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Research Article

The role of soil, water and forest conservation on vegetation cover and landscape greenness in degraded areas of upper Blue Nile

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Abstract

Recently, large-scale soil, water, and forest conservation/protection practices have been implemented in Ethiopia. This study aimed to evaluate the impact of soil, water, and forest conservation/protection on vegetation cover and landscape greenness in the Gumara watershed. Landsat satellite imageries were used to analyze the changes using land use/cover and net difference vegetation index (NDVI) and its differencing methods. Over the period 1995-2017, forestland and shrub-woodland covers increased by 48.4% (2.8-4.2%) and 8.3% (20.2-21.9%), respectively. Similarly, the NDVI result showed high improvements in landscape greenness and vegetation density. A 13.5% of the watershed area experienced a significant increase, of which 61.4% was observed on forest and shrub-woodland covers. The watershed area covered by very high (NDVI>0.4) and high (NDVI 0.3-0.4) vegetation density classes were increased by 189.2 and 145.5%, respectively. Upon the increasing human pressure and related problems, the observed improvement of vegetation cover and landscape greenness show the positive impact of soil, water, and forest conservation/protection practices done for the last two decades. Therefore, strengthening the current efforts and investing more in sustainable and evidence/priority-based soil, water, and forest conservation measures that are ecologically friendly with diversified livelihood importance can bring a more effective result of land rehabilitation.

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Introduction

Land use/cover changes become the main components of the global change of the environment and depict the impact of human activities on the natural environment (Zhao et al., 2017). It has been a continuous process since human existence (Zeleke and Hurni, 2001; Hishe et al., 2020) and has become a global concern due to its drastic implications on livelihoods(Bewket, 2002). However, the alarming increase in population escalated the rate of change of LUC because of the high demand for agricultural land (Hishe et al., 2020) and the need for forest resources for day-to-day necessities in both rural and urban communities. Population growth in conjunction with other processes is leading to much more rapid deterioration of natural resources in developing nations (Bewket, 2002; Fisseha et al., 2011). The growth of the population raises the need for cultivable land, energy, and grazing land, mainly in the land resource-dependent developing countries like Ethiopia. This resulted in a drastic change of LUC in the last four to five decades in the country (Zeleke and Hurni, 2001; Bewket and Abebe, 2013; Demissie et al., 2017). Almost all of these studies reported a continuously high reduction of forestland and grassland mostly encroached by croplands. On the contrary, despite the reduction of natural vegetation, manmade forest cover showed an increasing trend in the country (Fisseha et al., 2011; Yalew et al., 2016).

Different proximate and underlying causes that drive the LUC change have been identified, including cropland expansion, infrastructural expansion (roads, homesteads, urban areas), and greater demand for natural resources (construction, fire-wood, sources of income, etc.) (Geist and Lambin, 2002; Belay and Mengistu, 2019). Forest degradation in Ethiopia was occurred mainly due to charcoal and wood making, conversion of land to cultivated land, and overgrazing (Zeleke and Hurni, 2001; Bewket and Abebe, 2013), which are primarily related to high population pressure placing pressure on available resources. As a result, large portions of available forest areas, bush lands, and grassland have been converted to crop and settlement landscapes (Hishe et al., 2020).

Land use/cover conversion causes an unparalleled change in the environmental processes and the ecosystem, extending from local to global scales (Yalew et al., 2016). It causes a significant effect on hydrology, land degradation, climate change, biodiversity, and ecosystem services (Bewket and Abebe, 2013; Zhao et al., 2017), the microclimate, and water table (Hishe et al., 2020). Since, the main cause of soil erosion is land cover degradation (Adimassu et al., 2014; Ganasri and Ramesh, 2016), the alarming rate of natural land cover conversion can cause soil erosion and land degradation. This is because the pattern of LUC conversion is from erosion-resistant natural cover to the most vulnerable cultivated, bare and settlement areas. Fisseha et al. (2011) indicated that due to land degradation some proportion of cultivated and grazing lands have already been severely degraded to the level that could not support any vegetation growth.

The Upper Blue Nile basin is among the most diverse and very important (Hurni et al., 2005; Yalew et al., 2016) but, recently, the most degraded river basin in Ethiopia (Bewket, 2002). Gojjam in which is nearly totally drained by the Blue Nile River has been endowed with beautiful landscapes and good potential soils but becoming alarmingly threatened and endangered by land degradation (Zeleke and Hurni, 2001). The same study indicated that from 1957-1995, 3% of the land had been completely degraded. Similarly, 3.3% of the cultivated and grazing lands that were degraded severely are converted to barren land (Fisseha et al., 2011). In the area, steep slope lands (>30%) are being cultivated without conservation measures (Zeleke and Hurni, 2001).

These problems recently initiated the government to restore the degraded landscapes and reduce further damages by using different measures through free labor community mass-mobilization and other local-level conservation strategies in the Gumara watershed and Ethiopia at large. Some of them are physical soil and water conservation structures (such as soil and stone bunds, half-moon, percolation ditches, micro-basin, check dams) supported by grass strips and plantations, biological (plantation of both native and non-native trees in private and communal lands, area closure), forest conservation/protection, and other watershed management practices. However, the extent to which these efforts contributed to vegetation cover and landscape greenness are not sufficiently assessed.

