

Evaluation of Watershed Characteristics Effects on Stream Flow (A Case of Chacha Watershed, Abay Basin, Ethiopia)

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Abstract: Watershed characteristics of this study includes, land use or land cover, slope, and climate factors are an important factor that affects the streamflow in River basin. The objective of this study was to evaluate the effect of watershed characteristics on stream flow in Chacha watershed of Abay basin. In this study, the streamflow in the Chacha watershed was simulated using the semi-distributed hydrologic model, Soil and Water Assessment Tool (SWAT). The sensitive parameters analysis, SWAT output calibration, and validation for streamflow in the watershed were done using SWAT-CUP (SUFI-2-algorithm). The streamflow was calibrated, and results from calibration show acceptable range (0.88 for R^2 and 0.82 for NSE) between observed and simulated stream flow respectively. The results of validation were also acceptable range (0.87 for R^2 and 0.81 for NSE). In this study land use and land cover changes, climatic characteristics (rainfall and temperature variation), and slope variation of the topography were having an impact on the streamflow of the Chacha watershed. However, the land use and land cover impact have a more significant influence on the streamflow than other factors. This was due to the stream flow during 2018-LULC was increased by 6.8% over the 1998-LULC. This was the larger percent of increase over the other two factors in the study area. So, to reduce the streamflow in the study area model base land use mitigation measures was done for three basic scenarios by increasing the forest and decreasing the agricultural land with 5%, 10% and 15%. The result shows decreasing annual stream flow by 5.51%, 11.86% and 24.3% for each increment of forest land from the baseline respectively.

Keywords: Streamflow, LULC, Land-Use, Slope, Watershed-Characteristics, Chacha Watershed

1. Introduction

In Ethiopia where nearly 85% of the population participates mainly in agriculture and this activity is more dependent on the availability of water resources, the assessment, and management of available water resources is a matter of prime importance [2, 5, 11, 12]. Watershed characteristics over the watershed influence the water budget elements (infiltration, interception, evapotranspiration, surface and subsurface flow). It also affects the quantity and quality of water that reaches the streams [11, 9, 14]. Land and water resources degradation are the major problems in Ethiopian highlands. Poor land-use practice and poor management systems have significant role in causing high soil erosion rate, sediment transport, and most importantly the loss of water resources both in quantity and quality [2, 6, 7, 10]. The land and water resource of the watershed and its ecosystem are danger due to the nature of the watershed,

rapid population growth, deforestation, overgrazing, and soil erosion or soil detachment from the surface are the serious problems in Upper Blue Nile basin [22, 24, 25, 13]. To enhance national economic development, the great Ethiopian Renaissance Dam is one of the major project development attempts in the Blue Nile River Basin [15, 17, 18, 26]. The watershed characteristics include, slope, the land use/cover and climate factor have influential effect on streamflow within the watershed [16, 27-29]. Land degradation is a series problem in Ethiopia's highlands, particularly in the Blue Nile River Basin reflected in the form of soil erosion and soil fertility decline from time to time [19, 22, 30-31]. Chacha watershed is one of the affected watersheds in the region as soil erosion, sediment transport, and land degradation are great concerns. However, in this study area, the effect of watershed characteristics on streamflow is not yet studied. For this study a physically-based hydrological model, Soil and Water Assessment Tool (SWAT) was used

to for assessing the effect of watershed characteristics on streamflow in the study area. The general objective of this study is to evaluate the effect of watershed characteristics on streamflow in the Chacha watershed using the Soil and Water Assessment Tool (SWAT) hydrological model.

2. Methods and Materials

2.1. Description of the Study Area

The study watershed is located in Angolela Tara woreda

north showa zone Amhara region. It is 125 km far from north of Addis Abeba. The outlet point of the study area is located at UTM coordinates of 1054048 N and 550147 E and the elevation of the watershed is between 2679m and 3237m above sea level. The mean annual precipitation is about 1153.14mm and the annual minimum temperature and annual maximum temperature was -5.82°C and 22.1°C . The minimum monthly rainfall is 4.3mm in December and maximum 277.57mm in august. Similarly mean minimum and maximum temperature is 6.1 and 19.7 respectively.

