ORIGINAL ARTICLE

Hydrological responses of land use land cover change on the Hangar catchment, Blue Nile Basin

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ABSTRACT

Investigating the hydrological response due to land use land cover changes on catchment hydrology is important for optimum watershed management. This study is intended to comprehend the stream flow characteristics based on land use land cover changes on the hydrological response of the Hangar catchment, Blue Nile Basin, during 1984 – 2000. The soil and water assessment tool (SWAT) was utilized to simulate the hydrological responses. Then the sensitivity analysis was done using SWAT CUP. The most sensitive parameters are GW_DELAY (groundwater delay), CN2 (SCS runoff Curve Number for moisture condition), and Sol_K (saturated hydraulic conductivity). The hydrological response to land use land cover change has shown a 3.09% change in the mean annual discharge during the study period. Hence, land use land cover change has a significant effect on the hydrological components. Moreover, the sensitivity parameter values can be used to estimate the initial value of catchment hydrological modeling on the Blue Nile Basin. In conclusion, the results of this study are useful for sustainable land and water resources management to address multifunctional ecosystem benefits.

Keywords*:* runoff, SWAT model, catchment, multifunctional ecosystem

INTRODUCTION

Land is one of the major natural resources that support economic, social welfare, and various other human needs (FAO, 2011; FAO, 2013). Land use and land cover is a combined term used to describe the use of the land and type of the cover use on the land unit (Getachew and Melesse 2012).On the other way, land cover is referred to as the physical and biophysical cover over the surface of the earth including the distribution of vegetation, water, bare soil, and artificial structures; whereas, land use is defined by the purposes of the land including the arrangements, activities, and inputs that people undertake on a certain land cover type (Biru et al., 2015). Changes in LULC of an area can be caused by several natural and human driving forces: unlike human effects, immediate and often direct, natural effects such as climate change can affect changes over a long period (DeFries & Eshleman, 2004). Land use land cover changes have become a global concern because of their diverse environmental impacts (Lambin et al.,2003;Wongtui, 2012). Land use land cover changes are particularly increasing in developing countries that have an agriculture-based economy and a rapidly increasing human population (Tufa et al., 2014).

Land use land cover changes towards the expansion of cultivated land at the expense of forested areas is also a fundamental environmental problem in Ethiopia (Gashaw et al., 2014; Rientjes et al., 2011). Deforestation, intensive ploughing, and over-cropping of marginally productive land due to increasing population pressure all have resulted in devastating effects on the environment (Ashenafi, 2014; Baumber & Baumber, 2020; MoWE, 2010). For example, LULC change is responsible for altering the hydrological response of watersheds (Neupane & Kumar, 2015; Setegn et al., 2010). Land use land cover change is likely to alter the different hydrological components such as interception, infiltration, and evapotranspiration, thereby affecting runoff generation (both process and volume) and streamflow regimes(Kassa & Forech, 2009). (Getachew and Melesse, 2012) reported that the conversion of forest area to agriculture between 1985 and 2011 in the Angereb watershed has increased the mean wet flow by 39% and decreased the dry average flow by 46%. Furthermore, a study conducted by (Gebrehiwot et al., 2014) has indicated the increase of peak flow and reduction of the base flow at El Diem station of the Blue Nile basin during the period 1970-2010 was attributed to the change of vegetation cover into agriculture and grasslands.

Multiple studies have been conducted on the tributaries of the Upper Blue Nile basin with regards to the assessment of hydrological response(Gashaw, 2019; Hassaballah et al., 2017; Kidane & Alemu, 2015; Gebre, 2015; Woldesenbet et al., 2017). However, limited studies have been conducted on the Hangar catchment. Further; some of the studies did not consider and analyzed the sensitivity of the hydrological characteristics. This research has incorporated the sensitivity analysis. The study area is very important on water resources planning and management to enhance mutual benefits among tributaries. The Blue Nile basin is characterized by high population pressure, improper agricultural, and land use planning. These issues have impacted water use and availability. Unwise land and water resource management has led to intermittent hydrological flow and water use conflict among different uses and users (Koch et al., 2013). Therefore, it is important to assess and investigate the impacts of land use land cover on the hydrological characteristics of a catchment for robust water planning and management strategies to reduce the water use conflict. Hence, the objectives of this study aimed to assess the hydrological responses of land use land cover change on the Hangar catchment. This will help to understand the hydrological characteristics of the catchment for better decision-making on water resources utilization and management.

