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Sensitivity of SWAT Simulated Runoff to Temperature and Rainfall in the Upper Awash Sab-Basin, Ethiopia

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Abstract

This paper estimates the runoff sensitivity to change in temperature and rainfall by using Soil and Water Assessment Tool (SWAT) hydrologic model. Rainfall and temperature were perturbed to study the runoff sensitivity to these climate variables. Rainfall and Temperature play main role in the accessibility of runoff by influencing the contribution and timing of water sources. The SWAT model was run with monthly station-based temperature and rainfall data for the whole upper awash sab-basin (1980-2010). The hydrological model was calibrated for eight years (1993-2000), and the simulation results were validated with the historical stream-flow for four years (2001-2005) at outlet of Hombole gauging station. The impact of temperature and rainfall changes on the runoff in the sub-basin was estimated by using a sensitivity analysis; through the calibrated and validated SWAT hydrological model. The SWAT model has been used to study the impact of possible hypothetical scenarios of rainfall and temperature on the annual runoff of the Awash sub-basin. This was achieved through both separated and combined use of changes in the amount of rainfall (+/-20% and increase temperature (warming of up to 5°C). The results shown that runoff was sensitive to rainfall and temperature changes in the study area. It has been revealed that 1, 2, 3, 4 and 5°C increases of the annual temperature lead to reduces annual runoff by -0.085, -0.88, -1.75, -2.55 and -3.30% respectively. The runoff has a positive correlation with rainfall change; but, a negative correlation with temperature change. The results reveal that runoff was more sensitive to rainfall than that of temperature rise. Increased/decreased rainfall by 10% will result in increased/reduced annual runoff by 22% and 21% respectively. Generally, the results showed that changes in the climate variables had a significant effect on water availability.

Keywords: Climate; Rainfall; Temperature; Sensitivity analysis; Runoff; SWAT model

Introduction

Precipitation and temperature play vital role in the availability of intra-annual runoff by influencing the contribution and timing of different water sources [1]. The availability of water sources depends on temperature, precipitation and timing factors, which change the seasonal distribution of annual runoff [2]. According to report Zhang et al. [1], runoff was more sensitive to precipitation and temperature variation northern and southern slopes of the Middle Tianshan Mountains, China, after evaluating the sensitivity of runoff to different types of climatic disturbance. The One way of evaluating the likely climate change impacts on water resources is to apply different climate change scenarios to rainfall-runoff model to estimate runoff and stream flow [3]. According to the report by Mechal et al. [4], by perturbing the SWAT model input parameters taking into account a potential parameter range suggested by climate change projections; the sensitivity of recharge to meteorological parameters was examined for Ethiopia. Changes in the hydrological cycle where associated with changes temperature and precipitation [5].

Several studies have been conducted on the sensitivity of stream flow to climate changes for many parts Ethiopian basin [6-12]. Numerous Studies where done on Blue Nile river basin showed that the basin's water resource is very sensitive to incremental climate variability. According to the study report by Daba et al. [13], the change in climate variables such as reduce in precipitation and increase in temperature there by increase in evapotranspiration which is very sensitive parameter that can be affected by changing climate than any other hydrological component is likely to have significant impact on Stream flow.

This study addresses the responses of upper Awash sab-basin runoff to changes in temperature and rainfall. By upsetting temperature and rainfall, the climate variables that have a main effect on runoff and the possible impact of change in climate on runoff can be deliberated. The main objective of this study is to test the applicability of the SWAT hydrological model over upper Awash sab-basin through sensitivity studies and to assess the impacts of rainfall and temperature change on the annual runoff by using perturbations in temperature, rainfall and combined.

Study Area Description

This study carries out on the upper part of the Awash River Basin and which is located between 8°16'N to 9°18'N and 37°57'E and 39°17'E (Figure 1). The watershed covers about 7240 km². The mean annual rainfall of Upper Awash sub-basin where about 1019 mm over the last 30 years. The area received mean minimum, mean maximum and average temperatures of 12.07, 23.23 and 17.65°C respectively from the analyzed recorded data in 1980-2013. The major soil of the sub basin is characteristically by Vertisols [14].

Datasets

Hydro-meteorological data

The SWAT model requires daily weather data and spatial data.

