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ORIGINAL ARTICLE

# Effect of watershed characteristics on river flow for the case of two watersheds, Megech and Gumaro, Upper Blue Nile Basin, Ethiopia

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**Abstract**
Land degradation is a series of problems in Ethiopia's highlands, particularly in the Upper Blue Nile River Basin reflected in the form of soil erosion and reduce soil fertility from time to time. The effect of watershed characteristics on the river flow of those watersheds was evaluated by distributing a physically based hydrological model known as the soil and water assessment tool model. The model was calibrated for the river flow from 1992 to 2006 and validated for the period from 2007 to 2014. The performance of the model was evaluated based on performance rating criteria, coefficient of determination, and Nash and Sutcliff efficiency on monthly based value, the coefficient of determination ($R^2$) and Nash–Sutcliffe coefficient was greater than 0.6 and 0.5 for all scenarios on both watersheds, respectively. The land-use land-cover change scenario, the climate characteristics, and the slope change scenario was developed, from those analyses, it was found that has been a substantial decrease or increase in forest land, shrubland, grassland, and expansion of agricultural land. The mean annual streamflow of 2010 LULC decreased by 1.44% for 2010 from 2003 LULC and 5.23% for 2018 from 2010. Because of reduced cultivated land from 2010 up to 2018 and increased grassland and plantation in the Megech watershed and 2010 LULC decreased by 0.9% for 2010 from 2003 LULC and 2.04% in 2018 from 2010. This distributed physically based hydrological model has been applied for the evaluation of physical catchment characteristics with significant differences which was Cropland for Megech and Gumaro watersheds which were 67.28% and 61.5%, respectively, for the 2003 LULC, 64.94% Megech, and 58.89% for Gumaro watershed for 2010LULC and 51.95% for Megech and 42.12% for Gumaro watershed, similarly, Eutric Cambisols were covering large areas for both watersheds.

**Keywords** Physical catchment characteristics · SWAT model · SWAT-CUP · Physically based hydrological model · Megech and Gumaro watershed

## Introduction

Ethiopia has twelve major river basins. Most of them are untapped for modern irrigation and energy development. According to MoWR's (2006) water sector strategy report, only 1972.250 km$^2$ of potential irrigable lands are developed, so the existing irrigation development in Ethiopia, as compared to the resources the country has, is negligible. This might be besides financial constraints; the uncertainties of data on the rivers discharge are a problem for the development of the sector. Currently, there are great efforts toward developments in some river basins for energy generation and large-scale irrigation projects to sell power to neighboring countries and attain food self-sufficiency, respectively.

The flow and water quality of a river are based on land-use activities within the watershed and other specific characteristics of the watershed, such as physical catchment properties (PCC) and management of watercourse features is an integral part of preserving safe productive rivers for agricultural and drinking purposes (Furlan et al. 2012). Land destruction, migration of people, and loss of water quality are major problems in Ethiopia's highlands due to inadequate land-use practices and unsuitable management structures that play a major role in causing land degradation, sediment transport, depletion of agricultural inputs, and, most significantly, loss of water supplies in both quantity and quality (Setegn et al. 2010). Land degradation is a major cause of the deposition of sediment in major reservoirs in Ethiopia, particularly in Blue Nile River Basin reflected in

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the form of soil erosion and soil fertility decline from time to time (Abtew and Melesse 2008).

Megech and Gumaro Watersheds are one of the watersheds draining into the sub-basin of Lake Tana, and this watershed is under a pressure because of the growing population and increasing demand for water mainly for irrigation, which is not practiced well nowadays in the catchment, and also a great demand of water for domestic and livestock consumption purposes. Therefore, the improvement of techniques to assist in the sustainable management of the water resource system of the catchment is a crucial issue as water is a limited resource. Megech and Gumaro watersheds from the outlet have an area of 425.5800 km$^2$ and 353.9460 km$^2$, respectively, which have an impact on the Blue Nile River Basin. This shows that the problem of both watersheds is significant in Blue Nile River Basin development.

This problem occurred due to the unregulated drainage available in this field of research and yet there is no detail studied in the watershed of Megech and Gumaro related to the effects of watershed characteristics on river flow. Therefore, the main objective of this study is to evaluate the effect of watershed characteristics on river flow for the two watersheds Megech and Gumaro watersheds in the upper Blue Nile basin.

## Materials and methods

### Description of the study area

Megech and Gumaro watersheds are located at the source of the Blue Nile River in the Amhara Regional State's North Gondar District, near Lake Tana. Megech watershed is located on the right side of the Gondar-Bahir Dar main road, about 3 km southeast of Azezo, and Tewodros Airport (Fig. 1). Megech watershed is located upstream of the dam with a steep mountainous area Within the watershed, the limits of which were marked at 1:50,000 (Fig. 1), Gondar town and Angereb reservoir are located.

The flow of the Megech river during the rainy months has a high velocity, and the sediments borne by the floods are mainly boulders, gravel, sand, and silt. That's the normal behavior of a mountainous river, the Megech river. The total upstream watershed area is 425.57 km$^2$, completely

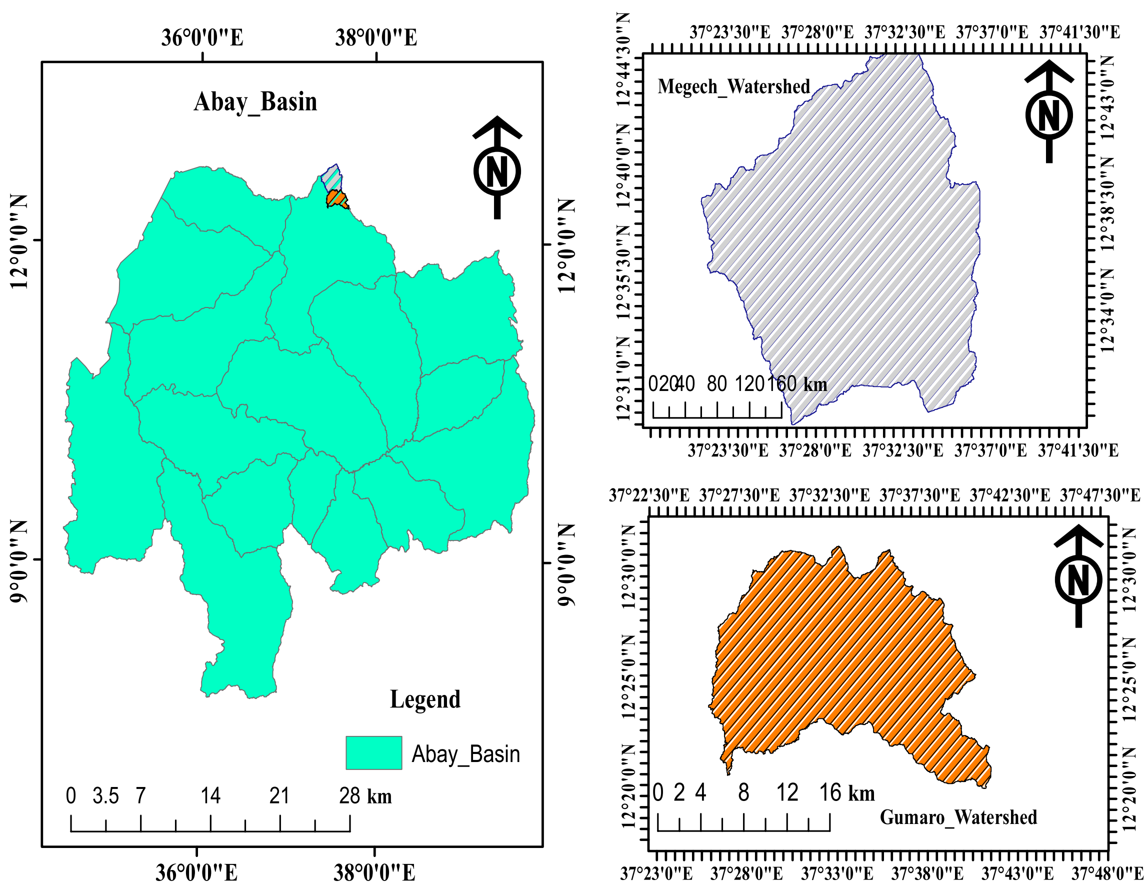



**Fig. 1** Location map of the study area

calculated. Watershed runoff, running to the reservoir from 12° 29′ latitude to 37° 27′ E longitude.

The Gumaro watershed, located in Ethiopia's northwestern Amhara region at the border of the Megech watershed between 12° 25′ 35.052' N and 37° 33′ 13.981′ E longitude (Fig. 1), has an area of 353.94 $km^2$. The mainstream (Gumaro river) drains into Lake Tana and originates from the watershed's northern mountainous portions. Megech and Gumaro watersheds have rugged topography with an elevation range of over 3000 m asl in the upper part and about 1850 m asl in downstream parts and 2880 m asl in the upper part and 1750 m asl in the lower part, respectively.

The climate of the Megech watersheds is characterized by a rainy season from May to October, with rainfall ranging from 67 to 306 mm/year and the annual maximum temperature ranges from 23oc in July to 30oc in March, while the minimum temperature ranges from 11oc in January to 13.6oc in April and May for Megech watershed. Gumaro rainfall ranges from 769 to 1204 mm/year, and the mean minimum and maximum monthly temperatures are 13.59 °C and 26.9 °C in April and May.

## Data collection and analysis

For this study, daily river discharge data, metrological data, land use, and soil data were collected. The daily river discharge data from the two rivers (Megech and Gumaro) and soil map collected from the Ministry of Water, Irrigation and Electricity (MoWIE), daily metrological data such as rainfall, minimum, and maximum temperature, relative humidity, wind speed, and daily sunshine hours collected from Metrological Agency of Ethiopia (EMA).