Several studies were conducted on LUC change in Ethiopia, but little information is available concerning the impact of conservation/protection measures on LUC change (Haregeweyn et al., 2012). Limited studies have observed significant effects of conservation practices (Haregeweyn et al., 2012; Hishe et al., 2017), although most of them are centered in the rainfall scarce areas of Ethiopia. The case in the northwestern highlands is rare, which demands evaluating their impacts in the sub-humid/humid agro-ecologies. Therefore, site-specific evaluation of the impacts of conservation measures is vital to learn lessons and for sustainable watershed management and rehabilitation. In this regard, the objective of the study was to evaluate the impacts of soil, water, and forest conservation/protection practices on vegetation cover and landscape greenness in the sub-humid Gumara watershed, upper Blue Nile basin.

Materials and Methods

The study area

The study area (Gumara watershed) is located in Dega Damot district, west Gojjam administrative zone of Amhara region, Northwestern Ethiopia (Figure1). The watershed is geographically located at 10° 50' 15" to 11° 0' 40" N latitude and 37° 30' 40" to 37° 41' 22" E longitude. It covers an area of 204.4 km^2. Gumara is among the headwater streams of the Upper Blue Nile Basin that originates from the northwestern continuation of the Choke Mountain in Gojjam. The watershed has elevations between 1864 and 3235 m a.s.l. It is part of the northern highland dominated by the Oligo-Miocene volcanic trap basalt rock covered by the early tertiary volcanoes and part of the Cenozoic volcanic and sedimentary rock formations (Abbate et al., 2015). Typical soilscovering the watershed includes haplic luvisols, haplic nitisols, and haplic alisols (MoWR, 1998). Haplic alisols cover the dominant portion (43.76%) of the watershed. The long-term (1997-2017) mean annual rainfall depth of the area was approximately 2000 mm, received in a unimodal pattern. The rainfall situation shows high seasonal variability, with over 75% of the rainfall occurring between May and September. The annual average temperature is 16.6°C, ranging between a minimum value of 9°C in January and a maximum value of 25.8°C in April.

Major land use/covers include cultivated land, forestland, shrub-woodland, grazing land, and bare land. However, the watershed is an agricultural watershed, in which cultivated land and grazing land covers about 58.09% and 6.5%, respectively (Belayneh et al., 2019). The vegetation cover of the area diminishing with time but still *asta* (*Erica Arborea*), *kosso* (*Hygenia Abyssinica*), *woira* (*Oliva African*), *girar* (*Acacia Abyssinica*), *tid* (*Juniper*), *bahirzaf* (*Eucalyptus tree)*, and other trees are found in the watershed. Subsistence agriculture, in the form of a mixed crop and livestock system, is the main source of livelihood for about approximately 90% of the watershed community. The population density of the area was 184 in 2007 (Central Statistical Authority [CSA], 2007).

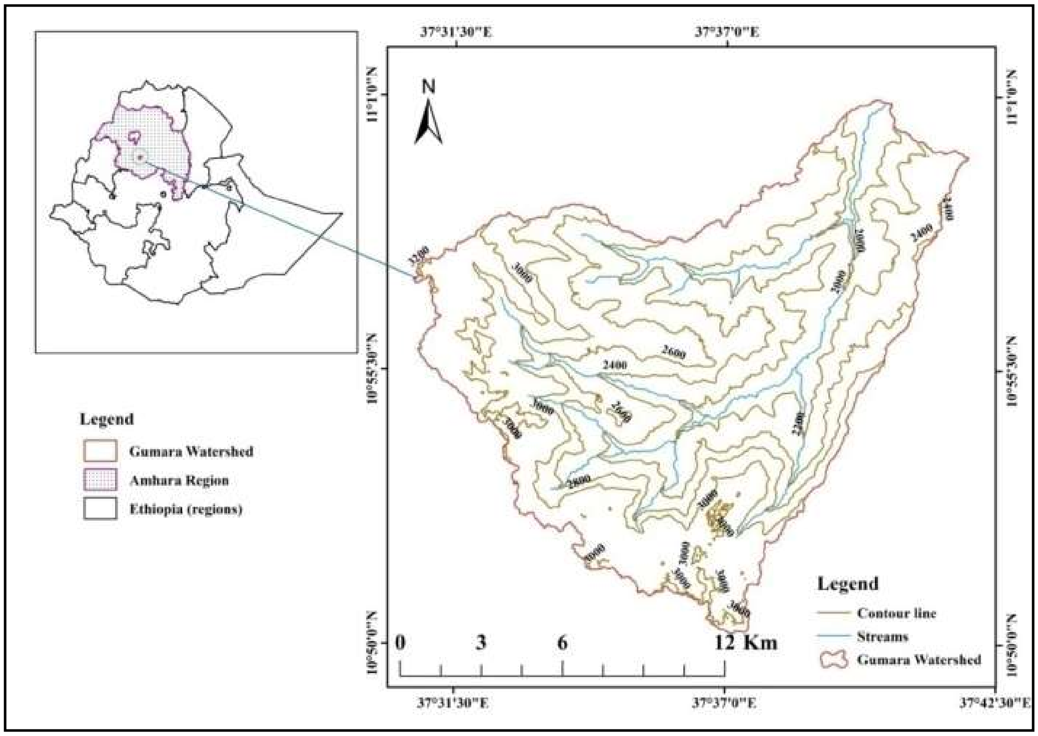

Figure1.Location map of Gumara watershed, northwestern Ethiopia.

Data used

Two Landsat imageries of Thematic Mapper (TM) and Operational Land Imager (OLI) of 1995 and 2017 acquired during the dry season, cloud-free imageries were downloaded from the USGS earth explorer website (http://earthexplorer.usgs.gov) with a path of 169 and raw of 052 (Table 1). Imageries acquired in February for both reference years were purposively selected; because it is cloud-free and captured after crop harvest.