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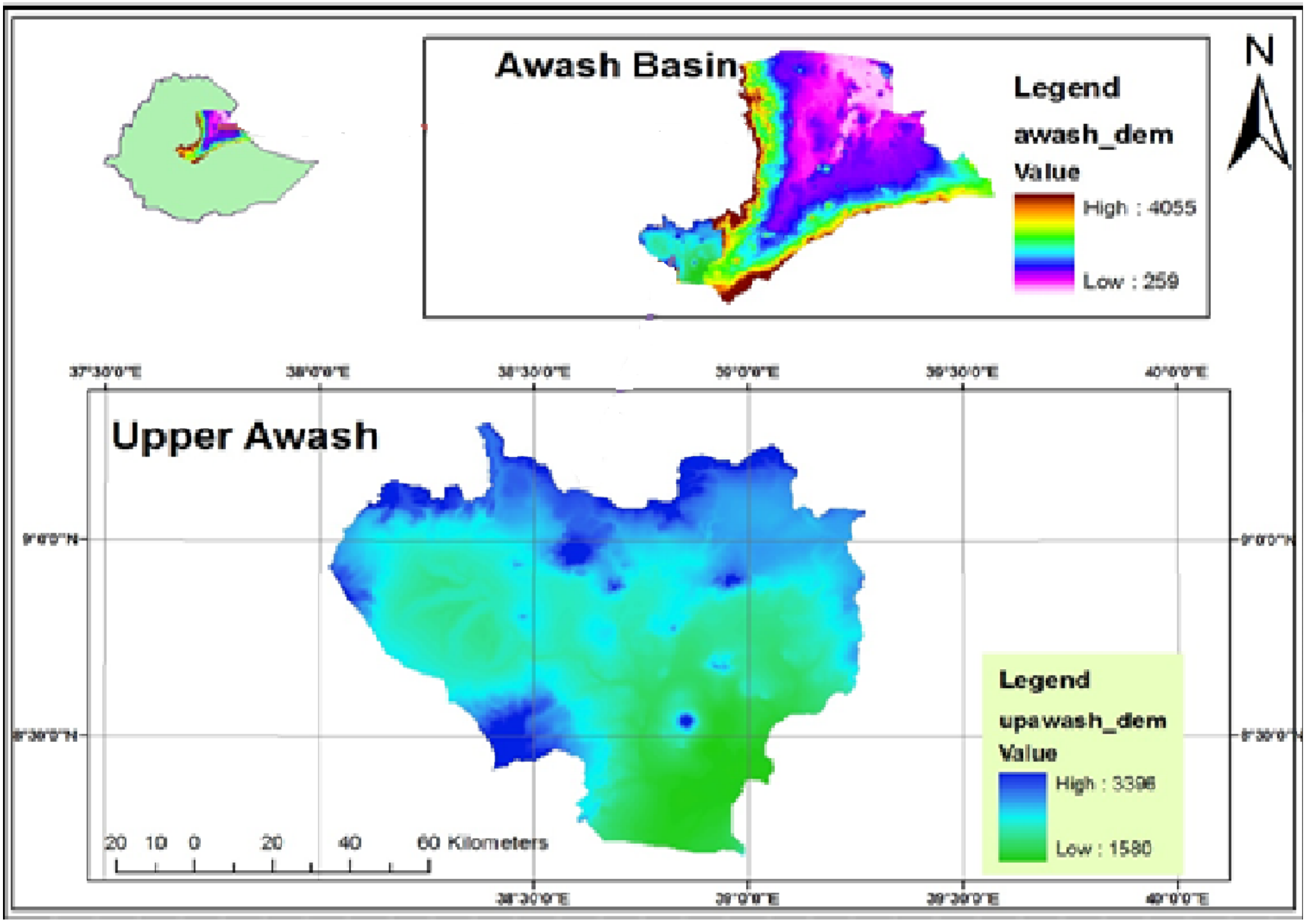

Figure 1: Study area.

The daily weather data required to run the SWAT hydrological model were acquired from the National Meteorology Agency (NMA). The daily data for maximum and minimum temperature, rainfall, relative humidity, and wind speed were obtained. These data cover a period of 30 years from 1980 to 2010.

Spatial data

For the setup of the SWAT model, Shuttle Radar Topographic Mission (SRTM 90 m) resolution DEM (http://gdex.cr.usgs.gov/gdex/) were obtained to analyze the drainage patterns of the land surface terrain and delineate the watershed. Sub-basin parameters such as the stream network, slope length of the terrain and slope gradient characteristics such as channel length, width and slope were derived from the DEM (Figure 2).

Soil and land use data

The soil and land use data were used for the definition of the Hydrological Response Units (HRUs). SWAT hydrological model requires different soil physicochemical properties and soil textural such as hydraulic conductivity, soil texture, organic carbon content, available water content and bulk density for different layers of each soil type. Soil physical and chemical properties data base for the upper awash basin was from [15,16], based on the soil types of the upper Awash basin, information from project documents and measured and calculated infiltration and hydraulic conductivity values from the major soils of the Awash basin. Soil and land use data were obtained from Integrated Development Master Plan Project, Awash River basin of semi detailed Soil Survey and the Soils of upper awash Area, Ethiopia by (Oromia Water Works Design and Supervision Enterprise [14] (Figure 3a and 3b).