## Hydrological data

For both Megech and Gumaro watersheds, the streamflow data obtained from MoWIE have longer time series data. Regular time-series data from 1992 to 2014 GC were used for this analysis. These data were used for a SWAT hydrological modeling parameter and to see their relation to the characteristics of the watershed.

## Meteorological data

Ethiopian meteorological agency classified meteorological stations into four, each identified by a code. Code one stations (primary stations) are stationed at which observations such as rainfall, relative humidity, maximum and minimum temperature, wind speed, and sunshine duration were taken every three hours.

## Digital elevation model (DEM) hydro-processing

DEM is required to extract the watershed and prepare a dataset for further processing as input for hydro-processing purposes. A 12.5 m resolution DEM is used in this analysis by downloading from USGRS earth explorer.

## Evaluation of physical catchment characteristics (PCC)

All points enclosed within an area from which rain falling at these points would contribute water to the outlet are known as a watershed. The physical catchment characteristics (PCC) including geography, physiography, geology, land use, and cover condition are typically influencing runoff in the watershed.

### Land use–land cover

Changing the magnitude and pattern of the precipitation, peak flow, groundwater levels, land use, and cover condition would influence the hydrological balance of the watershed. A land cover map was obtained from USGRS in this analysis by downloading a Landsat image and classifying the image using ERDAS imagine 2012 after classification accuracy assessment was done between the classified image and the ground truth point by a matrix error method.

### Climate characteristics

For a given area, the climatic characteristics include precipitation, temperature, wind, relative humidity, and other metrological elements over a long period. For this analysis, climate index, also referred to as the index of humidity/aridity, is the ratio of mean annual long-term precipitation to mean annual long-term possible evapotranspiration (Atanaw et al. 2015).

## Model setup

### Watershed delineation

The first step in providing feedback to the SWAT model is to delineate the watershed from a DEM. To have spatial characteristics, inputs entered in the SWAT model are ordered. Until continuing with spatial input data, i.e., the soil map, LULC map, and DEM would be projected into the same parameters.

### Hydrological response units (HRU)

Arc-SWAT's HRU analytics tool helped load land use, soil type, and slope chart into the project. This would overlap the delineated watershed by Arc SWAT, and the planned land use and type of soil. In addition to land use and soils, HRU analyses in SWAT include divisions of HRUs by slope level.

### Weather generation

The SWAT model comes with an automated generator of weather data. However, running the model requires some input data. The appropriate input data are the daily precipitation levels, maximum and minimum temperature, solar radiation, wind speed, and relative humidity.

## Model calibration and validation

### Calibration

Calibration is the process by which parameters for the model are modified to fit the model performance with the observed data. The simulated discharge along with the observed data at the outlet of the watershed would be used for model calibration and validation.

### Validation

The model was tested against an independent collection of calculated results, to use the validated model to predict the efficacy of future potential. This testing of a model is generally referred to as model validation on an independent collection of data.

### Model evaluation

The value of $R^2$ is a measure of the relationship strength between the observed and simulated values and the value of $R^2 > 0.6$ (Malagó et al. 2015). The simulation efficiency of the Nash–Sutcliffe (NSE) shows how well the observed vs simulated value plot matches the 1:1 line. If the value calculated is the same as all forecasts, then NSE is 1. If the NSE is between 0 and 1, the difference between the measured and the expected value is indicated (Abbaspour et al. 2007).

## Results and discussion

### Slope classification

The slope is one of the factors which affects river velocity coming from the watershed. Where higher slope results in a higher velocity of flow, therefore the water would travel quickly to reach the river outlet (Zhang et al. 2015). For these studies, a higher slope which is greater than 20 has a higher velocity and shows that the area is steeper which might lead to the erosive action of water erosion since infiltration was less in the area (Table 1) and (Fig. 2).

### Land use and the land cover map

The model was performed based on the climate data from 1992 to 2014, the three land use–land cover maps developed three models run by using land use–land cover, slope change analysis, and climate data change were used to assess the impact of watershed characteristics streamflow.

To evaluate the variability stream flow by land use–land cover change, three independent SWAT Runs were carried out on monthly time steps using 2003, 2010, and 2018

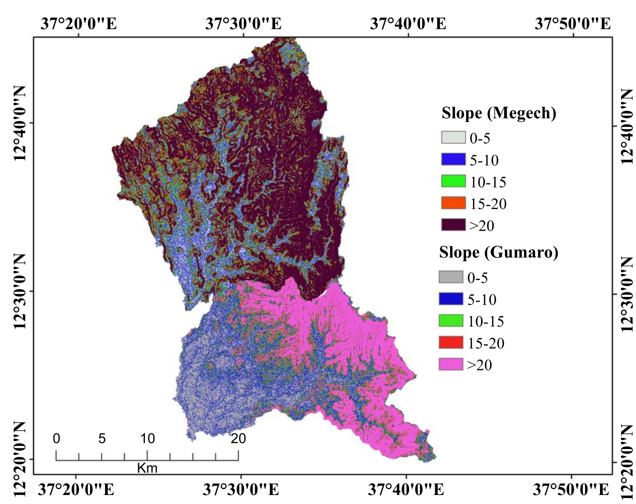



**Fig. 2** Slope classification for the two watersheds

**Table 1** Slope classification

| Class | Slope rang | Gumaro_area (ha) | Gumaro _area (%) | Megech area (ha) | Megech area (%) |
|---|---|---|---|---|---|
| Class 1 | 0–5 | 8148.5 | 23.04 | 489.2 | 0.96 |
| Class 2 | 5–10 | 8194.6 | 23.17 | 1411.3 | 2.77 |
| Class 3 | 10–15 | 4133.4 | 11.69 | 4948.7 | 9.72 |
| Class 4 | 15–20 | 3013.05 | 8.52 | 2957.1 | 5.81 |
| Class 5 | > 20 | 11880.2 | 33.59 | 41089.9 | 80.73 |

land use–land cover maps. The SWAT model parameter was observed from each run, based on the simulation output the streamflow variability caused by land use–land cover change was assessed, and a comparison was made on streamflow change from the model output. In the 2003 land use–land cover map, cultivated land was the covered largest area which was 67.28% of the total watershed area for the megech watershed and 61.5% for the Gumaro watershed (Table 2, Fig. 3A).

**Table 2** Land use–land cover map of 2003

| | | Megech LULC (2003) | | Gumaro LULC (2003) | |
|---|---|---|---|---|---|
| Major LC | SWAT Code | Area (Km$^2$) | Area (%) | Area (Km2) | Area (%) |
| Built up area | URB | 8.68 | 1.96 | – | – |
| Cultivated land | CRL | 302.64 | 67.28 | 217.39 | 61.5 |
| Forest land | FRST | 8.85 | 2.002 | 0.83 | 0.23 |
| Grass land | GRSL | 77.22 | 17.46 | 11.91 | 3.37 |
| Shrubland | SBL | 50.58 | 11.298 | 122.52 | 34.66 |

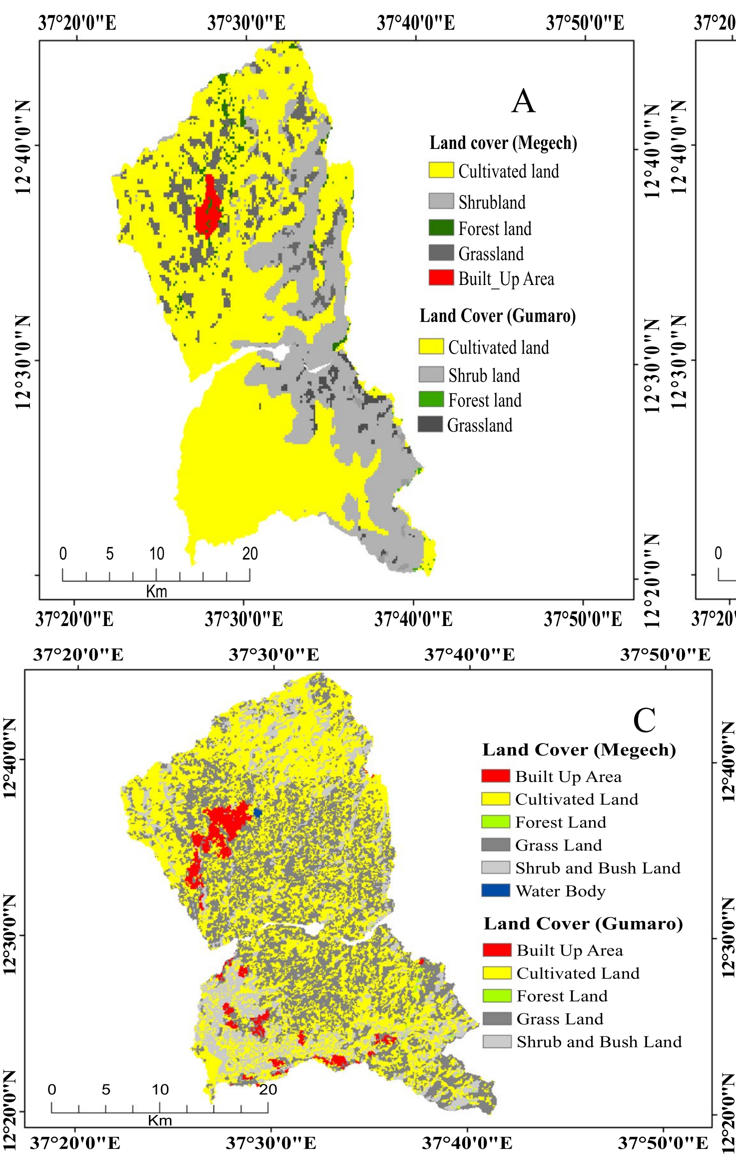



**Fig. 3** LULC classification for both watershed at 2003 (**A**), 2010 (**B**), and 2018 (**C**)

Land use–land cover in 2010, cultivated land was the covered largest area which was 64.94% of the total watershed area for the Megech watershed and 58.89% for the Gumaro watershed (Table 3) and (Fig. 3B). And also, In the LULC in 2018, cultivated land was the covered largest area which was 51.95% of the total watershed area for the Megech watershed and 42.12% for the Gumaro watershed (Table 4) and (Fig. 3C).