Image pre-processing

Prior to the actual LUC classification analysis, different pre-processing and image enhancements were performed to make the imagery clear and simple for classification. Pre-processing of the satellite imageries is vital to establish a more direct association between the then biophysical phenomena with the acquired data (Abd El-Kawy et al., 2011). All satellite imageries and the ASTER GDEM were geo-referenced using 1:50, 000 topo-sheet map and projected to Universal Transverse Mercator (UTM) zone 37 and World Geodetic System (WGS_84). Topographic correction is the removal/reduction of topographic effects (multi-scale) in satellite imageries (Bishop and Colby, 2011). The topographical condition of the area affects surface irradiance. The study watershed represents a complex terrain including a very steep slope (about 20% of the land has a slope >45%). Therefore, the non-Lambertian model of the C-correction method, which is recommended for undulating topography (Teillet et al., 1982), was applied using a topographic correction toolbox developed (Lima and Ferreira, 2018).

Table 1. Details of the data used for LUC analysis.

Satellite (sensor)	Path/raw	Acquisition date	Source	Spatial resolution
Landsat 8 (OLI)	169/052	02/02/2017	USGS	30 m
Landsat 5 (TM)	169/052	06/02/1995	USGS	30 m

The C-correction is the most commonly used, effective, and recommended method for topographic correction of multispectral satellite imagery (Hantson and Chuvieco, 2011). Besides, histogram equalization, haze reduction, noise reduction, mozaiking, subsetting, re-sampling, and layer stacking were performed.

Supervised image classification

Before image classification, a reconnaissance survey was conducted, and preliminary information about major LUCs in the watershed for both the current and past were collected from the local elderly farmers. Depending on the survey and the researcher's experience of the area, six LUC categories were identified and described (Figure 2). The LUC categories include forestland (FL), shrub-woodland (SWL), cultivated land (CL), grassland (GL), bare land (BL), and settlement area (SA). A supervised classification method was employed using the maximum likelihood algorithm procedure for both reference years. The imagery classification for 1995 was supervised using training points extracted from 2001 high-resolution Google Earth® Pro imageries and elderly farmers' interviews. Signatures for 2017 were generated from ground truth data collected from the field using GARMIN VISTA HCx handheld GPS ±3 m spatial resolution in 2018. Although there is no rule of thumb or universally accepted uniform sample size determination for LUC classification, a minimum sample size of 50 (for each LUC category) is recommended for classifications with less than 12 categories (Congalton and Green, 2009). Similarly, for accuracy assessment, 30 reference points for each LUC category (Congalton and Green, 2009) were collected to gather with that of the training points for the signature file. Accordingly, for this study, a total of 480 training points were collected for each reference year, of which 180 were used for accuracy assessment.

Table 2. Land use/cover categories and their descriptions.

LUC category	**Description**
Forestland (FL)	It comprises an area covered by dense and tall trees, both natural vegetation and manmade developed/dense plantations.
Shrub-woodland (SWL)	It includes land covered by scattered trees, short trees, shrubs, bushes, and less developed plantations.
Cultivated land (CL)	Includes areas used for annual and perennial crops, fallow lands, and small-scale irrigation lands.
Grassland (GL)	An area covered with grasses and used for cattle grazing including degraded partially wetlands.
Settlement area (SA)	Land used by urban settlements, schools, health centers, and rural homesteads.
Barren land (BL)	It consists of stony and rocky areas with no grass or vegetation cover and degraded wide gullies, wide streambeds.

The accuracy of the classified LUC maps was evaluated using the error (confusion) matrix and Kappa coefficient. The confusion matrix evaluates the overall and individual LUC classification accuracy of the classified image, whereas the Kappa coefficient determines the agreement between the classified image and the reference data. Kappa coefficient is appropriate for accuracy assessment if a stratified random sampling method is used for the collection of training points (Senseman et al., 1995). To detect LUC changes/conversion patterns (from-to) of the period 1995-2017 between pre-defined categories, a change matrix analysis was performed. The conversion from one LUC to others for the period 1995-2017 analyzed. The analysis was performed using ERDAS® 9.2 and ArcGIS® 10.3.

Normalized difference vegetation index analysis

Normalized difference vegetation index (NDVI) is a numerical expression of live green vegetation in an area using visible and near-infrared bands of the electromagnetic spectrum. The NDVI method gives the best results of vegetation change detection and changes in vegetation growth (Gandhi et al.,2015). High absorbance of the visible light and reflectance of NIR implies healthy vegetation (Hishe et al., 2017) and vise versa. The NDVI was computed by the visible red reflectance (band 3 for TM and band 4 for OLI) and near-infrared reflectance (band 4 for TM and band 5 for OLI) of the satellite imagery bands (Eq. 1). The NDVI value extends from -1 (water bodies, exposed rocks, snow, etc.) to 1 (very dense vegetation). It can be expressed as:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \qquad \text{Eq. 1}$$

Once the NDVI map for the two years was generated, changes were detected using three methods. 1) the NDVI maps of both reference years reclassified using recommended vegetation greenness/density classes (Siraw et al., 2020), and increase and decreases in each category can be identified (% and ha). 2) The vegetation greenness change detection for the period 1995-2017 was analyzed using the NDVI differencing (dNDVI) technique following the procedures described in Mancino et al. (2014). In this regard, the

1995 NDVI map was subtracted from the 2017 NDVI map on a pixel-by-pixel basis to compute the dNDVI image of 1995 and 2017 (Eq. 2). This gives values extending between -1 and 1.

$$\mathrm{dNDVI} = \mathrm{NDVI}_{2017} - \mathrm{NDVI}_{1995} \qquad \text{Eq. 2}$$

It is expected that negative and positive values in the dNDVI pixels imply reductions and expansion of vegetation cover, but re-computing the pixel values using mean and standard deviation based threshold value is a very important step to identify the real changes in vegetation (Pu et al.,2008; Mancino et al., 2014). Thresholds were determined following the technique described in Mancino et al. (2014).

