Impact of Land Use Land Cover Dynamics on Stream Flow: A Case of Borkena Watershed, Awash Basin, Ethiopia

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Abstract. In the recent decade, the change in land use and land cover have changed the ecosystem services more rapidly than the previous similar periods. Land use land cover (LULC) change is the major factor that affect the watershed response. The main objective of this study was to assess the impact of land use and land cover change on the response of the Borkena watershed. The LULC change analysis was evaluated using supervised classification in ENVI software. The SWAT model was used to assess the impact of LULC change on streamflow for the period from 1996 to 2016. The study result revealed that the Borkena watershed experienced significant LULC changes from 1986 to 2016. Most of the grass land, cultivated land, and shrub land were changed to build-up and bare Land. The LULC map showed an increase of buildup area and bare land by 3.6% and 5.9%, respectively. There was a good agreement between simulated flow and observed data with a coefficient of determination (R^2) and Nash-Sutcliff Efficiency (NSE) values of 0.81 and 0.79 in calibration, and 0.75 and 0.74 in validation periods, respectively. The evaluation of the SWAT hydrologic response due to the change in LULC showed that monthly streamflow was increased by 5.4 m^3/s in the wet season and decreased by 0.5 m^3/s in the dry season, and there was a significant effect ($p < 0.05$) of LULC change on watershed response. The changes in land use have resulted in changes in streamflow, due to the expansion of urbanization and land degradation.

Keywords: Land use land cover · StreamFlow · SWAT model · Awash basin · Ethiopia

1 Introduction

The Land use and land cover change in the recent decade, have changed the ecosystem services more rapidly than the previous similar periods [1]. This is due to the increased agricultural activity the cost of forest cover for food production, increased urbanization, overgrazing, and increased demand for ecosystem services. In addition, the change in climate has also contributed for the rapid changes in land use land cover. These all-dynamic activities had led to environmental changes and degradation of the ecosystem services [3]. Water resource management studies are related with the hydrological

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processes in all watershed scales [2]. These processes are affected by several factors: including anthropogenic activities and natural factors [4]. The land use/land cover (LULC) dynamics has significant effect on the watershed response: the surface runoff pattern, baseflow volume, groundwater recharge, and soil moisture content [5].

The impact of LULC dynamics on the watershed response can be analyzed using Soil & Water Assessment Tool (SWAT) model using remote sensing data and geographical information system (GIS). Because there is a strong relationship between watershed properties and watershed processes [6]. Due to the rapid growth of population, urbanization, and industrialization activities, the Borkena watershed is one of the most fragile natural systems in the upper Awash basin [7]. However, there is limited study in the upper Awash basin, where LULC, climate change, and climate variability have significant impacts on the hydrology of the watershed. Therefore, understanding the effect of the LULC change on watershed hydrology is crucial. Rapid LULC change alters the environment and has a pronounced impact on the water balance of a watershed [8]. Therefore, understanding of how LULC change affects watershed hydrology is vital for sustainable natural resources management. The objective of this study was to assess the impact of land use and land cover change on the response of the Borkena watershed.

2 Methodology

2.1 Description of the Study Area

The Borkena watershed is located in the Amhara national regional state, South Wollo zone, and including the and partly in the Oromia special Zone (Fig. 1). The Borkena watershed contributes a lot to Awash River basin. It drains from the mountainous chains and escarpments found in the northern plateau which is adjacent to the Afar rift down to the southeastern direction and after joining the Jara River, it finally drains the Awash River.

Borkena watershed covers about 1677 km^2. The gauging station of the watershed is found near to Kemsie town at $10^o38'$ N latitude and $39^o56'$ E longitude. The topography of the watershed is very undulating and the elevation ranges from 1378 m to 3499 m above mean sea level, therefore it is grouped under the "Woina Dega Agroecology" Ethiopian climate classification system.

The climate of the Borkena watershed varies from sub-humid to subtropical and the main annual rainfall over the catchment is 1028 mm and most of which is concentrated in the main rainy months that lasts from July to September and contributes about 84% of the annual rainfall [7]. The soil in the study area includes predominantly chromic cambisols, lithosols, regosols, rock surface, and chromic vertisols where the chromic cambisols dominates the north part of the study area as shown in Fig. 2.

