LAND USE DYNAMICS AND LANDSCAPE CHANGE PATTERN ON THE PATCH DRY AFROMONTANE FOREST HYDROLOGY OF NORTHERN ETHIOPIA

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Abstract

Land-use is a key factor in hydrological modelling. Land use changes are important aspects of global change and affect regional water cycles, environmental quality, biodiversity and terrestrial ecosystems. This study was performed on the state forest of northern Ethiop. The aim to: (1) evaluate land-cover changes and patch fragmentation in a landscape containing forest patches over (1986-2018) of 32 years and (2) estimate the potential impacts of the land use land cover (LULC) dynamics on hydrological response (3) evaluate the spatial and temporal scales modify various aspects of the climate-vegetation-soil-streamflow system. (4) understand and quantify the hydrological processes in a rapid land use dynamic. Landsat satellite images of TM (1986), TM (2001), and OLI (2018) were used. All images were classified using maximum likelihood image classification technique. LULC and surface hydrological change analysis was carried out using post classification comparison. Soil Conservation Systems Curve-Number model, which is used to extract the curve number for watersheds was then employed to formulate the impact of climate and land-cover changes on hydrological response over a period of 32 years (1986–2018). Results showed that seven LULC classes were successfully captured with overall accuracy ranging from 82.7% to 90.2% and Kappa statistic of 0.822 to 0.924. The classification result for 1986 revealed that cultivated land (44.78) followed by shrublands (32.02%). However, shrub land is becoming the dominant (36.64%) followed by decreasing the rate of cultivated land by (28.68%) with an increasing forest land by (from 7.18 to 18.63%), were the dominant LULC types from 1986-2018. LULC change indicated a rapid reduction in cultivated land during the study period. Observed changes in direct surface runoff, runoff coefficient, and storage capacity of the soil have been partly linked to changes in LULC associated with expanding bare land and built-up areas. This land use change aggravates the runoff potential of the area by a mean of 213.58 mm year^{-1}. Therefore, combined effects of climate induced moisture stress and landcover led to water abstraction upstream threatened runoff-response at a rate of 0.86 x 106 m^3 year^{-1}. Observed rainfall and modelled runoff showed strong positive correlation of $R^2 = 0.707$ and $p \leq 0.000$. The changes were also common along the slope gradient and agro-ecological zones with varying proportions. Further detailed study is suggested to investigate drivers and consequences of changes and its magnitude on forest hydrology of the dry Afromontane forest landscapes.

Keywords: Hydrological modeling; Landsat; state forests; SCS-CN; Afromontane forest;

1. Introduction

Anthropogenic activities have substantially changed natural landscapes, especially in regions which are extremely affected by population growth and climate change such as East African countries. Changes in land use and land cover have vital environmental consequences at local, regional and global scales[1]. At the regional and world scales, these changes have profound implications for world radiation and energy balances, alterations in biogeochemical cycles, perturbations in hydrological cycles, global warming and increase of natural disasters such as flood, drought and loss of biodiversity at genetic and species levels [2-5]

Land-cover changes also affect regional climates through changes in surface energy and water balance[6].Tropical dry forests are among the most threatened ecosystems in the world as a consequence of intensive anthropogenic disturbance[7]. Changes in forest (due to both natural disturbance and human activities) affect how incoming precipitation is partitioned between evapotranspiration and streamflow. In a recent global assessment[8] forest changes explained, on average, 30% of annual streamflow variations.

Land-use and land-cover (LULC) change has become a fundamental and essential component in current strategies for monitoring environmental changes and managing natural resources[9, 10]. Increasing anthropogenic activities around the biosphere are causing large-scale alterations of the Earth's land surface, which affect the effectiveness of global systems. Increasing anthropogenic activities around the biosphere are causing large-scale alterations of the Earth's land surface, which affect the effectiveness of global systems[3, 5]. LULC and its resources have been used for the social, material, cultural, and spiritual needs of humans, while, in the process, humans have caused significant changes[10, 11] . The rapid changes of LULC, particularly in developing countries[10, 12, 13], have resulted in the reduction of different vital resources including water, soil, and vegetation[14, 15]. Furthermore, the actions leading to LULC changes have a local cause. However, because of their speed, extension, and intensity, they have numerous and critical global implications[16], particularly on natural resources. The increasing change is alarming and can significantly impact the local, regional, national, and worldwide environment [17, 18]. Changes in land cover triggered by cultivation and heavy livestock grazing pressure are proximate causes for severe dryland degradation and desertification in many parts of Sub-Saharan Africa[19-22].