Methods

Soil and Water Assessment Tool (SWAT) model

SWAT was developed to forecast the effect of land management practices on sediment, water, land use, and agricultural chemical yields in large watersheds with varying soils, and management conditions over long periods of time [17]. The SWAT model simulates eight major hydrological components: weather, erosion and sediment, hydrology, transport, crop growth, pesticides, nutrients, soil temperature and agricultural management. The main hydrological processes that can be simulated by the SWAT model includes: surface runoff, evapotranspiration (ET), channel routing, deep aquifer flow, shallow aquifer, percolation and infiltration [18]. SWAT requires daily values of precipitation, minimum and temperature maximum, relative humidity, wind speed and solar radiation. They can be given to the model as a user defined measured time series or can be generated within SWAT from a monthly data and its statistics summarized over a number of years. A weather generator WXGEN model is included in SWAT which can generate the above stated data or fill in gaps for measured

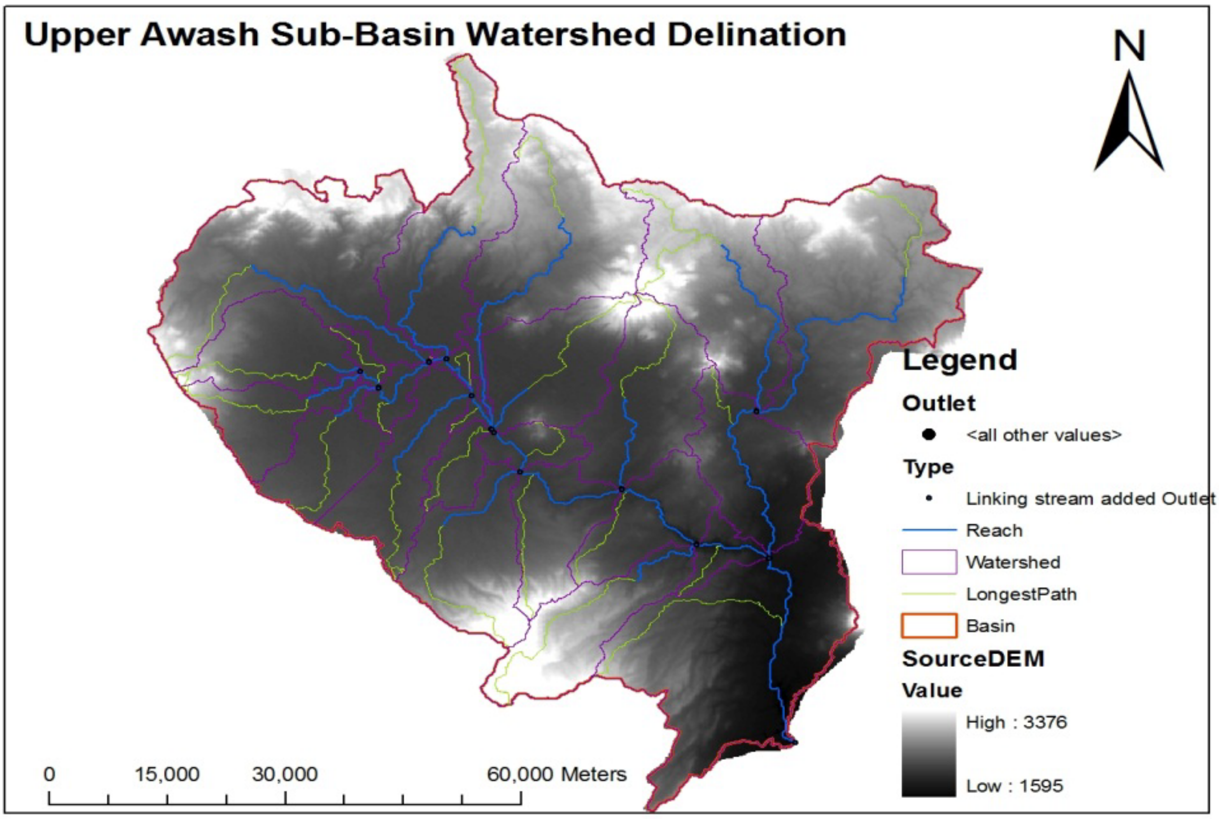

Figure 2: DEM of study area.

records. The inside SWAT model is constructed on the contiguous US condition. However, it can be brought to local conditions by providing a user defined database (userwgn.dbf) [19].

The SWAT system is embedded within a Geographic Information System (GIS) that can integrate various spatial environmental data including soil, land cover, climate, and topographic features. Watershed hydrology simulation is done in two divisions separately. The first division is the land phase of the hydrological cycle that controls the amount of sediment, water, pesticide and nutrient loadings to the channel in the sub basin. The 2nd division is routing phase of the hydrologic cycle that can be defined as the movement of sediments, water, organic chemicals, and nutrients through the channel network to the outlet of the watershed.

