Abyss. J. Engg. & Comput. Vol. 1, No. 2, 2021, 9-21

Abyssinia Journal of Engineering & Computing

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

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ABSTRACT

Land use and land cover in recent decades have changed ecosystems more rapidly and extensively than in any comparable period. Land used land cover (LULC) change is one of the major factors that affect the watershed response. The LULC change analysis was performed by using supervised classification method in ENVI software. The study results showed that the watershed experienced significant LULC change from 1986 to 2016. During the study period, most parts of the grass land, cultivation land, and shrub land were changed to build-up area and bare Land. The LULC map shows an increase of buildup area and bare Land by 3.6% and 5.9% respectively over the last 31 years. The SWAT model was used to assess the impact of LULC change on stream flow for the period 1996 to 2016. The result showed that there was a good agreement between observed and simulated stream flow with a coefficient of determination (R^2) and Nash-Sutcliff efficiency (N_{ef}) values of 0.81 and 0.79 for calibration, and 0.75 and 0.74 for validation periods, respectively. The evaluation of the SWAT hydrologic response unit (HRU) due to LULC change between the years 1996 and 2016 showed that monthly stream flow was increased by 5.4 m^3/s in wet season and decreased by 0.5 m^3/s in dry season from 1996 to 2016. Understanding the effect of LULC change on stream flow is crucial for knowledge-based decision making in the development of water resources projects.

Keywords: LULC change; Stream flow; ENVI; SWAT model

INTRODUCTION

Land use and land cover in recent decades have changed ecosystems more rapidly and extensively than in any comparable period[1]. This has occurred as on sequence of increase of agriculture, resettlement, rapid population growth, overgrazing, removal of vegetation, and rapidly growing demand on natural resources. In addition to these powerful natural processes and phenomena, such as the bad weather conditions and natural terrain, has also been identified as changes in land use land cover[2]. These dynamic activities have led to environmental changes, which have led to unprecedented pollution and the depletion of natural resources[3].

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Hydrological modeling and water resource management studies are correlated to the spatial processes of the hydrological cycle at the level of watersheds, sub-watersheds, and catchment areas[2]. This cycle is enhanced by several factors, including natural and anthropogenic activities[4]. In particular, the change of land use/land cover (LULC) has a significant impact on watershed hydrology by influencing the size and the pattern of surface runoff, groundwater, and soil moisture content[5].

Hydrological impacts due to land use/cover changes and land use modifications can be predicted through remote sensing, geographical information system (GIS), and the Soil & Water Assessment Tool (SWAT) model because there is a direct relationship between spatially distributed watershed properties and watershed processes[6]. Borkena watersheds are among the most sensitive natural system and are yet the experience of a variety of challenging issues in land resource management due to the rapid growth of population, urbanization, and industrialization[7]. Rapid land-use change alters the environment resulting in a pronounced impact on the water balance[8]. Therefore, providing a scientific understanding of how LULC change affects watershed hydrology is very important or vital for sustainable land and water resource management. The main objective of this study was to assess the impact of land use and land cover change on stream flow of the Borkena watershed.

METHODOLOGY

The Description of the study area

The study area is located in Amhara national regional state, South Wollo Zone, and including the three Woredas of Oromia special Zone (Fig. 1). The Borkena River is one of the main tributaries of the Awash River. 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 1677.3 km^2. The outlet of the watershed is found near to Kemsie town at 10^0 38'N latitude and 39^0 56'E longitude. The topography of the watershed is very undulating and the elevation ranges from 1378 m to 3499 m above mean see level, therefore it is grouped under Woina Dega Agro ecology.

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 for 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 on Fig. 2.

Traditional grazing on communal lands has also been practiced for thousands of 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.

Method and Material

Sources and Types of Data

To meet the objectives of this research, different types of data were collected from both primary and secondary data sources including satellite imagery and field data. Data collected included 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 LU/LCC of the study area. Includes satellite images downloaded from USGS -GLOVIS (www.glovis.usgs.gov). All images used in this study had 30m spatial resolution and below 10% cloud cover (Table 1).

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 (Table 2). Meteorological station which is within the watershed and some are in the vicinity of the watershed boundary and the data included water discharge or the daily stream flow data from the year 1996 to 2016 was obtained from the Hydrology Department of the MoWIE. It was used for performing sensitivity analysis, calibration, and validation of the SWAT model. In this research the missed meteorological data were calculated by using Arithmetic and Normal ratio methods by observing the surrounding stations. 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 arithmetic method.

The average monthly and annual data of those used station are shown in Fig. 4.

The 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 e.g., UTM by the removal of distortions from sensor geometry. Radiometric correction, on the other hand, involves correcting unwanted sensor or atmospheric noise and correcting the data for sensor irregularities [10]. The satellite images used in this study were projected to Universal Transverse Mercator (UTM) projection system Zone 37N and datum of World Geodetic System 84 (WGS84).