The problem of land cover dynamics is more severe in the highlands of Ethiopia, which account nearly 44% of the total landmass and have been cultivated for millennia [23, 24]. The use and management of natural resources and returning the Brobdingnagian degraded landscapes to protecting and/or productive systems, have substantial importance to realize the goal of property development in Ethiopia[20-22]. Although some studies on streamflow patterns with respect to land cover dynamics enables an assessment of sustainability of land use systems, because the stream flows are reflections of the ecological state of the entire watershed[1, 10, 25-27]. This study used mainly integrated high-resolution temporal LULC maps derived from satellite remote sensing classification with hydrological modeling to evaluate the long-term impacts of LULC change on dry Afromontane forest hydrological consequences of changing LULC and provide quantified information for decision makers in land use planning and water resource managements. Therefore, this article adapts the conventional SCS-CN model in different ways by incorporating the variation of daily curve numbers with respect to the variability of antecedent rainfall, with integrated land use land cover change images and grid-based hydrological soil texture classification groups (HSG). Therefore this article is mainly concentrated on identify : (1) evaluate land-cover changes and patch fragmentation in a landscape containing forest patches over (1986-2018) of 32 years and (2) estimate the potential impacts of the land use land cover

(LULC) dynamics on hydrological response (3) evaluate the spatial and temporal scales modify various aspects of the climate-vegetation-soil-streamflow system. (4) understand and quantify the hydrological processes in a rapid land use dynamic.

2. Materials and Methods

2.1. Study area description

Topographically, Northern Ethiopia is characterized by undulating to steep terrain that is frequently divided by stream incisions. Northern Ethiopian climate thus shows extreme climatic variations within short distances, such as from very dry tropical to sub-humid and subtropical to highly moist tropical climates. Average annual rainfall varies from 200 mm in the arid lowlands to over 2,200 mm in parts of the southwestern highlands. Mean annual temperatures vary from over 35°C in the lowlands to less than 15°C in the highland areas.

Figure 1: Desea State forest Area

2.2. Methodology

2.2.1. Remote sensing data collection and processing

Satellite images for the years 1986, 2001, and 2018 were acquired to analyze the spatio-temporal patterns of the LULC of the fragmented state forests of Desea' natural forest areas. Landsat 5-Thematic mapper (TM) and Landsat-8 Operational Land Imager(OLI)images for the selected years were obtained from the US Geological Survey (USGS) Centre for Earth Resources Observation and Science (EROS) found in http://glovis.usgs.gov/.A brief description of the collected satellite images including satellite and sensors used, resolution, acquisition date, 168/051 path/row of each images for each period is summarized in Table 1.The data acquisition dates were all during the dry season to avoid phenological effects and ensure cloud-free images.

Table 1 .Landsat Images used for the Analysis of LULC (Source: http://glovis.usgs.gov).

Sensor	Month/Day/Year	Resolution	Path /Row
Landsat 5 TM	12/15/1986	30 m	168/51
Landsat 5 TM	01/28/2001	30 m	168/51
Landsat 8 OLI	01/13/2018	30 m	168/51

The LULC change was analyzed using multi-temporal satellite imageries of Landsat to understand the temporal and spatial variations. The images were geo-referenced using (Ground Control Points) GCPs[28] and the projection was made using the Universal Traverse Mercator (UTM) system with WGS84, zone 37 N. The bands used from the Landsat images as a false color composite are those which have given the better visualization of the land surface features. Table 1 indicates the fundamental characteristics of Landsat images used; the date of data acquisition selected purposely to achieve relatively cloud-free images.

The LULC classification was based on identifying and delineating the training sites using the ground observation points, and visually interpreting detailed topographic maps and Google Earth images. The cloud-free scenes of the Landsat images were obtained from the United States Geological Survey (USGS), earth explorer website(https://earth explo rer.usgs.gov/).

Supervised classification methods were applied using ERDAS Imagine by defining signature files and assigning the number of LULC classes. Main classes were grouped to merge classes with a similar value like the center class following (ERDAS 2013), then the LULC classes defined by this method were verified by ground truth values and using geo-referenced topographic map. Finally, supervised classifications of all images were carried out using the Maximum Likelihood Classifier technique of parameter rule.

