Evaluation of Climate Change Impact on Stream Flow in Upper Awash River Basin, Ethiopia

Kiya Kefeni[1 *] Tamirat Dessalegn[1] Negese Roba[1]

1. Department of Water Resources Engineering , School of Civil Engineering and Architecture, Adama Science and Technology University, Adama, Ethiopia

1*. Corresponding author: kefenikiya@gmail.com

Abstract

Studies of climate change impact on water resources are very crucial for planning and management to alleviate poverty; and for sustainable development specially in developing countries. This study assessed the likely impacts of climate change on stream flow in the Upper Awash basin of Ethiopia using the Soil and Water Assessment Tool (SWAT). Change of projected climate variables (temperature and precipitation) for the 2030s (2021-2040) and 2050s (2041-2060) and estimated impacts of the projected variables on stream flow under RCP4.5 and RCP8.5 scenarios were analyzed. Future climate data from CORDEX Africa was dynamically downscaled using single Regional climate models and corrected for bias using delta change approach. Performance of the SWAT model was evaluated using R^2, NSE, and P_{BIAS}. *During calibration (1999-2003) of the model, values 0.75, 0.74 and -7% were obtained for* R^2, NSE, and P_{BIAS}. *Whereas during validation period (2004-2006) values 0.79, 0.78 and 3.1% were obtained for* R^2, NSE, and P_{BIAS}. *The finding of this study indicates that streamflow will decrease by 6.51% and 12.33% at 2030s and 2050s under RCP4.5 scenario respectively. Likewise for RCP8.5 scenario the stream flow will decrease by 10.76% and 26.74% at 2030s and 2050s respectively.*

Key Words: Climate change, CORDEX Africa, RCM, SWAT, Upper Awash

Introduction

One of the most significant potential consequences of climate change in the long-term would be changes in regional hydrological cycle. According to Bates *et al.*, 2008 the global climate change has the potential to impose additional pressures on water availability. The main contributors in the significant changes in global climatic patterns are the increasing concentrations of atmospheric greenhouse gases (GHGs), which subsequently leads to global warming (IPCC, 2014). Zhi and Jiming , 2017 also conclude that the increase in concentration of greenhouse gases (GHG) seems to be one of the major driving forces behind the climate change. Evapotranspiration and precipitation are the two vital hydrologic variables that can be affected by changing temperature. For instance, rising temperature will have a major impact on the magnitude and frequency of extreme precipitation events in some regions (Zhi and Jiming , 2017). Based on different climate change scenarios the temperature is expected to rise with two or more degree centigrade, rainfall predicted to increase in some places and to decrease in other parts (IPCC, 2014)

Developing countries, such as Ethiopia, will be more vulnerable to climate change mainly because of the larger dependency of their economy on agriculture which is very sensitive to climatic variations (Kassie *et al.*, 2013). Therefore, assessing and evaluating the significance of climatic change impacts on water availability of the basin at catchment and sub-basin scale is crucial for water resource development.

Climate models are the main tools for developing projections of climate change in the future. Global climate models (GCMs) are one suitable tool for the assessment of climate variability and change (Claudia and Jan, 2010). Current GCMs have spatial resolution on the order of 100– 250 km and have the potential to simulate the main characteristics of general circulation at the range of this scale (Almseged and Rientjis, 2015; Claudia and Jan, 2010). However, GCMs are not capable of capturing the detailed processes associated with regional climate variability and changes (Taye *et al.*, 2018). Hence, a Regional Climate Model (RCM) is the best tool for dynamic downscaling of climate features in order to make predictions for a particular region (Raneesh, 2011). Also finding of Taye *et al.*, 2018 proves that regional climate models (RCM) are better suited for regional impact studies.

Simulations of watershed hydrology are extensively used for water resources planning and management. Generally, to utilize water in a sustainable manner, it is necessary to understand the quantity and quality in space and time through studies. Therefore, the objective of this study is to evaluate the impacts of climate change on stream flow of the upper Awash sub-basin using semi-distributed SWAT model.