MATERIALS AND METHODS

Description of the study area

The Hangar catchment is located in the South-Western part of the Blue Nile Basin of Ethiopia, and it is one of the sub-catchments of the Blue Nile. The Hangar catchment lies between latitudes of 9^0 04′ N and 9^0 30′ N; and longitudes of 36^0 31′ E and 36^0 36′ E. The catchment is bordered by the Wonbera sub-basin on the North, the Fincha sub-basin on the East, and the Didessa sub-basin on the South and the South-West sides. It covers an estimated area of 7,901 km^2(Fig. 1). The Hangar river drains from a large area north of Nekemte town and flows from the high plateau area through sharp steep canyons into a low, wide, flat basin which has been eroded through the "plateau," that is Volcanic and Triassic sandstone and into the crystalline rocks basement (Ashenafi, 2007; Awulachew et al.,2007). The altitude of the catchment ranges between 827 masl and 3203 masl. The main flood plain in the catchment is about 1300 masl and bounded by hilly uplands ranging from 2500 to 3000 masl, with the longest flow path is about 140 km(Ashenafi, 2007).

Land cover of the Hangar catchment has undergone major dynamics in the past three decades. According to (Yalew et al., 2012) the majority of the land in the catchment is under mixed farming practice, moderately to intensively cultivate land use. Among the dominant crops grown in the area are maize, sorghum, sesame, groundnut, and other oil seeds (e.g. safflower). Grasslands and bushlands are also observed in the catchment, especially in the highland areas. Only a small proportion of the catchment is covered with forest. (Yalew et al., 2012) produced episodes of LULC using Landsat TM imageries for the Hangar catchment for the years 1984 and 2000. In this study, we use these LULC maps land-use maps as inputs for the SWAT model (Fig 2 a and b).

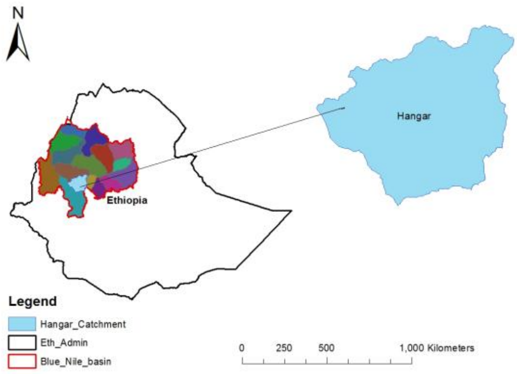


Figure 1. Location map of the Hangar catchment.

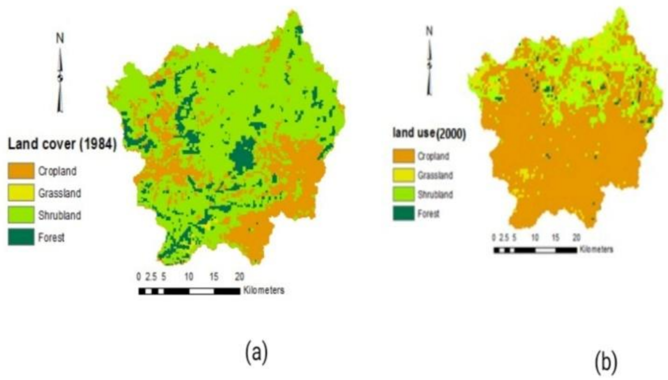


Figure 2. Land-use maps of the Hangar catchment: 1984 (a) and 2000 (b).

The soil type of the study area predominantly falls into two major soil units in the FAO-UNESCO-ISRIC system: the Haplic Nitisols and Haplic Alisols. Haplic Nitisols are deep, red, and well-drained clay-loam soils with a clay content of more than 30% (Deckers et al., 2002). Haplic alisols are clay-rich and very acidic soils common in humid and (sub-) tropical regions (Deckers et al., 2002). The geology of the catchment is mainly dominated by Sandstones and Basalts (Fig.3). In addition, there are also Granite and Clastics deposits (Yilma and Awulachew, 2009).

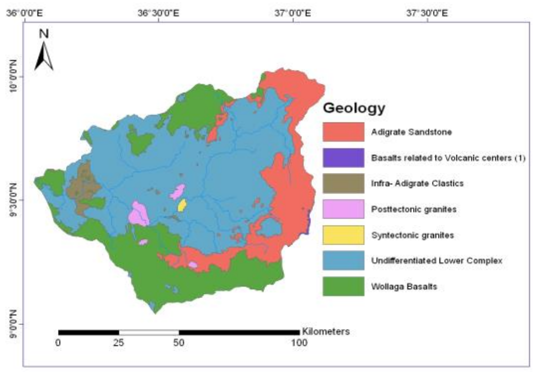


Figure 3. Geology of the Hangar catchment

Materials

The SWAT hydrological model requires a number of datasets to be defined for the physical catchment representation. Data required for this study included spatial and hydro-meteorological data. The spatial data were digital elevation model (DEM), land cover map, soil survey maps, and derived slope class maps. These data were used to derive raster layers. The hydro-meteorological data include weather data and streamflow data. The weather data were utilized as an input to simulate the Hangar catchment hydrologic response; whereas the streamflow data was used for the calibration and validation of the SWAT model outputs (Table 1).