2.2.2. The SCS-CN Model

The SCS-CN method is based on the water balance equation and two fundamental hypotheses. Although direct runoff estimation is usually carried out at two abstraction ratios i.e., 0.05, and 0.2, researches in the highlands of northern Ethiopia[29-31] recommended λ = 0.05 as an optimum initial abstraction ratio based on least squares fitting for most experimental plots. The model's statistical algorithm can be written as

$$Q_d = \frac{(P - I_a S)^2}{(P + (1 - I_a)S)}, \qquad \text{when} \quad p > I_a S \qquad (1)$$

$$Q_d = 0 \qquad \text{when } P < I_a S \qquad (2)$$

$$I_a = \lambda S \qquad (3)$$

Where Q_d is estimated runoff (mm), P is the measured daily rainfall (mm), I_a is the initial abstraction (mm), λ initial abstraction ratio and S is the maximum water retention parameter (mm) determined from weighted CN value. S is related to the dimensionless runoff curve number (CN). See equation below.

$$S = \frac{25400}{CN} - 254 \qquad (4)$$

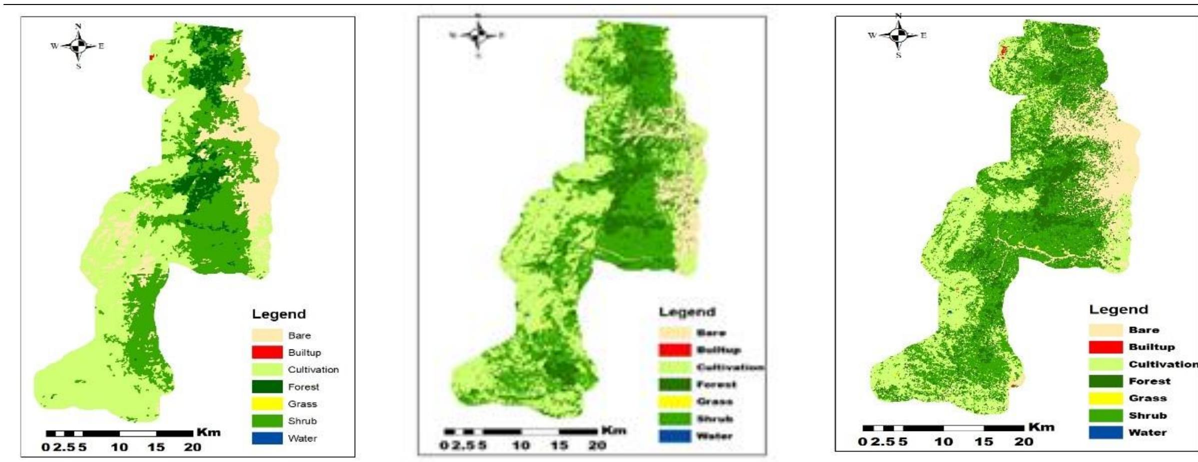
3. Result

3.1. LULC dynamics of the dry Afromontane forests of Desea' state forest

The most dominant land use land cover types in 1986, 2001, and 2018 were shrubland, cultivated land, forest land, grassland, water, and built-up area, respectively (Table 2). In 1986, the highest portion of the total area was covered by cultivated land (44.78%) followed by shrubland (32.02%) and 15.98% of Bare land (Figs. 2). Forest land (7.18%), and built-up area shared 0.04% of the total area (Table 2 and Table 3). While in the year 2001 shrubland (38.63 %) followed by cultivated land (38.13%)were the dominant land cover types, in 2018, the largest portion of the land was shrubland (36.64%), followed by cultivation area (28.68%), forest land (18.63%) and bare land(14.79%), (Table 2). Grasslands, built-up and water land area accounted for 1.06%, 0.11%, and 0.09%, respectively (Figure 2).

