Research Article
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Land use land cover changes on soil carbon stock in the Weshem Watershed, Ethiopia

Abstract

This improper land use extremely affected the Weshem Watershed in Ethiopia. Moreover, land use and land cover changes are linked with human intervention. The human intervention has caused disturbance of the natural ecosystem and decline of soil organic matter (SOM) and soil carbon stock. To under these changes we focused on the effects of the land use/cover changes, on soil carbon stock of the Agricultural land (A), forestland (F), and open grazing land (G) in the Weshem Watershed, Ethiopia over the three decades period of 2001, 2009 and 2017. Using integrated use of Remote Sensing (RS) and Geographic Information System (GIS).Soil samples were taken from each land use from 0-15 cm and 15-30 cm soil depths. Soils physicochemical were determined using standard laboratory procedures. The result showed that from 2001-2017 years forestland area showed an increasing trend as compared the agriculture and open grazing lands. The SOCst in forestland was higher than both agriculture and open grazing lands. Total organic matter and CEC were high and the soil bulk density was low in forestland as compared to other land use types. The highest soil SOCst (9.99 Mg ha^{-1}) value was recorded in forest-to-forest land use changes, and low value of SOCst (5.78 Mg ha^{-1}) was obtained in agriculture land. The lowest SOCst value was in land use changes from agriculture to agriculture.

Keywords: land use changes, soil carbon stock, land utilization, techniques, bulk density, land cover

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Introduction

Land use changes can contribute to soil degradation and deterioration of soil physical and chemical properties.[1] The changes may decrease in vegetation cover and disturbance of the natural ecosystem decline of soil organic matter (SOM), and plant nutrient.[2] Particularly, forest cover change to cultivated land decreased soil fertility, increased rates of erosion and loss of soil organic matter and nutrients.[3] In natural forest and protected forestland, SOC could be high as compared to other land uses.[4]

At global scale carbon cycle, controls soil fertility, soil structure, and water-holding capacity, reducing soil erosion, and enhancing crop productivity. Land use and land cover dynamics are affected by human actions, which results in decline of available water, soil, vegetation and animal feed at landscape level. Carbon in most soils is stored in the form of soil organic matter, composed of decaying plant, animal, fungal and bacterial matter. Soil organic carbon is the largest terrestrial pool affected by temperature, moisture, and biota. It comes to equilibrium with time when carbon inputs and environmental factors are relatively stable. SOCst is a source of energy for microorganisms, and strongly influences soil physical, chemical, and biological characteristics.

Land use changes have remarkable effects on soil properties. Land use changes from forest cover to cultivated land hinders addition of litter, that increase rates of erosion, loss of soil organic matter and plant nutrient. source of carbon emission to the atmosphere are burning of fossil fuels, land use and land cover change. Notably, SOC increases soil aggregate stability by increasing cohesion of aggregates, which reduces the loss of fine soil particles, and land use changes can accelerate SOCst loss through erosion or vegetation removal. Main objective of this study is to assess the effects of the land use/cover changes on soil carbon stock of the Agricultural land (A), forestland (F) and open grazing land (G) in the Weshem Watershed, Ethiopia over the three decades period of 2001, 2009 and 2017 by integrated use of Remote Sensing (RS) and Geographic Information System (GIS).

Materials and methods

Weshem Watershed is located about 360 km to the Ethiopia capital city of Addis Ababa, Ethiopia (Figure 1). The mean annual temperature ranges from 13.8°C to 20.1°C and the mean annual rainfall varies from 1200mm to 1800mm. The common land use system in the watershed mixed farming system. The dominant soil types of the Weshem Watershed are Eutric Vertisol and Lithitic Leptsol. To evaluate SOCst 18 soil samples were taken from 1m* ($1m^2$) quadrant randomly from each land use types from 0-15 cm, 15-30 cm soil depth. Each depth aggregated and pooled into a single composite sample to represent the sample quadrant. Approximately, 1 kg of composite soil samples were air-dried at room temperature (25°C) was put into plastic bags labeled and taken to a soil laboratory for physical and chemical analysis, soil bulk density was sampled with core sampler and determined by Black and Hertage method (1986). Soil pH was measured in an aqueous soil extract in distilled water (1:2.5 soil: water) using a pH meter (glass -calomel combination electrode) and Electrical Conductivity (EC) were measured in the extract using a conductivity meter as described in.[5] Cation Exchangeable Capacity cmol/kg soil was estimated using a titrimetric method by distillation of ammonia that displaced by sodium.[6] Soil organic carbon was determined according to the Walkley and Black method.[7]