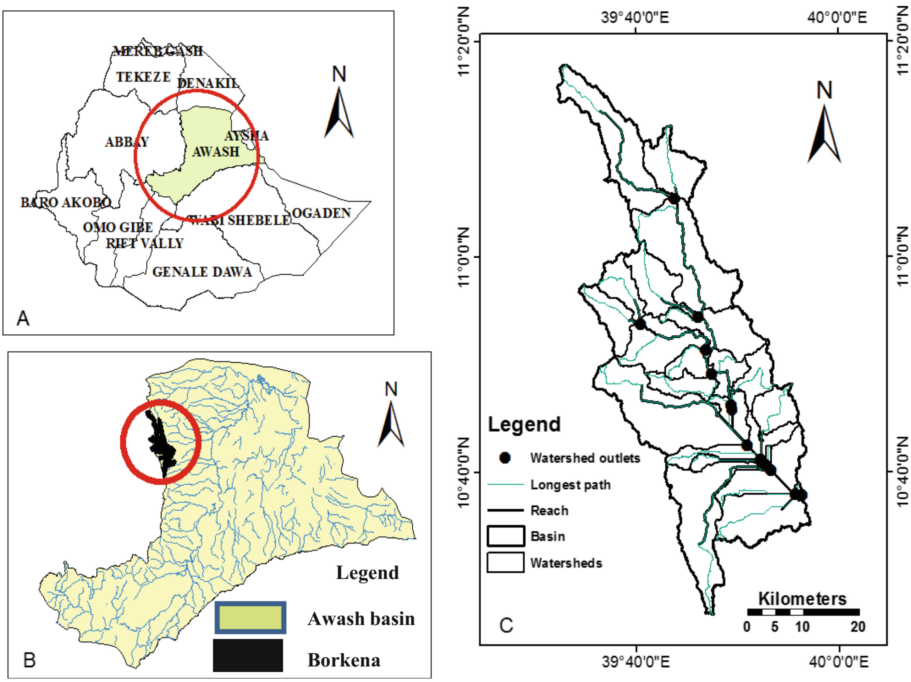

Fig. 1. Location map of Borkena watershed

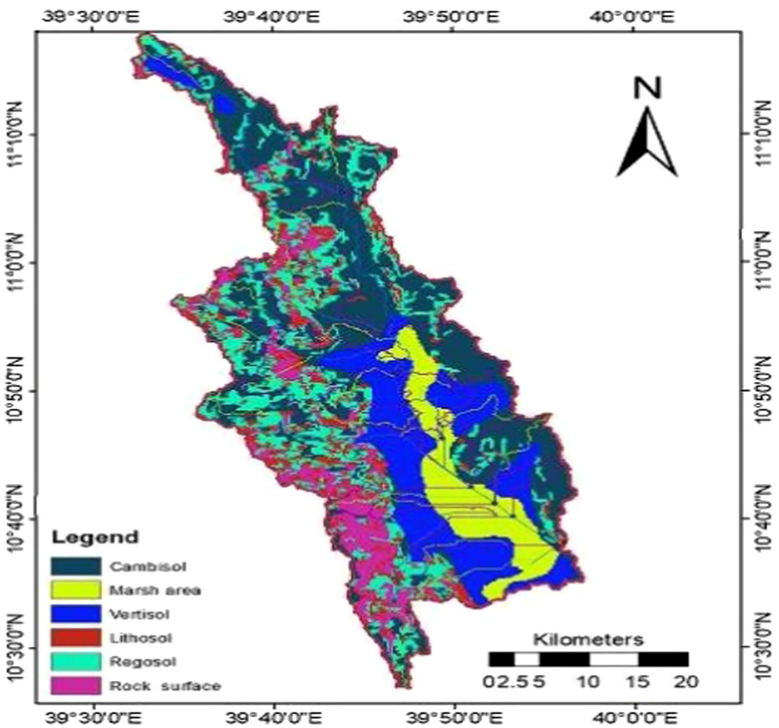

Fig. 2. Soil Classification map of the study area

Traditional grazing on communal lands has also been practiced for years with little or no modification. In addition to the long years of agricultural activities in the area, the present size of human and livestock population pressure has led to the overutilization of land resources where people are faced to turn mountain slopes into farmlands. The Land-use the land cover of the study area which was classified by the Ministry of Water Resource, Irrigation, and Energy in 1987 [9] is shown in Fig. 3.

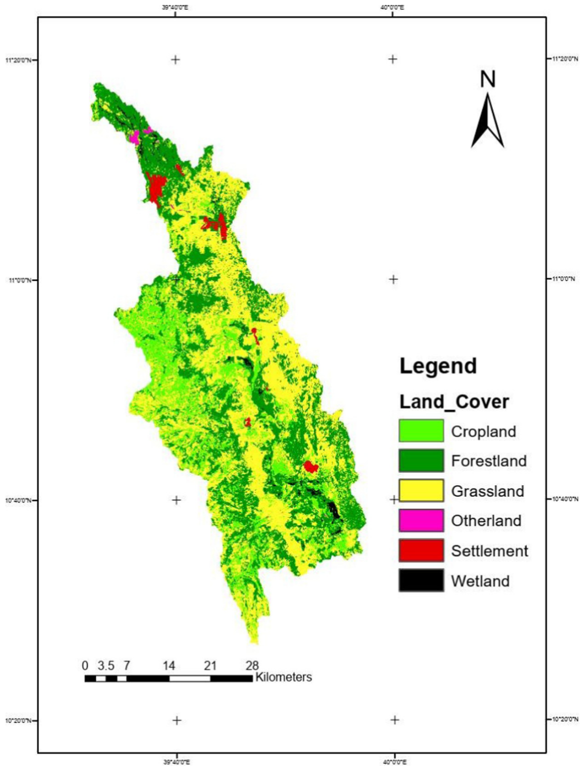

Fig. 3. The Land use land cover of the study area, which was classified by the Ministry of Water Resource, Irrigation and Energy in 1987