## Accuracy assessment of classified image

Accuracy evaluation is an important component of any project. Its classification contrasts the classified image with another source of data that is considered reliable ground truth data. Ground truth data could be guided by the analysis of invisible, current classified hypothetical, or GIS data layers with high resolution. The most common method of determining the accuracy of the classified map is to construct a random point from the ground truth data and compare it in an uncertainty matrix with the classified data.

From these assessments, the overall accuracy for the classified image was 94% for Megech (Table 5) and 95% for Gumaro (Table 6) watershed, respectively, which indicates that the image obtained from classification and the ground truth were and the analysis was good. The error commission for each classification was analyzed by reducing user accuracy from the full percentage of analysis (Tables 5, 6).

## Soil classification

Soil data are another spatial input required by the Arc SWAT model for the major soil classification using soil map data.

**Table 3** Land use–land cover map of 2010

| Major LC | SWAT code | Megech LULC (2010) | | Gumaro LULC (2010) | |
|---|---|---|---|---|---|
| | | Area ($Km^2$) | Area (%) | Area ($Km^2$) | Area (%) |
| Built Up area | URB | 10.47 | 2.37 | 5.01 | 1.4173 |
| Cultivated land | CRL | 287.21 | 64.94 | 208.19 | 58.89 |
| Forest land | FRST | 40.24 | 9.1 | 28.73 | 8.13 |
| Grass land | GRSL | 57.19 | 12.93 | 30.91 | 8.74 |
| Shrubland | SBL | 40.28 | 9.11 | 72.62 | 20.54 |
| Water body | WATR | 0.0053 | 0.0012 | – | – |

**Table 4** Land use–land cover map and classification at 2018

| Major LC | SWAT code | Megech | | Gumaro | |
|---|---|---|---|---|---|
| | | Area ($Km^2$) | Area (%) | Area ($Km^2$) | Area (%) |
| Built-up area | URB | 18.16 | 3.68 | 10.07 | 2.8 |
| Cultivated land | CRL | 256.03 | 51.95 | 149.02 | 42.12 |
| Forest land | FRST | 0.02 | 0.004 | 1.2 | 0.33 |
| Grass land | GRSL | 160.28 | 32.52 | 121.9 | 34.43 |
| Bar land | BARR | 57.85 | 11.74 | 71.845 | 20.3 |
| Water body | WATR | 0.53 | 0.11 | – | – |

**Table 5** Result of accuracy assessment for Megech

| Automated classification result | Built-up | Cultivated | Forest | Grass land | Shrub and bush land | Water | Row total | User's accuracy |
|---|---|---|---|---|---|---|---|---|
| Built-up | **24** | 0 | 0 | 1 | 0 | 0 | 25 | 96.0 |
| Cultivated | 0 | **54** | 0 | 1 | 1 | 0 | 56 | 96.4 |
| Forest | 1 | 0 | **13** | 1 | 0 | 0 | 15 | 86.7 |
| Grass land | 1 | 2 | 1 | **45** | 0 | 0 | 49 | 91.8 |
| Shrub and bush land | 1 | 0 | 1 | 0 | **32** | 1 | 35 | 91.4 |
| Water | 0 | 0 | 0 | 0 | 0 | **20** | 20 | 100.0 |
| Column total | 27 | 56 | 15 | 48 | 33 | 21 | *200* | |
| Producers accuracy | 88.9 | 96.4 | 86.7 | 93.8 | 97.0 | 95.2 | | |

The bold shows the same relationship between the classification from the vertical and horizontal for the accuracy assessment

**Table 6** Result of accuracy assessment for Gumaro

| Automated classification result | Cultivated | Forest | Built-up | Grassland | Shrub bush | Row total | Error commission | User_accurecy |
|---|---|---|---|---|---|---|---|---|
| Cultivated | **48** | 0 | 0 | 0 | 1 | 49 | 0.020 | 98.0 |
| Forest | 0 | **11** | 0 | 0 | 1 | 12 | 0.083 | 91.7 |
| Built-up | 0 | 0 | **24** | 0 | 0 | 24 | 0.000 | 100.0 |
| Grassland | 1 | 1 | 0 | **41** | 0 | 43 | 0.047 | 95.3 |
| Shrub_bush | 2 | 0 | 1 | 1 | **37** | 41 | 0.098 | 90.2 |
| Column total | 51 | 12 | 25 | 42 | 39 | *169* | | |
| Error commission | 0.1 | 0.1 | 0.04 | 0.02 | 0.05 | | | |

The bold shows the same relationship between the classification from the vertical and horizontal for the accuracy assessment

**Table 7** Megech watershed soil classification

| Soil type | Area (Km$^2$) | Area (%) |
|---|---|---|
| Leptosols | 9.23 | 1.9 |
| Eutric cambisols | 312.63 | 63.4 |
| Eutric fluvisols | 3.69 | 0.8 |
| Eutric regosols | 68.75 | 13.9 |
| Calcic xerosols | 18.78 | 3.81 |
| Orthic luvisols | 0.17 | 0.035 |
| Calcic cambisols | 11.52 | 2.4 |
| No data | 2.48 | 0.503 |

**Table 8** Gumaro watershed soil classification

| Soil type | Area (Km$^2$) | Area (%) |
|---|---|---|
| Eutric cambisols | 177.8 | 51.5 |
| Dystric nitisols | 11.2 | 3.3 |
| Eutric regosols | 63.4 | 18.4 |
| Chromic vertisols | 65.5 | 18.9 |
| Calcic xerosols | 25.6 | 7.4 |
| Leptosols | 1.90 | 0.6 |

Major soil type classifications of the Megech and Gumaro watersheds have been tabulated in (Tables 7, 8, and Fig. 4). Eutric cambisols covered the largest area for both watersheds and Chromic vertisols for Gumaro and Eutric regosols for Megech watersheds were the second covers largest area.

## Sensitivity analysis

In rainfall-runoff modeling, it is often not possible to find the unique best parameter set, different parameter sets may be given similar good results during calibration. To reduce uncertainty and to define the optimum parameter set, it is essential analysis on model parameters. Sensitivity analysis has been carried out for 27 parameters. But only a few sensitive parameters were considered and the parameters with their mean relative sensitivity value at the outlet after calibration for the study area watersheds were selected.

Tables 9 and 10 used to show the best parameter used to give the best fit parameter for calibration and validation analysis and the base flow alpha factor, curve number, depth in the shallow aquifer, and initial depth of water in the shallow aquifer was found to be the top sensitive parameters.

## Model calibration and validation

The SWAT model has a large number of parameters and many outputs; thus, an initial collection of parameters improves the calibration and validation process and eliminates the uncertainties associated with different parameters. Manual and automated methods of calibration were applied. Initially, the parameters were manually calibrated until the model simulation results for the period 1992 to 2006 as per the model output indicates, appropriate result. Next, the ultimate parameter as initial values for the autocalibration process, 16 values that were manually calibrated were used. For validation, streamflow data for eight years from 2007 to 2014 were used. The performance measurements of the statistical model used in the calibration process were also used in streamflow validation.

### Scenario I: calibration and validation using land use–land cover (LULC) 2003

The land cover map for the Gumaro watershed in 2003 covered about 61.5% cultivated land, 3.37% grassland, 0.23% by forest land, and 34.66% of shrubland (Table 2 and Fig. 3A). The land cover map for the Megech watershed in 2003 covered about 67.28% of cultivated land, 17.46% of grassland, 2.002% of forest land, 11.298% of shrubland, and 1.96% by built-up area (Table 2 and Fig. 3A). Then, by using this land use classification calibration and validation for both watersheds have been done (Figs. 5, 6).

Fig. 4 Soil classification

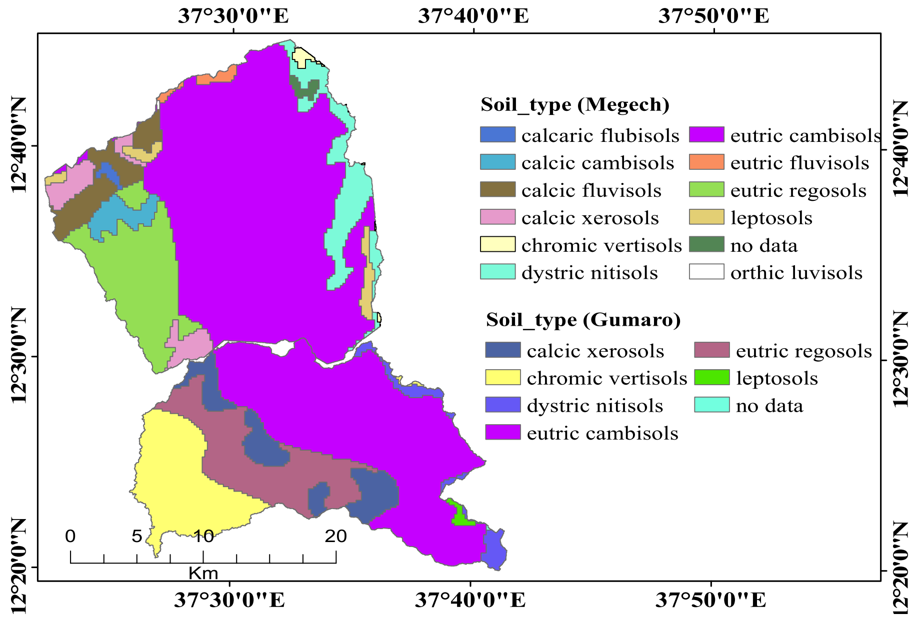



Table 9 Results of sensitivity analysis for Gumaro watershed

| Flow parameter (SWAT) cod | Lower bound | Upper bound | Fitted value | Sensitivity rank |
|---|---|---|---|---|
| CN2 | −0.25 | 0.25 | 0.185 | 1 |
| ALPHA_BF | 0 | 1 | 0.0179 | 2 |
| GWQMN | 0 | 5000 | 512.603 | 5 |
| REVAPMN | 0 | 500 | 332.1 | 6 |
| SOL_AWC | −0.25 | 0.25 | 0.102 | 3 |
| CANMX | 0 | 10 | 1.369 | 4 |
| ESCO | 0 | 1 | 0.0908 | 11 |
| SOL_K | −0.25 | 0.25 | 0.167 | 10 |
| GW_ | 0.02 | 0.2 | 0.1529 | 7 |
| REVAP | 0 | 150 | 92.109 | 9 |
| CH_K2 | 0 | 1 | 0.98 | 8 |
| RCHRG_DP | | | | |