Table 2: Land use land cover change of Desea' State Forest

CLASS_NAME	%_1986	%_2001	%_2018
Bare	15.98	8.43	14.79
Built-up	0.04	0.02	0.11
Cultivation	44.78	38.13	28.68
Forest	7.18	14.26	18.63
Grass	0.00	0.41	1.06
Shrub	32.02	38.63	36.64
Water	0.00	0.12	0.09
Total	100	100	100



1986 2001 2018

Figure 2. Land cover change of the study

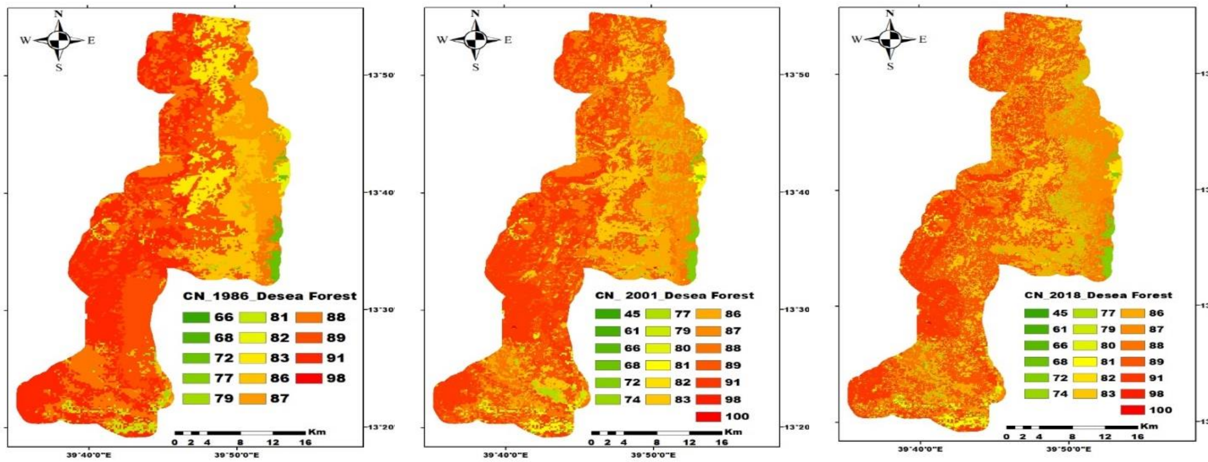


Figure 3.Curve Number based on their DEM of the study area

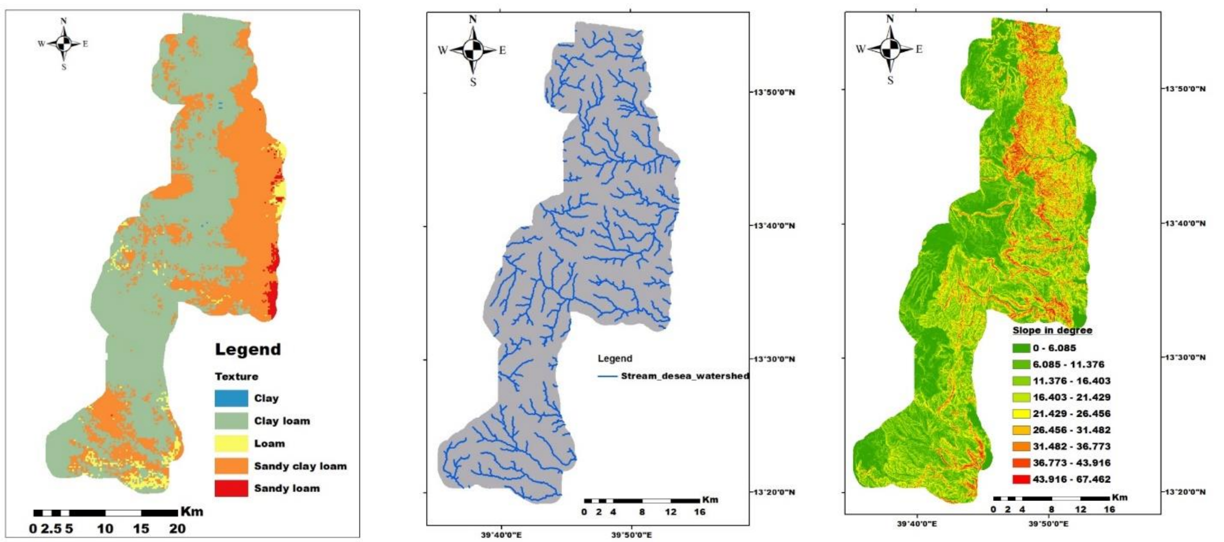


Figure 4: Soil textural classification, stream flow and Slope of Desea' State Forest