$(\mathrm{dNDVI} > \mu + \mathrm{n}\delta)$, $(\mathrm{dNDVI} < \mu - \mathrm{n}\delta)$ and $(\mu - \mathrm{n}\delta < dNDVI < \mu + n\delta)$

Where μ is the mean of dNDVI pixels, and δ is the standard deviation, n is the range of dispersion around the mean (1, 1.5, and 2 were applied in different studies, but 1.5 gives a more accurate result (Mancino et al., 2014). Thus, 1.5 was used in this study.

The right tail $(\mathrm{dNDVI} > \mu + \mathrm{n}\delta)$, left tail $(\mathrm{dNDVI} < \mu - \mathrm{n}\delta)$, and middle $(\mu - \mathrm{n}\delta < dNDVI < \mu + n\delta)$ implies significant increase, significant decrease, and no-change of landscape greenness, respectively. Thus, the two tails indicate the real and significant changes. 3) The last method is the determination of the share of each pre-defined LUC category from the observed changes (increase or decrease, in ha and %). This can give an important result that determines which LUC category experienced greater reduction and increase. The general methodological framework used in this study is presented in Figure 2.

The interview technique

The image analysis results were supported by socioeconomic data collected using interview groups. Twenty-seven household heads were interviewed about LUCs, soil, water, and forest conservation/protection practices and related challenges. Farmers over the age of 45 years were selected using a snowball sampling method to better recall the past LUCs of the watershed. The snowball sampling method helps to select farmers who stayed a long time in the area, wise, believed to have better remembering ability on LUCs, its change, and SWC practices. The interview was also involved experienced staff members of the natural resources management unit (five members), kebele natural resources experts (three members), and agricultural professionals (three members).

Results and Discussion

Accuracy assessment

The producers and users accuracy, error (confusion) matrix, and Kappa coefficient analysis results of both 1995 and 2017 maps are presented in (Table 3). The result shows that the overall classification accuracy for 1995 and 2017 was 84.44 and 90.56%, respectively. This implies that the classification is acceptable for all reference years (Congalton and Green, 2009). Similarly, the corresponding Kappa coefficient result was 0.81, and 0.89 indicating a good agreement between the classified image and reference data for 1995 and 2017, respectively (Landis and Koch,1977).

Change of land use/cover over the period 1995-2017

The LUC map of the Gumara watershed for the years 1995 and 2017 was developed (Figure 2) and quantified (Table 4). In 1995, the dominant LUCs were cultivated land, shrub-woodland, and grasslands, representing an area of 55.8, 20.2, and 15.4%, respectively. The area of forest cover was very low (2.8%; 576.4 ha) in this reference year. A significant variation was observed over the period 1995-2017.

Table 3. Accuracy assessment result of 1995 and 2017 LUC maps.

LUC classes	**1995 map**		**2017 map**	
	Producers accuracy	**User accuracy**	**Producers accuracy**	**User accuracy**
Forestland	86.67	96.30	90.00	100.00
Bare land	80.00	100.00	83.33	89.29
Grassland	86.67	76.47	90.00	96.43
Settlement area	73.33	100.00	93.33	100.00
Shrub-woodland	83.33	80.65	96.67	90.63
Cultivated land	96.67	70.73	90.00	72.97
Overall accuracy	84.44	84.44	90.56	90.56
Kappa statistics	0.81	0.81	0.89	0.89

The vegetation cover, which is mainly considered to constitute forestland, shrub-woodland, and grassland, represented 38.4% of the watershed area in 1995. The value decreased to 32.6% in 2017. The observed reduction in vegetation cover can be primarily explained by the rapid rate of decrease of grasslands; reduced by more than half (-59%) within this period. However, the area covered by forest and shrub-woodlands showed improvements. For instance, shrub-woodland and forestland increased by 8.3%

(4136-4480 ha) and 48.4% (576-855 ha) by a rate of 0.06 and 0.08 ha km^{-2} yr^{-1}, respectively in the period 1995-2017. Grasslands are the most vulnerable land, which registered an increasing rate of reduction and the main area of expansion for other land uses. The observed increase in forest cover, particularly from 1995 to 2017 is the result of natural resources conservation/protection practices implemented in the watershed. The existing natural forests have been expanding in their spatial extent and canopy cover because of conservation/protection practices. The local natural resources experts and developmental agents, together with the local community, have agreed to protect communal forests from various human activities such as not cutting a tree for charcoal, wood making, construction, and other purposes. A motto called "cutting a tree is just like killing a man", which was used as a strategy to conserve/protect forest resources and to make the community consciousness about the significance of forest conservation, has been deeply internalized by the local community. As a result, currently, deforestation practices on communal forests are becoming minimal. The animal and human interference with natural vegetation have been limited. The households used their private plantations for the day-to-day needs of forest products.