Table 1. Summary of spatial data sets used in this study

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

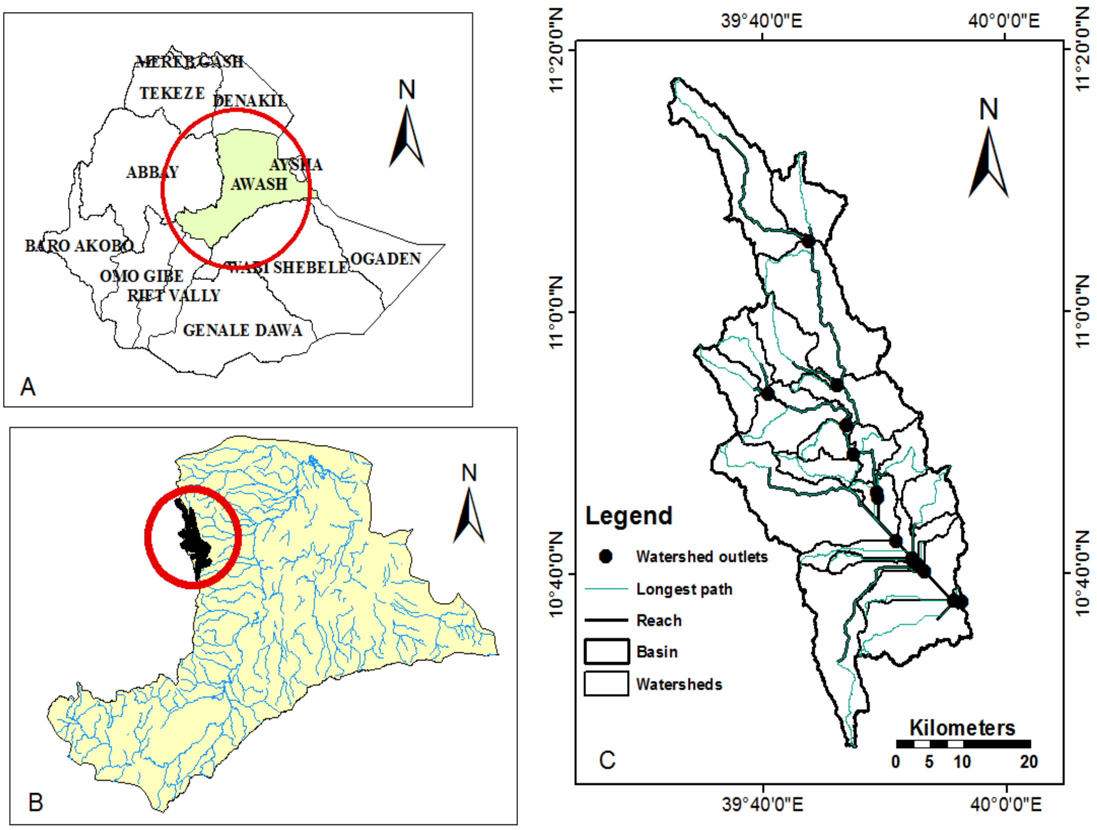


Fig. 1. Location map of Borkena watershed

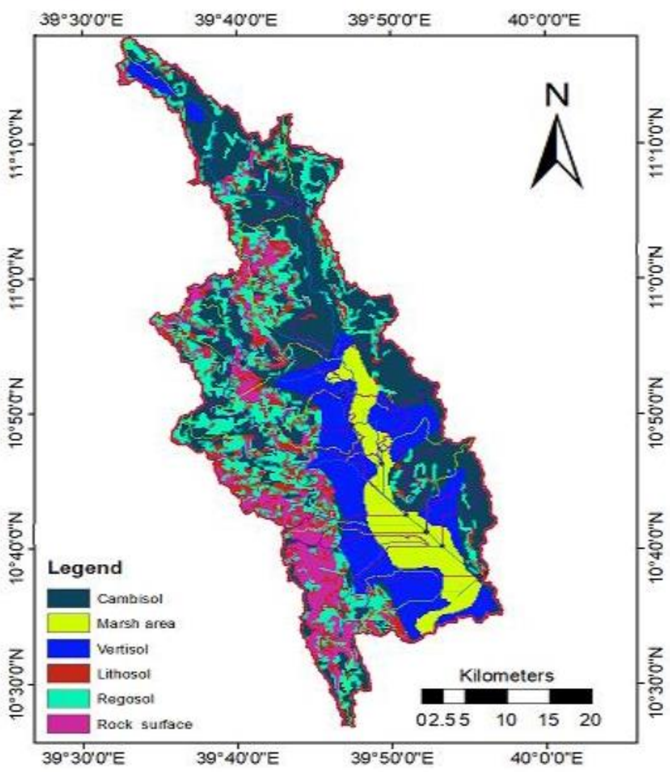


Fig. 2. Soil Classification map of the study area

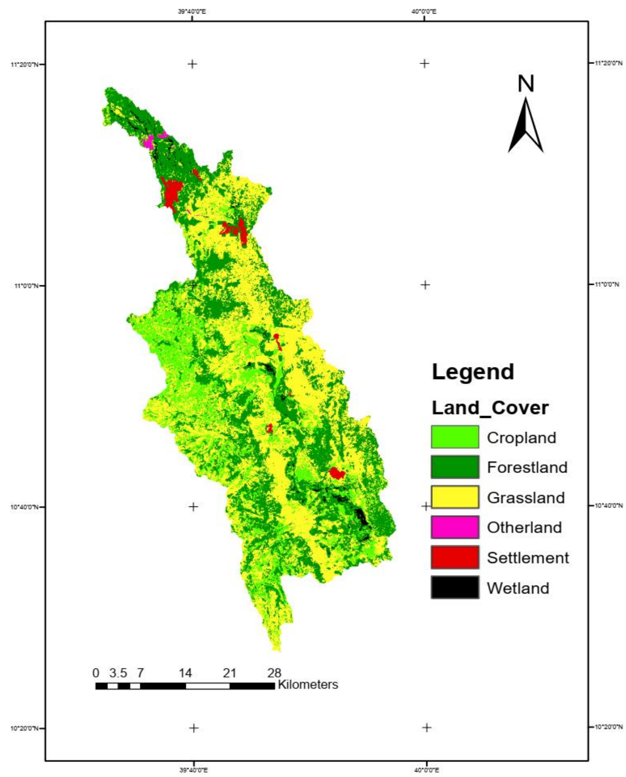
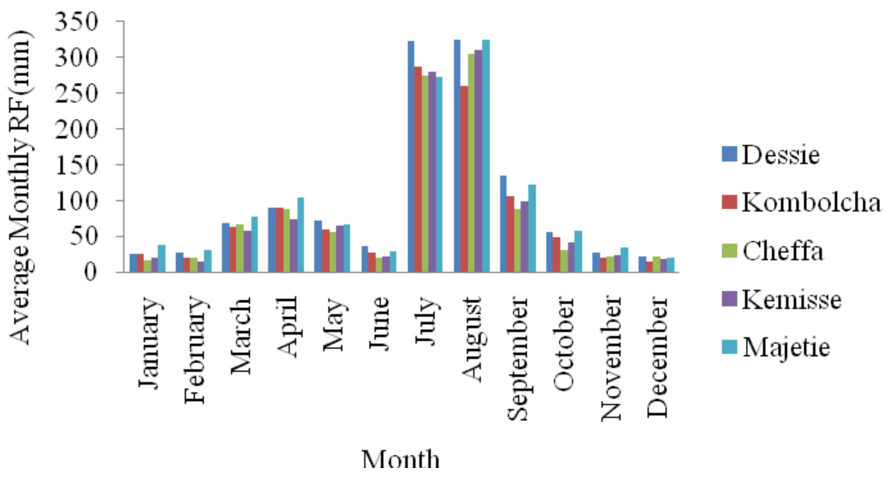