Table 10 Results of sensitivity analysis for Megech watershed

| Flow parameter (SWAT) cod | Lower bound | Upper bound | Fitted value (Megech) | Sensitivity rank |
|---|---|---|---|---|
| CN2 | −0.25 | 0.25 | 0.17167 | 2 |
| ALPHA_BF | 0 | 1 | 0.07927 | 1 |
| GWQMN | 0 | 5000 | 312.457 | 5 |
| REVAPMN | 0 | 500 | 298.6 | 6 |
| SOL_AWC | −0.25 | 0.25 | 0.1932 | 9 |
| CANMX | 0 | 10 | 3.976 | 4 |
| ESCO | 0 | 1 | 0.4918 | 11 |
| SOL_K | −0.25 | 0.25 | 0.2107 | 10 |
| GW_ | 0.02 | 0.2 | 0.10209 | 7 |
| REVAP | 0 | 150 | 131.9 | 3 |
| CH_K2 | 0 | 1 | 0.708 | 8 |
| RCHRG_DP | | | | |

### Scenario II: calibration and validation using land use–land cover (LULC) 2010

The land cover map for the Gumaro watershed in 2010 covered about 58.89% of cultivated land, 8.74% of grassland, 8.13% by forest land, 20.54% by shrubland, and 1.4173% by built-up area. The land cover map for the Megech watershed in 2010 covered about 64.94% of cultivated land, 12.93% by grassland, 9.1% of forest land, 9.11% by shrubland, 2.37% by built-up area, and 0.0012% water body. At that point, by utilizing this land use characterization calibration and validation for the two watersheds have been done (Figs. 5, 6, 7, 8).

### Scenario III: calibration and validation using LULC 2018

The land cover map for the Gumaro watershed in 2018 covered about 42.12% of cultivated land, 34.43% of grassland, 8.13% of forest land, 20.3% by shrubland, 0.33% by forest land, and 2.8% by built-up area. The land cover map for the Megech watershed in 2018 covered about 51.95% cultivated land, 32.52% grassland, 0.004% by forest land, 11.74% by shrubland, 3.68% by built-up area, and 0.11% by waterbody. At that point, by utilizing this land use characterization calibration and validation for the two watersheds have been done (Figs. 9, 10).

The SWAT model was simulated for the three-time periods corresponding to the land use map of 2003, 2010, and 2018. Simulation runs were conducted on monthly basis to compare the modeling outputs using 2003, 2010, and 2018 land maps for both watersheds. A comparison of streamflow from the model output using a land use map

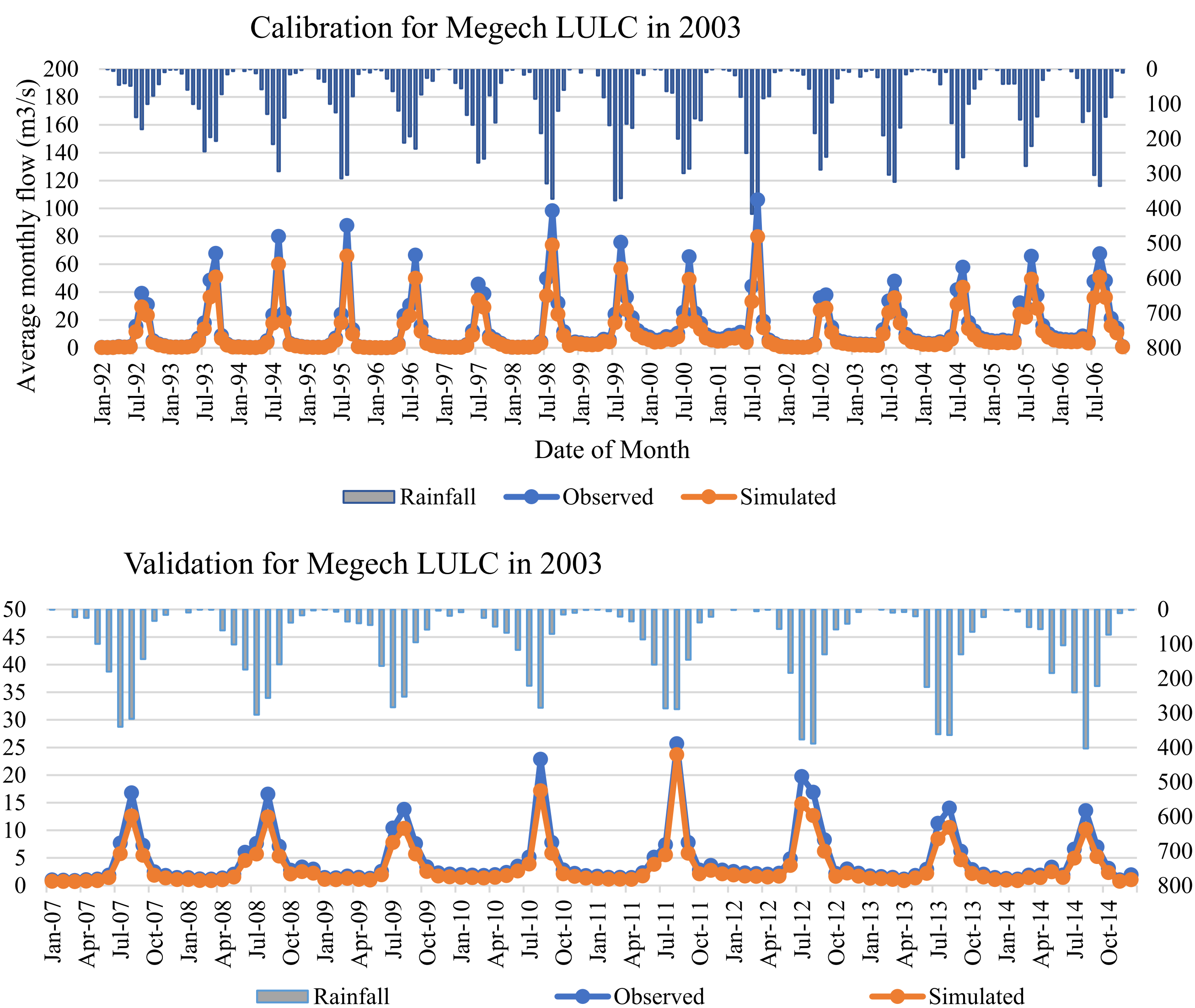



**Fig. 5** Megech observed and simulated streamflow for the calibration and validation

and average annual streamflow from the watershed were presented, showing the significant change, and the result would be described in (Tables 9, 10).

The result indicated that the mean annual streamflow of 2010 land use–land cover (LULC) decreased by 1.44% for 2010 from 2003 LULC and 5.23% for 2018 from 2010. Because of reduced cultivated land from 2010 up to 2018 and increased grassland and plantation in the Megech watershed and 2010 land use–land cover (LULC) was decreased by 0.9% for 2010 from 2003 land use–land cover (LULC) and 2.04% for 2018 from 2010. In the hydrological balance of Lake Tana upper Blue Nile, Ethiopia, he concludes that expansion and reduction of agricultural land were strong relations for increasing and decreasing of streamflow from the watershed and decreased streamflow when increased afforestation (Alemu 2011).

## Model evaluation

After calibrating for flow, it was executed and the hydrographs are well captured. The agreement between the measurement and simulation is generally good, which is verified by NSE and $R^2$, and an acceptable result was obtained according to the model evaluation guideline (Tables 11, 12). The results of these tests illustrated that the monthly coefficient of determination ($R^2$) and Nash–Sutcliffe coefficient were 0.67 and 0.75 for the calibration period, 0.71 and 0.79 for the validation period. The calibration and validation period of the model was 23 years from 1992 to 2014 G.C. The SWAT model was run after sensitivity analysis based on the fitting value from SWAT Cup output. The percent bias of the model for this