Soil organic carbon stock pool was calculated using the formula Pearson et al.,[8] formula:

$$SOC = \%C * D * BD \quad \text{(Equation 1)}$$

Where, SOC = Soil Organic Carbon [Mg ha^{-1}

BD = Bulk Density (g/cm^3)

D = Depth of the Soil Sample (cm) %

C = Carbon Concentration [%]

Calculation of Bulk Density and carbon concentration was calculated by the following equation Pearson et al.[8]

$$BD\ sample = (ODW - RF) / CV \quad \text{(Equation 2)}$$

Where:

BD sample= Bulk density (g/cm^3)

ODW = Oven dry mass, total sample in grams

CV = Core volume in cm^3

RF = Mass of coarse fragments (> 2 mm) in grams

arbon concentration (percentage) was calculated by the following equation

$$C = (amount\ of\ solute) / (amount\ of\ solution) \quad \text{(Equation 3)}$$

For this study three dominant land use types, i.e. Agricultural land (A), forestland (F) and open grazing land (G) of Weshem Watershed with different land cover/land use changes were selected in a systematic way. Taking 2001 as a reference year for each land use type, the change options were considered. Those LULC changes was from A to A, A to F, A to G, F to F, F to A, F to G, G to G, G to F, and G to A. Landsat imagery data (3m resolution) Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) were downloaded from http://glovis.usgs.gov, where free Landsat image was available (Figure 1). A brief description of them is given in Table 1. ARC GIS10.3 software was use to stack and develop function in it to stack each layer to produce one single layer composing of each band. Then from the stacked band, the study area was extracted.

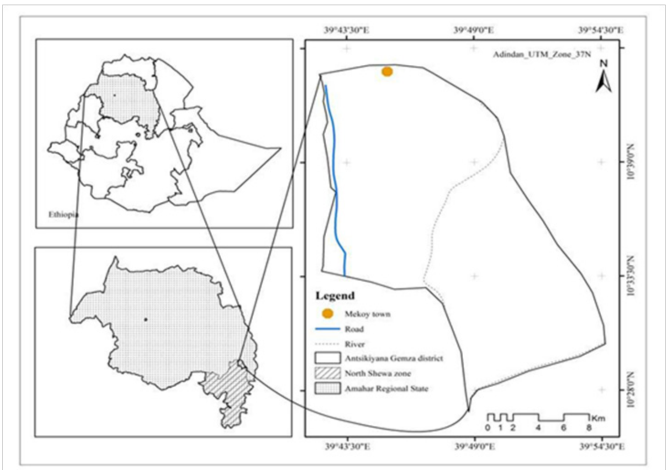

Figure 1 Study area map.

Landsat imagery data scenes of the selected study area were used to analyze the trends of land cover of three periods (2001, 2009, and 2017). The download satellite images were in tiff format and the layer stacking of bands was performed in the ArcGIS10.3. Mosaicking the layer stacked image tabs were masked and then clipped with the study area shape file. Image rectification was done to correct distortions resulting from the image acquisition process. All GIS data were projected to their respective Universal Transverse Mercator (UTM) projection system and datum of World Geodetic System (WGS, 1984), ensuring consistency between datasets during analysis. Landsat images were corrected for atmospheric, sensor, and an illumination variance through radiometric calibration procedures. Image classification for both years (2001, 2009, and 2017) was performed through supervised classification using the maximum likelihood classifier, which includes Selection of signature of different features (training sites) by digitization of selected area on the image. Selection of signature was based on field knowledge and existing literature and map. Obtained signatures act as an input for digital image classification. Based on giving signature the whole study area was classified into three classes. Based on the quality of results, training samples were refined until a satisfactory was obtained. Classified images were recorded to the respective classes (i.e. Forest, open grazing, and agricultural land).