Surface runoff calculations

Surface runoff occurs when the rate of water application to the ground surface exceeds the rate of infiltration. To estimate surface runoff, SWAT hydrological model provides two methods. These are the Green & Ampt infiltration and SCS curve number method. The SCS curve number procedure is a function of the land use, soil's permeability and soil water conditions. Where the SCS runoff equation is an empirical model that came into common use in the 1950s (Eq 1).

$$Q_{surf} = \frac{\left(R_{day} - I_a\right)}{\left(R_{day} - I_a + S\right)} \quad (1)$$

Where, Q_{surf}: The accumulated runoff (rainfall excess) (mm); R_{day}: The rainfall depth for the day (mm); I_a: The initial abstractions (canopy interception, surface storage, infiltration prior to runoff) (mm); S: The retention parameter.

Consequently, surface runoff will only happen only when $R_{day} > I_a$. Retention parameter S is defined Eq. 2 as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (2)$$

Where, CN- is the curve number and the initial abstractions I_a- is commonly approximated as 0.2S, then Eq. 1 becomes:

$$Q_{surf} = \frac{\left(R_{day} - 0.2S\right)^2}{\left(R_{day} + 0.8S\right)} \quad (3)$$

Where, Q_{surf}: Surface runoff; R_{day}: The rainfall depth for the day (mm); S: The retention parameter.

Model calibration, validation and performance

Tuning of model parameters based on checking results against observations to ensure similar response over time is called model calibration. This includes comparing the model simulated outputs with the recorded stream flows. In the calibration process the model parameters may vary until recorded stream flow patterns are accurately simulated.

In order to apply the calibrated model for estimating the effectiveness of future simulation, the SWAT model tested against an independent set of observed data. Testing of a model on an independent set of data set is called model validation. After model predictive ability was proved as being reasonable in both the validation and calibration phases, the model was used for future predictions under different management

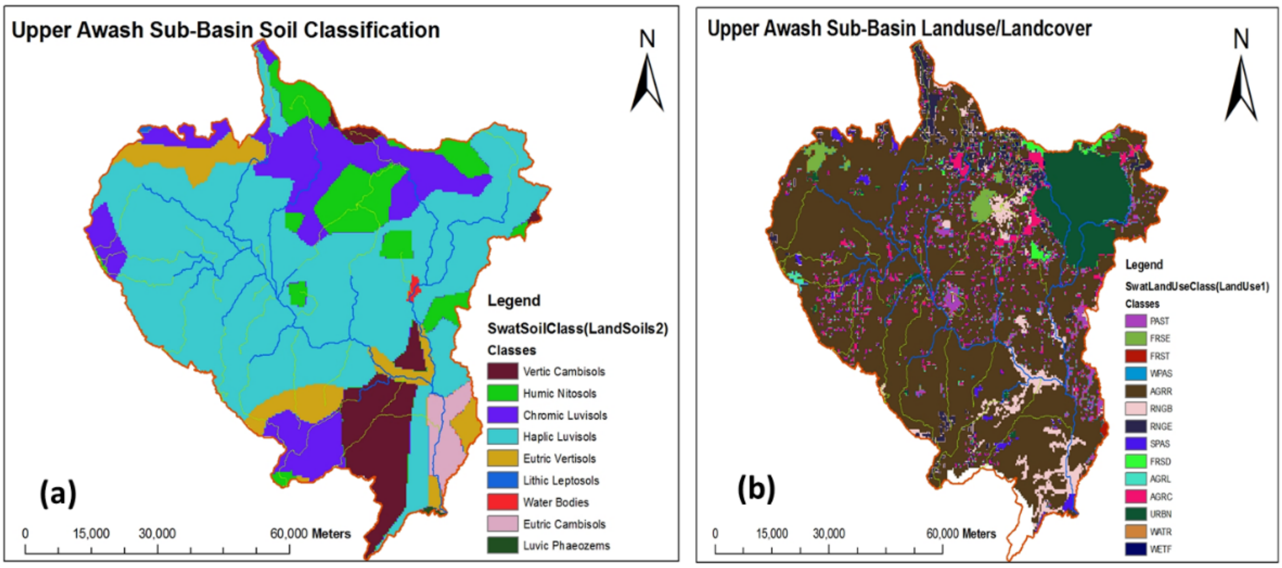

Figure 3: A spatial map of the upper Awash sub-basin showing soil (a) and land use (b) types of classification.

scenarios. The performance of SWAT model was evaluated using statistical analyses to determine the reliability and quality of predictions when compared to observed values. Nash-Sutcliffe simulation efficiency (E_{NS}) and Coefficient of determination (R^2) were the goodness of fit statics used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the simulated and observed values. The Nash-Sutcliffe simulation efficiency (E_{NS}) indicates how well the plot of simulated versus observed value fits the 1:1 line. If the measured value is the same as all predictions, E_{NS} is 1. If the E_{NS} is between 0 and 1, it indicates deviations between predicted and measured values. If E_{NS} is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction [20]. The R^2 and E_{NS} values are explained in Eq. 4 and 5 respectively.