2. MATERIALS AND METHODS

2.1 Description of the Study area

The proposed sub-basin is located in the western highland part of the Awash river basin and covers part of the basin above Hombole gauging station, including the capital city Finfinne (Figure 2.1). The geographic location of the basin is between latitudes of 7°53'N and 12°N and longitudes of 37°57'E and 43°25'E (Tajin *et al.*, 2016). Awash River rises on the high plateau near Ginchi town west of Finfinne and flows along the rift valley into the Afar triangle, and terminates in salty Lake Abbe on the border with Djibouti. The total length of the main course is about 1200 km and it is the principal stream of an endorheic drainage basin covering parts of the Oromia, Somali, Amhara, and Afar region (Yitea,2015)

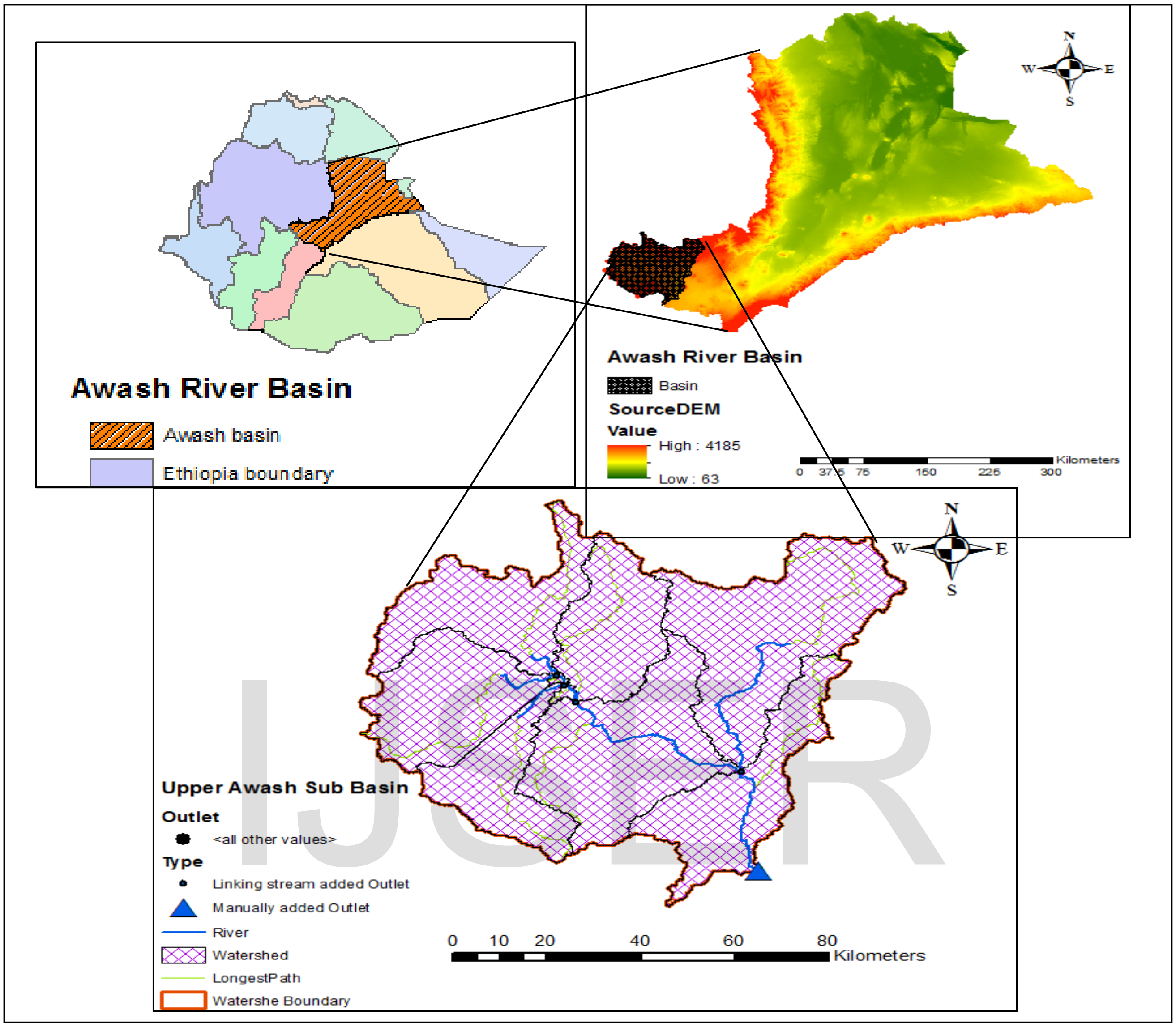

Figure 2-1 Location of upper Awash sub-basin.