The field Information regarding each land use type was collected through field observation and GPS coordinates. The images were analyzed by using ArcGIS 10.3. The areas which were converted from each of the classes to any of the other classes were then computed.[8] The rate of LULC changes was also calculated using the following equation:

$$Rate\ of change\ of\ LULC\ \left(ha^{-1}yr^{-1}\right) = (A - B) / C\ \ (3.1)$$

(Equation 4)

Where: A = Recent area of the LULC (ha)

B = Previous area of the LULC (ha), and

C = Time interval between A and B in years.

An accuracy classification, assessment was carried out to verify to what extent the produced classification was compatible with what actually exists on the ground. It involved the production of references (samples) that evaluated the product classification (Table 2). These references were produced from Google Earth and GPS points during fieldwork, which were independent of the ground truths used in the classification (Table 2). With this method, it was then be possible to find out the sources of errors. Cohen kappa within the error matric was used to determine the error encountered during classification of satellite images.[9]

Generally, accuracy assessment was very important measurement to determine how accurate the referenced data agreed with classified images of the remotely sensed data. For all maps, produce accuracy, user accuracy, and Kappa statistics were computed. Overall, all the three maps met the minimum 87% accuracy. For the study area supervised classification was carried out for the three images of (2001, 2009 and 2017), and on the training areas and the different false color composites of 4, 3, and 2 were identified. Then the change detection analysis was carried out by visual comparison of features and detailed quantitative approaches (Figure 2). Using the application of supervised image classification methods, three major land use and land cover types were identified (Table 2). For accuracy, Cohen Kappa within the error matric was used to determine the error encountered during classification of satellite images.[9]

Matrix of land use and land cover changes

The result image analysis, were presented in the form of a flow chart.

Data analysis

Soil data on soil organic carbon were subjected to Factorial design following the general linear model (GLM) procedure using SAS 9.4 version statistical software.

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Table 1 Landsat Data Used in Land Use and Land Cover Classification

Sensors/image	Study Area	Bands	Pixel Size/Ground Resolution (m)	Observation Date	Producer
Landsat 7 ETM+	Weshem Watershed	7	30*30	05-11-2001	USGS
				05-11-2009	
				04-11-2017	

Table 2 Description of Land Use and Land Cover Types Identified

Land use land cover classes.	LULC description
Agricultural land sorghum, and Teff), cash crop chat and horticultural crop	Areas allocated to rain fed cereal crop (such as corn, onion, tomato sweet potato) and other vegetation
Forest land	Areas covered with tall and dense trees forming a closed or nearly closed canopy (70–100 %) and without apparent or reported human impacts. This unit also includes under canopy trees mixed with low bushes and open areas. It was made to include human made plantation forest and natural forest Dominant tree species.
Open grassland	Formerly this land use took place where small grasses and shrubs are predominant.