2.2 Method and Material

Sources and Types of Data. To achieve the objectives of this study, primary and secondary data including satellite imagery data were collected. The data included remote sesig spatial data, hydrological data, and meteorological data.

Satellite Image and GIS Data Collection. Time series LandSat images of 1986, 1996, 2006, and 2016 were used to analyze the LULC dynamics of the Borkena watershed. Satellite images were downloaded from USGS-GLOVIS (www.glovis.usgs.gov). All images used in this study were 30 m spatial resolution and below 10% cloud cover (Table 1).

Table 1. Summary of spatial data sets

Dataset type	Acquisition Date	Pixel Resolution (m)/Scale	Path/Row	Producer
Satellite data				
Landsat TM	1986-02-13/25	30 m	168/052 & 53	USGS
Landsat TM	1996-01-23/25	30 m	168/052 & 053	USGS
Landsat ETM +	2006-02-12/19	30 m	168/052 & 053	USGS
Landsat OLI/TIRS	2016-02-02 & 2016-01-24	30 m	168/052 & 053	USGS
Ancillary data				
Field data GPS point for each land-use class: May, 2019 - June, 2019				

Meteorological and Hydrological Data. The meteorological data were obtained from the National Meteorological Agency of Ethiopia (NMA) at Bahir Dar branch for Kombolcha, Dessie, Kemisie, Cheffa, and Majetie meteorological stations which are located in the watershed and some of them are in the outside of the watershed. The daily streamflow data from the year 1996 to 2016 was obtained from the Ministry of Water, Irrigation and Energy (MoWIE). These data were used in the SWAT model to do sensitivity analysis, calibration, and validation purposes. In this study, the missed meteorological data were calculated by using Arithmetic and Normal ratio methods by observing the surrounding stations. The normal annual ratio method was selected to fill some of the missed data when the difference of the normal annual precipitations and 10% of normal annual data are greater than other stations normal annual precipitation with the correspondence time. The missed hydrological data were filled by an arithmetic method (Fig. 4) (Table 2).

Table 2. Availability and classes of meteorological data

Station name	Precipitation	Temperature	Relative humidity	Solar radiation	Wind speed	Stationclass	Station coverage area (Km^2)	Recording periods
Dessie	x	x	–	–	–	III	169	1996–2016
Kemisie	x	x	–	–	–	III	423.5	1996–2016
Cheffa	x	x	x	x	x	I	607.5	1996–2016
Kombolcha	x	x	x	x	x	I	320	1996–2016
Majetie	x	x	x	x	x	I	316.4	1996–2016

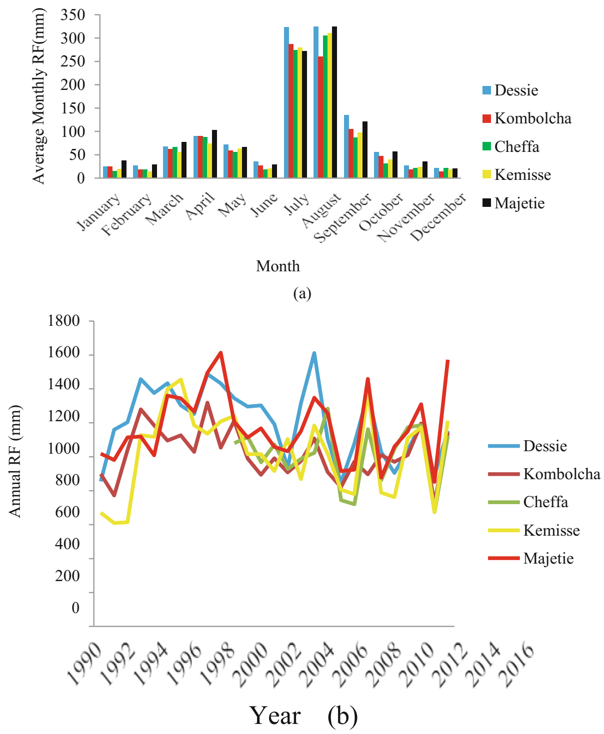

Fig. 4. Average rainfalls pattern of the stations at (a) Monthly and (b) annual scale

2.3 Data Processing and Analysis

Image Pre-processing. The Geometric and Radiometric corrections and image enhancement were conducted by ENVI before the image classification. Geometric correction involves the conversion of data to ground coordinates for example to Universal Transverse Mercator by the removing the distortions from sensor geometry, Radiometric correction, on the other hand, involves correcting unwanted sensor due to atmospheric noise and correcting the data for sensor irregularities [10]. The satellite images used in this study were projected to UTM projection, Zone 37N and datum of WGS84.