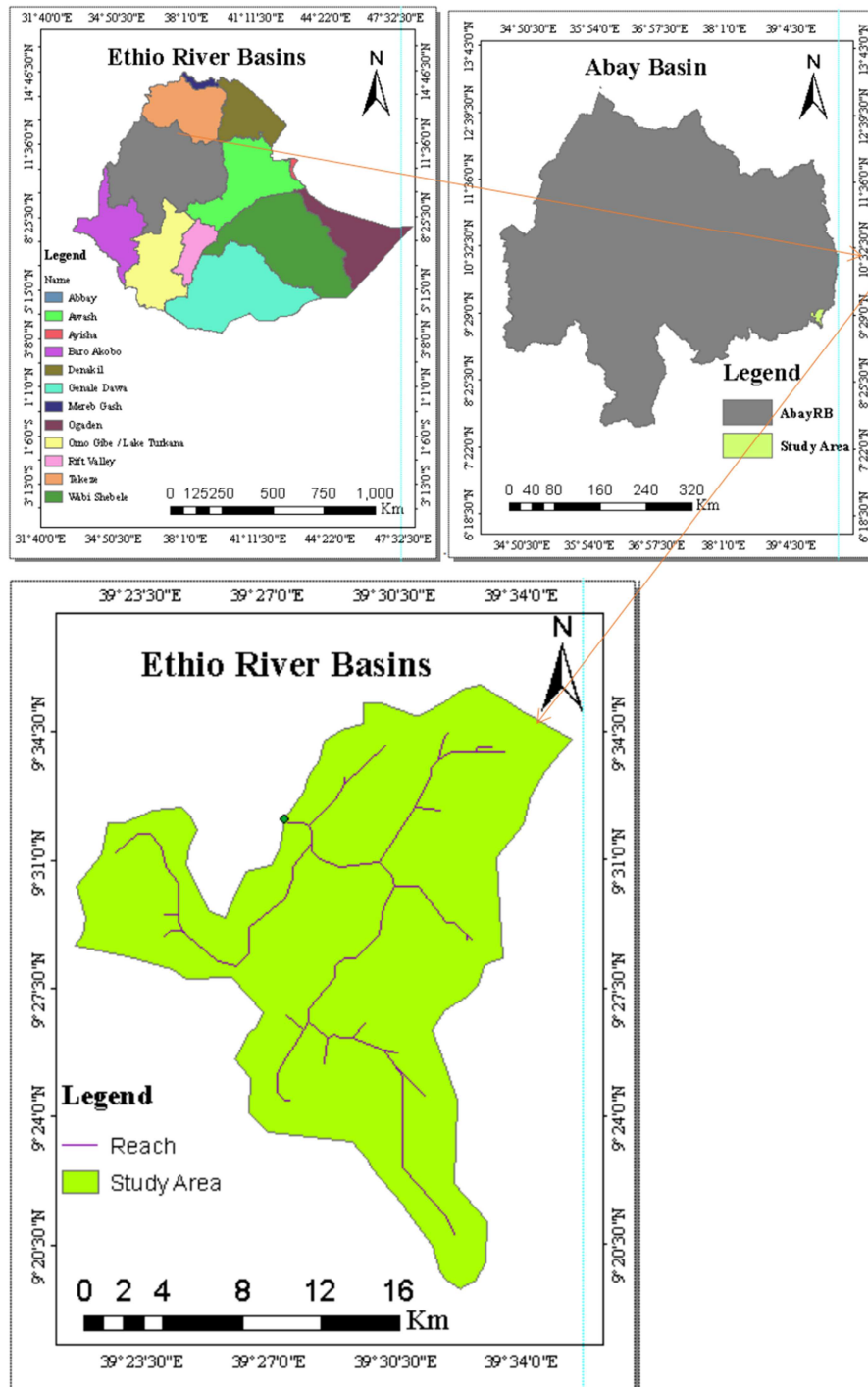


Figure 1. Location of the Study Area.

2.2. Soil Types and Geology

The soil type has classified based on the physical and chemical characteristics [14]. Depth, color, structural development, texture and evidence of profile development such as presence of diagnostic horizons, reaction to 10% HCl and PH value are some of the classification criteria based on which soil map has been produced [23]. The soil map of the study area was also obtained from Ministry of Water, irrigation and electricity of Ethiopia. The major soil type in the study watershed is Chromic Cambisols, Eutric Cambisols, Eutric Nitisols, Haplic Xerosols, Pellic Vertisols and Vertic Cambisols.

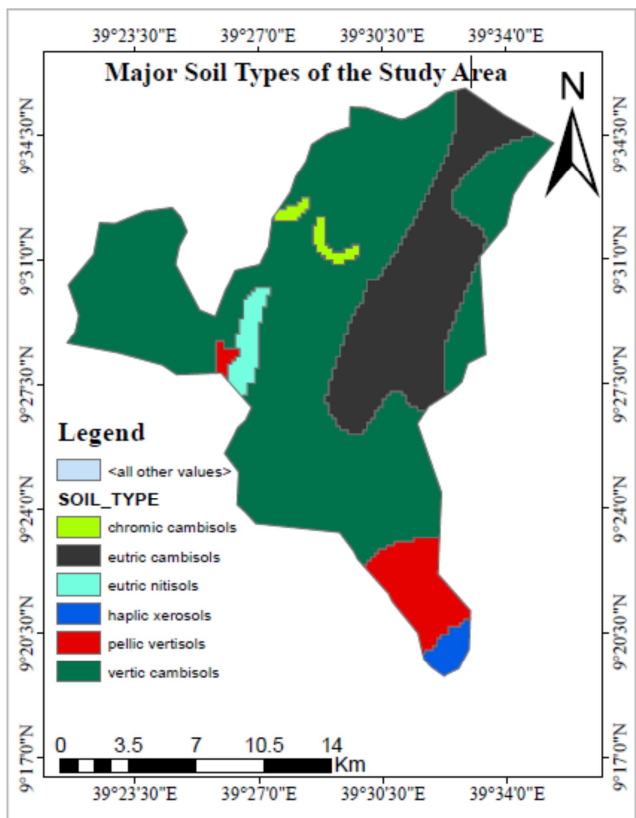


Figure 2. Soil map of Chacha watershed.

2.3. Land Use and Land Cover

The land use land cover data combined with the soil cover data generates the hydrologic characteristics of the basin or the study area, which in turn determines the excess precipitation, recharge to the groundwater system and the storage in the soil layers [16-17]. In Chacha watershed, there are Eight land use/land cover types such as cultivated land, shrub and bush land, grass land, forest land, marsh land, wood land, water body and built up area [4]. Among these types, cultivated land is the dominant one in the watershed that covers most of the land area. The SWAT model has predefined four letter codes for each land use category [21]. These codes were used to link or associate the land use map of the study area to SWAT land use databases [20]. While, preparing the lookup-table, the land use types were made

compatible with the input needs of the model [29].