Fig. 3. The Land use land cover of the study area which was classified by the Ministry of Water Resource, Irrigation and Energy in 1987

Table 2. Availability and classes of meteorological data

Station name	Precipitation	Temperature	Relativehumidity	Solarradiation	Wind speed	Class's name	Station coverage area(Km2)	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



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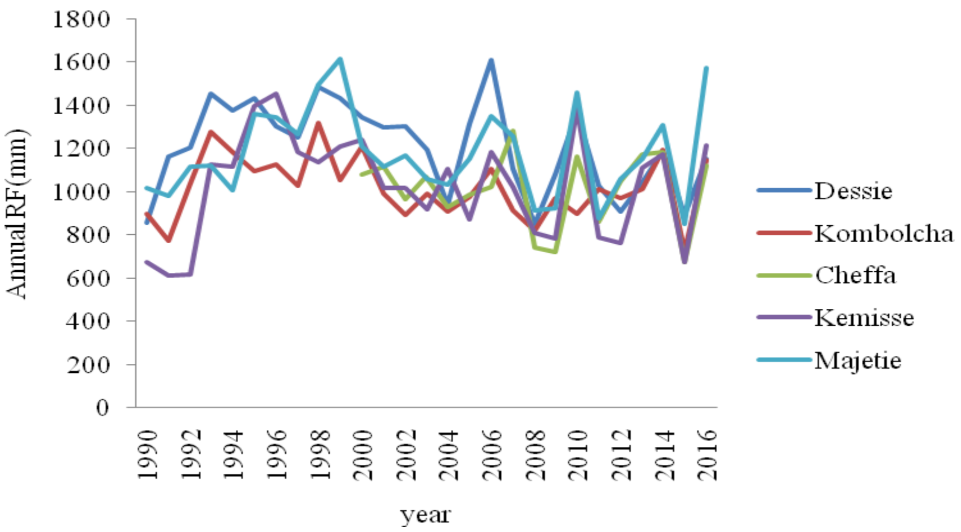


(b)