Table 1: Data use and sources

type	Source	References
DEM (30*30 resolution)	Google Earth Engine (GEE) satellite repository site(ASTER)	(GEE, 2016)
Weather(daily precp, max and min temp)		Ethiopian Meteorological agency
Soil	Data obtained from a secondary document	(Awulachew et al., 2009)
LULC (1984 and 2000)	Landsat TM Raw	(Yalew et al.,2012),)
Observed streamflow (1984-2000)	Ethiopian Minister of water and energy	

Methods

SWAT Hydrological modeling

SWAT is a physically-based basin-scale continuous-time distributed parameter hydrologic model that uses different data like soil, land use, Digital Elevation Model (DEM), and weather data for hydrologic modeling and operates on a daily time step. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management.

This model is selected because the SWAT hydrological model is often utilized in the Upper Blue Nile basin to investigate LULC change impacts on hydrological responses. Besides, it is a physically-based model, uses readily available inputs, is computationally efficient, enables users to study long-term impacts on various scale catchments, and is easily interfaces with geographic information systems (GIS). The detailed model structure of the SWAT model is available in the user manual document (Arnold et al, 2012).

SWAT model setup

After all the input data were prepared, the ArcSWAT project was set up using the readily available data. ArcSWAT breaks preprocessing into four main steps: watershed delineation, hydrologic response unit (HRU) analysis, weather data definition, and SWAT simulation. A brief description of the SWAT hydrologic component used in this study is discussed below.

The watershed and subwatershed delineation was performed using 30 x 30 m resolution DEM data using the ArcSWAT model watershed delineation function. After applying the water delineation steps the whole catchment is subdivided into sub-catchments (Fig. 8).

Next, follows the hydrologic response unit analysis step, ArcSWAT characterizes the delineated watershed in terms of the threshold values of land use, soil, and slope percentage combination. The ArcSWAT toolbar menu is provided with different commands that enable land use, soil, and slope characterization. These tools allow loading the land-use map and soil map of the study area, evaluate slope characteristics and determine the land use/soil/slope class combinations in the delineated sub-watersheds. The HRU analysis in the ArcSWAT was performed independently for each of the watershed parameters and finally overlaid during the analysis.

Land use land cover was done by importing the raster format land-use map into the current project database; the code given to each land use in the attribute table field of the land-use map was selected so that the model converts it to grid value on the map. A lookup table that defines this code for reclassification was prepared by referring to the actual land uses in the study area. The lookup table (user table) was then loaded and the land-use layer was reclassified to the defined land use. The information contained in the land use map tells how the different uses of the surface are distributed inside the area. From Fig. 4 and Table 2, it can be seen that the sub-basin in 1984 is mainly occupied by cropland with more than 38.94 % and forest by 10.8% but in 2000 (Fig. 5; Table 2) cropland is 78% and forest 3.26% which implies more than 62% is a decrease in a forest. The soil part was done as the same procedure as land use land cover. To define the projected raster of the soil map was loaded onto the interface and then reclassified to match the values with the given names (SWAT code) from the lookup table (Fig.6; Table 3).

Table 2: Land use cover in Hangar catchment (1984 and 2000)

Land cover	Total area in 1984 (%)	Total area in 2000 (%)
Cropland	38.94	78
Shrubland	44.55	14.42
Grassland	5.71	4.32
Forest	10.8	3.26

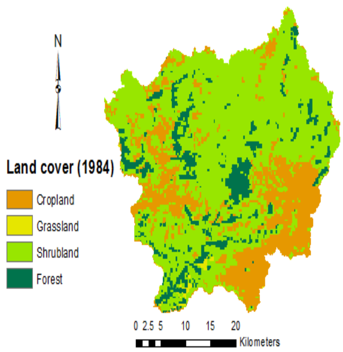


Figure 4. Land use map of Hangar catchment in 1984

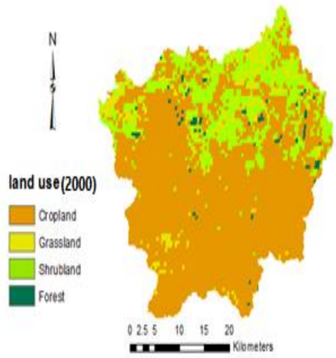


Figure 5. Land use map of Hangar catchment in 2000

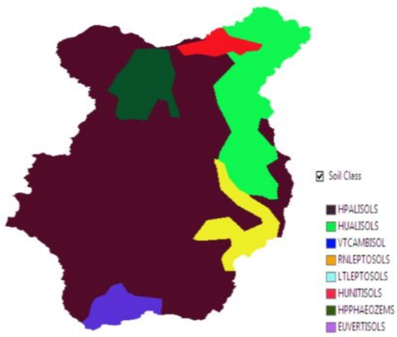


Figure 6.Soil map of the Hangar catchment

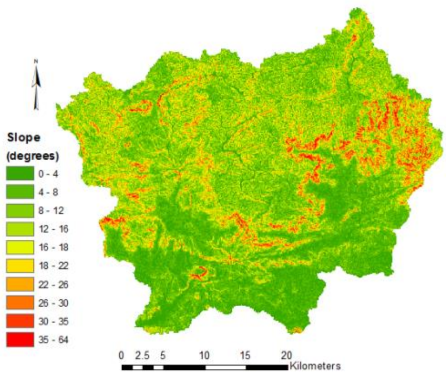


Figure 7. Slope classes of the Hangar catchment

Table 3. Area covered by different soil types in the Hangar catchment (Awulachew et al., 2009).