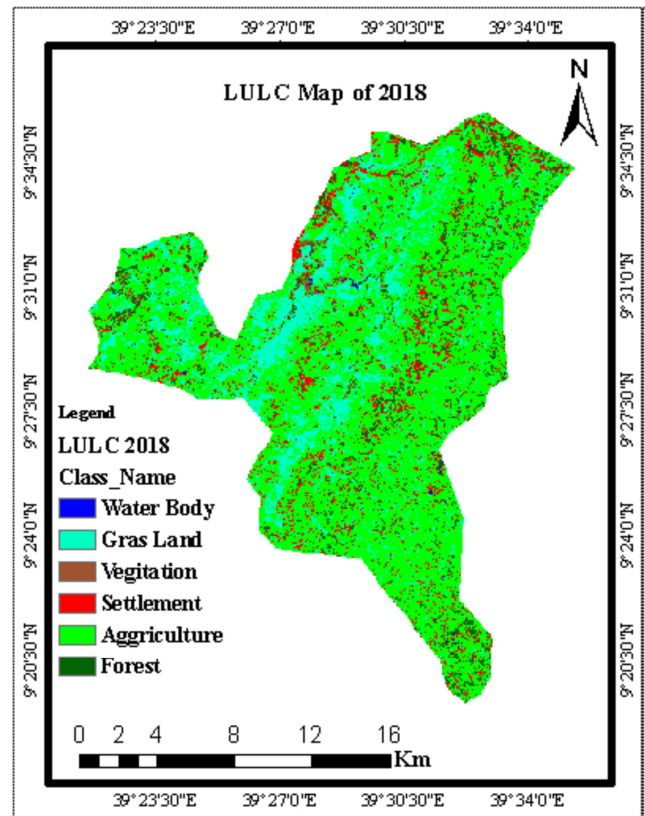


Figure 3. Land use land cover map of Chacha watershed.

2.4. Data Collection and Analysis

It is known that in any research the results of the study depend on the quality, relevance, consistency, and adequacy of the input raw data used. Because of that, the analysis of data is the primary task before using raw data as input data to run the model to generate the required output of the study [8]. In raw data, missing values are commonly occurred for different reasons, when data are stored for a different purpose [3]. Therefore, filling the gaps that exist in raw data is the first step in the analysis of data for the required use [8]. The hydrological data was required for performing sensitivity analysis for calibration and validation of the model [7, 23]. The daily Chacha watershed stream flow data (1998-2018) is quite sufficient and were collected from Ministry of Water and Energy Bureau. The Arc SWAT model demands the daily precipitation, maximum and minimum temperature, relative humidity, solar radiation, and wind speed data which is collected from the Ethiopian National Meteorological Agency (ENMA). The weather data used for this study were collected from five meteorological stations such as Chacha station, Debre Berhan station, Ankober station, Kotu station, and Gina_ager station. Land use land cover data and Soil data were the other data which was collected for this analysis the soil Data were collected from the Ethiopian Ministry of Water and Energy Bureau. The satellite imagery for the years 1998, 2008 and 2018 were used to generate the land cover map.

2.4.1. Filling Missing Rainfall Data

For this study, missing values was estimated from neighboring stations around the missed record station [33]. These are the station average method, normal ratio method, quadrant method, inverse-distance weighting method, and regression methods [32]. From the installed precipitation data gauging stations in and around the Chacha watershed, the percent of missing precipitation value are 11.2%, 13.4%, 12.6%, 11.7% and 10.7%, at Chacha station, Debre Berhan station, Ankober station, and Kotu station, and Gina_ager station respectively. For this reason, the normal ratio method

had been chosen for the estimation of missing precipitation data for this study [27]. Because a Normal Ratio method (NR) was the best method to estimate the missing precipitation value greater than 10% and less than 15%, within a given station [8].

2.4.2. Data Consistency

The method for checking the consistency of a hydrological or meteorological record is considered to be an essential tool for analysis purposes [8]. For this study double mass curve method was used in order to estimate the consistency of four stations in the study area and as shown in Figure 4 below the station rainfall dates were consistent.

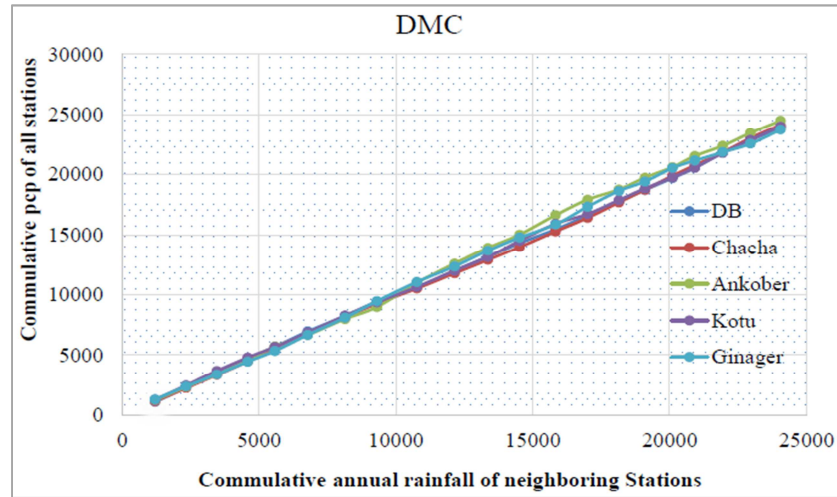


Figure 4. Rainfall Data Consistency for all gauging Station.