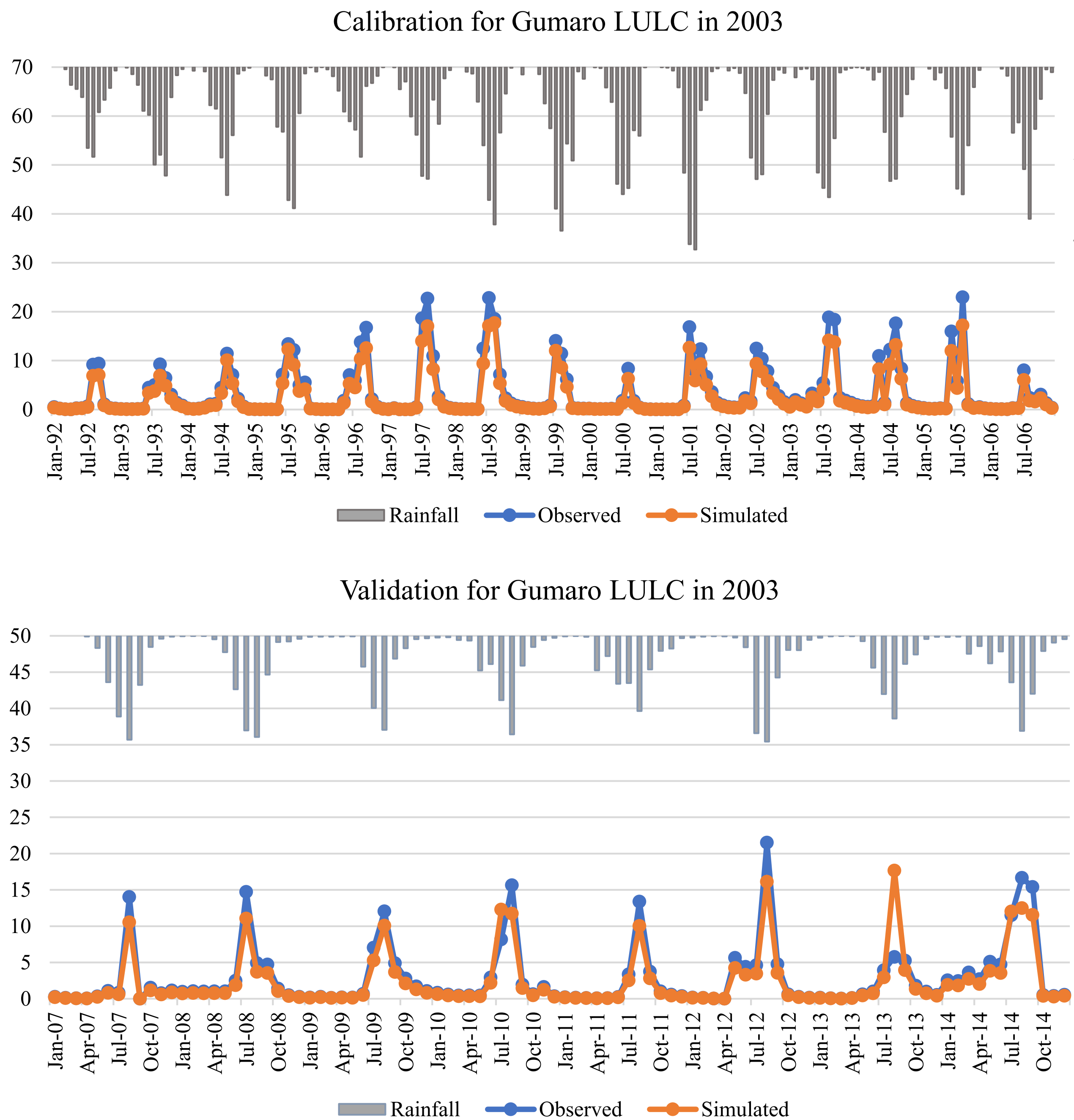



**Fig. 6** Gumaro observed and simulated streamflow for the calibration and validation

study is 12.4% for calibration and 9.63% for validation for the Megech watershed. The performance of the model was evaluated based on performance rating criteria, coefficient of determination, and Nash and Sutcliff efficiency. The overall performance of the two watersheds gives a satisfactory result. The physical catchment characteristics have high differences in $R^2 > 0.6$ and NSE > 0.5. So, the model performance of this study was given good results for all land use–land cover (Tables 11, 12).

## Rain falls effects on streamflow

Rainfall influences the streamflow in multiple ways for the watershed, the rate of rainfall, the period of rainfall, and the amount of annual rainfall that affect the streamflow. An average annual rainfall sum of 23 years from 1992 to 2014 GC for this analysis and run on SWAT model using all the 2003, 2010 and 2018 LULC climate data were used for this study. The change of streamflow by changing rainfall is shown in Table (13). The model output result showed that run from

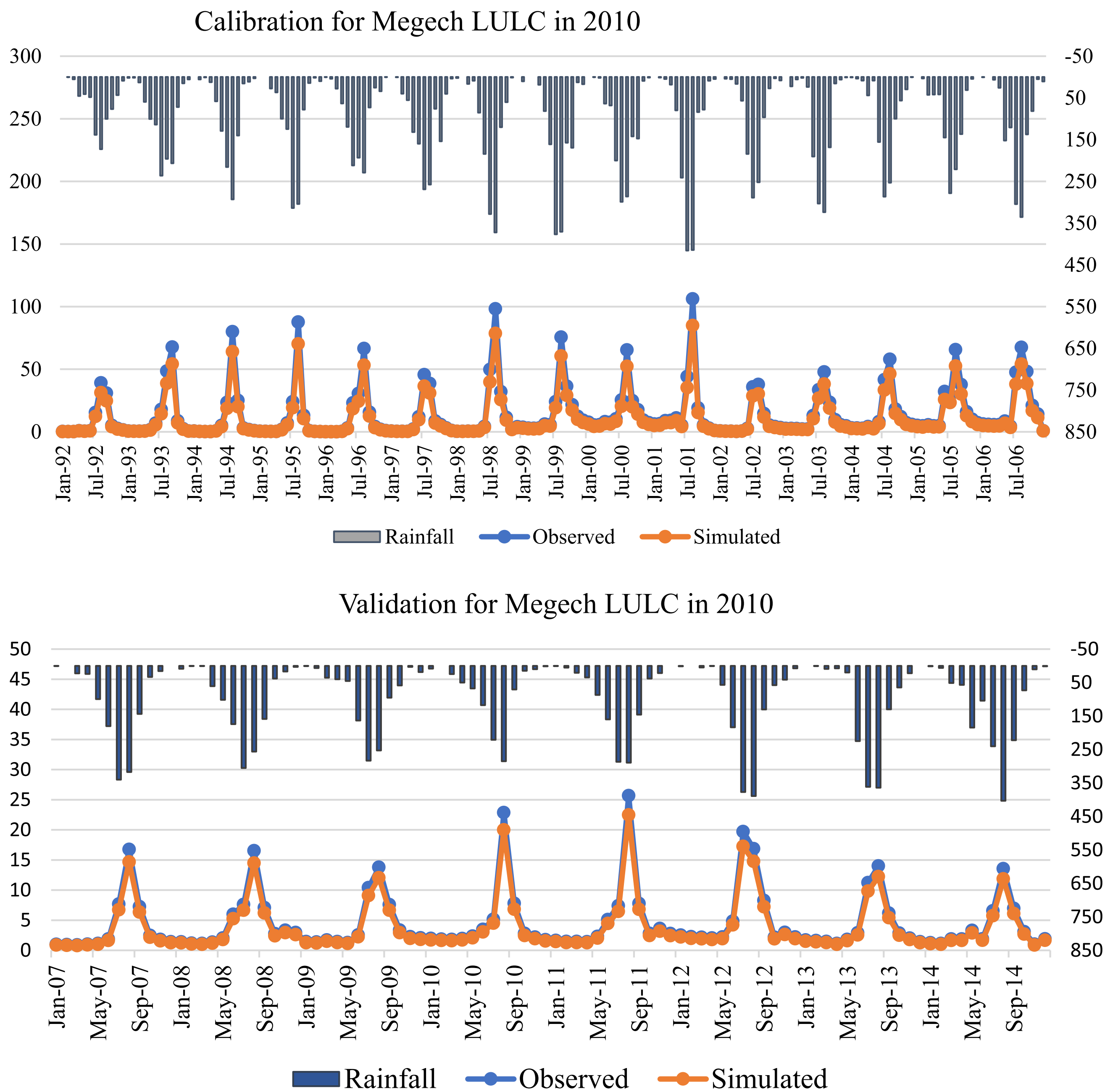



**Fig. 7** Megech observed and simulated streamflow for the calibration and validation

(1992–2014), the annual average rainfall was 1167.9 mm/year for the Megech watershed and 998.5 mm/year for Gumaro. In the first SWAT model run, the annual streamflow from the watershed obtained 4.45 mm/year and from the next model run the annual streamflow was 13.92 mm/year for the Megech watershed and 3.44 mm/year from the first run and 2.82 from the next run for Gumaro watershed (Table 13). This result shows that the average annual rainfall was increased compared to the first average annual rainfall for the Megech watershed and the annual streamflow from the watershed was decreased as compared to the first run for the Gumaro watershed. Rainfall amount was a significant effect on streamflow that generate from the watershed, so the conclusion that from this study is rainfall amount is an effect on the streamflow in both watersheds.

## Slope effect on streamflow

The average slope of the tributary channel in each sub-basin is used to evaluate the change of slope to change streamflow. The scenario of the study was developed based on the increased and decreased slope by 5% above the average