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

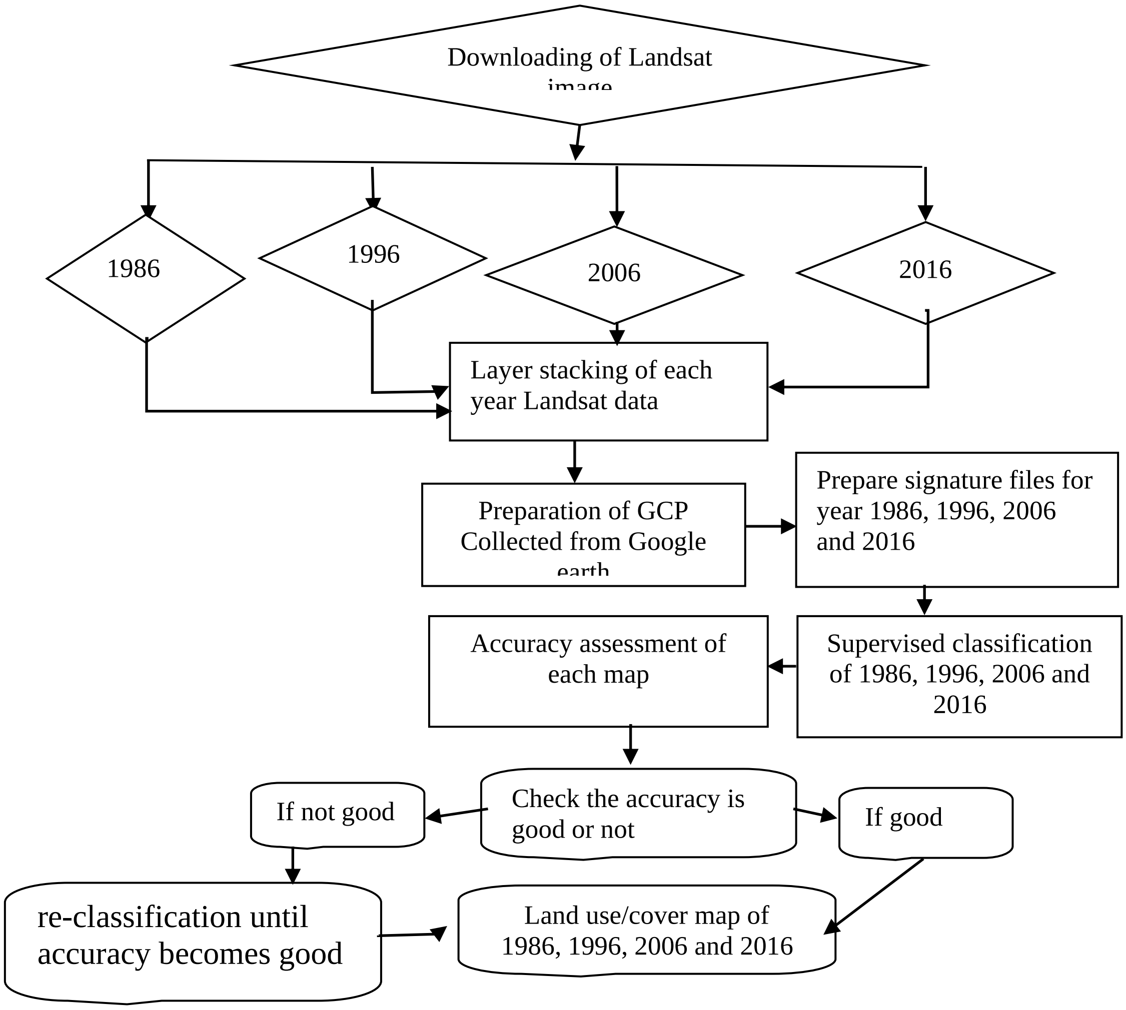


Fig. 5. Methodology of Land use and Land cover classification

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 classification and enhancement for this study were performed using ENVI. ENVI was also used for the preparation of land use land cover data for SWAT input.

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 tools of ENVI were used for the classification of satellite images. The methodology of land use land cover map was show on Fig. 5

A signature level taken was between 15 and 20 for each of the land cover classes as ground truth/verification. Post-classification enhancements were used to reduce the classification errors stemming from base fields, cities, and classes that have similar responses like some crop areas and wetlands. Accordingly, an error matrix was produced for all images in this study.

Land Use and Land Cover Change Detection Analysis

Post classification comparison was used to quantify the extent of land cover changes over the period 1986 and 2016. The estimation of the rate of change for the different land covers is computed based on the following formulas[11].

$$\%\text{Cover change} = \frac{\text{Areai yearx} - \text{Areaiyear x+1}}{\sum_{i=1}^{n} \text{Areai yearx}} * 100$$

Were

Area year x is the area of cover i on the first date

Areai year x+1 is the area of cover i on the second date

$\sum_{i=1}^{n} \text{Areai yearx}$ is the total cover area at the first date

SWAT Model set-up and simulation

SWAT and SWAT-CUP Model Description

SWAT model (i.e., ArcSWAT) is an extension of ArcGIS, which is developed by the United States (US) Department of Agricultural Research Service (ARS). SWAT is a physically based semi-distributed continuous time-scale hydrological model, which works on a daily time step. This model can simulate runoff, sediment, nutrients, pesticide and bacteria transport from agricultural watersheds [1].The hydrological response units(HRU's) are utilized to consider spatial heterogeneity in terms of land cover, soil type and slope class within a water shed. It simulates the hydrological cycle parameters based on the water balance represented in equation below within the watershed [6].