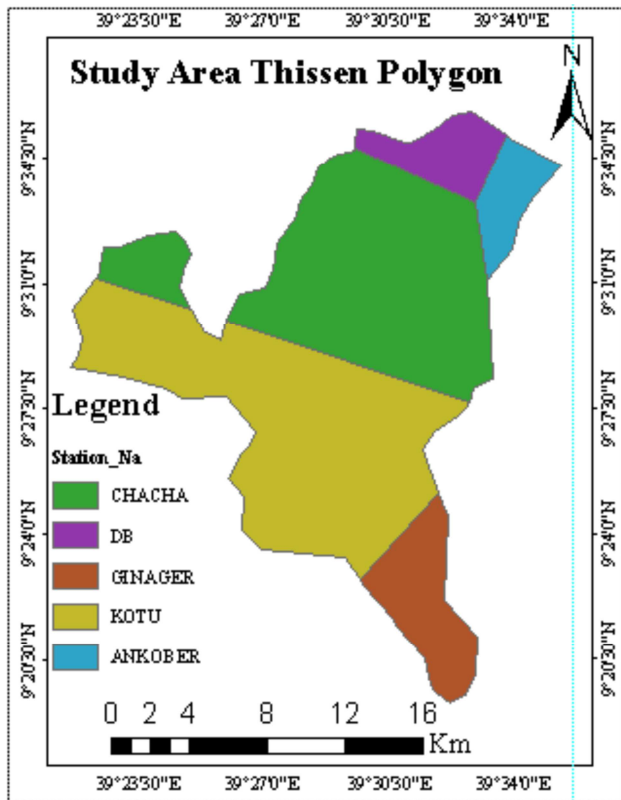


Figure 5. Thiessen Polygon of the Chacha Watershed.

2.4.3. Estimation of Aerial Rainfall

In this study, Thiessen polygon method was used to estimate mean areal rainfall because of its sound theoretical basis and availability of computational tools [14].

$$Pav = \frac{\sum_{i=1}^n p_i A_i}{\sum_{i=1}^n A_i} \quad (1)$$

Where Pav is mean areal precipitation (mm), P_i is mean annual precipitation (mm) and A_i is coverage area at i th the station, within Thiessen polygon respectively.

2.5. Methodology

The study required different materials and methods to arrive at the stated objectives. Meteorological, hydrological, digital elevation model, land use and land cover and soil data were required. Those data were selected based on the objective of this research which answered the problem to the study area. The SWAT model interface with Arc GIS and SWAT Cup is used to evaluate watershed characteristics on stream flow [28]. Arc GIS 10.5 and its extension Arc SWAT 2012 were used for hydrological model [12]. The stream flow simulation by the SWAT model was calibrated and validated by comparing simulated stream flow with observed values [7]. The basic data set that are required to develop an input database for the model are: topography, soil, land use and climatic data [18]. In general the following conceptual frame

work indicates that the overall methods and analysis to be followed throughout the study of this research is shown in figure 6.

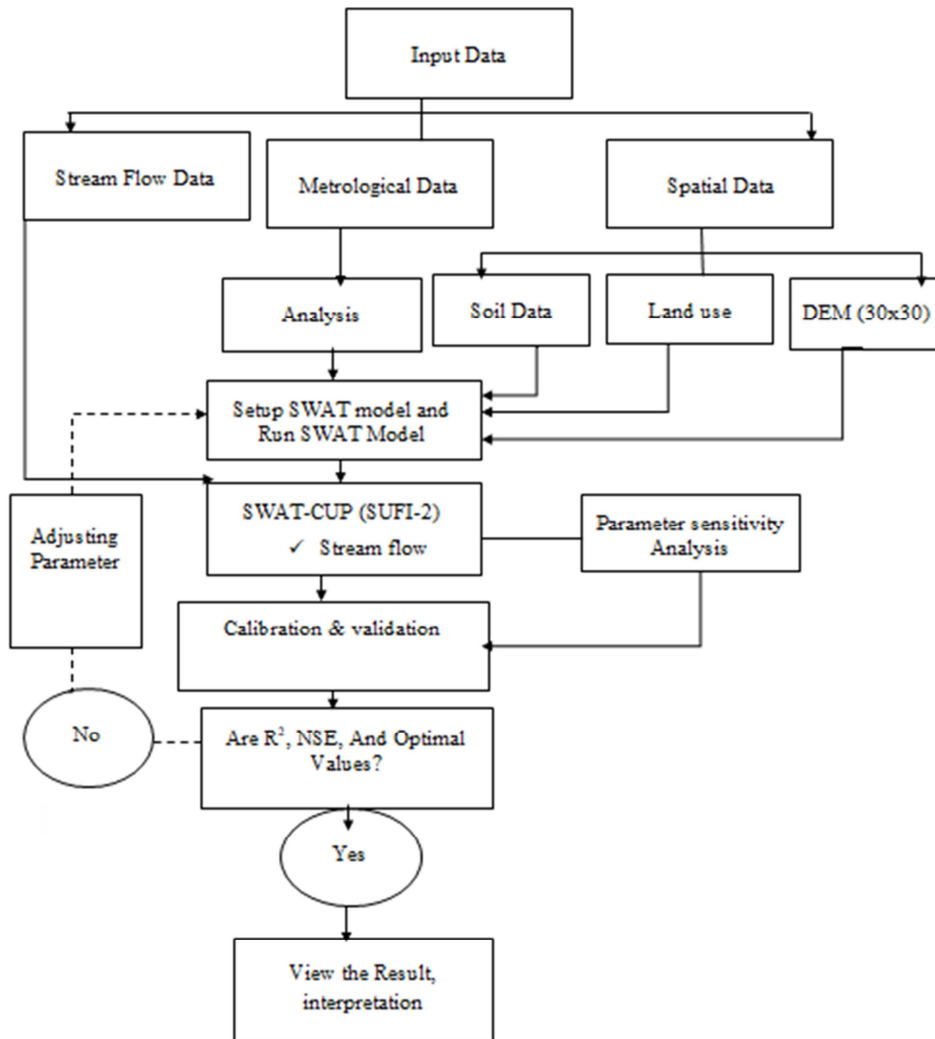


Figure 6. The step processes of the model setup, simulation calibration and validation.

