	SWAMP	WOODLAND	2015 TOTAL
LULC 2015	Cropland (ha, %)	**228192.1**	9546.4	101843.4	3750.8	22313.7	365646.4
		70.60	20.28	40.64	28.33	37.74	52.74
	Forest land (ha, %)	9539.4	**19580.6**	20442.1	870.30	10409.8	60842.1
		2.95	**41.59**	8.16	6.57	17.61	8.78
	Shrubland (ha, %)	69486.5	3263.0	**79284.3**	2043.1	7459.1	161536.0
		21.50	6.93	**31.64**	15.43	12.62	23.30
	Swamp (ha, %)	169.6	0.00	1688.7	**1755.8**	152.89	3766.97
		0.05	0.00	0.67	**13.26**	0.26	0.54
	Woodland (ha, %)	15811.8	14686.9	47343.3	4819.23	**18781.8**	101443.0
		4.89	31.20	18.89	36.40	**31.77**	14.63
	2001 Total (ha, %)	323199.4	47077.0	250601.7	13239.2	59117.3	**693234.5**
		100.00	100.00	100.00	100.00	100.00	**100.00**

N.B. Entries on the cell of the matrix along the diagonal in bold and underlined indicated no change was observed in LULC classes, i.e., no loss or no gain.

During the study periods (1978-2015), the trend of cropland increased consistently from 204,910.3 ha in 1978 to 365,646.4 ha in 2015. On the contrary, the forest land has reduced dramatically from 128,942 ha in 1978 to 47,671.91 ha in 2015. This could be attributed to the period when severe drought and famine affected the country, and nationally planned resettlement and villagization programs were implemented by the socialist Derg regime government to combat the effects of drought and increase agricultural productivity (Woube, 2005). The programs aimed to move farmers from densely populated highlands (Wollo and Tigray regions) and drought affected areas into compact settlements in sparsely populated potential areas, mostly in Keffa and Jimma area (Rahmato, 2009). The slight increment of forestland during 2015 could be attributed to the expansion of reforestation programs and establishment of protected forests area for biosystem conservation. Moreover, the shrubland and woodland also showed remarkable reductions. In consistent, greater degree of LULC changes have been reported by Yohannes *et al.,* 2018 in Abaya-Chamo Basin; Ariti *et al.,* 2015 in central Rift Valley of Ethiopia; Gebrelibanos and Assen, 2015 in the highlands of Northern Ethiopia; Bewket and Abebe, 2013 in Gish Abay watershed, and Zeleke and Hurni, 2001 in the Northwestern Ethiopia. The expansion of these land-use types has largely been a result of the conversion of open grassland, shrub grassland, riparian vegetation and forest and dense trees.

In GRC, LULC changes have undergone significant alterations and transformations that showed the whole dimension of the forest destruction between 1978 and 2015. The obtained results from field observation, discussions with key informants and focus group discussions revealed that the expansion of cropland at the expense of other LULC classes was due to the shortage of agricultural lands and demographic dynamics. These have been, in turn, caused by unplanned government induced resettlements and socio-economic transformation and introduction of new cereal based farming system. These results are confirmed also by other studies revealing that the root causes of LULC changes were mainly due to population growth and government induced resettlement of several thousands of people during the Derg regime (1974-1987) and the current regime to southwest Ethiopia (Kassa *et al.,* 2017). Other studies (FAO, 2016; Bekele, 2011) reported that Ethiopians are facing rapid deforestation that has been fueled by population growth. The rate of deforestation in Ethiopia is estimated to be 160,000 to 200,000 hectares per year (Bekele, 2011; Mulugeta and Woldesemait, 2011). Moreover, large numbers of resettled moved into the study catchment following 1984/5 drought and famine demanding cultivated land and introduced the new types of cereal crops which, in turn, increased the demand for agricultural land. This is also confirmed by Denboba (2005) that the introduction of the new types of cereal crops increased the demand for agricultural land and consequently decreased the wooded grassland and natural forest covers. In line with our findings, in Ethiopia, a dramatic increase in cropland at the expense of grassland, shrubland and forestland due to the increase in population dynamics has also been documented (Bewket, 2002; Bewket and Sterk, 2005; Bewket and Abebe, 2013; Denboba, 2005; Moges and Holden, 2009; Hailemariam *et al.,* 2016; Kibret *et al.,* 2016; Wubie *et al.,* 2016). Studies elsewhere (Hassan *et al.,* 2016; Appiah *et al.,* 2015; Reis, 2008; Dessie and Kleman, 2007) also revealed similar findings with varied time and magnitude. Other studies (e.g. Dessie and Kleman, 2007; Bewket and Abebe, 2013; Hassen and Assen, 2018; Minta *et al.,* 2018) have revealed that LULC change is brutal and there has been expansion of agricultural land at the expense of natural forestland and marginal areas without any appropriate conservation measures. Hence, the largest proportion of vegetation cover has been changed due to rapid deforestation that might be resulted from agricultural expansions over grazing, resettlement and new settlement in the GRC.