Swat Class	Soil Type	Total Area (%)
Hpalisols	Loam	5.67
Hualisols	Loam	3.2
Vtcambisols	Clay	2.04
Rnleptosol	Sandy Loam	4.96
Hunitisols	Loam	69.63
Hpphaeozems	Loam	14.5
Total		**100%**

The slope range in the defined watershed was determined in the slope classification procedure. Since the terrain of the Hangar catchment has high elevation differences, multiple slope definition was selected in the slope discretization and therefore, three slope classes were used for classification (Fig.7). Finally, after land use, soil and slope were defined, the three layers were overlaid to produce a combined distribution of these watershed parameters for each of the delineated sub-watershed. The hydrologic response units were defined such that land use, soil, and slope were altogether considered during catchment modeling. This needs setting the HRU thresholds to eliminate minor land uses` soil groups, and slope classes in each sub-basin during a simulation (Fig.8). ArcSWAT reapportions the remaining HRUs to 100% and considers them for the simulation. SWAT user's manual suggests that a 20% land-use threshold, 10% soil threshold, and a 20% slope threshold are adequate for most modeling applications(Winchell et al., 2010). In this study, the threshold levels were set to 15% for land use, 10% for soil, and 5% for slope. These thresholds were appropriate to exclude spatially in significant land uses, soils, and slopes to save simulation time and file storage space as reducing the thresholds would incredibly boost the number of HRUs. Accordingly, the Hangar catchment was divided into 140 HRUs, each with unique land use, soil, and management combinations.

Figure 8. Watershed map of the Hangar catchment

SWAT model Sensitivity, Calibration and Validation Analysis

The model simulation was done from 01/01/1984 to 31/12/2000. Then the sensitivity analysis was done to assess the input parameters with respect to their impacts on the model output. It is important to support the model validation and calibration procedure to reduce the uncertainty existing in the model run (Abbaspour, 2014). In this study, the initial parameter set was selected based on previous studies on similar watersheds. It was done to differentiate parameters that greatly affect streamflow in the study area from the entire parameter set of the model. The most sensitive parameters on flow due to change in land use land cover and management practices at Hangar catchment were identified through a calibration procedure. Streamflow simulation considers numbers of hydrological input parameters of groundwater (.gw), management (.mgt), soil (.sol), hydrologic response units (.hru), routine (.rte) and sub-basin (.sub) etc. Thus, a sensitivity analysis was performed for the entire period (1984-2000) with 12 model parameters that could affect streamflow (Table 4). Global sensitivity was applied to differentiate sensitive parameters. Then, the sensitive parameters were identified based on the sensitivity indices (Table 5).

Table 4..SWAT model parameters selected for sensitivity analysis(Arnold et al, 2012).

Parameter Name	Description	Default range
CN2	SCS runoff Curve Number for moisture condition	35 to 98
ALPHA_BF	Base flow alpha factor (days)	0 to 1
GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0 to 5000
ESCO	Soil evaporation compensation factor	0 to 1
Sol_AWC	Available water capacity of a soil layer (mm/mm)	-0.25 to 25
Sol_K	Soil hydraulic conductivity (mm/hr)	-0.25 to 25
REVAPMN	Threshold depth of water in the shallow aquifer for groundwater evaporation to occur (mm)	0 to 100
GW_REVAP	Groundwater evaporation coefficient	0.02 to 0.2
CH_K2	Hydraulic Conductivity in main Canals (mm/hr)	0 to 150
CH_N2	Manning's value for main channel	-0.01 to 0.31
Sol_BD	Moist bulk density (Mg/m3)	1.1 to 1.9
GW_DELAY	Groundwater delay (day)	0 to 500

Table 5.Sensitivity classes of swat parameters(Arnold et al, 2012)

Sensitivity Class	Sensitivity Index (I)	Sensitivity Level
I	0 ≤ I < 0.05	Small to negotiable
II	0.05 ≤ I < 0.2	Medium
III	0.20 ≤ 1	High
IV	I ≥ 1.0	Very high

In this study, the SWAT model was calibrated from 1984 to 1989 and validated from 1990- to 1995. Initially, automatic calibration procedures were used to estimate the best parameter sets of the study area. Twelve model parameters were selected with their default ranges to initialize the calibration process. The calibration was done by the SWAT-CUP tool, then following sequential uncertainty fitting version-2 (SUFI-2) algorithm using monthly streamflow data.