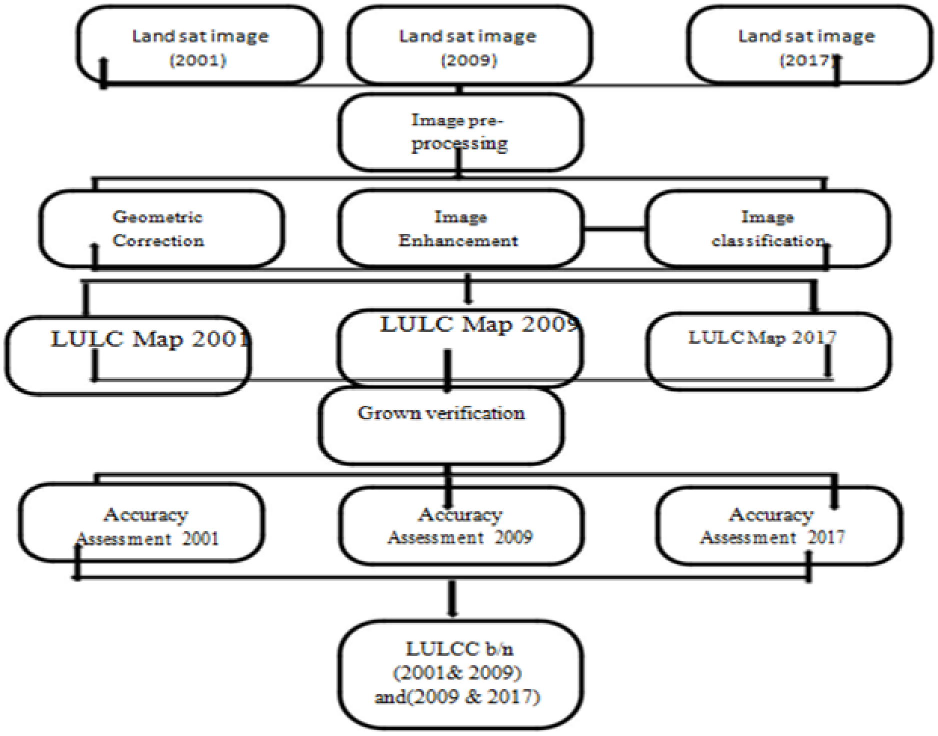

Figure 2 The General methodology for the Study of LULCC.

Results and discussion

Land use and land cover changes

Land cover are a physical asset if properly used by land users.[10–12] The magnitude or shifts of the land use changes are rapid and devastating unless properly managed by land users (Table 2). Conversion and modifying of one type of land use to another may result in loss of natural resources and agro biodiversity.[13–17] similarly; the data in Table 2 showed that drastic shift of land cover changes from 2001-2017 years in Weshem Watershed. Evidently, the conversion in the year 2009 for forestland was 569.29ha (60.54%), agricultural land 328.39ha (34.92%), open grazing lands 42.64 ha (4.51%) of the total watershed area. The increase forest area was due to the awareness created by international organizations working at the watershed, national extension agents. Farmers in the watershed also understood the environmental and economic importance of the forest resource for their livelihood. Ellis[18] in his study also confirmed farmers' awareness plays great role in natural resources management.

In contrast, the 2017 forest coverage was 466.9ha (49.65%) of the total watershed area. The second largest land cover about 360.20ha (38.31%) of the total watershed area belonged to agriculture, and the least coverage was for open grazing land had about 113.22ha (12.04%) the total watershed area (Table 3 & Figure 3). Expansion of cropland by unemployed young labor forces resulted in decline of grazing land. Improper land resources utilization imbalances the equilibrium of the existing land uses.[19,20] The data processed by GIS reveals that there is a considerable change in forest cover at a faster pace (Figure 2). Image analyses from 2001 to 2009 years showed that during these

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periods forest cover increased clearly at the rate of 60.53%. The main factor for fast restoration was due to Sustainable Land Management Project (SLMP) and World Vision Ethiopia afforestation activities that greatly affected the restoration of forest cover in the area (Table 4). However, the open or communal grazing and agricultural lands showed a decreasing trend of land use coverage. Alemu et al.,[13] confirmed also changes from one land cover type to another land use changes and centralized ownership by the Government hindered traditional land management, which should have been the precursor of modern land use systems. As a result, land degradation accelerated at rapid pace due to land use and land cover changes (LULC), climatic variation, and human activities in Woshem Watershed. Besides, the expansion of cultivated land figured on the satellite images in Weshem Watershed resulted from land conversion by employed youths, as means of survival. The other driving force to land use changes include population growth and pressure, soil mining, fragmented farm size and land tenure systems. Lambin and Meyfroidt, indicated also the demand for food for the growing population and over exploitation of the land resources are the driving forces for the dismissing forest cover and biodiversity degradation on the globe; this holds true for study too (Figure 4).

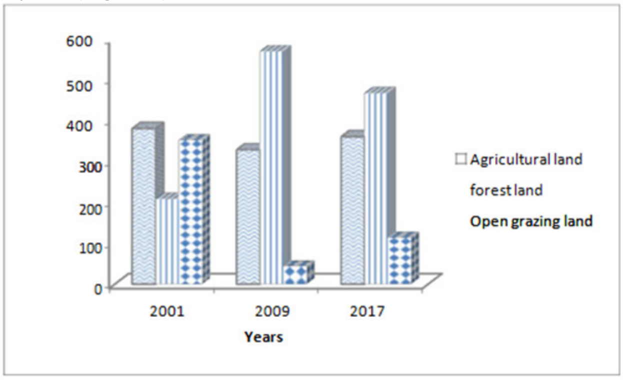

Figure 3 LULC of Weshem Watershed for the Years 2001, 2009, and 2017.