$$R^2 = \left[\frac{\sum_{i=1}^{N}(o_i-\bar{o})(p_i-\bar{p})}{\left[\sum_{i=1}^{N}(o_i-\bar{o})^2\right]\left[\sum_{i=1}^{N}(p_i-\bar{p})^{0.5}\right]}\right] \quad (4)$$

$$E_{NS} = 1-\frac{\sum_{i=1}^{N}(o_i-p_i)^2}{\sum_{i=1}^{N}(o_i-\bar{o})^2} \quad (5)$$

Where: N: number of compared values ∞; O_i: observed data; O: observed mean; P_i: simulated data - simulated mean.

ENS can have values ranging from -∞ to 1. If the simulation is accurate, E_{NS} is equal to one. If the accuracy of the simulation results is smaller than the average value of the measured variables, then E_{NS} will have a negative value.

Climate sensitivity analyses

The Upper Awash sub-basin values of monthly rainfall, minimum and maximum temperatures were as an input to the SWAT hydrological model. The remaining like other climatic parameters, soil hydrologic parameters and land use used in model development under current climate conditions were assumed to be constant. The SWAT model computes the impacted daily rainfall by simply multiplying the daily rainfall multiplier by the corresponding baseline daily rainfall values; whereas the impacted daily temperatures are calculated by adding the average daily delta values of the maximum and minimum daily temperature to the corresponding average baseline daily temperature as shown in Eq. 6 and 7.

$$R_{day} = R_{day} * \left(1+\frac{adj_{pcp}}{100}\right) \quad (6)$$

R_{day}: The precipitation falling in the sub-basin on a given day (mm H_2O); adj_{pcp}: The percentage change in rainfall.

$$T = T + adj_{tmp} \quad (7)$$

T: the daily temperature (°C); adj_{tmp}: is the change in temperature (°C).

Rainfall and temperature scenarios

Climate sensitivity scenarios analyses were achieved by perturbing the station data (the validated SWAT model with observed station data) as input. Climate sensitivity analyses were made by perturbing the meteorological input parameters (rainfall and temperature) of the baseline SWAT model. In this study eight rainfall and four temperature change scenarios were considered. The perturbations applied were with rainfall changes of -20, -15, -10, -5, +5, +10, +15 and +20% and temperature increase of +1, +2, +3 and +4°C and combination of both rainfall and temperature perturbations.

Results and Discussion

Flow calibration and validation

Calibration performed for eight years (January 1, 1993 to December 31, 2000) and one year taken as warm-up period. As depicted in Figure 4a, the calibration results were good agreement between the simulated and observed monthly flows at the outlet of sub-basin. This can be verified by the correlation coefficient (R^2=0.85), the Nash-Sutcliffe simulation efficiency (E_{NS}= 0.80). The validation ascertains the performance of the SWAT model for simulated stream flows in periods different from the calibration periods, but without any further change in the calibrated parameters. Validation result was performed for four years (January 1, 2001 to December 31, 2004) and in which one year taken as warm-up period. The correlation coefficient (R^2=0.83) and the Nash-Sutcliffe simulation efficiency (E_{NS}=0.78) shows very good agreement between simulated and observed values (Figures 4 and

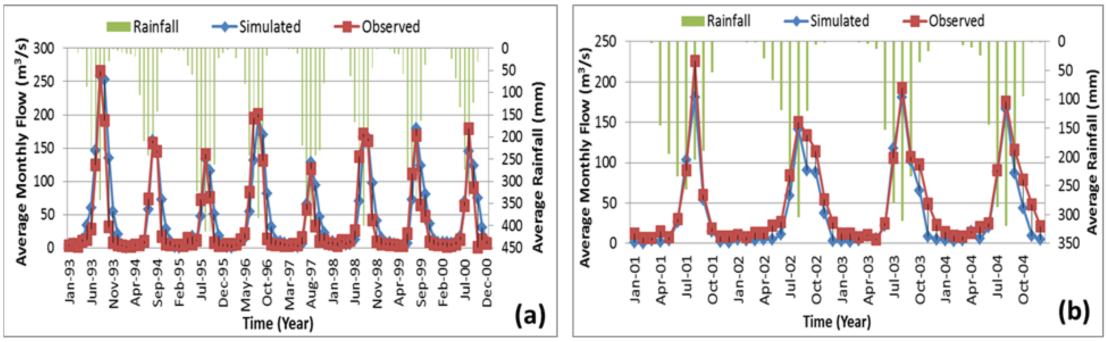

Figure 4: Calibration (a) and validation (b) results of average monthly observed and simulated stream flows at the outlet of Hombole gauged station.