Model performance evaluation

Various statistical methods are used for evaluating catchment model performance, including the mean and standard deviation (SD) of the simulated outputs, relative error (RE), coefficient of determination (R2), root mean square error (RMSE), Nash-Sutcliffe efficiency (NSE) and percent bias (PBIAS) (Moriasi et al., 2007; Nash & Sutcliffe, 1970; Santhi et al.,2007)For this study, the performance of the SWAT model simulation was in Hangar catchment was evaluated by comparing observed and simulated streamflow data using the coefficient of determination (R^2), Nash-Sutcliffe efficiency (NSE), and the percent bias (PBIAS) methods.

The Nash–Sutcliffe efficiency (NSE) indicates how well the plots of observed versus simulated data fit. NSE is given by equation:

$$NSE = 1 - \frac{\sum_{i-1}^{n}(Y_i^{obs} - Y_i^{sim})^2}{\sum_{i=1}^{n}(Y_i^{obs} - Y_i^{meanobs})^2} \ldots\ldots\ldots\ldots \text{eq(1)}$$

Where, Y_i^{obs} is the i[th] observation value, Y_i^{sim} is the i[th] simulated value ;$Y_i^{meanobs}$ is the mean observed value and n is the total number of observations.

The value of NSE ranges from 1 (best) to negative infinity. NSE value < 0 indicates the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Nash and Sutcliffe, 1970). NSE values greater than 0.5 indicate that the simulated value is a better predictor than the mean measured value and is generally viewed as acceptable performance (Santhi et al.,2001)

PBIAS is an error index describing the average tendency of simulated values to be larger or smaller than observed data (Moriasi et al., 2007; Gupta et al.,1999).

$$PBIAS = \frac{\sum_{i-1}^{n}(Y_i^{obs} - Y_i^{sim})}{\sum_{i=1}^{n}(Y_i^{obs})} * 100 \ldots\ldots\ldots \text{eq (2)}$$

Where Y_i^{obs} is observed daily values i of the modeling period and Y_i^{sim} represents simulated daily values.

Model performances are generally considered satisfactory if NSE> 0.5 and PBIAS<±25% (Moriasi et al., 2007).

$$R^2 = \left[\frac{\sum_{i=1}^{n}(Q - \bar{Q})(Q' - \bar{Q}')}{\sqrt{\sum_{i=1}^{n}(Q - \bar{Q})^2}\sqrt{\sum_{i=1}^{n}(Q' - \bar{Q}')^2}}\right]^2 \ldots \text{eq (3)}$$

Where Q is observed streamflow,

Q' the simulated streamflow

$\bar{Q}$ and $\bar{Q}`$ are the mean observed and simulated streamflow, respectively.

The optimal statistical value occurs when the value reaches 1. This statistic shows the goodness of fit between simulations and observations(Nash & Sutcliffe, 1970).

RESULTS AND DISCUSSIONS

Model sensitivity analysis

Before calibration, sensitive parameters were identified and classified as indicated in Table 4 and Table 5. Parameters corresponding top-value less or equal to 0.05 are categorized as more sensitive parameters in their degree of sensitivity (Lenhart et al., 2002). Thus, among others, GW_DELAY (groundwater delay), CN2 (SCS runoff Curve Number for moisture condition), and Sol_K (saturated hydraulic conductivity) are the most sensitive parameters relatively as indicated in Fig.9 below in descending order (from bottom to top).

In this study the analyses of LULC patterns, the cropland increased at the expense of vegetated cover types in 1984 and 2000 (summarized in Table 2, and Fig. 4 and Fig. 5). During this period, cropland has expanded from 38.1% in 1984 to 78% in 2000. In contrast, forest, shrubland, and grasslands had decreased from the 1984 land cover to 2000 period. For example, forest coverage decreased from 10.8% in 1984 to 3.26% in 2000. Similarly, shrubland and grasslands also decreased from 44.30% to 14.42% and 5.71% to 4.32%, respectively. Model calibration and validation

The graphical comparison of the parts of the observed and simulated flow for the calibration (1984-1989) and validation (1990-1995) periods are presented in Fig.10 and 11. The results show that the simulation has captured the observed flow reasonably. Statistical performance indices are also shown in Table 7. The obtained R^2 (0.77) for calibration and 0.8 for validation values show very good consistency between the observed and simulated data (Fig. 12). This indicates less error variance between the two data (Moriasi et al., 2007). NSE above 0.75, PBAIS less than 10% were also attained. The positive values of PBAIS indicate the underestimation of the model. According to (Moriasi et al., 2007), the performance of the model is very good. The overall performance indices during the validation period are higher than the performance indices of the calibration period, which suggests an overall superior quality of data. In general, the performance indices obtained during the calibration and validation periods indicated a very good performance rate in simulating the hydrological characteristics. The validation process using an independent set of observed data is necessary to comprehend the degree of certainty of the model prediction. Model performance in calibration and validation periods may not be similar to some extent. For this study, validation was done using independent streamflow data of 1990 to 1995 using the calibrated parameters of the Hangar catchment without any change.