In GRC, the LULC change matrix results revealed that about 374,375.6 ha of the study catchment experienced alterations, while 46% of the catchment remained unchanged during the first period (1978-1987). In the second period (1987-2001), around 58.25% of LULC remained unchanged, while about 41.75% of the classes converted into any of the other LULC classes. In the third periods (2001-2015), almost half (50.14%) of the catchment area remained unchanged, while remained unchanged, while about 41.75% of the classes converted into any of the other LULC classes. In the third period (2001-2015), almost half (50.14%) of the catchment area remained unchanged, while the almost other half of the area (49.86%) of the catchment undergone alteration. In GRC, the conversion of forestland, woodland, shrubland and swamp to cropland might be mainly associated with the land demand for crop production to satisfy the food demand of the increasing human population, and loss of land productivity due to poor land management approach. To put in a nutshell, the LULC of GRC has undergone alteration and loss of forest cover as a result of agricultural expansion, settlement and population growth.

Major drivers of Land Use and Land Cover changes in Gojeb River Catchment

In GRC, expansion of cropland, introduction of new farming system, wood extraction for fire wood, timber, charcoal and construction material, and over grazing are the leading drivers of LULC changes. The expansions of cropland at the cost of other LULC classes and dramatic population growth and government induced settlements have been major immediate causes for the observed LULC changes. This was also supported by the results of focus group discussions and interviews with key informants. The need for production of food crops, timber and firewood and settlement land largely necessitated the conversion and transformation of LULC changes. The demographic data (CSA, 1996 and 2008) were used to see trends of population changes over the study period to compare the LULC change and population pressure. Accordingly, the data obtained from CSA of Ethiopia report for 1994 and 2007 revealed that the total population of GRC have increased from 1,885,161 in 1994 to 2,637,351 in 2007 census; while urban dwellers increased from 112829 (6%) to 242,046 (9.2%) respectively. Besides the demand for cropland expansion, the forest cover has been threatened also by demand for grazing lands, fuel wood, timber and charcoal production. For instance, out of the total of 495,367 *housing units*[1] of the study catchment, the majority (85.64%) of the households have been using firewood for cooking their daily consumptions and house construction with very insignificant access to electricity (0.2%) (CSA, 2008).

The major institutional and policy factors responsible for changes in LULC in GRC were the resettlement program. During 1985-88 of Derge regime, besides to natural population growth, about 50,000 households with approximately 250,000 people were relocated to Keffa region (Dejene, 1991). These data showed that population pressure on land resources increased the demand for croplands, fuel wood, and construction materials. The census reports also indicated that most of the total population in the catchment (about 94% in the 1994 and 90.82% in the 2007) resides in the rural areas and largely depends on land resources as means of livelihood. These suggest that population growth is a major

[1] A *housing unit* is defined as a separate and independent place of abode, either intended for habitation or not intended for habitation but occupied as a living quarter by a household at the time of the census (CSA, 2008).

driving force in LULC changes of GRC. Besides, about 85.64% of the households living in the catchment have been using fire wood for cooking their daily consumptions with very insignificant accessibility of electricity (0.2%) (CSA, 2008). The data indicated that the livelihood of the residents is highly dependent on forest resources for fuel wood, charcoal and construction material resulted in LULC changes.

In Ethiopia, several factors have been mentioned as the causes of LULC changes which holds true in the case of GRC. These are agricultural expansion, government land policy, overgrazing, population pressure, institutional and policy factors (political unrest, poverty, unstable land-tenure system, property right over forest, immigration, resettlement programs), forest fire, inappropriate conservation approaches and lack of awareness (Hassen and Assen, 2018; Minta *et al.*, 2018; Kleemann *et al.*, 2017; Siraj *et al.*, 2018; Ariti *et al.*, 2015). The 1975 land proclamation of the socialist Derge regime confiscated all lands from the landlords and distributed to the landless which in turn caused a large deforestation for the purpose of agricultural expansion (Yeshaneh *et al.*, 2013). Similarly, Denboba (2005), reported that forest conversion in the Keffa zone is mainly driven by expansion of cultivated land and settlements as a result of population increase and socioeconomic changes. Other authors (Gashaw *et al.*, 2014; Kindu *et al.*, 2015) found that population growth, expansion of cultivated land and settlement were the top significant drivers of LULC changes in Ethiopia. Moreover, Hassen and Assen, (2018) revealed that there have been substantial LULC changes in Gelda catchment of Ethiopia, driven mainly by population pressure, institutional and policy factors. The study result is also consistent with the previous studies in other parts of Ethiopia where population pressure and expansion of agricultural crops are the major drivers of LULC changes (Hurni *et al*., 2005; Dessie and Kleman, 2007; Gebrelibanos and Assen, 2015; Yesuf *et al.,* 2015).