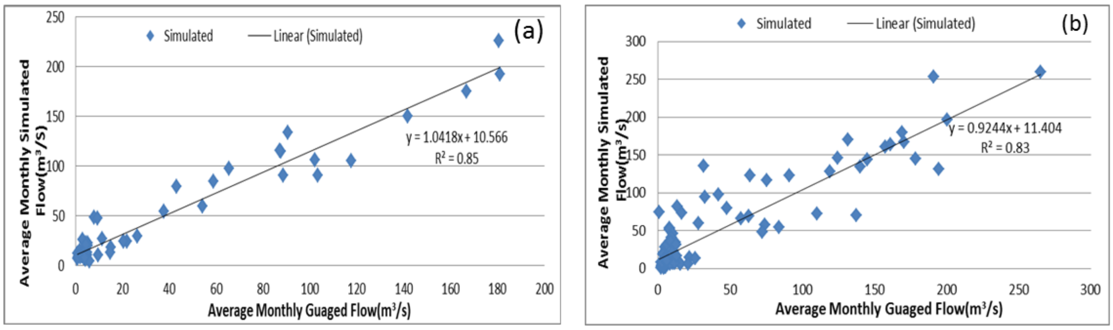

Figure 5: Scatter plot of monthly gauged versus simulated flow at Hombole gauged station for (a) calibration and (b) validation periods.

5). Both validation and calibration results fulfilled the requirements suggested [21] for R^2>0.6 and E_{NS}>0.5.

Runoff sensitivity to temperature change

The temperature perturbation is applied by adding the prescribed change to the baseline simulation temperatures [10]. Each scenario was then run for the same simulation period as the baseline simulation. The perturbations scenarios applied were with temperature increases by +1, +2, +3 and +4°C and rainfall changes by -20%, -10%, -5%, +5%, +10%, +15% and +20% and combination of the above temperature and rainfall perturbations.

The relative sensitivity of runoff to changes in temperature, holding the rainfall fixed was relatively modest compared to the rainfall. The runoff responses to temperature scenarios indicated that a +1, +2 and +3°C increases in temperature would provide a 0.085%, 0.54%, and 1.75% reduction in runoff respectively. There should decrease in annual runoff by 2.55% with a 4°C rise in the temperature assuming no change in the rainfall. Even an increase temperature by 3°C without rainfall change would result in a 1.75% decrease in surface runoff.

Upper awash sub-basin runoff showed a larger sensitivity from +3 to +4°C than from 1 to +2°C temperatures. This is mainly due to an increase in evaporation losses from the soil. When the temperature rises, the available water at the top surface of the soil gets lost easily whereas it is difficult to evaporate water from the deeper layers of the soil.

Even without any changes in rainfall, there will be significant changes in surface runoff due to warming. In general, increasing temperatures will result in decreasing surface runoff. The results shown in Table 1 also reveal that an increase in temperature of 5°C would cause a reduce in the annual runoff. There was decreased in annual runoff by 3.3% with a 5°C rise in the temperature assuming no change in rainfall. Similar study report by Mengistu and Sorteberg [10], shown that average the annual stream flow responses to temperature change with no rainfall change were -4.4% K^{-1}, -6.4% K^{-1}, and -1.3% K^{-1} for the Abbay, Baro Akobo and Tekeze river basins respectively. According Arora et al. [22], the average value of increase in snowmelt runoff for +1°C, +2°C and +3°C scenarios are obtained to be 10, 28 and 43%, respectively.

Runoff sensitivity to change in rainfall

Similarly, a sensitivity analysis of the runoff to the rainfall change assuming no temperature change was carried out. This analysis revealed that an increase in the rainfall would significantly affect the annual runoff. The results have shown an uneven distribution of the change in runoff despite a uniform change in rainfall. Decreased or increased in rainfall by -/+10% have result in reduced by -21% and increased by +22% in the surface runoff of the sub-basin respectively. As showed above the runoff of the sub-basin is more sensitive to rainfall than that of the temperature rise. Increased by +5% in rainfall would increase average annual runoff by 11%, while a 10% rainfall increase would almost double the average annual runoff (Table 2). The perturbation with 20% increase to the measured rainfall values shows 46% increase to the annual mean surface runoff, whereas 20% reduce to the observed rainfall values shows 40% decrease in average surface runoff. Similarly, according to Berhane [23], surface runoff is the most sensitive hydrologic variable to rainfall change, 10%, 20% and 25% rainfall increments to the baseline rainfall caused 38%, 82% and 106%

Parameters	Temperature Scenarios (°C)				
	1	2	3	4	5
Surface runoff (mm)	-0.085	-0.88	-1.75	-2.55	-3.3

Table 1: Runoff sensitivity to increase in temperature.