The physical settings of the study area are characterized by the heterogeneity of the large natural systems such as orographic groups, the high plains, mountains and plateaus (Yitea, 2015). Based on physical and Socio-economic factors the Upper Awash Basin is topographic level of all lands above 1500 m. The climate of the Awash basin is humid to sub-humid in the highlands and semi-arid to arid in the rift valley. Annual rainfall ranges from 850mm to 1000mm in the plain area and mountains of Upper Awash River basin respectively. Mean annual temperature is about 15°C in the highlands and around 21°C in the lowlands. The Sub-basin receives approximately 70% -75% of its annual rainfall during the wet season which covers the months June–September (Daba, 2014).

2.2 Model Description

There are a number of integrated physically based distributed models. Among which, researchers (Neitsch *et al.*, 2011; Gassman *et al.*, 2005) have identified SWAT as one of the most promising and computationally efficient model. SWAT is a semi-distributed watershed model developed by the Agricultural Research Service of the United States Department of Agriculture (USDA) to simulate the impact of land-use and management practices on the quantity and quality of water and to quantify sediment and agricultural chemical yields in large and complex watersheds with changing soils, land use, and management conditions over long time periods (Neitsch *et al.*, 2011). SWAT is a physically based, basin-scale, spatially distributed, continuous daily time step and computationally efficient hydrological model. SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman *et al.*, 2005).

The SWAT hydrological cycle simulation is based on the water balance equation (Neitsch *et al.*, 2011) shown in Equation (1).

$$SWt = SW_o + \sum_{i=1}^{n} (\mathrm{Rday, i - Qsurf, i - Eact, i - Wseep, i - Qlat, i}) \quad (1)$$

Where;

SWt is the final soil water content (mm); *SWo* is the initial soil water content on day *i*(mm); *Rday* is the amount of precipitation on day *i*(mm); *Qsurf* is the amount of surface runoff on day *i*(mm); *Eact* is the actual evapotranspiration on day *i*(mm; *Wseep* is the amount of water entering the vadose zone from the soil profile on day *i*(mm water); Q_{lat} is amount of return flow on day *i*(mm) and *t* is the time (days).

Based on watershed physical characteristics either SCS CN method or Green and Ampt infiltration method has been suggested for SWAT to generate runoff (Reza Kabiri, 2014). Because of the unavailability of sub daily weather data for Green and Ampt method, SCS CN method was used in this study to predict surface runoff from watershed.

2.2.1 Model Inputs

In order to run the SWAT model, it was necessary to prepare several sets of spatially distributed data. For this study, spatial data include elevation, soil type, and land use/land cover were collected from Ethiopian Ministry of Water, Irrigation and Energy (MOWIE).

The temporal input data for the model are meteorological and stream flow datasets. For this study, the meteorological data elements such as daily precipitation, minimum and maximum air temperature, relative humidity, wind speed and sunshine hours for thirty years (1985-2014) of six representative weather were obtained from the National Meteorology Agency (NMA). Station those have missing meteorological data values were filled using weather generator model (WXGEN). Other parameters required in user weather generator were calculated using pcpSTAT.exe and dew02.exe computer program. Stream flow data of the Hombole gauging station from (1995-2013) was collected from Ministry of Water, Irrigation and Electricity (MoWIE) and were used for performing calibration and validation of the model.

2.2.2 Model Calibration, Validation and performance evaluation

In SWAT model calibration, the parameters are adjusted within their physical acceptable range in such a way that practical agreement between simulated and observed stream flows is accomplished. To perform parameter calibration and uncertainty analysis different programs are introduced. SWAT-CUP is one of the programs which are currently used by different researchers. It is a public domain and used for calibration, uncertainty or sensitivity analysis procedures linked with SWAT. It enables sensitivity analysis, calibration, validation and uncertainty analysis of SWAT models. Automatic calibration and uncertainty analysis incorporated in SWAT 10.4 through SWAT-CUP software developed and tested by Abbaspour (2007), with the semi-automated program SUFI2 was used for this study.