Table 6. List of sensitivity parameters default and modeled values

Parameter	Definition	Range	SWAT default value	Modeled value
GW_DELAY.gw	Ground water delay(days)	0-500	31	6.54
SOL_K	Saturated hydraulic conductivity (mm/hr)	-0.25-0.25	0.15	-0.12
CH_K(2)	Effective hydraulic conductivity in main channel(mm/hr)	0.025-200	12	6
CN2.mgt	runoff curve number value(land cover)	35-98	changes per HRUs	65-98
CH_N2.rte	Manning1s value for main channel	-0.32	0.014	0.116
SOL_BD	Moist bulk density (Mg/m3)	1.1-1.9	1.3	1.5
SOL_AWC.sol	Available water capacity[mmH2O/mm soil]	0-1	Changes per soil	0.39
ALPHA_BF.gw	Base flow alpha factor[days]	0-1	0.048	0.8

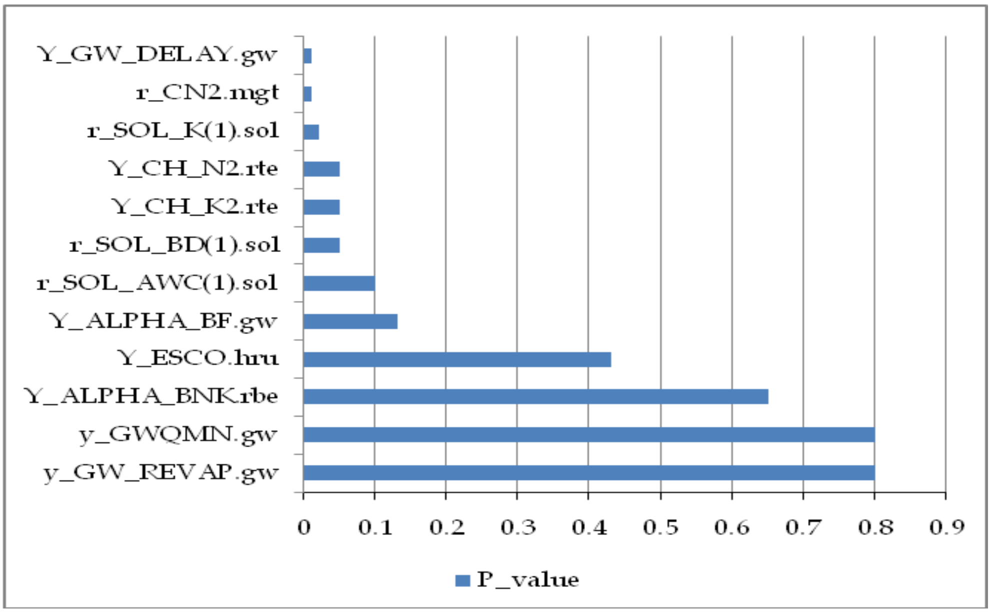


Figure 9. List of sensitive parameters and best-fitting values.