Land Use Land Cover Classification. Image classification involves categorizing raw remotely sensed satellite images into a fewer number of individual LU/LC classes, based on the reflectance values. Image enhancement and classification for this study were performed using ENVI. ENVI was also used for the preparation of land use land cover data for SWAT input. The Landsat data image of the catchment which shows the land use land cover for four different years of 1986, 1996, 2006, and 2016 were downloaded and used for ENVI for further image enhancement, processing, and re-classification. The supervised classification routine of ENVI were used for the classification of images take from satellite.

A signature level taken was between 15 and 20 for each of the land cover classes as ground truth/verifi- cation. The main technique for accuracy assessment is using change maps for evaluating each class and computing the expected accuracy by error matrix's [5]. Post-classification enhancements were used to diminish the classification errors from base fields, cities, and classes that have similar responses with crop areas and wetlands. Accordingly, an error matrix was produced for all images in this study (Fig. 5).

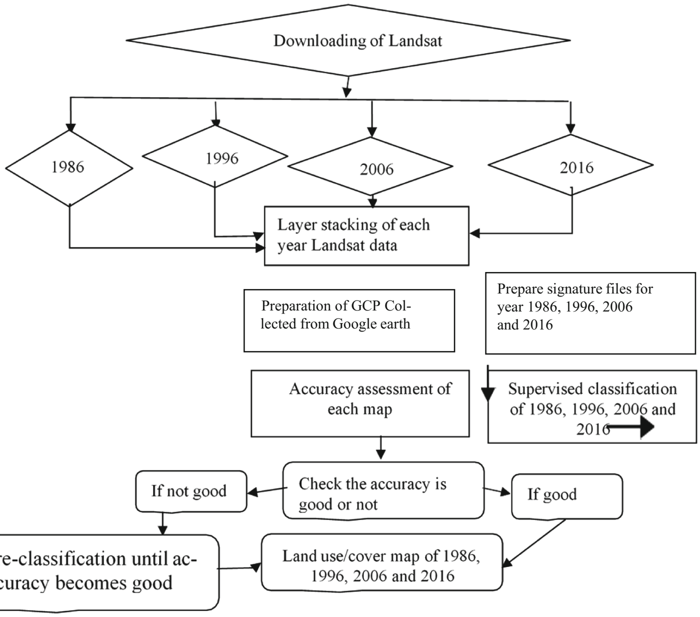

Fig. 5. Methodology of land use and land cover classification

Land Use and Land Cover Change Detection Analysis. Comparison of the classified images was used to determine the extent of land cover changes over the period of 1986 and 2016. The rate of change of the different land covers was estimated based on the following formulas [11].

$$\%coverchange = \frac{area_i\mathrm{year}_x - area_i year_{x+1}}{\sum_{i=1}^{n} area_i year_x} * 100$$

where,
$area_i\mathrm{year}_x$ is the area cover I on the first date;
$area_i year_{x+1}$ is the area of cover I on the next date;
$\sum_{i=1}^{n} area_i year_x$ is the total area at the first date.

2.4 SWAT Model Set-Up and Simulation

SWAT and SWAT-CUP Model Description. SWAT model (i.e. ArcSWAT) is an extension of ArcGIS, developed by the United States Department of Agricultural Research Service (ARS). The globally widely used SWAT model is a semi-distributed physically based hydrological model. The model is able to simulate runoff, sediment, nutrients, and pesticide transport from agricultural watersheds [1]. Hydrological response units (HRU's) are utilized to consider spatial heterogeneity within a watershed. Using the water balance approach of the model, it simulates the hydrological parameters as shown in the equation below [6].

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

where,
$SW_t -$ is the final water content (mm)
SW_o- is the initial water content (mm)
$R_{day} -$ is the amount of Precipitation on day i (mm).
$t -$ is the time (day)
$Q_{surf} -$ is the surface runoff on day i (mm)
$E_a -$ is the evaporation on day i (mm)
$W_{seep} -$ is the amount of water entering the vadose zone day i (mm), and
$Q_{gw} -$ is the return flow on day i (mm)

The SWAT built in sensitivity analysis tool was used to do the sensitivity analysis of the parameters. The sensitivity analysis tool is helpful to model users in identifying parameters that are most influential in governing streamflow response. The calibrated parameters were used to run SWAT model with the input data including digital elevation model, soil map, land use map, rainfall, and observed streamflow. Details of model sensitivity analysis, calibration, and validation concepts are discussed in the next sections.