During calibration and validation of a hydrological model it is necessary to assess the performance of the model. This is done by statistically comparing the model output and observed values using various statistical measures. Model evaluation is normally based on its ability to simulate major hydrological processes in a watershed. Model performance assessment is normally carried out by comparing the model predictions at the basin outlet with the corresponding observed records (Moriasi *et al.*, 2007). Evaluation of model performance involves assessing the 'goodness-of-fit' of the simulated and the observed hydrological variables such as stream flow. There are a large number of model performance measures available to a hydrologist. For this study, three model performance evaluation techniques such as; coefficient of determination, Nash-Sutcliffe coefficient and P_{BIAS} recommended by Moriasi *et al.* (2007) were used.

3. Result and Discussions

3.1 Model calibration and Validation

3.1.1 Calibration

Once the sensitive parameters for the model are identified, the next step is to calibrate and validate the model. Both manual and automatic calibration (using SUFI-2) calibration procedures were used in this study. For model calibration five years Awash River data (1999-2003) at Hombole gauging station and two year data's (1997-1998) was used for model warm up. The performance of the model was evaluated using R^2, E_{NS} and PBIAS statistical measures. Evaluations were performed at monthly time scales and the result of statistical parameters during calibration obtained were 0.75 for R^2, 0.74 for E_{NS} and -7% for P_{BIAS}. The values indicate that there is good agreement between observed and simulated stream flow. Figure 3.1 below shows hydrograph comparison during model calibration.

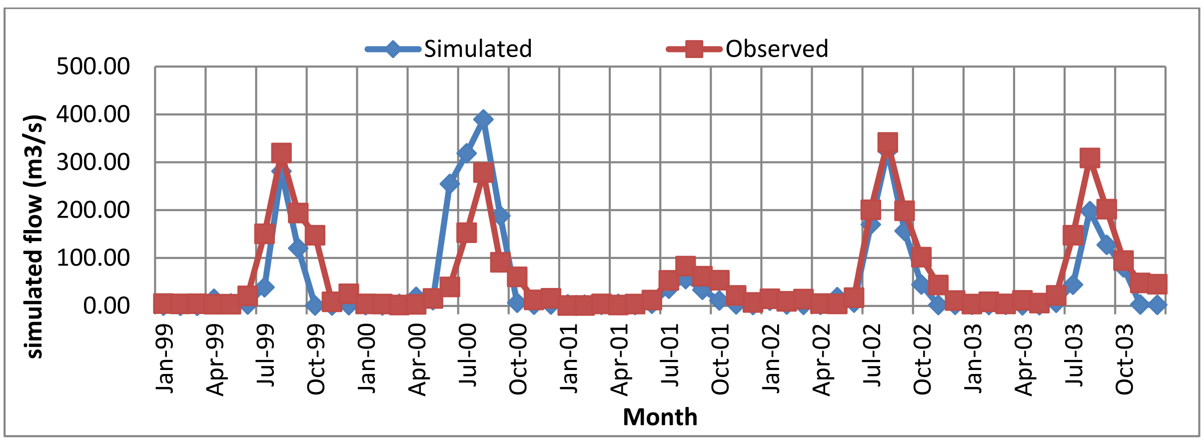

Figure 3-1 Hydrograph comparison during model calibration

3.1.2 Validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Three year monthly basis data (2004-2006) were used for model validation without any adjustment of fitted value during calibration and values of 0.79 for $R^{2,}$ 0.78 for E_{NS} and 3.1% for PBias were obtained. Values obtained for performance indices shows good agreement as they are within recommended values by Moriasi *et al.*, (2007). Figure 3.2 illustrates hydrograph during validation.