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

Were,

SWt is the final soil water content (mm)
SWo is the initial water content (mm)
t is the time (days)
Rday is the amount of precipitation on day i (mm)
Qsurf is the amount of surface runoff on day i (mm)
Ea is the amount of evapo transpiration on day i (mm)
Wseep is the amount of water entering the vadose zone from the soil profile on day i (mm), and
Qgw is the amount of return flow on day i (mm)

The sensitivity analysis was made by using a built-in SWAT sensitivity analysis tool and SWAT CUP. The sensitivity analysis tool is helpful to model users in identifying parameters that are most influential in governing streamflow response. The calibrated SWAT model is run with the input data including digital elevation model (DEM), soil map, land use map, rainfall, and streamflow.

Model Sensitivity Analysis, Calibration, and Validation as discussed below

Sensitivity Analysis

When a SWAT simulation is taken place there is a discrepancy between measured data and simulated results[12]. So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. The sensitivity is used to estimate the rate of change of model outputs with respect to the change of model inputs. Sensitivity analysis was conducted for the Borkena watershed hydrology to determine the parameters needed to improve simulation results and better understand the behavior of the hydrologic system and evaluate the applicability of the model. Initially, the SWAT simulation was specified to carry out the sensitivity analysis and location of the sub-basin where observed data was compared against simulated output.

Further, selected parameters were entered for the sensitivity analysis with the default lower and upper parameter bounds. Thus, 27 flow parameters were included for the analysis with default values [6]. Finally, the mean relative sensitivity (MRS) values of the parameters were used to rank the parameters and their category of classification.

Table 3. The category of sensitivity

Class	MRS Sensitivity	Category
I	0.00 ≤MRS<0.05	Small to negligible
II	0.05≤MRS<0.2	Medium
III	0.2≤MRS<1	High
IV	MRS>1	Very high

The category of sensitivity was defined based on the classification presented in Table 3[13].

Model Calibration

The time series of discharge at the outlet of the catchment which found near to Kemsie town at 100 38’N latitude and 390 56’E longitude was used as data for calibration and validation for SWAT model, the model was calibrated using the measured streamflow data for 13 years from 1996 to 2008, and the sensitive parameters which govern the watershed were obtained and ranked according to their sensitivity. The 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. The time series data used in this study were shown in Fig. 6

Model Validation

To utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. Streamflow data of 8 years from 2009 to 2016 were used for validation. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenarios.

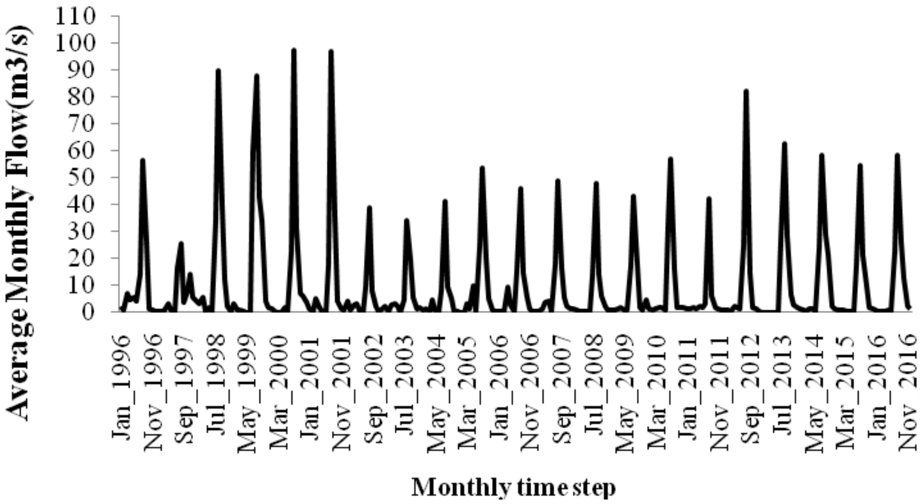


Fig. 6. Average monthly streamflow data of Borkena River

Evaluation of streamflow variability due to LULC change

The flow of a stream is directly related to the amount of water moving off the watershed into the stream channel. It is affected by land use, weather, increasing during rainstorms and decreasing during dry periods. After the image was merged, Google earth was used to identify information classes. Further, the impact of LULC on the variability of streamflow was evaluated for the year 1996 to 2016. Three independent SWAT runs were carried out on a monthly time step for the year 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. The overall methodology of this study are shown on Fig. 7.