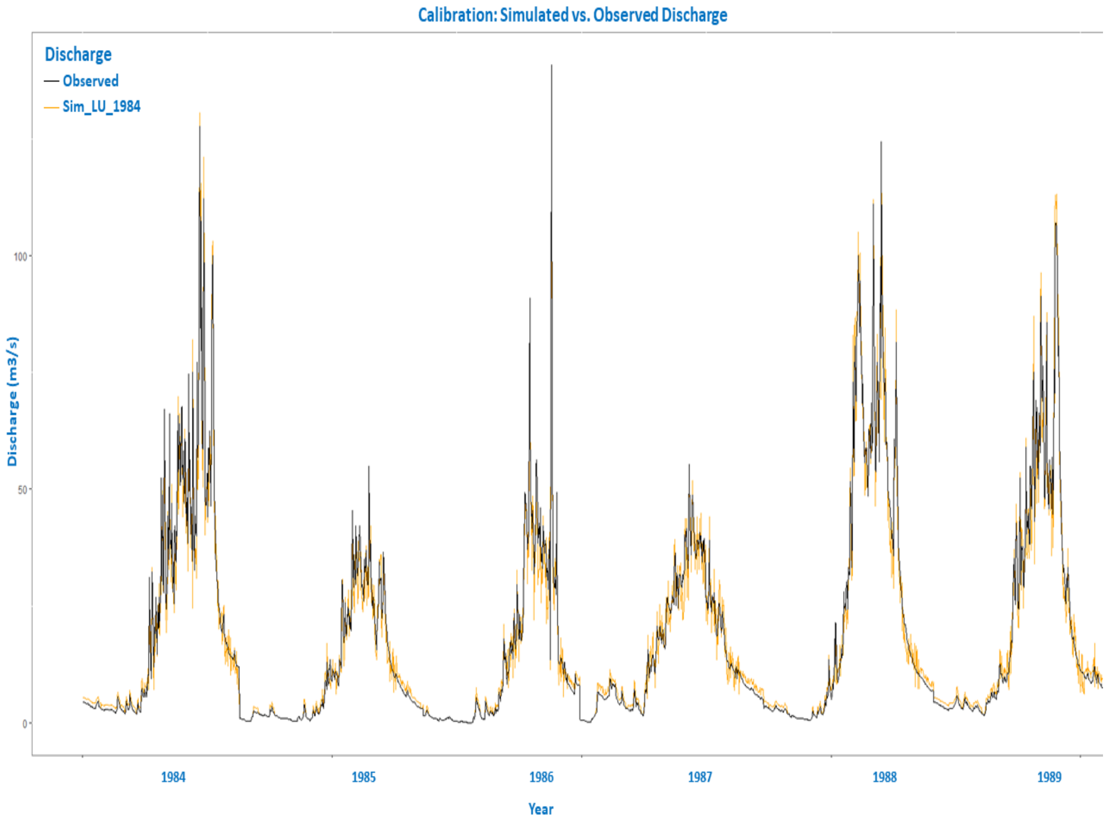


Figure. 10. Calibration of the SWAT model

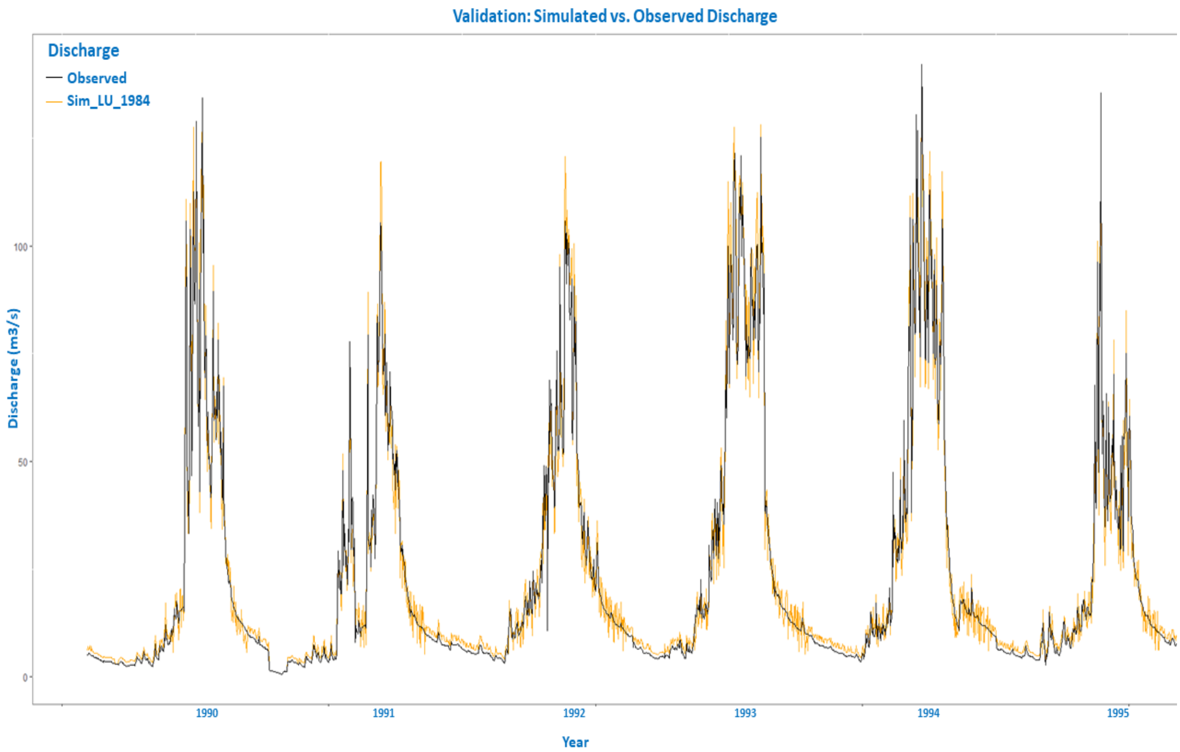
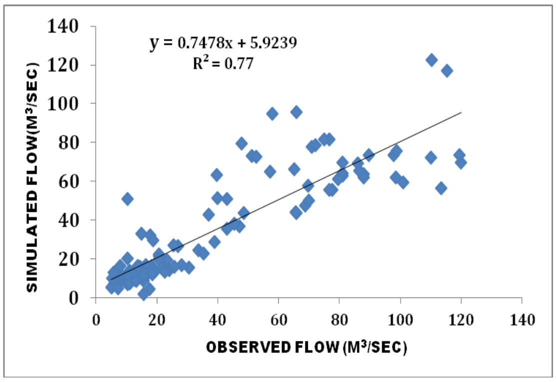


Figure 11. Validation of the SWAT model



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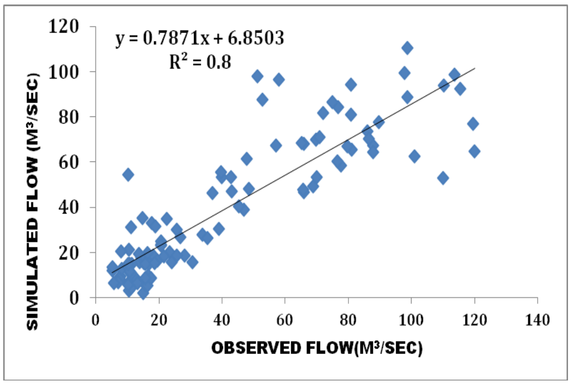

b

Figure 12. Regression analyses of simulated and observed flow during calibration (a) and validation (b).