3. Results and Discussion

3.1. Land Use and Land Cover Change Analysis

The satellite imagery of Chacha watershed shows that; the catchment has undergone numerous land use/cover changes in recent decades. Forest cover and grass land are decreased markedly between 1998's and 2018 by 33.13% and 34.65% respectively, especially for the regions in the western and the northwest region of the watershed. The decrease due to

expansion of urbanization attributed to the cutting of trees in the forests for various uses such as firewood and clearing for cultivation and agricultural purposes. The agricultural land increase between 1998 and 2018 by 18.03% and vegetation land between 2008 and 2018 were 31.75% at most part of the catchment. This increase could be linked with high increase population growth. The built-up area also changed between 1998 and 2018 by 30.38% due to rapid development of urban centers such as the expansion of the town Chacha and surrounding.

Table 1. Land use and land covers in 1998, 2008 and 2018 in the Chacha watershed.

LULC Classes	LULC map (km2)			Area change (km2)			Area change (%)		
	1998	2008	2018	1998-2008	2008-2018	1998-2018	1998-2008	2008-2018	1998-2018
Agriculture	182.98	211.72	215.98	28.74	4.26	33.00	0.16	0.02	0.18
Forest	29.13	22.95	19.48	-6.18	-3.46	-9.65	-0.21	-0.15	-0.33
Gras Land	86.66	59.63	56.63	-27.03	-3.00	-30.03	-0.31	-0.05	-0.35
Settlement	18.86	21.83	24.59	2.97	2.76	5.73	0.16	0.13	0.30
Vegetation	0.00	1.89	2.49	1.89	0.60	2.49	-	0.32	-
Water Body	2.31	1.92	0.76	-0.39	-1.15	-1.54	-0.17	-0.60	-0.67

3.2. Stream Flow Modeling

3.2.1. Sensitivity Analysis

Sensitivity analysis was performed on flow parameters of SWAT on monthly time steps with observed data of the Chacha River. Sensitivity analysis was performed on flow

parameters of SWAT on monthly time steps with observed data of the Chacha River gauge station. For this analysis, 26 parameters were considered and only 12 parameters were identified to have significant influence in controlling the stream flow in the watershed.

Table 2. Sensitivity analysis rank for streamflow using *p*-value.

Parameter Name	Max_value	Max_value	t-Stat	P-Value
R_CN2.mgt	-25%	25%	-10.26	0.001
V_GW_DELAY.gw	0	2	-3.96	0.0018
R_RCHRG_DP.gw	-25%	25%	1.88	0.002
R_SOL_K (...).sol	0	1	5.281	0.0021
R_CANMX.hru	0.02	0.2	1.31	0.024
R_REVAPMN.gw	-25%	25%	2.05	0.06
R_CH_K2.rte	0	150	1.44	0.065
V_ALPHA_BF.gw	0	1	2.05	0.07
R_ESCO.bsn	0	10	2	0.08
R_SOL_AWC (...).sol	30	450	4.71	0.082
V_GWQMN.gw	0	1	-0.2	0.84
R_GW_REVAP.gw	0	500	-0.17	0.87

Parameters corresponding to *p*-value less or equal to 0.05 are categorized as more sensitive parameters in their degree of sensitivity [34]. According to the result obtained thorough analysis of the parameter, Soil Conservation Service Runoff Curve Number for moisture condition (CN2), Ground Water Delay (GW_DELAY), ground water recharge (RCHRG_DP), Saturated hydraulic conductivity (SOL_K), and CANMX were found to be the most sensitive parameter as compared to the other selected parameters.

3.2.2. Flow Calibration and Validation

Calibration was done for sensitive flow parameters of SWAT with observed average monthly stream flow data. The stream flow data of Chacha river is 1998-2018 was recording out of this 1998-2011 for calibration and 2012- 2018 for

validation. In this procedure, the values of the parameters were varied iteratively within the allowable ranges until the simulated flow as close as possible to observed stream flow [7]. The result of calibration and validation analysis is presented in figures 7, 8 and table 3 belows.

According to Santhi. C. et. al (2012) [35] values of $R^2 > 0.6$ and $NSE > 0.5$, the calibration of the daily and monthly simulated stream flow are usually considered as adequate. The model performance was evaluated using R^2 , and NSE values, for given observed data based on the SUFI-2 optimization function execution. The statistical value of the model performance was $R^2 = 0.88$, and $NSE = 0.82$. Therefore, the results of stream flows indicate that SWAT model is a very good predictor for stream flow of Chacha Watershed.

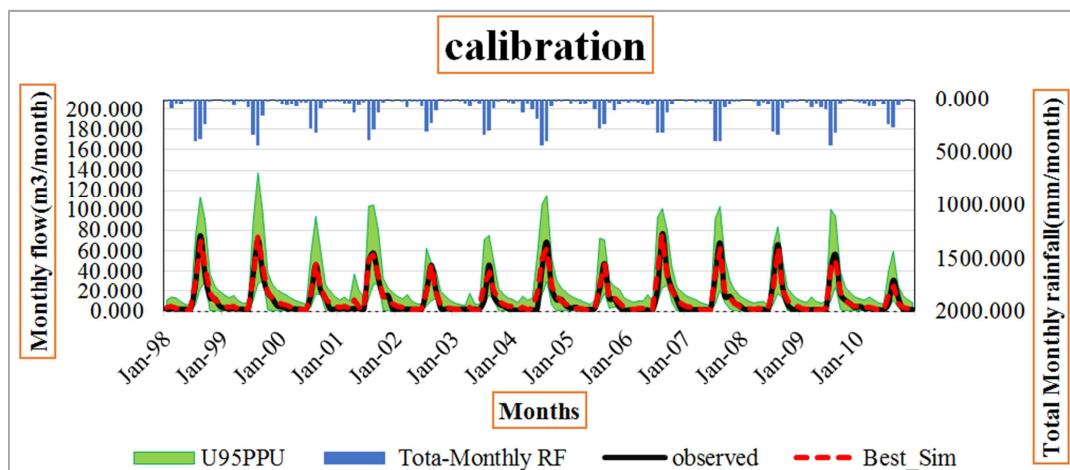


Figure 7. Calibrated average monthly stream flow (1998 to 2010).