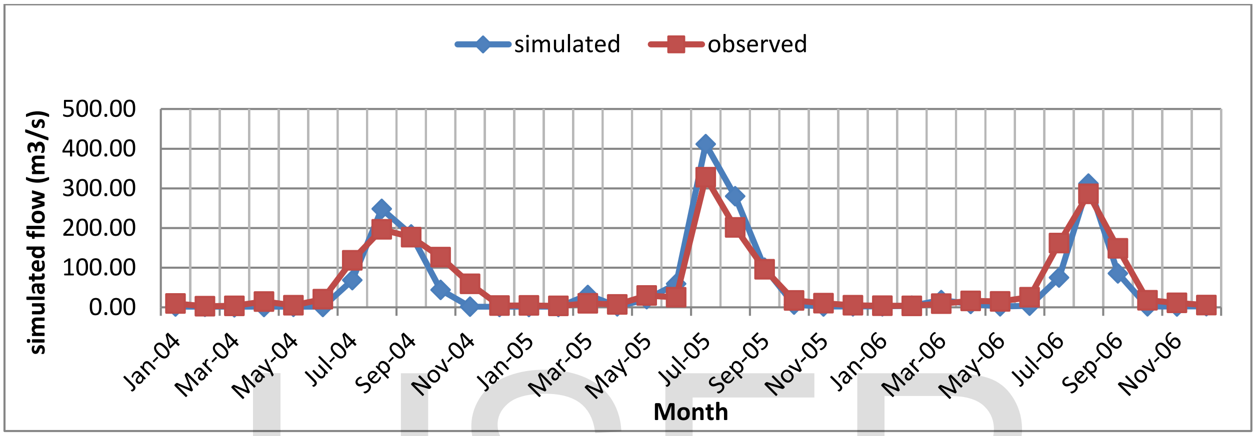

Figure 3-2 Hydrograph comparison during model validation

Generally, according to Moriasi *et al.*, (2007) model performance in terms of replicating the observed hydrograph is acceptable during calibration and validation. With this performance the model under estimated the observed stream flow compared to the simulated mean monthly stream flow in 2000 during calibration and 2003and 2004 during validation period. One of the factors that have contributed to uncertainty of the model might be the effect of the SWAT parameters that are considered to have negligible influence on the stream flow but cumulative of which would have affected the model performance. Unconsidered factors in modeling processes that resulted in the model error are also other factors.

3.2 Projected changes in mean monthly, seasonally and annual stream flow

Future stream flow was simulated for two scenario periods 2030's (2021-2040) and 2050's (2041-2060) considering river flow (1997-2006) as baseline flow. The stream flow projection takes place by assuming the projected precipitation and temperature inputs to SWAT and also considering land use/land cover, soil and other parameters similar to present in the future. The mean monthly and annual percentage change in flow for both (RCP4.5 and RCP8.5) scenarios for the period 2030s and 2050s are presented in Figure 3.3a and b respectively. The percentage change of mean monthly flow increases for months January, February, March, April, July, August, November and December and also decreases in months May, June, September and October is observed for both 2030s and 2050s under RCP 4.5 scenario.

The mean monthly stream flow result shows that future monthly stream flow decreases in all months and annual during 2030’s and 2050’s, under RCP 8.5 scenario. Dile *et al*., 2013 conclude that decrease in flow volume observed in months which showed a decrease in monthly rainfall. Generally results showed that the impact of climate change cause a decrease in mean monthly flow volume between -0.89% to –18.01% during 2030s and between -0.44 to -32.98% during 2050s under RCP4.5 scenario.