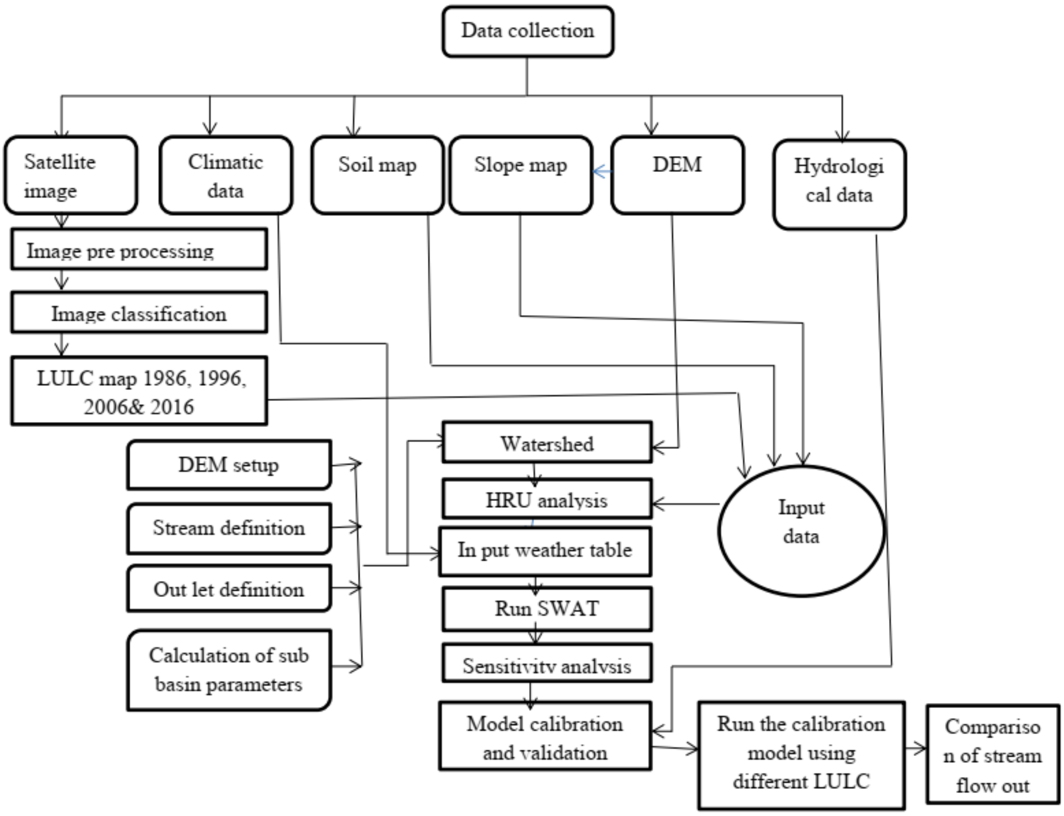


Fig. 7. The conceptual Methodology framework of the study

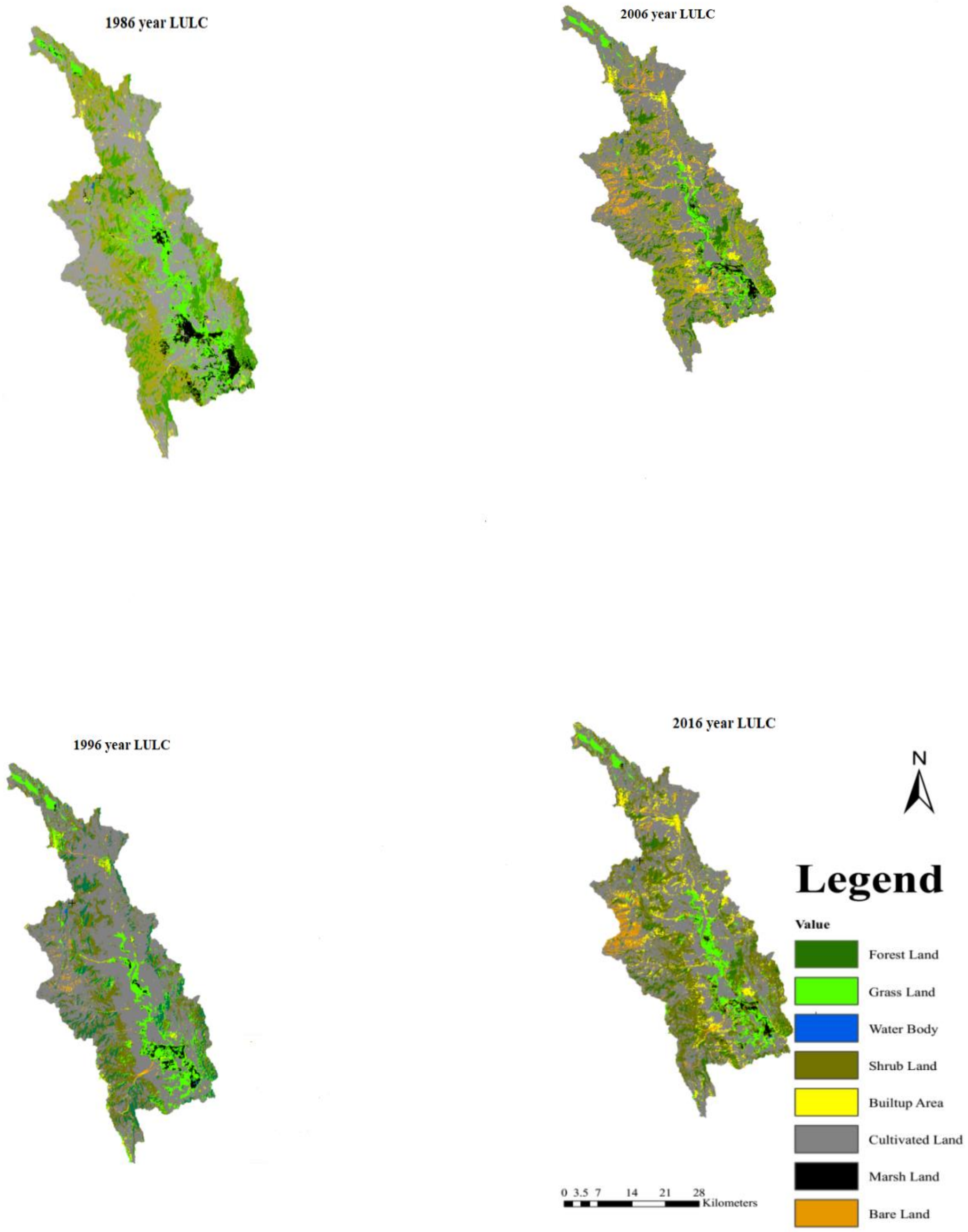


Fig. 8. Land use land cover map over 30 years

RESULTS AND DISCUSSIONS

Land Use Land Cover Change Analysis

The land cover detection the map showing eight (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)) classes of land use/cover were created unifying these classes for 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 53.02% coverage, followed by Shrub Land, Grass land, and Forest land with 19.88%, 11.32%, and 11.23% coverage respectively. Marsh land, Bare land, Built-up area, and Water Body covers small percentages, i.e. 2.70%, 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 45.71%, with shrub land 21.3%, grass land 7.01%, bare land 6.92%, built-up area 4.45%, forest 5.13%, and marsh land 0.84%, and water body 0.064%.

These results remarked, there were 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 land use/ cover resulted in a change in on the other land cover types.

The land use and land cover detection was done by using ENVI and GIS. (Fig. 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 of built-up area and bare lands in both periods. On the other hand, forest lands were decreased.

This change is due to the demand of urban expansion. According to Kebrom Tekle and Lars Hedlund [7],the urban expansion has great impact on hydrology of the area.

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 influence on the streamflow of the watershed.

Stream Flow Calibration and Validation Analysis