Sensitivity Analysis. In a SWAT simulation, it is common to have a discrepancy between the simulated results and the observed data [12]. Determining the parameters which affects the results most is important to minimize this discrepancy. The sensitivity is used to estimate the rate of change of model outputs concerning the change of model inputs. To determine the influential parameters in the model, for a better understanding of how the Borkena hydrologic system behaves, and further evaluation of the model performance, sensitivity analysis was conducted. Identifying the location of the sub-basin where observation data was collected is important to ease comparison of the simulated result and observed data. For the sensitivity analysis, the 27 parameters selected with the default lower and upper bounds were used [6]. Finally, the parameters mean relative sensitivity values were used to rank the parameters and their category of classification. The sensitivity category was defined based on the classification as shown in Table 3 [13].

Table 3. The sensitivity category

Class	MRS sensitivity	Category
I	0.00 $\leq$ MRS < 0.05	Small to negligible
II	0.05 $\leq$ MRS < 0.2	Medium
III	0.2 $\leq$ MRS < 1	High
IV	MRS > 1	Very high

Model Calibration. The time series of river flow data at the outlet of the watershed which found near to Kemsie town at 10°38′N latitude and 39°56′E longitude was used for calibration and validation of the model, 13 years of observed data (from 1996 to 2008) was used to calibrate the model, and the most sensitive parameters that affect most the watershed response were identified and ranked according to their sensitivity ranks. These parameters were automatically calibrated by using SWAT CUP for the first 13 years until the model simulation result becomes acceptable as per the model performance measures (Fig. 6).

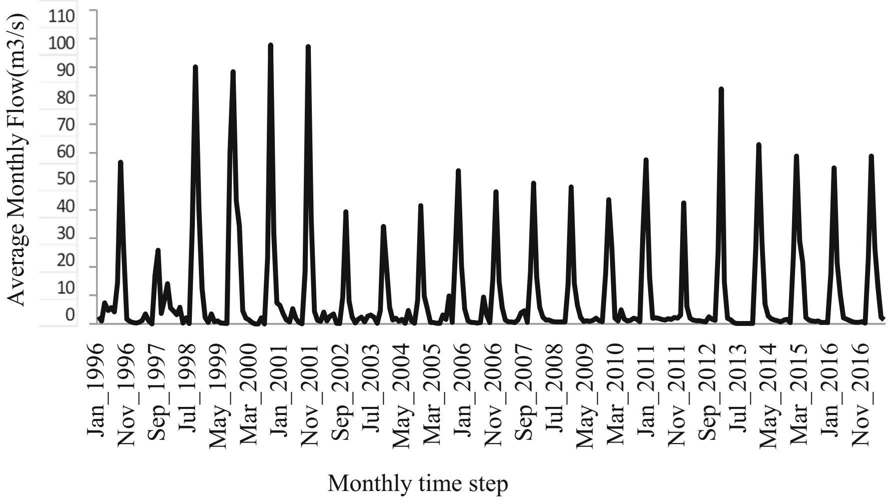

Fig. 6. Average monthly streamflow data of Borkena River

Model Validation. For validation, the performance of the model was tested with an independent 8 years (from 2009 to 2016) set of observed data. The model predictive capacity will be determined in both calibration and validation phases, when the objective functions are met. Based on the performance the model, it will be used for future predictions under different scenarios.

To evaluate the goodness-of-fit of model coefficient of determination (R2), and the Nash Sutcliff Efficiency (NSE) were applied. R2 ranges from 0 that indicates poor model performance to 1 that indicates the best model performance, generally higher values indicating less error variances.

2.5 Evaluation of Streamflow Variability Due to LULC Change

The watershed streamflow is the amount of water leaving the watershed outlet in the stream channel. The quantity of watershed response is affected by watershed characteristics (including land use) and weather (increase during rainy periods and decrease during dry periods). The impact of LULC on the variability of streamflow was evaluated for the year 1996 to 2016. In the three independent periods, SWAT model was run on a monthly time step for the years 1996, 2006, and 2016 LULC, keeping other input parameters unchanged. Finally, seasonal streamflow variability due to LULC change was assessed based on the simulation outputs. A one-way analysis of variance (ANOVA) for one factor (land use land cover change) at 5% significance level was conducted (Fig. 7).