3.2. Impact of rainfall on runoff discharge

The precipitation (Figure 5)time series of the Desea State forest sub-basins of the catchment runoff estimates positively and ($R^2 = 0.707$, $P<0.000$) strong correlation (Table 3 and 4). Runoff is very much a function of the catchment climate and topographic characteristics. On an annual timescale, a strong association should be detectable between catchment precipitation and runoff anomalies. The impact of these precipitation Changes on the discharge flows of Desea forest over the last 40 year has been considerable and has had consequent implications for water resource management of the dry Afromontane forests.

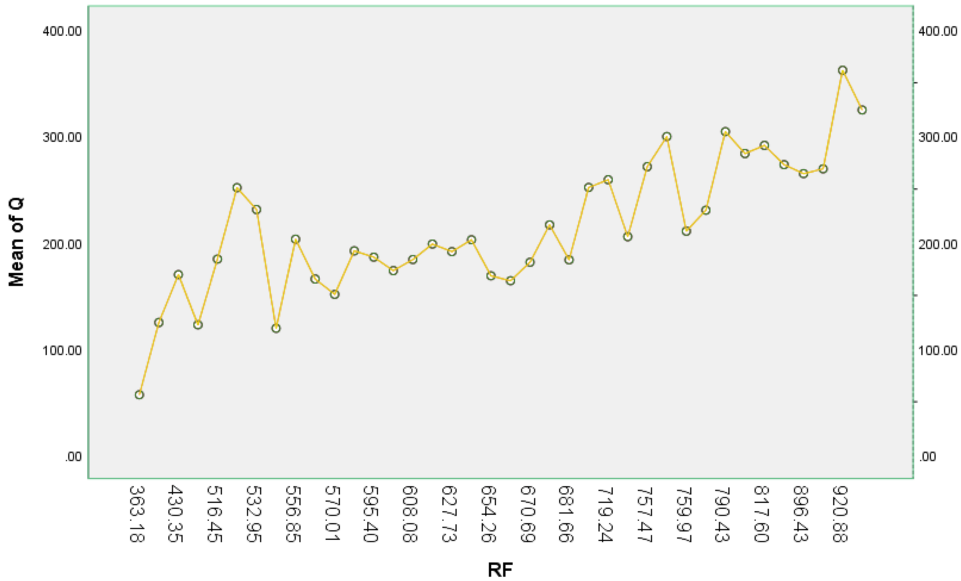


Figure 5 rainfall on runoff discharge

Table 3: Model Summary of RF Vs Discharge

Model Summary									
					Change Statistics				
Model	R	R^2 Square	Adjusted R Square	Std. Error of the Estimate	R Square Change	F Change	df1	df2	Sig. F Change
	.841[a]	0.707	0.690	35.28857	0.707	42.242	2	35	**0.000**
a. Predictors: (Constant), RF, Year									

Table 4: ANOVA Table of discharge due to the function of time series Rainfall

ANOVA					
Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	105205.905	2	52602.952	42.242	**.000[b]**
Residual	43584.913	35	1245.283		
Total	148790.818	37			
a. Dependent Variable: Q					
b. Predictors: (Constant), RF, Year					

4. Conclusion and recommendations

Based on the results obtained, the following conclusions are drawn:

- The watershed experienced a significant land use land cover change between 1986, 200 1 and 2018. It is concluded that the decrease in cultivated land and grassland are accomp anied by the increase in forest land, water land and built up areas.
- The observed changes on direct surface runoff, runoff coefficient, and storage capacity o f the soil from study area have been partly linked to the changes in land use/cover associ ated with expanding rural built-up and explanation of bare land of catchment resources (e xpansion of degraded grazing lands and reduction of vegetative cover, particularly shrub s and woodland areas). The most sensitive parameter which resulted from the analysis w as the Initial SCS curve number.
- Continuation of the land use/land cover change is becoming a serious threat to the Desea reservoir state forest area. The land use/land cover change should be controlled in the watershed and some measures should be taken for the stabilization of the land c over change.
- The study only simulates flow but considerate the sediment dynamics in response to land use change and hence its impact on the reservoir management and operation is us eful to consider for future studies.

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