3.2.3. Model Validation

After calibration was done manually and getting acceptable values of NSE and R^2 , validation was checked

using monthly-observed flows. The model validation also showed a very good agreement between simulated and measured monthly flow with the NSE value of 0.81 and R^2 0.87. Therefore, the results of stream flows indicate that

SWAT model is a very good predictor for stream flow of Chacha Watershed.

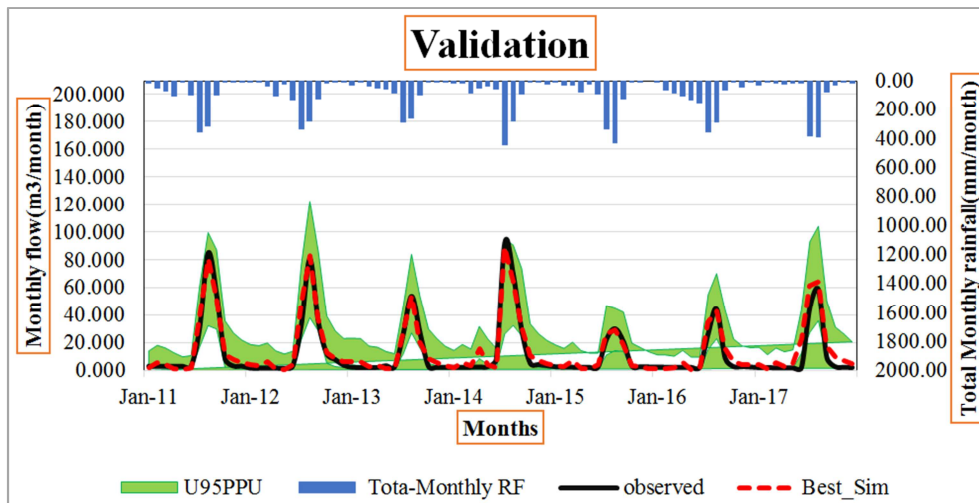


Figure 8. Validated average monthly stream flow (2011 to 2017).

Table 3. Calibration and validation result using SUFI-2 method.

Objective functions		calibration	Validation
R ²	SUFI-2	0.88	0.87
NSE	SUFI-2	0.82	0.81

3.3. Impact of LULC Change on Streamflow

In this study, Streamflow change was evaluated with the land use and land cover change observed in the period 1998-

2018. For this case to reduce the impact of other factors on stream flow, only land use/cover parameter were changed by putting other factor constant [24].

Table 4. Annual surface runoff, ground water flow and streamflow for each land use.

Flow	LULC of 1998	LULC of 2008	LULC of 2018
Mean annual SURQ (mm)	211.63	221.81	227.17
Mean annual GWQ (mm)	7.94	7.7	7.52
Streamflow (m ³ /sec)	45.49	47.68	48.83

Table 5. Monthly surface runoff and streamflow for each land use.

month	1998-LULC		2008-LULC		2018-LULC	
	SURF (mm/month)	Streamflow (m ³ /sec)	SURF (mm/month)	Streamflow (m ³ /sec)	SURF (mm/month)	Streamflow (m ³ /sec)
Jan	0.850	0.183	0.920	0.198	0.920	0.198
Feb	2.190	0.471	2.300	0.494	2.290	0.492
Mar	8.240	1.771	8.590	1.847	8.720	1.875
Apr	9.580	2.059	10.040	2.158	10.280	2.210
May	5.370	1.154	5.660	1.217	5.820	1.251
Jun	12.300	2.644	13.070	2.810	13.290	2.857
Jul	81.420	17.503	84.950	18.262	87.020	18.707
Aug	75.120	16.148	78.640	16.905	80.720	17.352
Sep	14.650	3.149	15.520	3.336	15.960	3.431
Oct	1.350	0.290	1.500	0.322	1.520	0.327
Nov	0.490	0.105	0.540	0.116	0.550	0.118
Dec	0.070	0.015	0.080	0.017	0.080	0.017

From the Above Table 4 result showed that the mean annual streamflow of 2008 land use/cover increased by 4.6% compared to 1998 land use/cover and on the other hand, the stream flow at 2018 land use increased by 2.4% and 6.8% compared to 2008 and 1998 land use respectively. This is due to the increment of agricultural land and settlement from

1998 up to 2018 and the decreasing of grassland and forest coverage in the watershed. Generally, watershed hydrological response with respect to change in land use/cover within Chacha watershed showed that the river flow regime has changed, with increase in mean annual surface runoff from 211.63mm/year to 227.17mm/year throughout the selected

periods of this study area.

3.4. Effect of Precipitation and Temperature Change

In this case, monthly precipitation and temperature were used to run the SWAT model and keeping the other climatic data (humidity, wind speed, solar radiation) constant. The scenarios (1,2) were done with the daily precipitation and temperature data recorded from 1988-2003, 2004-2018,

which are 15, and 16 years recorded data respectively. From this study, the average annual surface runoff shows Decrease by 4.33% in the second scenario than the first scenario. The variation in precipitation data was the factor that causes the variation in surface runoff which contributes to the streamflow in the basin [15]. The results show that the precipitation and temperature characteristics have a significant effect on a streamflow in the Chacha watershed.