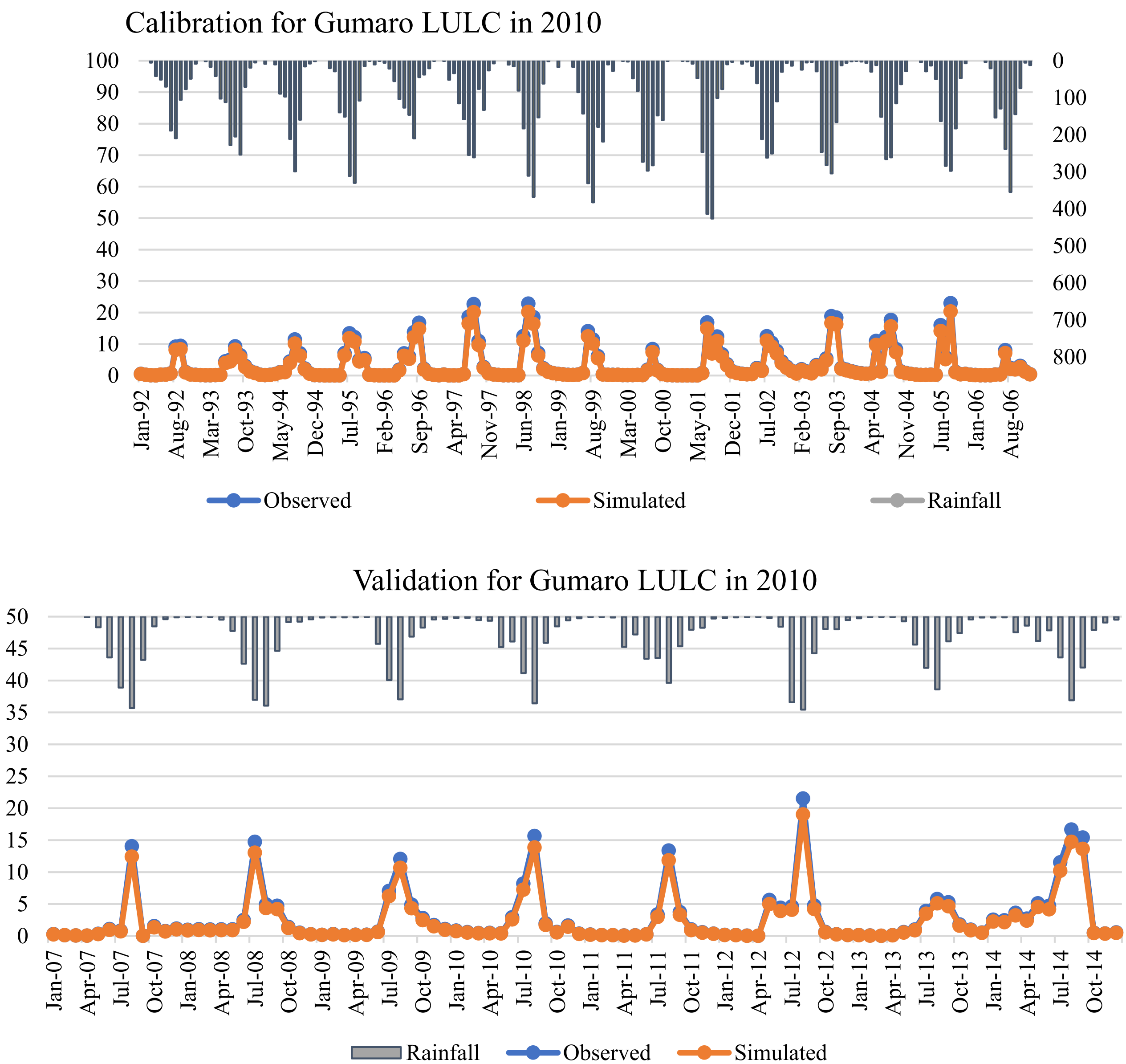



**Fig. 8** Gumaro observed and simulated streamflow for the calibration and validation

tributary channel slope. Each sub-basin tributary channel slope increases by 5%, 10%, 15% from the average slope and using the SWAT executive run. The text out from SWAT mode and the SWAT executive was run by increasing the slope. The result of the model is presented in Tables (14, 15, 16, 17) by different scenarios.

### Scenario I: slope increased above the average tributary slope

### Scenario II: Slope decreased above the average tributary slope

The model result (Tables 15, 16) showed that slope was a significant effect on streamflow change, the slope increased by 5%, 10%, and 15% the streamflow was increasing, and the slope decreased by the same slope change the streamflow was reduced to a small extent (Tables 18, 19, 20).

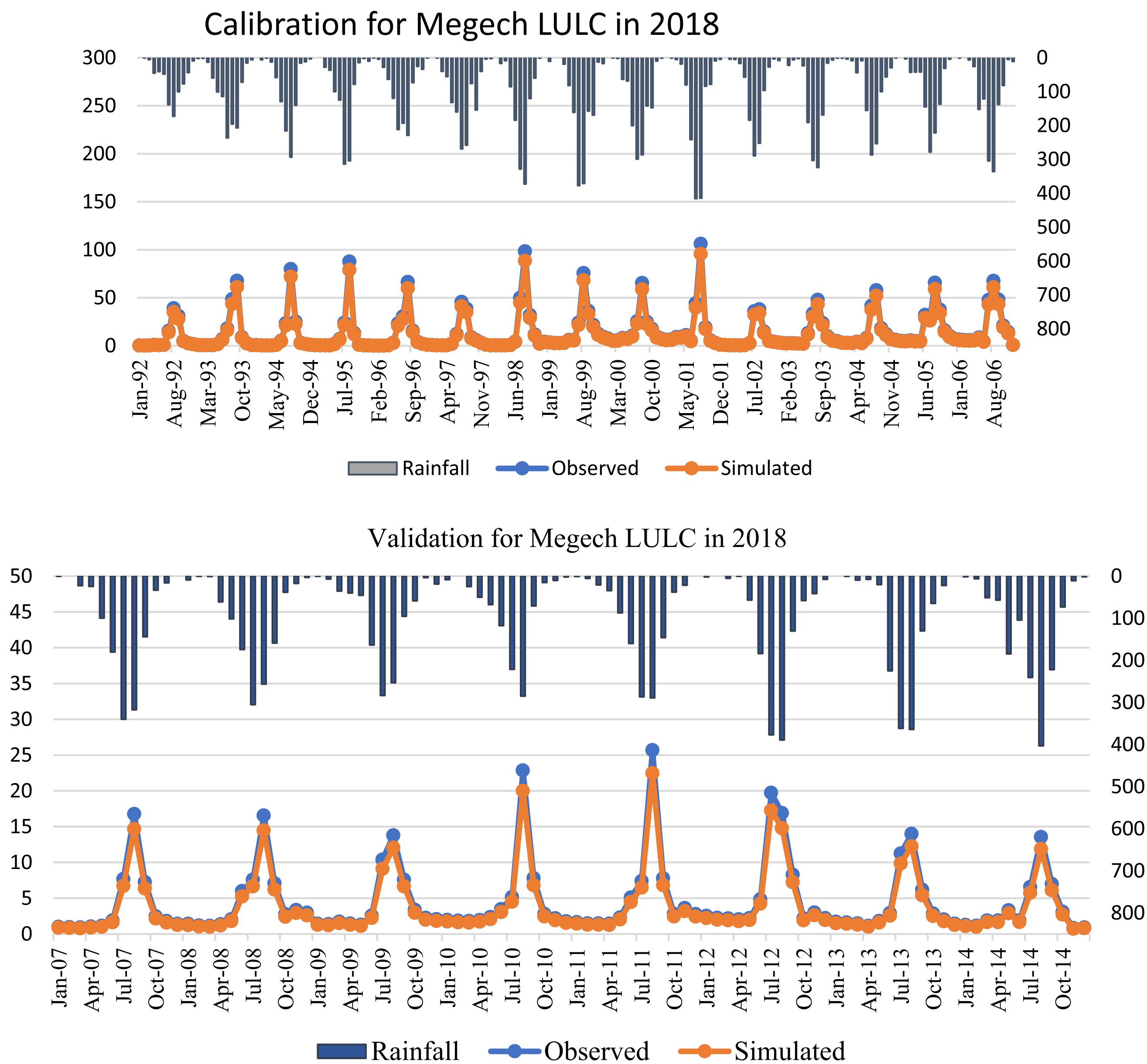
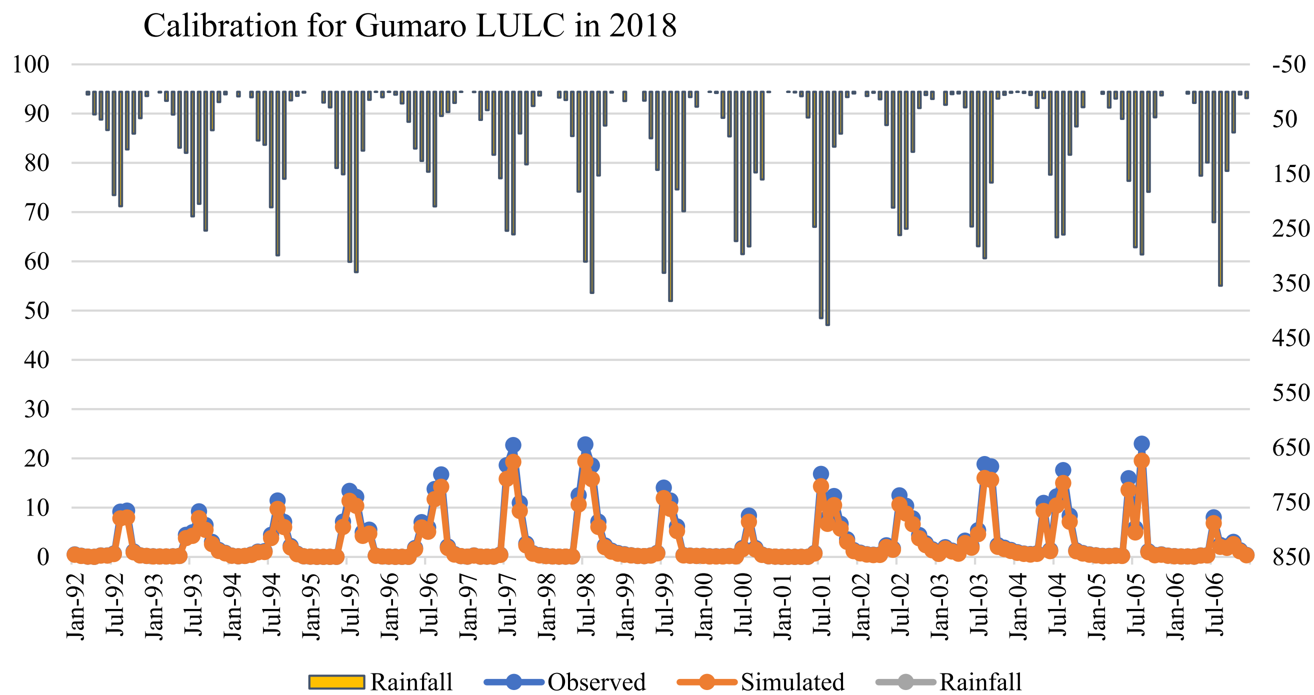



**Fig. 9** Megech observed and simulated streamflow for the calibration and validation

## Effects of climate data on streamflow using climate index

The climate index was an important parameter to evaluate the impact of the climate index on streamflow by comparing the value of the climate index since the larger climate index shows that more streamflow discharge is produced by the watershed and the smallest climate index shows that small discharge was produced by the watershed (Alemu 2011).