Table 3 Areas of LULC of Weshem Watershed for the Years 2001, 2009, and 2017

Land use type	2001		2009		2017	
	Area (ha)	(%)	Area (ha)	(%)	Area (ha)	(%)
Agricultural land	380.25	40.44	328.39	34.92	360.2	38.31
forest land	208.55	22.18	569.29	60.54	466.9	49.65
Open grazing land	351.52	37.38	42.64	4.53	113.22	12.04

Table 4 Rate of Changes in LULC Classes of Weshem Watershed

Types	2001 to 2009		2009 to 2017	
	ha/year	%/ year	ha/year	%/ ear
Forest	45.09	0.59	-12.79	-1.36
Agriculture Open	-6.48	-0.08	3.98	0.42
grazing	-38.61	-0.51	8.8	0.94

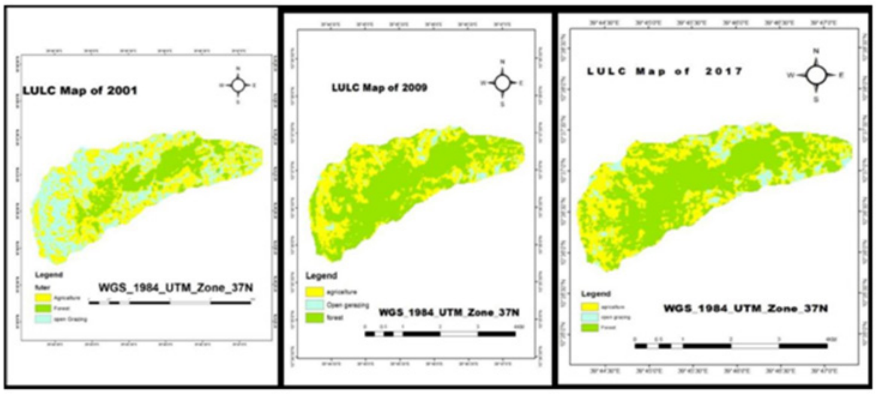

Figure 4 LULC Map of Weshem Watershed for the Years 2001, 2009, and 2017.

Holding the above view during 2001- 2009 forestland increased at the rate of 45.09ha/year (0.59%), while open grazing land decreased dramatically at the rate of 38.61ha/year (0.51%) and agricultural land decreased at the rate of 6.48ha/year (0.08%), respectively. In Contrast, rate of changes (Table 4) from 2009 to 2017, open grazing land increased by 8.8ha/year (0.94%) and agricultural land also increased by 3.98ha/year (0.42%), and forestland also decreased by 12.79ha/year (1.36%).

Soil physical and chemical changes

Soil bulk density varied from 1.10 g/cm^3 to 1.14 g/cm^3 in agricultural land, from 0.09g/cm^3 to 1.57g/cm^3 in open grazing land, and from 0.78g/cm^3 to 1.45 g/cm^3 , respectively (Table 5). The increase of bulk density in open grazing land as compared to the forest and agricultural land was attributed to the reduction of soil organic matter and from livestock trampling effect. Low value of bulk density improves soil structure, water and solute movement, and soil aeration.[21]

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Soil CEC is an important indicator of soil quality of different land uses.[3] In agreement to the above statement CEC was highest on forestland 25.5c mol(+)/kg) and followed by open grazing land (24.02c mol (+)/kg), whereas it was the lowest on agricultural land 15.5c mol(+)/kg (Table 5) which is closely related to high organic matter content of the forest soil (Table 5). As the soil carbon decreases the CEC decreases too, and the role it plays as a source of energy for microorganisms diminishes.[22] Similarly, the total soil carbon content (TOC) was high in forestland high as compared to agriculture and open grazing land uses. This was the result of soil carbon sequestration by forest cover and undisturbed and stable forest ecosystem. In addition to that, organic carbon content under forests soil increased as compared to the rest of land utilization types. Several authors[23–25] reported that removing vegetation cover reduces recycling of organic carbon to the soil.