Table 6. Rainfall change effects on stream flow.

month	1988-2003 scenario		2004-2018 scenario	
	SURF (mm/month)	Streamflow (m ³ /sec)	SURF (mm/month)	Streamflow (m ³ /sec)
Jan	1.100	0.236	0.920	0.198
Feb	2.850	0.613	2.300	0.494
Mar	11.200	2.408	8.590	1.847
Apr	11.400	2.451	10.040	2.158
May	5.200	1.118	5.660	1.217
Jun	9.380	2.016	13.070	2.810
Jul	86.660	18.629	84.950	18.262
Aug	67.660	14.545	78.640	16.905
Sep	15.200	3.268	15.520	3.336
Oct	1.030	0.221	1.500	0.322
Nov	0.830	0.178	0.540	0.116
Dec	0.010	0.002	0.080	0.017

3.5. Slope Effect on Stream Flow

The slope is one of the factors which influence the stream flow velocity, where a higher slope results in a higher velocity of flow, therefore the water will travel quickly to reach the river outlet [1]. In this case, the effect of slope on stream flow was evaluated using the FAO slope classification as initial output and by Keeping other parameters constant,

the three slope scenario were developed by increasing the main/tributary channel slope to show the difference characteristics of slope effect on streamflow model in Chacha watershed. The scenario of the study was developed based on increasing the slope by 5%, 10%, and 15% above the average tributary slope. The result of the model was presented in Table 7 and Figure 9.

Table 7. Monthly stream flow change for slope increased by 5%.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av. flow	0.85	2.19	8.24	9.58	5.37	12.3	81.42	75.12	14.65	1.35	0.49	0.07
5%	0.86	2.2	8.28	9.66	5.43	12.45	82.21	75.94	14.81	1.36	0.5	0.08
10%	0.86	2.21	8.32	9.72	5.47	12.49	82.39	76.15	14.88	1.39	0.52	0.08
15%	0.86	2.2	8.31	9.73	5.49	12.54	82.65	76.44	14.92	1.37	0.5	0.08

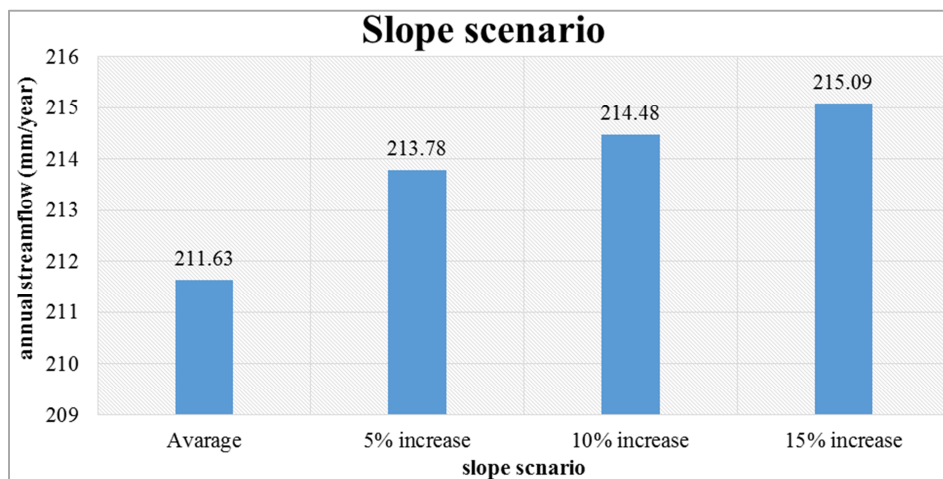


Figure 9. Annual Streamflow change for slope increased by 5% change.

In this study, the above model result showed that the annual average streamflow was increased by 1.01%, 1.33%, and 1.61% in Scenario-I, scenario-II, and scenario-III respectively. However, the monthly streamflow shows insignificant change from the average slope streamflow in each slope scenarios.

3.6. Comparative Watershed Characteristics Effect on Stream Flow

In this study the land use/land cover, climate factor

(precipitation, and temperature), and slope of the channel (hillside) was assessed to evaluate the effect of watershed characteristics on streamflow and were summarized as flow in Table 8 and Figure 10.

From this analysis, all largest percentage of annual stream flow was generated from land use and land cover change scenario (Figure 10). Therefore, in this study the comparative analyses show that the land use and land cover change has most significant effect in stream flow over other watershed characteristics.

Table 8. Watershed characteristics and model output for each scenario.

No	Watershed characteristics	Developed Scenarios	Annual Stream flow Model result (mm/year)
1	Land use/ land cover	1998-LULC-scenario	211.67
		2008-LULC-scenario	221.81
		2018-LULC-scenario	227.17
2	Precipitation and Temperature	1988-2003	211.38
		2004-2018	203.31
		5% increase	213.78
3	Main channel slope	10% increase	214.48
		15%increase	215.09