Parameters	Rainfall Scenarios (%)							
	-20	-15	-10	-5	5	10	15	20
Surface runoff (mm)	-39.8	-30.3	-20.8	-10.6	11.03	22.5	34.2	46

Table 2: Runoff sensitivity to change in rainfall.

	Change surface Runoff (%)				
	T_{+1}	T_{+2}	T_{+3}	T_{+4}	T_{+5}
R_{-10}	-10.46	-10.86	-11.3	-11.69	-12.07
R_{-5}	-5.36	-5.76	-6.2	-6.6	-6.97
R_0	-0.04	-0.44	-0.88	-1.27	-1.65
R_{+5}	5.47	5.07	4.63	4.24	3.86
R_{+10}	9.58	10.78	10.34	9.95	9.58

Note: The subscriptions of R, T denote the rainfall change (%) and temperature (°C)

Table 3: Runoff Sensitivity to rainfall and temperature variables.

increment to the main annual surface runoff. Similar study report by Mengistu and Sorteberg [10], shown that mean annual stream flow responses to a precipitation change with no change in temperature were 19%, 17%, and 26% per 10% change in precipitation for the Abbay, Baro Akobo and Tekeze river basins respectively.

Sensitivity of runoff to the combined effect of temperature and rainfall

The combined runoff sensitivity analysis for the sub-basin was carried out for the temperature changes from +1°C to +5^0 C and the rainfall changes from -10% to +10% (Table 3). Comparing the relative sensitivities of the runoff when both temperature and rainfall were changed with the linear combination of sensitivities for the separate temperature and rainfall changes shows a combined response that is very similar to the linear combination of the separate temperature and rainfall response.

Therefore, a 10% increase in the rainfall and a 4°C rise in the temperature may result in 9.95% increase in the surface runoff (Table 3). A temperature rises of 4°C and a rainfall decrease of 10% result in -11.69% decreases in surface runoff of sub-basin. An increase of rainfall by 10% and 4°C increase in temperature result in increased runoff by 9.95%. A 2°C increase in temperature and a 10% reduce in rainfall would result in -10.86% reduction in runoff. This study indicated that a 2°C increase in mean annual temperature combined with a 10% increase in mean annual rainfall would result in a 10.78% increase in runoff. Due to the combined influence of change in weather parameters, there is a considerable change in surface runoff.

Generally, the study reports show an increase in rainfall scenarios resulted in an increase in annual runoff and in contrast, an increase in temperature causes a decrease in annual runoff. Climate scenarios that coupled with an increase in rainfall and an increase in temperature showed a counterbalancing impact on simulated annual runoff.

These results are consistent with those reported in previous studies, both in magnitude and sign, and appear to support the findings that runoff is more sensitive to changes in rainfall than to changes in temperature. However, upon closer inspection it is apparent that the changes in runoff caused by the hypothetical temperature changes are smaller (as a percentage of current runoff) than the rainfall changes.

Similar studies were reported [7], decrease in rainfall by 20% coupled with a 2°C and 4°C increase in temperature would provide a 38% and 40% decrease in the annual runoff respectively. Whereas a 20% increase in rainfall coupled with a 2°C and 4°C increase in temperature would result in a 43% and 41% increase in the annual runoff respectively. Similarly, Mechal et al. [4], indicates that a combination of reduced precipitation and increased temperature has negative impact on recharge within the entire watershed, whereas a combination of increased precipitation and decreased temperature leads to a general increase in recharge. The study report by Berhane [23], shown that hydrology is more sensitive to changes in precipitation than to temperature changes. Increase in temperature result in increases evapotranspiration, and increased air temperature increases the vapor pressure deficit increasing the evaporative demand and reducing the surface runoff [23].

Conclusions

In order to study the response of the SWAT model due to variations in different rainfall and temperature scenarios, SWAT model was applied to simulate the basin scale runoff response to changing climate.

The SWAT model has been calibrated and validated against the observed stream flow. Model performance has been assessed by using objective functions: Nash Sutcliffe efficiency (NSE) and Coefficient of determination (R^2). The result of model calibration and validation indicated that SWAT model simulated reproduces the runoff with acceptable accuracy for the sub-basin. The coefficient of determination and Nash-sutchlife simulation efficiency values obtained from the model performance criterion which is used to evaluate the model result proved this fact.

The study results indicated that an increase in rainfall resulted in an increase in annual runoff. In contrast, a temperature increase caused a decrease in annual runoff. Climate scenarios that coupled an increase in rainfall with an increase in temperature showed a counterbalancing impact on simulated annual runoff. The runoff has a positive correlation with rainfall change but a negative correlation with temperature change. As showed in result, the runoff of the upper awash is more sensitive to rainfall than that of the temperature rise. The sensitivity of annual runoff to changes in rainfall or temperature as well as to a combination of both is found to be non-uniform across the sub-basin.

Therefore, climate sensitivity scenarios analysis shown that rainfall being the main driver in the runoff computation and its annually variability has a direct impact water availability.