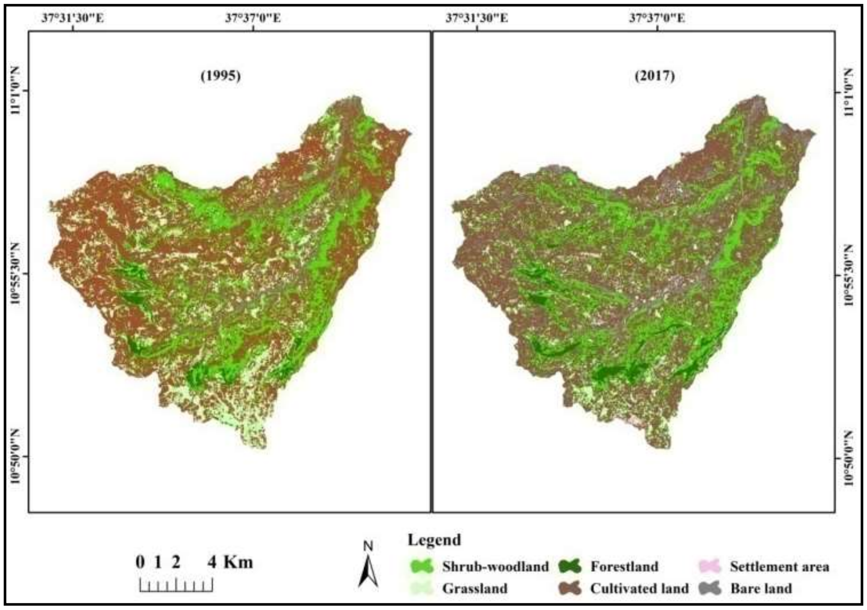

Figure 2. Land use/cover map of Gumara watershed for the years 1995 and 2017.

Area ex-closure practice with no animal and human interference also contributed to the increased vegetation cover by improving shrub-woodland regeneration and increasing its density and health. Indeed, the plantation of trees such as the Eucalyptus tree, Juniperus tree, and different native tree plantations have greater contributions. Different stakeholders such as the local government-led community plantations, school-led plantations, and small-scale farmers' plantations in their plot of land are among the main contributors for improved vegetation cover. On the other hand, new plantation and protection of existing trees on the right and left sides of gullies to control and minimize gully erosion can also share a significant proportion of vegetation cover. Farmers' interview groups also indicated that these practices contributed to local ecological restoration in the watershed.

Table 4. Area coverage of LUCs in 1995 and 2017 and the change in the period 1995-2017.

LUC	Area coverage				Change over the period		
	1995		2017		1995-2017		
	ha	%	ha	%	ha	%	rate (ha km^{-2} yr^{-1})
Cultivated land	11399	55.8	11862	58.0	462.7	4.1	0.10
Forestland	576.4	2.8	855.3	4.2	278.9	48.4	0.06
Bare land	1071.0	5.2	1330.7	6.5	259.7	24.2	0.06
Grassland	3148.7	15.4	1327.6	6.5	-1821.2	-57.8	-0.41
Settlement area	105.2	0.5	580.7	2.8	475.5	451.9	0.11
Shrub-woodland	4136.7	20.2	4480.7	21.9	344.1	8.3	0.08

The findings of this study are in agreement with similar studies conducted in different watersheds treated with conservation activities. Although most research findings showed alarming decreases in forest cover since the 1950s (Zeleke and Hurni, 2001; Fisseha et al., 2011), some reported improvements even starting from the 1960s and 1970s. For instance, Bewket (2002) documented a persistent increase in forest cover over the period 1957-1998, even if the rate of change was comparatively low. Watershed management practices resulted in a significant increase of plantations and ex-closures by 177 and 135% in the Enabered watershed over a short period 2004-2009 and >100% between 2000 and 2006 in the Mai Zeg-Zeg watershed, in northern Ethiopia (Haregeweyn et al., 2012).

Cultivated land showed relatively modest/slow increase (4.1%) by 0.1 ha km^{-2} yr^{-1} rate (Table 4). Unlike the alarming increase in cropland observed in the 1950s to 1990s, such a modest increase observed recently might be because of soil, water, and forest conservation/protection measures. Similar research results in different parts of Ethiopia relate these to the positive effect of soil, water, and forest conservation practices (Nyssen et al., 2009; Hishe et al., 2017; Belayneh et al., 2020). Some others argue that it is becoming slow because almost all the potential areas have already been cultivated and the remaining are not suitable for cultivation (Moges et al., 2020; Zeleke and Hurni, 2001).

The observed increase in bare land was due to degradation of cultivated and grazing lands and expansion of streams and gullies. Further, the little attention given to rehabilitate the already degraded areas was a very important factor for its expansion than its rehabilitation. Farmers' interview groups stressed that the land once degraded and out of production was neglected even from the SWC campaign works. Although minimizing the vulnerability of potentially productive areas is equally important, rehabilitation/reversing the already degraded landscape is among the main targets of conservation programs. The significant increase in the barren land in this study agreed with the result of Zeleke and Hurni (2001), who found a rise of bare land from 0.1% in 1957 to 3% in 1995 and from 0.2 to 2.7 between 1995 and 2015 in the Tata watershed (Siraw et al., 2020).

Land use/cover change patterns over the period 1995-2017

The period 1995-2017 is dominantly characterized by the transition from grassland and shrub-woodland to cultivated land, from cultivated, grassland to shrub-woodland, and from shrub-woodland to forestland (Figure 3; Table 5). Cultivated land slightly increased mainly because of the conversion from grazing and shrub-woodland. The increase in cultivated land was realized due to the conversion of 8.2 and 6% of the grassland and shrub-woodland, respectively. On the other hand, 2.2% of the shrub-woodland was converted to forestland from 1995 to 2017. This is mainly due to the increase of canopy and density due to forest conservation with reduced human and animal interferences, area ex-closure, and plantations.