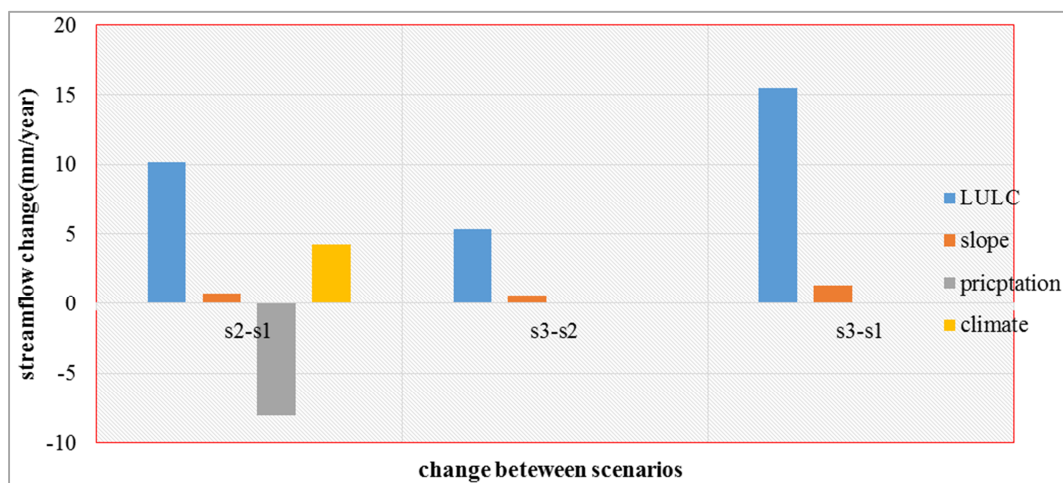


Figure 10. Streamflow change for each change of scenario and watershed characteristics.

3.7. Mitigation Measure

These scenarios are based on the field experience and the actual existence of the land use type change that most of the agricultural land is occurring while the existing forest type is being transformed to agricultural land use type. In this study three scenario were developed Baseline: 2018-LULC, Scenario-I: 5% of Agricultural land change to Forest land, Scenario-II: 10% of Agricultural land change to Forest land, Scenario-III: 15% of Agricultural land change to Forest land the result of modeling showed that the streamflow in the watershed was decreased by 5.51%, 11.86%, and 24.3% for Scenario-I, scenario-II, & scenario-III respectively. Therefore, applying such techniques in the watershed will be an effective solution that can control the streamflow problems to reduce soil erosion in the watershed.

Table 9. Average monthly stream flow for developed scenario for LULC use.

Month	2018-LULC	Scenario-I	Scenario-II	Scenario-III
Jan	0.92	0.91	0.9	0.88
Feb	2.29	2.31	2.31	2.2
Mar	8.72	8.6	8.46	8.04
Apr	10.28	10.03	9.88	9.21
May	5.82	5.67	5.5	5.16
Jun	13.29	13.21	12.86	11.98
Jul	87.02	84.82	82.35	77.97
Aug	80.72	78.5	76.01	71.69
Sep	15.96	15.49	14.97	13.89
Oct	1.52	1.5	1.46	1.29
Nov	0.55	0.54	0.53	0.49
Dec	0.08	0.08	0.08	0.07
Total flow	227.17	221.66	215.31	202.87

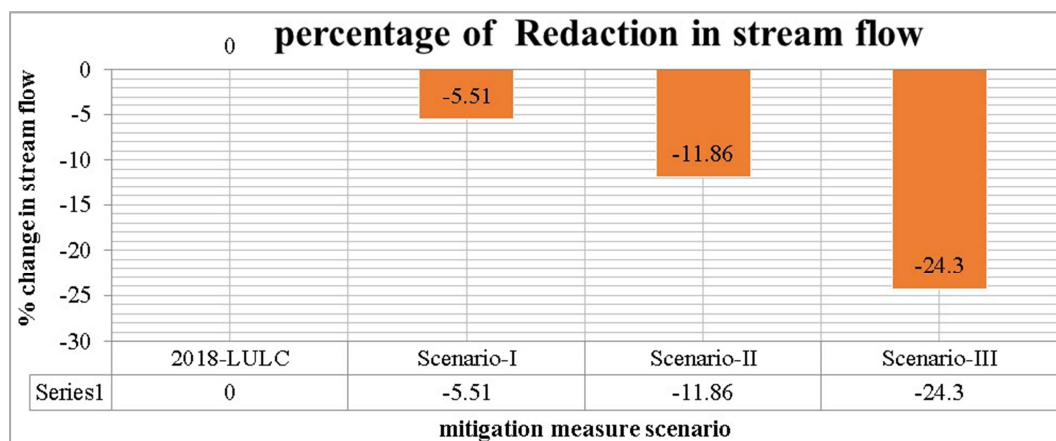


Figure 11. Annual streamflow percentage changes for developed scenario.

4. Conclusions

In this study, Soil and Water Assessment Tool (SWAT), the semi distributed hydrological model was used to evaluate watershed characteristics effect on the streamflow of the Chacha watershed, Abay basin, Ethiopia. For simulation of watershed streamflow, DEM, historical land use and land cover data and soil data were used regardless of other factors that influence the streamflow in the watershed. The results from calibration show vary good range (0.88 for R^2 and 0.82 for NSE) between observed and simulated stream flow respectively. Generally, The simulated average annual streamflow in scenario 2018-LULC data show an Increase by 4.6% and 6.8% as compared with the value in scenario used 1998-LULC and 2008-LULC respectively. For rainfall effect on stream flow the 2nd scenario (2004-2018) annual stream flow was decreased by 4.33% compared to the 1st (1988-2003) scenario. In this study, the slope classification system was the other factor, and three (5%, 10%, and 15% increase) scenarios were developed during HRU analysis using multiple slope classification to evaluate the slope effect on the streamflow. Results show the annual streamflow increases by 1.01%, 1.33%, and 1.61% in the developed scenarios as compared with the value of the model when using the FAO slope classification system. In this study, the land use/land cover had a significant effect on streamflow compared to other watershed characteristics.

Finally, the mitigation measure was proposed by developing scenario by changing the one land use/land cover to the other land use/land cover. in this study three scenario were developed by changing agricultural land to forest with 5%, 10%, and 15% increase. During this scenario analysis, the annual stream flow was decrease by 5.51%, 11.86%, and 24.3% for scenario-I, II and III respectively.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Data Availability

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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