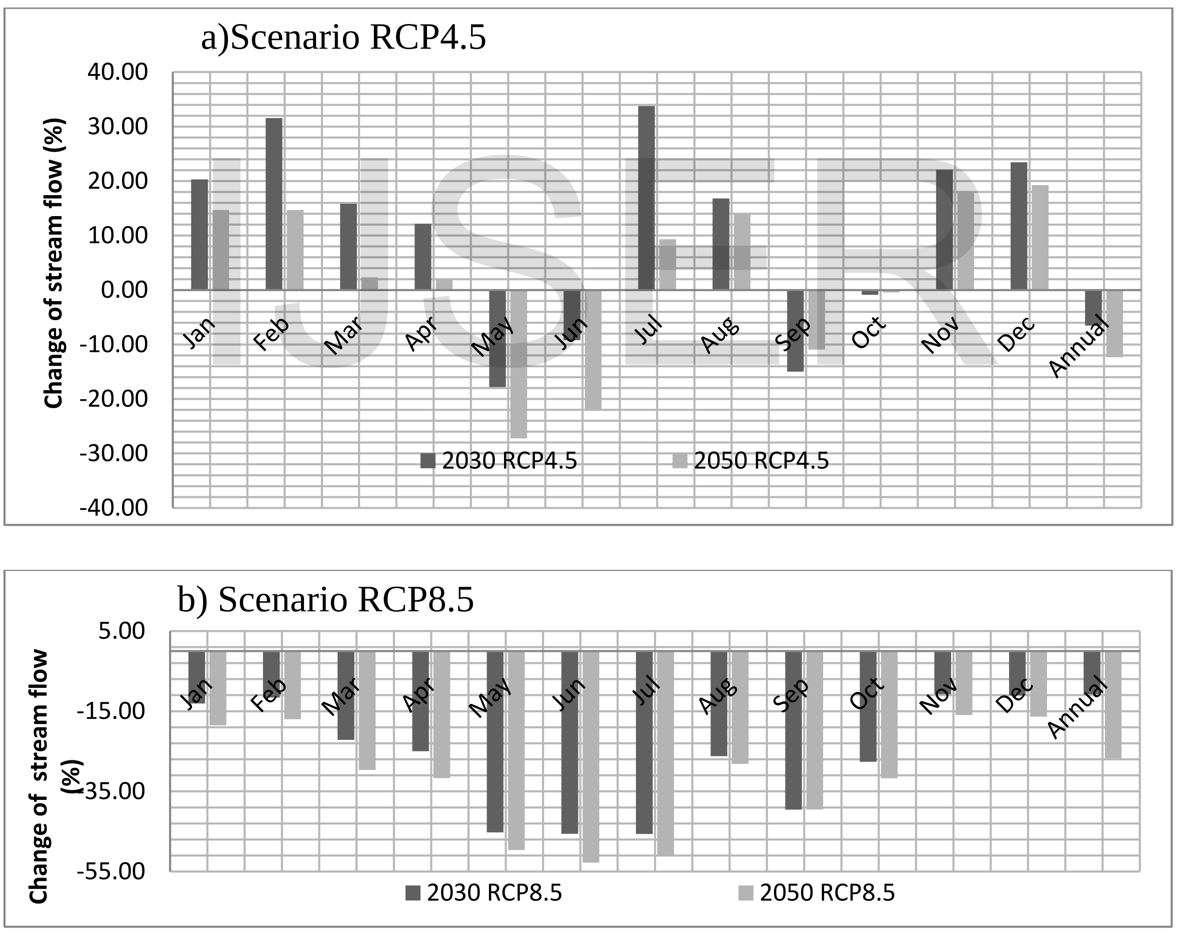

Figure 3-3 Mean monthly and annual percentage change of total flow pattern of Upper Awash sub-basin

The projected mean monthly stream flow decreases in range between 10.75 % to 45.61% under RCP4.5 scenarios in 2030s and 2050s respectively. Similarly for RCP8.5 scenarios the projected mean monthly stream flow decreases in range between 15.95% to 52.78% in 2030s and 2050s respectively.

At annual basis generally, decreasing trend of stream flow was observed in the study area at 2030s and 2050s under RCP 4.5 and RCP 8.5 scenarios. As can be noticed from figure (3 a and b) the projected annual stream flow decreased by 6.51% and 12.33% under RCP 4.5 scenarios in 2030s and 2050s respectively. Similarly for RCP8.5 the projected annul stream flow decreased by 10.76% and 26.74% in 2030s and 2050s respectively. Overall, decreasing pattern of the average total annual flow in future is mainly because of a decrease in average monthly flow in RCP 8.5 scenarios and RCP4.5. This is caused due to the fact that higher increment of projected maximum and minimum temperature as well as significant increase in evapotranspiration in the future over Upper Awash sub-basin. Also the decreasing pattern of the average total annual flow in future is higher in RCP8.5 than RCP4.5 due to high concentration of greenhouse gas, low technology development and no police implementation for climate in RCP8.5. This cause's high concentration of heat occurred in this scenario in future.

The seasonal variation of streamflow of the projected climate from the baseline period was compu ted for winter, spring, summer and autumn seasons (Table3.1). The seasonal projected stream flow shows increasing in all seasons for the first time horizon (2030s) under RCP4.5 scenario. Also for the second time horizon (2050s) the projected seasonal stream flow shows increasing except for autumn (MAM) season which shows decrease by -7.66% under RCP4.5 scenario. However, for RCP8.5 scenario the projected seasonal stream flow shows decreasing during both time horizon (2030s and 2050s).