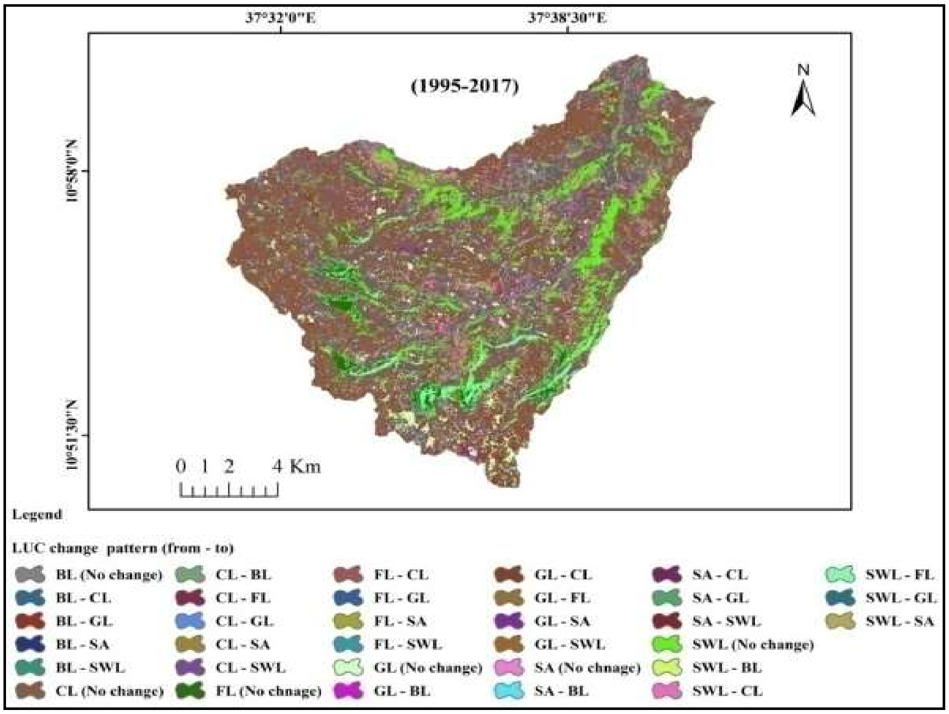

Figure3. Land use/cover conversion pattern over the period 1995-2017.

Table 5. A change matrix of LUC conversion pattern over the period 1995-2017.

	2017							
1995		**CL**	**FL**	**BL**	**GL**	**SA**	**SWL**	**Total**
	CL	40.5	0.1	4.2	2.1	1.5	7.3	55.7
	FL	0.1	1.7	-	-	-	0.9	2.7
	BL	3.0	-	1.5	0.1	0.2	0.4	5.2
	GL	8.2	0.1	0.6	3.8	0.5	2.3	15.5
	SA	0.3	-	-	-	0.1	0.2	0.6
	SWL	6.0	2.2	0.2	0.4	0.6	10.9	20.3
	Total	58.1	4.1	6.5	6.4	2.9	22	100

CL is cultivated land, FL is forestland, BL is bare land, GL is grassland, and SWL is shrub-woodland.

The dense forest once largely exposed to human interference and converted to sparse vegetation and shrub-woodlands has been re-vegetated to high density and canopy, which increases the total forest cover in the watershed. In 1995-2017, the area covered by forestland and shrub-woodland was increased from 23 to 26.1%, which is mainly explained by the conversion of 7.4% from cultivated land, and 2.4% from grassland. Forestland has been increased as a result of 2.2% of the shrub-woodland, 0.1% from grassland, and 0.1% from cultivated land. Within this period, 6% of the cultivated land, 2.2% of the forestland, 0.2% of the bare land, 0.4% of the grassland, and 0.6% of the settlement area were covered to shrub-woodlands. Further, 2.1% of the cultivated land and 0.4% of the shrub-woodland, and 0.1% of the bare land were converted to grassland. Considering the continuous increase of population that has a strong relationship with the high demand for cultivable land, energy, construction, and income generation, the observed improvement in vegetation cover implied the effect of soil, water, and forest conservation practiced over the period 1995-2017.

The implementation of conservation measures showed a slow expansion of cropland and increasing vegetation cover. Conversely, losses from total vegetation cover had reduced, though the conversion of grasslands to croplands contributes the greatest share of reductions in vegetation. The conversion of cultivated land to forestland might be attributed to plantation activities around homesteads and cover some proportion of the cultivated land by its canopies (Bewket, 2002). Although the increase of vegetation (mainly forest and shrub-woodlands) was higher, the reduction from vegetated land to non-vegetated land was also considerable. For instance, more than half of the grassland was converted to cropland, bare land, and settlement area constituting 8.2, 0.6, and 0.5%, respectively (Table 5). This is primarily attributed to the then high population pressure-driven uncontrolled expansion of cropland and overgrazing.

Vegetation greenness /density temporal variations

The NDVI map of 1995 and 2017 (Figure 4) and dNDVI map of the period 1995-2017 (Figure 5) showed the vegetation density/greenness and its change and presented in Tables 6 and 7. Positive and higher values indicate vegetation richness, but negative values and values close to zero imply non-vegetated areas. The NDVI values indicating vegetation density categories can be classified as very low (<0.1), low (0.1-0.2), medium (0.2-0.3), high (0.3-0.4), and very high (>0.4) (Siraw et al., 2020).