Calibration was done for the sensitive parameters of the SWAT model in the watershed using observed streamflow. The Calibration result showed that the coefficient of determinations (R^2) and the Nash-Sutcliffe Efficiency (NSE) are 0.81 and 0.79 respectively (Fig. 10a). 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 (Fig. 10b). In general, the model performance assessment indicated a good correlation and agreement between the monthly measured and simulated flows.

Evaluation of streamflow due to land use land covers change

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

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 4).

Table 4. Streamflow simulations on Mean annual streamflow and change for 1996, 2006, 2016 LULC

	Mean annual streamflow (m^3/s)			**Mean annual flow change due to LULC change of**					
	LULC map			**1996 to 2006**		**2006 to 2016**		**1996 to 2016**	
Period	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**

Table 5. Wet season and dry season streamflow simulation and their variability

	Seasonal streamflow (m^3/s) LULC						Seasonal streamflow changes due to LULC change of					
	1996		**2006**		**2016**		**1996 to 2006**		**2006 to 2016**		**1996 to 2016**	
Period	dry	Wet	Dry	Wet	dry	Wet	**Dry**	**wet**	**dry**	**wet**	**dry**	**wet**
1996-2016	2.34	31.52	1.94	.36	1.8	36.96	**-0.40**	**3.84**	**-0.14**	**1.6**	**-0.54**	**5.44**

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 change due to an increase of built-up area and bare lands for in both periods i.e. 1996-2006, 2006 -2016.

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 5**)**. 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.