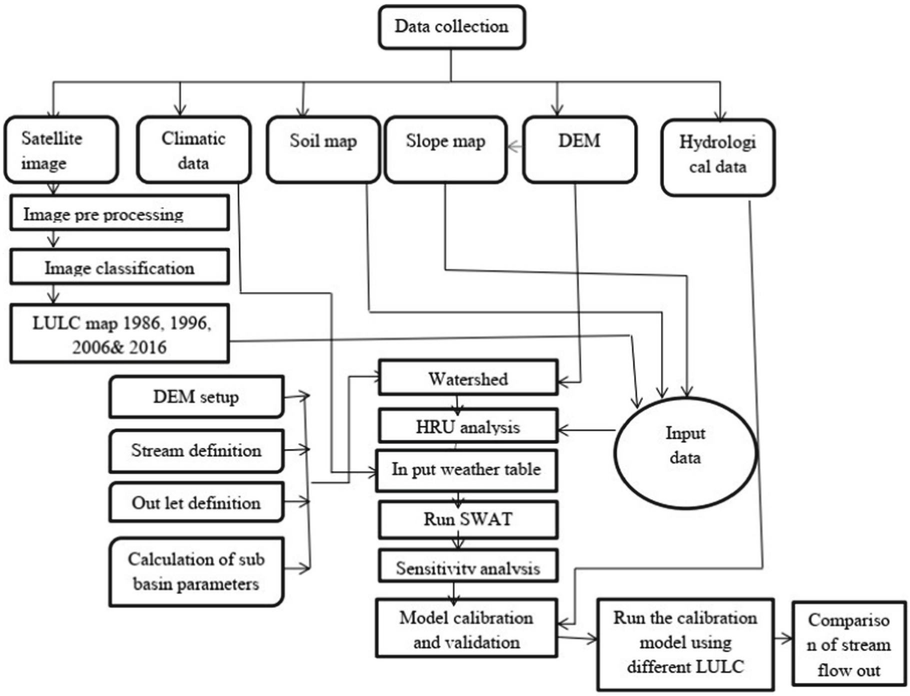

Fig. 7. The conceptual Methodology framework of the study

3 Results and Discussion

3.1 Land Use Land Cover Change Analysis

For the land cover detection, maps having eight classes of land use/cover were created: Cultivation land (CL), Grass land (GL), Shrub land (SL), Forest land (FL), Bare lands (BL), Waterbody (WB), Marsh land (ML), and Built-up area (BA) in the years 1986, 1996, 2006 and 2016.

According to the maximum likelihood classification of the 1986 Landsat satellite image; the land cover classes (Fig. 8) showed dominantly covered with cultivated land with 53% coverage, followed by Shrub Land, Grass land, and Forest land with 19.9%, 11.3%, and 11.2% coverage respectively. Marsh land, Bare land, Built-up area, and Water Body covers small percentages: 2.7%, 0.95%, 0.82%, and 0.08%, respectively.

The maximum likelihood classification results of the 2016 Landsat satellite image; the land cover classes (Fig. 8) were also dominated by cultivated land with 54.3%. Other land cover classes also cover the remaining 45.7%, with shrub land 21.3%, grass land 7.0%, bare land 6.9%, built-up area 4.5%, forest 5.1%, and marsh land 0.84%, and water body 0.06%. The Kappa coefficient for each land use land cover was also computed as: *K* value of 0.86, 0.87, 0.85, and 0.87 for the years 1986, 1996, 2006, and 2016, respectively. The result indicated the classification is better as the *K* values are it is more than 0.8.

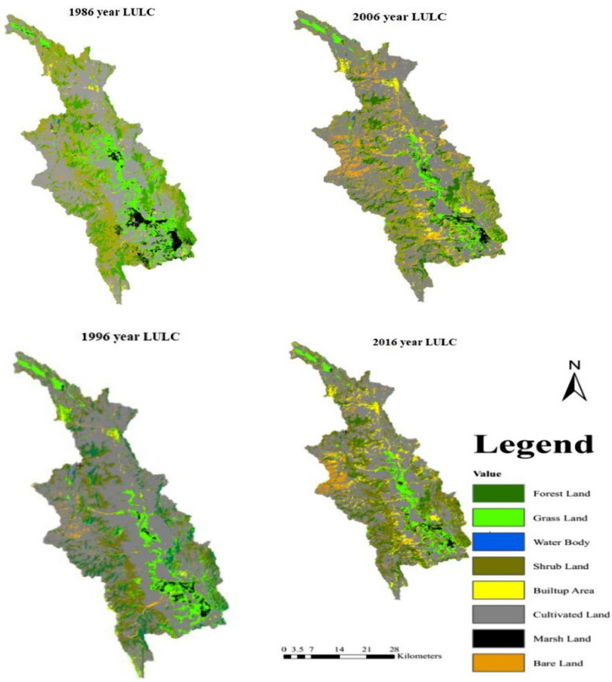

Fig. 8. Land use land cover map of the Borkena watershed over 30 years

These results remarked, there was a Bare Land and Built-up area expansion during the periods 1996–2006, with a rapid increase of Bare Land by 5.05% and rapid increase of Built-up area by 1.17% on one hand and a decrease of grass land, cultivated land, water body and shrub Land by 1.74%, 2.0%, 0.02%, and 1.76%, respectively. These reveals that the changes in one or more land use/ cover resulted in a change on the other land cover types.