The greenness of vegetation coverage in 1995 was much lower than in 2017. In 1995, the lowest value was -0.04, and the highest value was 0.65, whereas in 2017, the lowest and highest values are -0.002 and 0.74, respectively. The lowest NDVI value showed a slight increase, and the highest value showed a significant increase (increased from 0.65 to 0.74). Further, the change in vegetation density/greenness categories between 1995 and 2017 showed significant changes; the highest proportion is constituted by positive changes (NDVI increase). For instance, the area covered by greater density and healthy green vegetation (>0.4) was 3.6 and 10.3% in 1995 and 2017, respectively. Similarly, 8.3 and 20.3% of the watershed area was covered by high-density green vegetation (0.3-0.4) in 1995 and 2017, respectively. On the other hand, the area covered by low vegetation density (0.1-0.2) decreased from 54.9% in 1995 to 21.4% in 2017, which shows a significant change of landscape greenness in the watershed.

Figure 5 and Table 7 presented the changes in the vegetation greenness in terms of significant increase, decrease, and no change, computed using dNDVI analysis. The result revealed that 13.5% of the watershed area showed an increase, and 11.6% experienced reduction while the remaining was considered to have no significant changes. These changes are summarized by LUC categories (Table 7). From the total land area showing a significant increase in NDVI, 15.2 and 46.2% were observed in the forest and shrub-woodlands. But, their corresponding shares from the reductions were 1.1 and 11.3%. On the other hand, 54.9, 15.4, and 11.7% of the area explained by the decrease were covered by cultivated land, bare land, and grassland, respectively. The results in this study are in line with the findings of Siraw et al. (2020), who reported an increasing trend of landscape greenness in the conserved Tija Baji watershed. The study findings strongly support the positive impacts of soil, water, and forest conservation/protection practices in the watershed. It brought a significant improvement in vegetation density/greenness and health.

The commitment and understanding of the community led by the local government have resulted in these improvements in the vegetation cover. The 34.2% share of cultivated land from increased NDVI values can be explained by the plantation of grass strips, plantation of trees on bunds, and increased healthiness of the vegetation in the agricultural landscapes because conservation measures can increase water infiltration and soil moisture. Water availability in the soil strongly determines green vegetation and NDVI as well (Gandhi et al., 2015). Watershed management practices increase groundwater availability for vegetation and help to grow healthy (Singh et al., 2013). Similarly, Nyssen et al. (2010) indicated that SWC practices increase water infiltration and groundwater recharge, which might be taken as among the possible reasons for increased vegetation greenness and density in the watershed. Management of degraded areas with SWC measures decreases runoff, increases water infiltration, increases soil moisture content, and finally improves the density of vegetation (Hishe et al., 2017).

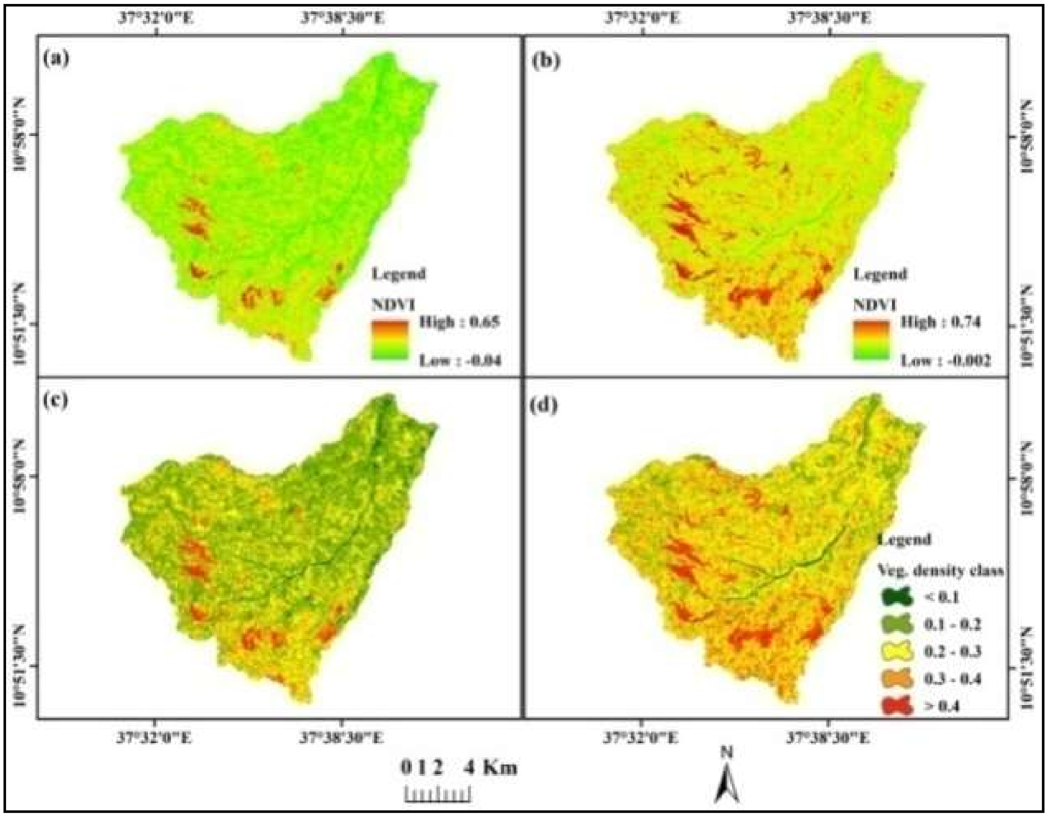

Figure 4. NDVI map of 1995 “a” and 2017 “b” and vegetation density map of 1995 “c” and 2017 “d”.