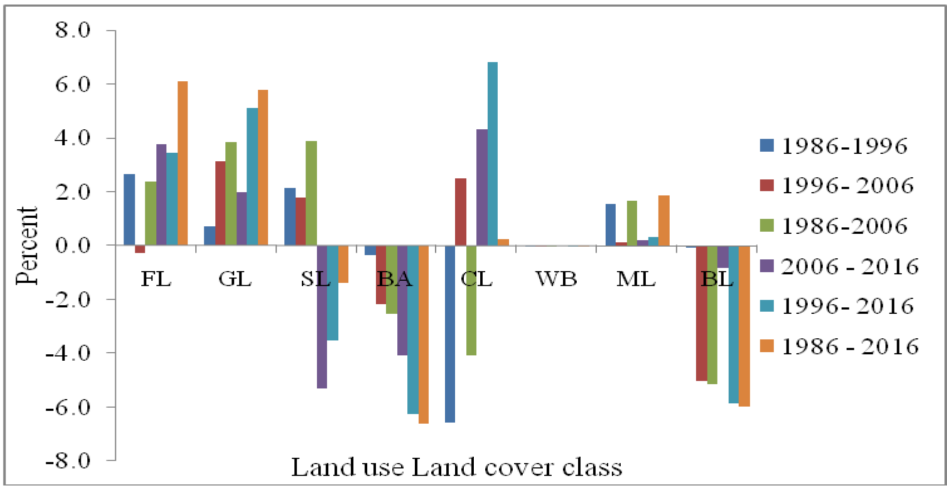
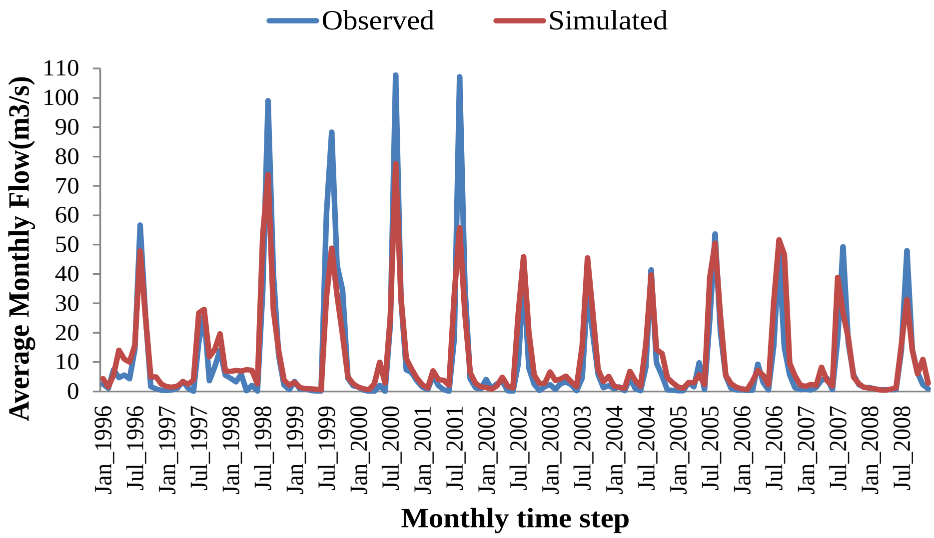
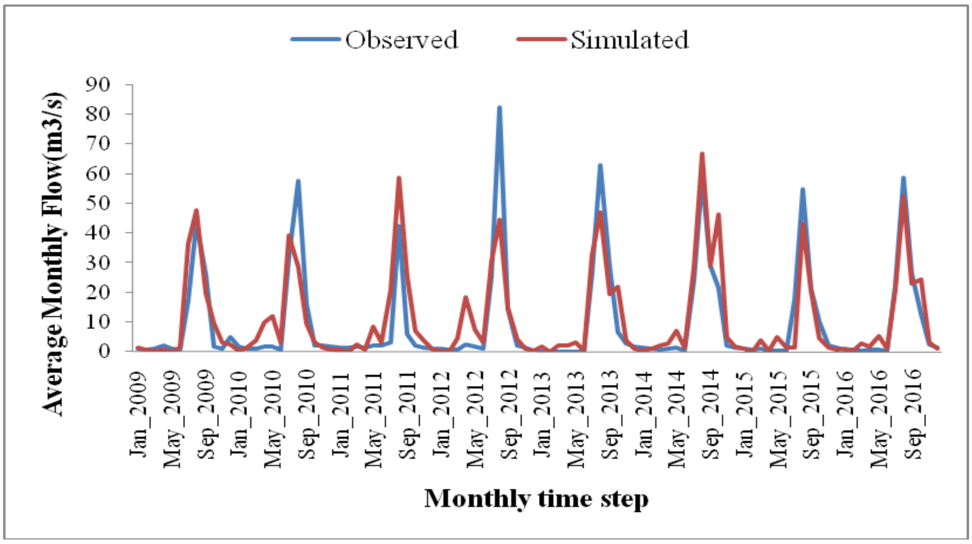


Fig. 9. The land use/cover change in percentage area of Borkena catchment



(a)



(b)

Fig. 10. Average Monthly Observed and Simulated Flow Calibration (1996-2008) and Validation (2009-2016) period

CONCLUSIONS

From this study, it can be concluded that the Borkena watershed has experienced a substantial change in land use 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 in-crease of the human population which changes the whole Borkena watershed in general and some sub-watersheds in particular. The scope of this study would be limited to evaluate the impact of land use/land cover change effect on streamflow in the catchment of Borkena. The study would not consider the impact of climate change and soil erosion on the water resources of the catchment.

The changes in land use have resulted in changes in streamflow, in which the expansion of urban and bare land results in an increase in surface runoff. This change (increase or decrease) in streamflow was due to LULC over a period of 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 as well as in other regions of Ethiopia.

ACKNOWLEDGEMENTS

The authors are thankful to Ministry of Water and Energy, National Meteorological Agency and Ministry of Agriculture, Ethiopia for providing necessary data. We also acknowledge the anonymous reviewers, whose comments greatly improved the paper.

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Conflict of Interest

The author declares no conflict of interest.