The land use and land cover change detection were done by ENVI and GIS. Figure 9 shown that the increasing and decreasing of land use land cover type from one year to another year. Generally, there was an increment of bare land, built up, and decrement of forest land, grass land, shrub land, and cultivated land.

It can be observed that there was an increase in built-up area and bare lands in both periods. On the other hand, forest lands were decreased. This change is due to the demand for urban expansion. According to Kebrom Tekle and Lars Hedlund [7], urban expansion has a great impact on the hydrology of the area.

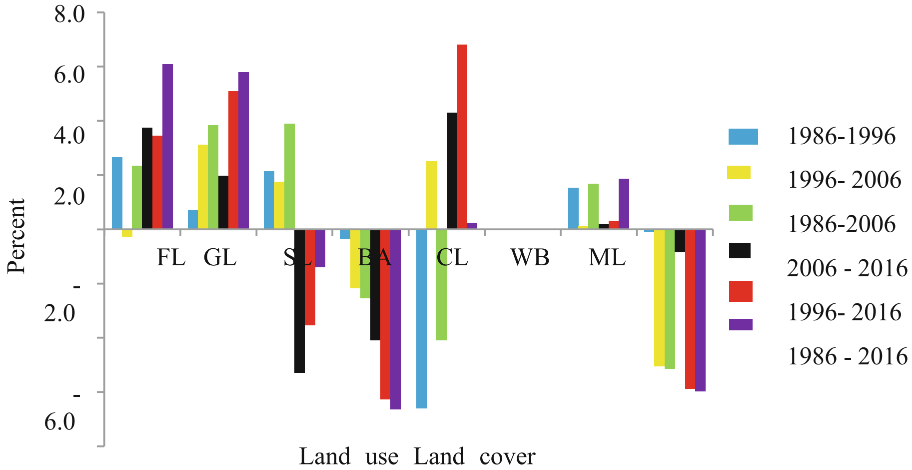

Fig. 9. The land use/cover change in percentage area of Borkena catchment

3.2 Streamflow Modeling

Sensitivity Analysis of Simulated Streamflow. For the SWAT model calibration of this study, out of 24 potential parameters, only 11 flow parameters have a significant effect on the streamflow of the watershed (Tables 4 and 5).

Table 4. List of parameters with fitted values after calibration using SUFI-2 for average monthly stream- flow

Parameter name	Description	Range		Fitted_Value
		Min_ value	Max_ value	
R CH_COV1.rte	Channel cover factor	−0.109	0.299	0.123
R SOL_AWC (..).sol	Available water capacity of the soil layer	−0.224	−0.20	−0.212
A GW_DELAY.gw	Groundwater delay (days)	6.791	8.908	8.886
A EPCO.hru	Plant uptake compensation factor	1.957	5.342	1.936
V ESCO.hru	Soil evaporation compensation factor	0.171	0.224	0.184
V RCHRG_DP.gw	Deep aquifer percolation fraction	0.449	1.338	0.881
V TLAPS.sub	Temperature lapse rate	29.209	30.312	29.551
V CH_N2.rte	Manning's "n" value for the main channel	1.281	1.858	1.299
V CH_EROD(..).rte	Channel erodibility factor	−1.278	−0.421	−1.012
V BIOMIX.mgt	Biological mixing efficient	0.565	0.578	0.576
R CN2.mgt	SCS runoff curve number	0	100	18.786

Table 5. Sensitive parameter

Parameter name	Sensitivity Rank	Description	-Stat	P-value
R CH_COV1.rte	1	Channel cover factor	−0.08	0.93
R SOL_AWC(..).sol	2	Available water capacity of the soil layer	−0.15	0.88
A GW_DELAY.gw	3	Groundwater delay	0.22	0.83
A EPCO.hru	4	Plant uptake compensation factor	−0.45	0.65
V ESCO.hru	5	Soil evaporation compensation factor	0.66	0.51
V RCHRG_DP.gw	6	Deep aquifer percolation fraction	−0.92	0.36
V TLAPS.sub	7	Temperature lapse rate	0.94	0.35
V CH_N2.rte	8	Manning's "n" value for the main channel	1.22	0.23
V CH_EROD(..).rte	9	Channel erodibility factor	−1.99	0.05
V BIOMIX.mgt	10	Biological mixing efficient	−2.08	0.04
R CN2.mgt	11	SCS runoff curve number	−15.8	0.01

Stream Flow Calibration and Validation Analysis. Calibration was done for the most sensitive parameters of the SWAT model inputs using observed streamflow. The Calibration result showed that the coefficient of determination (R^2) and the Nash Sutcliffe Efficiency (NSE) are 0.81 and 0.79, respectively. Additionally, the validation result showed that the coefficient of determinations (R^2) and the Nash Sutcliffe Efficiency (NSE) are 0.75 and 0.74, respectively. In general, the model performance indicated a good agreement between the simulated and measured flows in the monthly time step (Fig. 10).