The implications of Land Use Land Cover changes in Gojeb River Catchment

Land degradation begins with the loss of vegetation cover. LULC is one of the factors that determines the rate of soil loss due to removal of vegetation cover that exposing the land to soil erosion (Bewket, 2002; Denboba, 2005; Gebrelibanos and Assen, 2015). This process accelerates the creation of sheets, rills and gully erosions by reducing the protection of soil cover. Taking into account the highly erosive rainfall and rugged topography of the terrain in GRC, removal of forest cover will influence the hydrological processes and consequently increase the threat of soil erosion. Considering the observed LULC changes in cropland, shrubland and swamp, GRC could be prone to soil erosion. As a result, 56.4, 82.6, 84.7 and 76.6% of the total area of GRC in 1978, 1987, 2001 and 2015 respectively, was potentially exposed to soil erosion (Table 4 and 5). While, taking both forest and woodland as vegetation cover, 43.6, 17.5, 15.3 and 23.4% of the total area of GRC in 1978, 1987, 2001 and 2015 respectively, was not potentially susceptible to soil erosion (Table 5). Therefore, the expansion of cropland could increase the susceptibility of soils to erosion. Particularly, soil erosion would be more serious with the transformation of the steep mountain forestland, shrubland and woodland covers into cropland. For instance, Denboba (2005), in Shomba sub-catchment, reported that the estimated mean annual rate of soil erosion was 13.5 t $ha^{-1}yr^{-1}$ as a result of LULC change. In Ethiopia, LULC change has a great influence on biodiversity losses and ecosystems functioning (Denboba, 2005; Siraj *et al.*, 2018) and hydrological processes and reservoir sedimentation that shortening the life span of Hydropower Reservoirs (Bewket and Sterk, 2005; Welde and Gebremariam, 2017; Woldesenbet *et al.*, 2017). Hence, in the GRC, the loss of forest cover as the expense of cropland could have an obvious implication of soil erosion which in turn causes sedimentation of the subsequent Gibe III hydropower reservoir. Therefore, it is essential to prioritize and design environmentally friendly watershed management strategies and approaches so that the whole catchment can be holistically viewed and managed.

Conclusion

The study found that the Gojeb River Catchment has undergone significant LULC alterations during the study periods. The major changes were being reduction in areas under vegetation cover and expansion of croplands. The LULC change matrix results revealed that about 54, 41.75 and 49.86% of the study catchment has undergone alteration in the first (1978-1987), second (1987-2001) and third (2001-2015) study period, respectively. Over the study period, cropland gained about 160,736.08 ha (4344.22 ha/annum) and increased at the rate of 31.64, 19.81, and *13.13% during* the first, second and third periods, respectively. On the contrary, other LULC classes showed reductions. The maximum loss of forest cover was 81,270.14 ha which decreased at a rate of 9,030.02 ha per annum between 1978 and 1987 followed by losses during 1987 to 2001. Forestlands have undergone reductions of about an area of 68,099.91 ha with an annual loss of 1,840.54 ha for the entire study period. The conversion of forestlands, woodlands, shrublands and swamp to cropland might be mainly associated with the land demand for crop production to satisfy the food demand of increasing human population, and loss of land productivity.

In the GRC, the study revealed that expansions of cropland at the cost of other LULC classes, population growth and government induced settlements which result in socio-economic transformation during 1984/85 drought and famine were the major drivers of LULC changes. The need for production of food crops, timber and firewood and settlement largely necessitated the conversion and transformation of LULC changes. Population pressure on the land resources increased the demand for croplands, wood extraction for timber, and construction materials, deforestation for household energy consumption and income sources. In addition to its impact on the surrounding ecosystem functions and community livelihood, the LULC changes might have also implication on the life of Gibe III hydropower reservoir. Therefore, integrated and sustainable watershed management which could be achieved by improved sustainable land management practices, such as soil and water conservation technologies, have paramount importance to reverse land degradation. Besides, improved agricultural inputs could increase agricultural production and lessen cropland expansions. Promoting the development of non-agricultural sectors and easing population pressure on land, provision of modern alternative sources of energy are critical for sustainable land use. Generally, the LULC change detection analysis using remote sensing and GIS could provide useful baseline information to understand the spatiotemporal patterns of LU transitions and major contributors of LULC changes, thereby sustainable watershed management planning is possible. An integrated watershed management approach, whereby the whole of the catchment can be holistically viewed and managed, would be critical. Furthermore, it is imperative to examine and quantify the impact of LULC changes on soil erosion, hydrological processes and climate change.

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