Hydrological responses to changes in land use-land cover

Assessment of the hydrological impacts of land use land cover change for the Hangar catchment, the two LULC maps were used separately while all other SWAT inputs were similar. The model produces different hydrological components (e.g. annual flow, seasonal flow, surface runoff, lateral flow, groundwater flow, and water yield) on an annual and a monthly average basis were and then compared (Table 8).

Table 7. Calibration and validation period model performance results of the Hungar catchment

Methods	Calibration	Validation
Nash-Sutcliffe efficiency coefficient (NSE)	0.75	0.83
Percent bias (PBIAS)	-14%	17%
Coefficient of determination (R2)	0.77	0.8

Table 8. Mean annual hydrological components (1984-2000) during the two LULC periods in the Hangar catchment

	Stream flow (m3/s)			Hydrological components (mm)			
Year	**Annual**	**Wet season**	**Dry season**	**SURQ**	**LatQ**	**GWQ**	**Water yield**
1984 LULC	318.63	201.66	98.26	221.2	37.8	142.4	351.8
2000 LULC	328.44	229.32	95	236.7	29.1	133.3	363.2
Percent changes (%) (1984 and 2000)	3.09	4.35	-3.26	7.01	-8.7	-0.61	3.24

Mean annual streamflow changes

Streamflow was simulated for the two land use-land covers of 1984 and 2000. The mean annual streamflow for the two periods was calculated from the mean monthly streamflow data simulated for the two land use land cover maps. As depicted in Table 8, a 3.09% change was observed in mean annual discharge. The change observed on mean annual discharge can be explained by the catchment's land use-land cover change observed in the study period.

Seasonal streamflow changes

In order to analyze the changes in seasonal flows during the period (1984 and 2000), June, July, August, and September were considered as wet/rainy months; while December, January and February were taken as dry months. During the wet season, rainfall is at its peak, and a large amount of streamflow is generated from surface runoff. The contribution of surface runoff is more pronounced in these periods than in the dry season. This is also discussed by (Leta, 2021) who have studied the hydrological responses of land use land cover on the Nash watershed of the Blue Nile. They showed that the months of July, August, and September are the main months of the wet season in the study area which results in high peak flow on the river channels.

A decreased streamflow in the dry months and an increment for streamflow in the rainy months were observed through the study period. The streamflow comparison between the year1984 and 2000, shows 4.35% change for the wet season; and -3.26% changes for the dry season.

The finding of this study: the increasing trend of annual streamflow, wet season flow (June–September), and the decreasing trend of dry season flow (December-February), is consistent with studies carried out in the Blue Nile basin. For example,(Bewket and Sterk, 2005; Getachew and Melesse,2012)on Angereb watershed, (Bewket and Sterk, 2005) on Chemoga watershed and (Tekleab et al., 2014) on Jedeb mesoscale catchment, the trend in hydrological components were partially explained by changes in LULC and degradation of the watershed that involves the destruction of natural vegetation covers, expansion of croplands and overgrazing.

CONCLUSIONS

In this study, a significant expansion of cropland area at the expense of forest, shrublands, and grasslands have occurred between 1984 and 2000 in the Hangar catchment. The changes in land use land cover change have contributed to annual flow, wet season flow, surface runoff, and water yield in the catchment. Contrarily, it has reduced the dry season flow, groundwater flow, and lateral flow. Higher vegetation cover in 1984 resulted in a lower peak flow during the wet season and higher low flow during the dry season when compared to the lower vegetation cover in 2000. The reason is higher vegetation coverage in 1984 retains more overland flow (surface runoff) from easily joining the river discharge by permitting water to be retained in the soil and hence produced a lower peak-flow. While the lower vegetation coverage in 2000 produces more runoff due to less infiltration rate and contributed to higher streamflow during a peak flow during the wet season.

In this study, we used readily available global data from a previous study with a higher resolution DEM, soil and land use maps were used. However, SWAT simulations could be improved by using finer resolution maps and a detailed database for more robust results. Hence further studies are recommended with detailed sampled soil, land, and DEM data. The hydrological responses analysis has considered LULUC at two different periods, nevertheless, multiple periods of dynamic land use land cover changes would have illustrated a better variability in streamflow. Thus further studies may find it interesting to simulate hydrological impacts of dynamically changing land use land cover in the Hangar catchment, Blue Nile river basin.

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