Generally, the watershed characteristics that are considered in a single watershed; climate characteristics, land use–land cover, and slope were observed as the effects on streamflow change. From this analysis climate indexes for the Megech watershed were less than the Gumaro watershed, which shows that the Megech watershed produces more discharge than the Gumaro watershed. From this study, land use–land cover change, the slope change of the tributary channel, and the rainfall magnitude have analyzed the effects on streamflow, so this implies that, conclude that, land use–land cover change was the dominant factor to affect the streamflow in both watersheds that highly reduced streamflow.



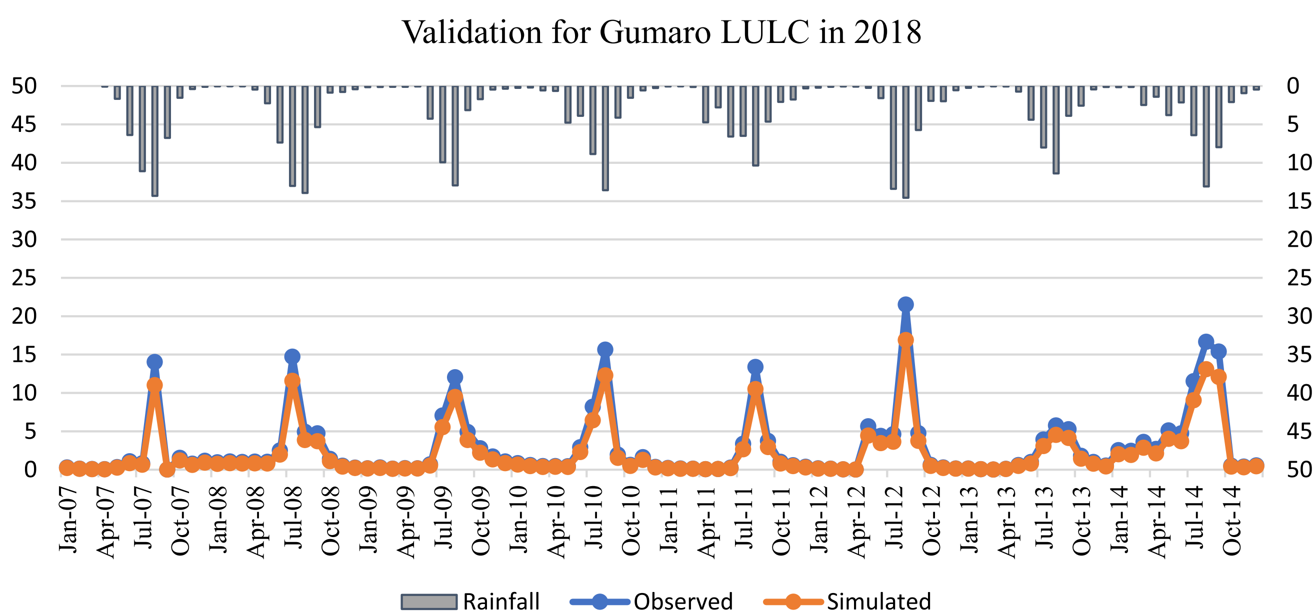




**Fig. 10** Gumaro observed and simulated streamflow for the calibration and validation

**Table 11** Mean annually simulated and observed streamflow for the Megech watershed

| Runoff (mm) | LULC-2003 | LULC-2010 | LULC-2018 |
|---|---|---|---|
| Observed annual streamflow | 18.37 | 18.37 | 18.37 |
| Simulated streamflow | 13.82 | 12.38 | 7.15 |

**Table 12** Mean annual simulated and observed streamflow for Gumaro watershed

| Runoff (mm) | LULC-2003 | LULC-2010 | LULC-2018 |
|---|---|---|---|
| Observed annual streamflow | 6.25 | 6.25 | 6.25 |
| Simulated stream flow | 5.92 | 5.02 | 2.98 |

**Table 13** Model evaluation result of Megech watershed

| Performance criteria | 2003 LULC | | 2010 LULC | | 2018 LULC | |
|---|---|---|---|---|---|---|
| | Calibration | Validation | Calibration | Validation | Calibration | Validation |
| R2 | 0.67 | 0.71 | 0.72 | 0.77 | 0.72 | 0.83 |
| NSE | 0.75 | 0.79 | 0.68 | 0.72 | 0.67 | 0.78 |
| PBIAS | 12.44 | 9.63 | 9.8 | 10.25 | 18.4 | 7.3 |
| Evaluation period | 1992–2006 | 2007–2014 | 1992–2006 | 2007–2014 | 1992–2006 | 2007–2014 |

**Table 14** Model evaluation result of Gumaro watershed

| Performance criteria | 2003 LULC | | 2010 LULC | | 2018 LULC | |
|---|---|---|---|---|---|---|
| | Calibration | Validation | Calibration | Validation | Calibration | Validation |
| R2 | 0.65 | 0.61 | 0.69 | 0.71 | 0.78 | 0.80 |
| NSE | 0.57 | 0.69 | 0.73 | 0.75 | 0.60 | 0.71 |
| PBIAS | 22.27 | 11.69 | 18.9 | 9.75 | 21.42 | 19.23 |
| Evaluation period | 1992–2006 | 2007–2014 | 1992–2006 | 2007–2014 | 1992–2006 | 2007–2014 |

**Table 15** rainfall amount effects on streamflow

| | Megech watershed | | Gumaro watershed | |
|---|---|---|---|---|
| | (Rainfall 1992–2006 G.C) mm | (Rain fall 2007–2014 G.C) mm | (Rainfall 1992–2006 G.C) mm | (Rainfall 2007–2014 G.C) mm |
| Jan | 1.62 | 2.55 | 0.31 | 0.65 |
| Feb | 1.48 | 2.23 | 0.30 | 0.59 |
| Mar | 1.57 | 2.42 | 0.20 | 0.67 |
| Apr | 1.53 | 2.69 | 0.20 | 0.57 |
| May | 2.06 | 3.62 | 1.39 | 1.66 |
| Jun | 3.58 | 9.38 | 3.74 | 2.18 |
| Jul | 9.46 | 32.52 | 9.83 | 6.77 |
| Aug | 17.50 | 65.47 | 13.11 | 12.98 |
| Sep | 7.36 | 27.71 | 8.04 | 5.08 |
| Oct | 2.79 | 9.87 | 2.52 | 1.27 |
| Nov | 2.40 | 5.36 | 1.07 | 0.84 |
| Dec | 2.07 | 3.27 | 0.53 | 0.54 |

## Summary and conclusion

The research aims to analyze the effects of watershed characteristics on streamflow by identifying sensitive watershed characteristics for the two watersheds and the effects were observed through hydrological modeling that was SWAT model to great certainty by using the SWAT CUP model. The result of the model was analyzed after model calibration and model validation, from land use–land cover change analysis, climate characteristics analysis, and a slope change analysis was concluded that land use and land cover change were significant effects on streamflow.

The performance of the model was evaluated based on performance rating criteria, coefficient of determination, and Nash and Sutcliff efficiency on monthly based value, the coefficients of determination ($R^2$) and Nash–Sutcliffe coefficient was greater than 0.6 and 0.5 for all scenarios on both watersheds, respectively. The land use–land cover

**Table 16** Monthly stream flow change for slope increased by 5%, 10%, and 15% (Megech watershed)

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. flow | 1.83 | 1.62 | 1.74 | 1.88 | 2.52 | 6.03 | 20.06 | 40.01 | 16.89 | 6.06 | 3.55 | 2.32 |
| 5% | 1.92 | 1.70 | 1.83 | 1.97 | 2.65 | 6.33 | 21.07 | 42.01 | 17.74 | 6.37 | 3.73 | 2.44 |
| 10% | 2.01 | 1.78 | 1.91 | 2.07 | 2.77 | 6.63 | 22.07 | 44.01 | 18.58 | 6.67 | 3.90 | 2.55 |
| 15% | 2.10 | 1.86 | 2.00 | 2.16 | 2.90 | 6.94 | 23.07 | 46.01 | 19.42 | 6.97 | 4.08 | 2.67 |

**Table 17** Monthly stream flow change for slope increased by 5%,10%, and 15% (Gumaro watershed)

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. flow | 0.35 | 0.33 | 0.30 | 0.27 | 1.22 | 2.63 | 7.40 | 11.01 | 5.77 | 1.72 | 0.82 | 0.44 |
| 5% | 0.37 | 0.34 | 0.31 | 0.28 | 1.28 | 2.76 | 7.77 | 11.56 | 6.06 | 1.81 | 0.86 | 0.46 |
| 10% | 0.38 | 0.36 | 0.33 | 0.29 | 1.34 | 2.90 | 8.14 | 12.11 | 6.35 | 1.89 | 0.90 | 0.48 |
| 15% | 0.40 | 0.38 | 0.34 | 0.31 | 1.40 | 3.03 | 8.51 | 12.66 | 6.64 | 1.98 | 0.94 | 0.50 |

**Table 18** Monthly stream flow change for slope decreased by 5%,10%, and 15% (Megech watershed)

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. Flow | 1.83 | 1.62 | 1.74 | 1.88 | 2.52 | 6.03 | 20.06 | 40.01 | 16.89 | 6.06 | 3.55 | 2.32 |
| 0.05 | 1.74 | 1.54 | 1.65 | 1.78 | 2.40 | 5.73 | 19.06 | 38.01 | 16.05 | 5.76 | 3.37 | 2.21 |
| 0.1 | 1.64 | 1.46 | 1.57 | 1.69 | 2.27 | 5.43 | 18.06 | 36.01 | 15.20 | 5.46 | 3.19 | 2.09 |
| 0.15 | 1.55 | 1.37 | 1.48 | 1.60 | 2.14 | 5.13 | 17.05 | 34.01 | 14.36 | 5.15 | 3.02 | 1.97 |