Table 5 Some of the soil physical and chemical properties in three different land uses

Land use	Parameters				
	pH	EC	BD	OC	CEC
Forest	7.34a	0.25a	0.99a	3.12a	26a
Agriculture Open	7.17a	0.17a	0.01a	2.03b	26.02a
grazing	7.32a	0.23a	1.20a	2.38b	16a

Soil carbon stocks

Table 6 showed that the highest carbon stock was recorded in agriculture as compared to forestlands changes of SOC (8.99 Mg ha^{-1}). The second largest SOC (8.69Mg ha^{-1}) was observed in land use changes from agriculture to open grazing land, and the least value of SOCst was obtained in agriculture-to-agriculture land use changes (5.78 Mg ha^{-1}). The lowest carbon stock content in agricultural land might be due to low TOC and loss of soil structure by continues mono cropping and removal of crop residues.

Table 6 Soil organic carbon stock distribution with in land use and soil depth

Land use change (2001 - 2017 years)	soil depth (cm)	SOC stock (Mg ha^{-1})
Agriculture to agriculture	0-15	5.78
	15-30	3.27
Forest to agriculture	0-15	5.89
	15-30	2.58
Open grazing to agriculture	0-15	7.76
	15-30	2.78
Agriculture to forest	0-15	8.99
	15-30	4.12
Forest to forest	0-15	8.09
	15-30	6.51
Open grazing to forest	0-15	8.16
	15-30	4.21
Agriculture to open grazing	0-15	7.37
	15-30	4.15
Forest to open grazing	0-15	8.69
	15-30	4.55
Open grazing to open grazing	0-15	7.1
	15-30	5.28

Land use changes can accelerate SOC stock loss through erosion or vegetation conversion, and SOC in surface soil and subsoil can change after native forest is converted to agricultural systems.[26,27] Improper tillage practices may also impede soil carbon recycling and exposes surface soil to sunlight, which hinders and risks the lives of microorganisms that digest the organic matter in the soil carbon. This confirms that, conversion of land uses to different land utilization type and vegetation cover removal has negative impacts in SOCst (Table 7). Thus addressing the land cover and land use changes in different land utilization type may give a clue in soil carbon sequestration.[28]

Table 7 The effects of land use land cover change on soil carbon stock

Land use change (2001 - 2017 years)	Mean±SE	Min	Max
Agriculture to agriculture	4.52±1.77	3.27	5.78
Forest to agriculture	4.23±2.34	2.58	5.89
Open grazing to agriculture	5.27±3.52	2.78	7.76
Agriculture to forest	6.55±3.37	4.12	8.99
Forest to forest	7.3±1.11	6.51	8.09
Open grazing to forest	6.18±2.79	4.21	8.16
Agriculture to open grazing	5.76±2.27	4.15	7.37
Forest to open grazing	6.62±2.93	4.55	8.69
Open grazing to open grazing	6.19±1.29	5.28	7.1

Certainly, land use changes can influence soil properties.[29] Changes from forest cover any land utilization type removes addition of litter that decreases nutrient content of soils, increase rates of erosion, loss of soil organic matter.[13] The conversion of land use from forest to plantation or agriculture leads to the emission of carbon due to biomass loss.[30,31–42]

Conclusion

Based on the results obtained the employment of GIS and RS applications it can be concluded that the land cover/land use practices in the study area was altered significantly in 2001-2017 years. This study verified the application of Geospatial techniques in analyzing land use land cover change in Weshem Watershed with application of the various components of GIS and it was possible to generate the quantitative data on land cover classes and land uses. Thus the main conclusions concluded are: From 2001-2017 years forest land area showed an increasing trend as compared to the agriculture and open grazing lands. The study will be applicable in addressing land use and land cover changes and its effects on SOCst. Changes from on land use to other land uses changed SOCst in the soil. The lowest SOCst value was in land use changes from agriculture to agriculture. SOCst in forestland was higher than both agriculture and open grazing lands.

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None.

Conflicts of interest

The author declares there are no conflicts of interest

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