Table 6. Area coverage of vegetation greenness/density categories.

Vegetation density / greenness category	Area coverage				Change over the period	
	1995		2017		1995-2017	
	ha	%	ha	%	ha	%
<0.1 (Very low density)	592	2.9	177	0.9	-415	-70.1
0.1-0.2 (Low density)	11219	54.9	4477	21.9	-6742	-60.1
0.2-0.3 (Medium density)	6187	30.3	9503	46.5	3316	53.6
0.3-0.4 (High density)	1687	8.3	4141	20.3	2454	145.5
>0.4 (Very high density)	733	3.6	2121	10.4	1387	189.2

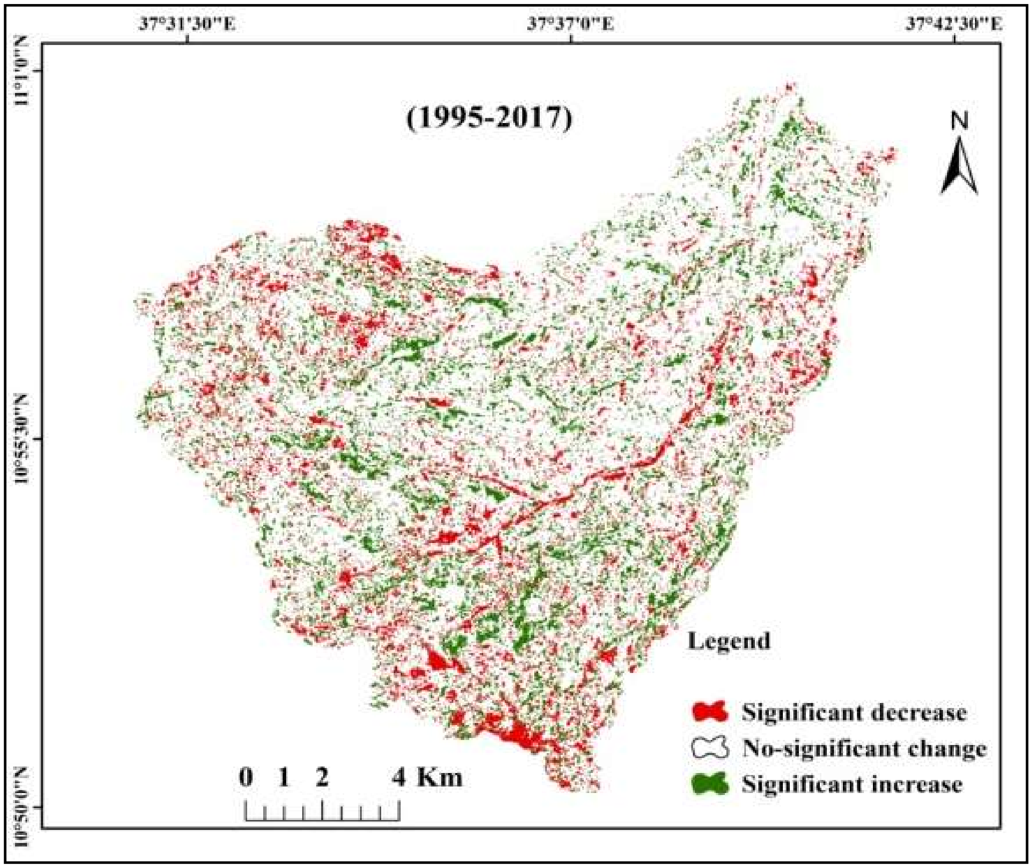

Figure5. The dNDVI map showing changes in vegetation greenness between 1995 and 2017.

Table 7. Vegetation greenness change detection results per LUC categories in the period 1995-2017.

LUC	Changes in NDVI									
	Increase				Decrease				No change	
	ha	%	Total		ha	%	Total		ha	%
			ha	%			ha	%		
Forestland	420.7	15.2	2778	13.5	25.4	1.1	2379	11.6	15262	75
Grassland	67	2.3			272	11.7				
Settlement area	48.8	1.8			129	5.4				
Shrub-woodland	1286	46.2			263	11.3				
Cultivated land	952.6	34.2			1278	54.9				
Bare land	-	-			362	15.4				

Conclusion

This study evaluated the effect of soil, water, and forest conservation/protection practices in improving the vegetation cover and greenness in the Gumara watershed, upper Blue Nile basin. Soil, water, and forest conservation practices have brought an important improvement in vegetation cover and landscape greenness. A significant increase of forest and shrub-woodland cover was observed over the period 1995-2017. The density of forests in some areas and greenness of the watershed landscape increased. In light of increasing population pressure and related high demand for natural resources, the observed increase in vegetation cover and landscape greenness shows the role of soil and water conservation/protection practices in landscape restoration. This implies that conservation initiatives can have a significant role to restore degraded landscapes and control/minimize further land degradation and soil erosion. Therefore, the government and other policymakers may use this as a good practice and scale-up in different degraded watersheds and areas that have similar agro-ecological settings. However, rehabilitation of already degraded lands has been minimal because of ignorance from the conservation activities. Therefore, the local administration, natural resources, and agricultural offices should revise their conservation plans to consider rehabilitation of the already degraded landscapes through suitable management measures. Besides, investing more efforts in sustainable watershed management measures that are ecologically friendly with diversified livelihood importance can bring a more effective result of ecological restoration.

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