ISSN 2229-5518

Table 3-1 Percentage change of projected seasonal stream flow pattern of Upper Awash sub-basin

		Time horizon	
Scenario	Season	2030s	2050s
RCP4.5	Winter (DJF)	25.11	16.21
	Spring (SON)	2.07	2.27
	Summer (JJA)	13.79	0.45
	Autumn (MAM)	3.41	-7.66
RCP8.5	Winter (DJF)	-11.91	-17.29
	Spring (SON)	-25.98	-29.07
	Summer (JJA)	-39.15	-44.04
	Autumn (MAM)	-30.79	-36.98

When comparing the winter (dry) season with the summer (wet) season; the dry season average projected stream flow increase by 25.11% and 16.21% in 2030s and 2050s respectively under RCP4.5. Also the wet season average projected stream flow increase by 13.79% and 0.45% in 2030s and 2050s respectively. Similar findings were captured by Daba , 2014.

4. Conclusions

Projected hydrological variability is important for future resource and hazard management. This study analyzed the response of stream flow to possible future climate change predicted using an Ensemble of three GCMs driving models and single RCM with dynamically downscaled approach. Physically based semi-distributed hydrological model (SWAT) was used to determine the impact of climate change on stream flow. Dynamically downscaling method was used to downscale the projected global rainfall and temperature for the 2030s and 2050s using data from three Ensemble GCMs driving models. Simulation of the changes in stream flow (runoff) was done using the soil and water assessment tool (SWAT) model. The impacts of the projected climate variables on stream flow show that the stream flow will decrease by -6.51% and -12.33% at 2030s and 2050s under RCP4.5 scenario respectively. Similarly for RCP8.5 scenario the stream flow will decrease by –10.76% and –26.74% at 2030s and 2050s respectively.

References

Alemseged, T.H. and Tom, R., 2015. Evaluation of regional climate model simulations of rainfall over the Upper Blue Nile basin. *Atmospheric research*, *161*, pp.57-64.

Bates, B., Kundzewicz, Z., Wu, S., Palutikof, J., 2008. Climate Change and Water.

Daba, M., 2014. Evaluating Potential Impacts of Climate Change on Surface Water Resource Availability of Upper Awash Sub-basin, Ethiopia rift valley basin.

IPCC (Intergovernmental Panel on Climate Change), 2014. Rainfall Projection for East Africa. Fifth Assessment Report: Cambridge University Press, Cambridge, UK.

Dile, Y.T., Berndtsson, R. and Setegn, S.G., 2013. Hydrological response to climate change for gilgel abay river, in the Lake Tana basin-upper Blue Nile basin of Ethiopia. *PloS one*, *8*(10), p.e79296

Gassman, W. P., Reyes, M. R., Green, C. H., and Arnold, J. G.: SWAT peer-reviewed literature: a review, Proceedings of the 3rd International SWAT conference, Zurich, 11–15 July, 1–18, 2005.

Kassie, B.T., Rötter, R.P., Hengsdijk, H., Asseng, S., Van Ittersum, M.K., Kahiluoto, H. and Van Keulen, H., 2014. Climate variability and change in the Central Rift Valley of Ethiopia: challenges for rainfed crop production. *The Journal of Agricultural Science*, *152*(1), pp.58-74.

Taye, M.T.; Dyer, E.; Hirpa, F.A.; Charles, K. Climate Change Impact on Water Resources in the Awash Basin, Ethiopia. *Water* 2018, *10*, 1560

Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L.Bingner, R. D. Harmel and T. L. Veith. 2007. Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. Trans.ASABE 50(3):885-900.

Neitsch, S., Arnold, J., Kiniry, J.,Williams, J., 2011. Soil & Water Assessment Tool Theoretical Documentation Version 2009. Tech. rep. Texas Water Resources Institute, College Station, TX.

Raneesh, K. Y. & Santosh, G. T. (2011). A study on the impact of climate change on stream flow at the watershed scale in the humid trophics. Hydrol. Sci. J. 56(6), 946–965.

Reza Kabiri, 2014. Simulation of Runoff using Modified SCS-CN method using GIS system, case study: Klang Watershed in Malaysia. Research Journal of Environmental Sciences, 8: 178-192.

Tajin K., Adane A. & Behilu H. (2016). Study of Water Allocation for Existing and Future Demands under Changing Climate Condition: Case of Upper Awash Sub River Basin.

Zhi Li and Jiming Jin , 2017. Evaluating climate change impacts on stream flow variability based on a multisite multivariate GCM downscaling method in the Jing River of China.