Generally, this study reports revealed that climate variables (mainly rainfall and temperature) would have a significant effect on the surface runoff and causing a possible reduction on the availability of water in the sub-basin.

Conflict of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

References

1. Feiyun Z, Lei B, Lanhai L, Quan W (2016) Sensitivity of runoff to climatic variability in the northern and southern slopes of the Middle Tianshan Mountains, China. Journal of Arid Land 8: 681-693.

2. Liu XK, Rao ZG, Zhang XJ (2015) Variations in the oxygen isotopic composition of precipitation in the Tianshan Mountains region and their significance for the Westerly circulation. Journal of Geographical Sciences 25: 801-816.

3. Xu CY (1999) Climate change and hydrologic models: A review of existing gaps

and recent research Developments. Water Resour Man 13: 369-382.

4. Mechal A, Wagner T, Birk S (2015) Recharge variability and sensitivity to climate: The example of Gidabo River Basin, Main Ethiopian Rift. Journal of Hydrology: Regional Studies 4: 644-660.
5. Bunbury J, Gajewski K (2012) Temperatures of the past 2000 years inferred from lake sediments, southwest Yukon Territory, Canada. Quaternary Research 77: 355-367.
6. Arsano Y (2005) Ethiopia and the Eastern Nile basin. Aquat Sci 67: 16-17.
7. Checkol DA (2006) Modeling of Hydrology and Soil Erosion of Upper Awash River Basin. Cuvillier Gottingen.
8. Setegen SG, Srinivasan R, Dargahi B (2008) Hydrological modeling in the Lake Tana basin, Ethiopia using SWAT model. Open Hydrol J 2: 49-62.
9. Elshamy ME, Seierstad IA, Sorteberg S (2009) Impacts of climate change on Blue Nile flows using bias-corrected GCM scenarios. Hydrol Earth Syst Sci 13: 551-565.
10. Mengistu DT, Sorteberg A (2012) Sensitivity of SWAT simulated stream low to climatic changes within the Eastern Nile River basin. Hydrol Earth Syst Sci 16: 391-407.
11. Taye MT, Ntegeka V, Ogiramoi NP, Willems P (2011) Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin. Hydrol Earth Syst Sci 15: 209-222.
12. Abraham LZ, Roehrig J, Chekol DA (2007) Calibration and Validation of SWAT Hydrologic Model for Meki Watershed, Ethiopia. Conference of International Agricultural Research for Development, University of Kassel Wizen Hausen and University of Gottingen.
13. Daba M, Rao GN (2016) Evaluating Potential Impacts of Climate Change on Hydro- meteorological Variables in Upper Blue Nile Basin, Ethiopia: A Case Study of Finchaa Sub-basin. Journal of Environment and Earth Science 6: 48-57.
14. Oromia Water Works Design and Supervision Enterprises (OWWDSE 2013) Upper Awash Integrated Land Use Planning Study Project. Interim report, Addis Ababa.
15. Chekol DA, Tischbein B, Eggers H, Vlek P (2007) Application of SWAT for assessment of spatial distribution of water resources and analyzing impact of different land management practices on soil erosion in Upper Awash River Basin watershed. Catchment, Lake Research (LARS 2007).
16. Berhe F, Melesse AM, Hailu D, Seleshi Y (2013) Water use allocation modeling using MODISM in the Awash River basin. Catena 109: 118-128.
17. Neitsch SL, Arnold JG, Kiniry JR, Williams JR, King KW (2002) Soil and Water Assessment Tool. Theoretical Documentation and User's Manual, Version 2000.
18. Arnold JG, Srinivasan R, Muttiah RS, Williams JR (1998) Large-area hydrologic modeling and assessment: Part I Model development. J Am Water Resour Assoc 34: 73-89.
19. Neitsch SI, Arnold JG, Kinrv JR, Williams JR (2005) Soil and water assessment tool, theoretical documentation, version 2005. USDA Agricultural Research Service Texas A and M Black Land Research Center, Temple.
20. Nash JE, Sutcliffe JV (1970) River flow forecasting through conceptual models. Part I: a discussion of principles. Journal of Hydrology 10: 282-290.
21. Santhi C, Arnold JG, Williams JR, Dugas WA, Srinivasan R, et al. (2001) Validation of the SWAT model on a large river basin with point and nonpoint sources. Journal of the American Water Resources Association 37: 1169-1188.
22. Arora M, Singh P, Goel NK, Singh RD (2008) Climate Variability Influences on Hydrological Responses of a Large Himalayan Basin. Water Resour Manage 22: 1461.
23. Berhane FG (2011) Model based assessment of potential impacts of climate change on the flow of the main headwaters of the Nile River: Equatorial Lakes Region and Blue Nile Basins. Master's Theses Paper, p: 167.