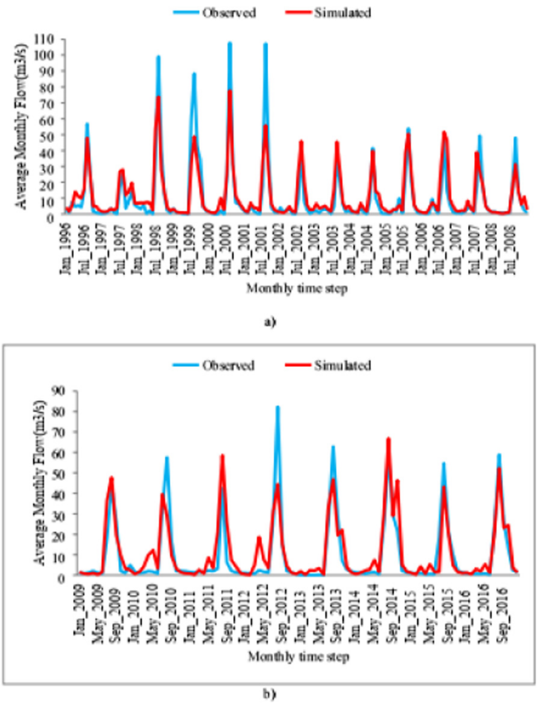

Fig. 10. Average monthly observed and simulated flow a) Calibration (1996–2008) and b) Validation (2009–2016) period

3.3 Evaluation of Streamflow Due to Land Use Land Covers Change

In this study the impact of LULC change on streamflow in the Borkena watershed was assessed. Seasonal variability of streamflow was also evaluated on wet (July, August, and September) and dry (January, February, and March) months.

Table 6. Streamflow simulations on Mean annual streamflow and change for 1996, 2006, and 2016 LULC

Mean annual streamflow (m^3/s)				Mean annual flow change due to LULC change of					
Period	LULC map			1996 to 2006		2006 to 2016		1996 to 2016	
	1996	2006	2016	m^3/s	%	m^3/s	%	m^3/s	%
1996–2016	11.53	12.6	13.3	1.07	9.3	0.70	5.56	1.77	15.35

The result indicates that mean annual streamflow was increased by 9.3%, 5.6%, and 15.4% in the LULC change 1996 to 2006, 2006 to 2016, and 1996 to 2016 respectively (Table 6). As a result, a high runoff was generated during this period; this increases the streamflow of 2006 as compared to 1996 and 2016 as compared to 2006 in the study periods. This stream changes due to an increase of built-up area and bare lands for both periods i.e. 1996–2006, and 2006–2016.

Table 7. Wet and dry seasons streamflow simulation and variabilities.

Period	Seasonal streamflow (m3/s)						Seasonal streamflow changes LULC change					
	1996		2006		2016		1996 to 2006		2006 to 2016		1996 to 2016	
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
1996–2016	2.34	31.52	1.94	0.36	1.8	36.96	**−0.40**	**3.84**	**−0.14**	**1.6**	**−0.54**	**5.44**

The amount of seasonal streamflow was decreased by 0.54 m^3/s due to LULC change from 1996 to 2016 in the dry season. There was also a change in stream flows in the wet season with an increase of streamflow by 5.44 m^3/s due to LULC change from 1996 to 2016 in the study period (Table 7). There was also a change in stream flows in the wet season with an increase of streamflow by 3.84 m^3/s and 1.6 m^3/s due to LULC change 1996 to 2006 and 2006 to 2016 in LULC change respectively. There was a significant effect ($p < 0.05$) land use land cover change on stream flow.

4 Conclusion

From this study, it can be concluded that the Borkena watershed has practiced a substantial change in land use and land cover over the past 31 years. It can be recognized that deforestation and increase of built-up area and bare lands were exhibited by a rapid increase of the human population which changes the whole Borkena watershed in general and sub watersheds. The scope of this study would be limited to evaluate the impact of land use/land cover change effect on streamflow in the Borkena watershed. The study was not considered the impact of climate change and soil erosion on the water and land resources of the watershed.

The dynamics in land use land cover have caused in changes in streamflow. The increase of urban area and bare lands increases surface runoff. This change (increase or decrease) in streamflow was due to LULC change over some time. Therefore, this study results can be used to encourage different users and policymakers for planning and management of water resources and the adoption of suitable adaptation measures in the Borkena watershed and other similar regions of Ethiopia.

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Conflicts of Interest. The author declares no conflict of interest.

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