**Table 19** Monthly stream flow change for slope decreased by 5%, 10%, and 15% (Gumaro watershed)

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Av. Flow | 0.35 | 0.33 | 0.30 | 0.27 | 1.22 | 2.63 | 7.40 | 11.01 | 5.77 | 1.72 | 0.82 | 0.44 |
| 5% | 0.33 | 0.31 | 0.28 | 0.25 | 1.16 | 2.50 | 7.03 | 10.46 | 5.48 | 1.63 | 0.77 | 0.42 |
| 10% | 0.31 | 0.30 | 0.27 | 0.24 | 1.10 | 2.37 | 6.66 | 9.91 | 5.19 | 1.55 | 0.73 | 0.39 |
| 15% | 0.30 | 0.28 | 0.25 | 0.23 | 1.03 | 2.24 | 6.29 | 9.36 | 4.91 | 1.46 | 0.69 | 0.37 |

**Table 20** Climate index analysis

| Annual precipitation (mm/year) | Annual evapotranspiration (mm/year) |
|---|---|
| Gumaro Watershed | |
| 998.5 | 105.6 |
| climate index = 998.5/105.6 = 11.05 | |
| Megech Watershed | |
| 1167.9 | 252.2 |
| Climate index = 1167.9/252.2 = 3.959 | |

change scenario, the climate characteristics, and the slope change scenario was developed, from those analyses, it was found that has been a substantial decrease or increase of forest land, shrubland, grassland, and expansion of agricultural land. After model calibration and model validation, from land use–land cover change analysis, climate characteristics analysis, and a slope change analysis was concluded that land use and land cover change were significant effects on streamflow in the watershed compared to climate and slope effects.

The mean annual streamflow of 2010 LULC decreased by 1.44% for 2010 from 2003 LULC and 5.23% for 2018 from 2010, because of reduced cultivated land from 2010 up to 2018 and increased grassland and plantation in the Megech watershed and 2010 LULC decreased by 0.9% for 2010 from 2003 LULC and 2.04% in 2018 from 2010. The result showed that the land use–land cover change has a great effect on annual streamflow in the watersheds, especially the expansion of agricultural land and deforestation significantly affecting the streamflow more than other watershed characteristic.

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## Declarations

**Conflict of interest** We (authors) have to declare that we have no known personal relationships that could have appeared to influence the work reported in this paper.

**Ethical approval** We confirm that the manuscript has been read and approved by all named authors. We further confirm and understand that the corresponding author is the sole contact for the editorial process.

**Consent for publication** We the author permitted the publication of the work.

**Consent to participate** We the authors had voluntarily agreed to participate in this research study.



## References

Abbaspour KC, Yang J, Maximov I, Siber R, Bogner K, Mieleitner J, Zobrist J (2007) Modelling hydrology and water quality in the prealpine/alpine Thur watershed using SWAT. J Hydrol 333:413–430

Abtew, Wossenu, Assefa M. Melesse, Dessalegne T (2008) Characteristics of monthly and annual rainfall of the Upper Blue Nile

Basin. Hydrol Ecol of the Nile River Basin under Extreme Conditions: 249

Adem AA, Tilahun SA, Ayana EK, Worqlul AW, Assefa TT, Dessu SB, Melesse AM (2016) Climate change impact on sediment yield in the Upper Gilgel Abay Catchment, Blue Nile Basin, Ethiopia. Springer, Cham, pp 615–644. https://doi.org/10.1007/978-3-319-18787-7_28

Alemu E (2011) School of graduate studies addis ababa institute of technology Effects of Watershed characteristics on River Flow for the Case

Aouissi J, Benabdallah S, Chabaane ZL, Cudennec C (2016) Evaluation of potential evapotranspiration assessment methods for hydrological modelling with SWAT—application in data-scarce rural Tunisia. Agric Water Manag 174:39–51

Arnold JG, Fohrer N (2005) SWAT2000: current capabilities and research. Hydrol Process Int J 572:563–572. https://doi.org/10.1002/hyp.5611

Atanaw F, Collick AS, Mcalister C, Taylor R, Steenhuis TS (2015) Effects of physical catchment characteristics on river flow (June), 1–11

Beven K, Binley A (1992) The future of distributed models: model calibration and uncertainty prediction. Hydrol Process 6(1991):279–298

Bronstert A, Plate EJ (1997) Modelling of runoff generation and soil moisture dynamics for hillslopes and micro-catchments. J Hydrol 198:177–195

Chekol AA (2013) Management and livelihood opportunity of Lake Tana fishery, Ethiopia. MS thesis. UiT The Arctic University of Norway

Davarzani H, Smits K, Tolene RM, Illangasekare T (2014) Study of the effect of wind speed on evaporation from soil through integrated modeling of the atmospheric boundary layer and shallow subsurface. Water Resour Res 50(1):661–680

Davies EGR, Simonovic SP (2011) Advances in water resources global water resources modeling with an integrated model of the social-economic-environmental system. Adv Water Resour 34(6):684–700

Divoky D, Concepts W, Water A (2010) Evaluating the impact of climate change on the management, pp 2613–2621

Dragoni W et al (2015) Possible response of two water systems in Central Italy to climatic changes. Adv Watershed Hydrol 397–424

Endalew ST, Yigezu YA, Mitter H, Schmidt E (2016) Progress on Socio-Economic Research in the Gumara-Maksegnit watershed. Beirut, Lebanon: International Center for Agricultural Research in the Dry Areas (ICARDA)

Frimpong EA (2005) Spatial-scale effects on stream biological integrity: land use relationships and cost effectiveness of habitat restoration. Doctoral dissertation, Purdue, University

Furlan A, Poussin J-C, Mailhol J-C, Le Bissonnais Y, Gumiere SJ (2012) Designing management options to reduce surface runoff and sediment yield with farmers: an experiment in south-western France. J Environ Manag 96(1):74–85

Gassman PW, Yingkuan W (2015) IJABE, SWAT, special issue: innovative modeling solutions, for, water resource problems. Int J Agric Biol Eng. https://doi.org/10.3965/j.ijabe.20150803.1763

Gleick PH (1993) Water and conflict: fresh water resources and international security. Int Secur 18(1):79–112

Griensven AV, Meixner T, Grunwald S, Bishop T (2006) A global sensitivity analysis tool for the parameters of multi-variable catchment models. J Hydrol 324:10–23. https://doi.org/10.1016/j.jhydrol.2005.09.008

Hopp L, McDonnell JJ (2009) Connectivity at the hillslope scale: Identifying interactions between storm size, bedrock permeability, slope angle and soil depth. J Hydrol 376(3–4):378–391

Luzio MD, Srinivasan R, Arnold JG (2003) Integration of watershed tools and swat model into basins 1. JAWRA J Am Water Resour Assoc 38(4):1127–1141

Luzio MD, Srinivasan R, Arnold JG (2004) A GIS-coupled hydrological model system for the watershed assessment of agricultural nonpoint and point sources of pollution. Trans GIS 8.1:113–136

Machiwal D, Jha MK (2009) Time series analysis of hydrologic data for water resources planning and management: a review. J Hydrol Hydromech 54(3):237–257 Malagó, Anna, et al. "Modelling nutrient pollution in the Danube River Basin: a comparative study of SWAT, MONERIS and GREEN models. Publ Off Eur Union (2015)

Malagó, Anna, et al. Modelling nutrient pollution in the Danube River Basin: a comparative study of SWAT, MONERIS and GREEN models. Publ. Off. Eur. Union (2015)

Mengistu AG, Van Rensburg LD, Woyessa YE (2019) Techniques for calibration and validation of SWAT model in data scarce arid and semi-arid catchments in South Africa. J Hydrol Reg Stud 25(May):100621. https://doi.org/10.1016/j.ejrh.2019.100621

Moriasi DN, Steiner JL, Arnold JG (2011) Sediment measurement and transport modeling: impact of riparian and filter strip buffers. J Environ Qual 40(3):807–814

Pakhmode V, Kulkarni H (2003) Hydrological-drainage analysis in watershed-programme planning: a case from the Deccan basalt, India. Hydrol J 25:23. https://doi.org/10.1007/s10040-003-0279-z

Refsgaard JC, Knudsen J (1996) Operational validation and intercomparison of different types of hydrological models. Water Resour Res 32(7):2189–2202

Setegn SG, Srinivasan R, Dargahi B (2008) Hydrological modelling in the Lake Tana Basin, Ethiopia using SWAT model. Open Hydrol J 2(1):49–62. https://doi.org/10.2174/1874378100802010049

Setegn SG, Srinivasan R, Melesse AM, Dargahi B (2010) SWAT model application and prediction uncertainty analysis in the Lake Tana Basin, Ethiopia. Hydrol Process Int J 24(September 2009):357–367. https://doi.org/10.1002/Hyp.7457

Tegegne G, Park DK, Kim YO (2017) Comparison of hydrological models for the assessment of water resources in a data-scarce region, the Upper Blue Nile River Basin. J Hydrol Reg Stud 14(November):49–66

Thyer M, Renard B, Kavetski D, Kuczera G, Franks SW, Srikanthan S (2009) Critical evaluation of parameter consistency and predictive uncertainty in hydrological modeling: a case study using Bayesian total error analysis. Water Resour Res 45(12)

Water Watch (2006) Remote sensing studies of Tana-Beles sub-basins, Wageningen, The Netherlands Ward G, Benaman J (1999) Models for TMDL application in Texas water courses: screening and model review. Report to Texas Natural Resource Conservation Commission, Center for Research in Water Resources, University of Texas at Austin

Zhang Z, Sheng L, Yang J, Chen X, Kong L, Wagan B (2015) Effects of land use and slope gradient on soil erosion in a red soil hilly watershed of Southern China. Sustainability 7:14309–14325. https://doi.org/10.3390/su71014309