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Evaluation of Climate Change Impacts on the Water Resources of Awata River Watershed, Genale Dawa Basin: Southern Ethiopia.

Tesfaye Gragn[1]*, Asfaw Kebede[2], Shimelis Berhanu[3]

[1]Bore Agricultural Research center, Oromia Agricultural Research Institute, P.O. Box, 21, Bore, Ethiopia
*Corresponding Author E-mail: tgragn@gmail.com; Tel.: +251-911-34-16-98
[2]School of Water Resource and Environmental Engineering, Institute of Technology, Haramaya University, P.O. Box, 138, Dire Dawa, Ethiopia
[3]Institute for Hydrogeology, Technical University of Freiberg, Gustav-Zeuner-Str. 12, Zi. 305 09599 Freiberg, Saxony, Germany.

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This research was conducted to study the impacts of climate change on water resources of the Awata River watershed. Statistical Downscaling Model version 5.1.1 has been used to downscale the daily maximum temperature, minimum temperature, and precipitation in 30-year intervals from the second generation of the Earth System Model (CanESM2) under two Representative Concentration Pathways (RCP) Scenarios (RCP4.5 and RCP8.5). Climate change scenarios for precipitation and temperature were developed for two future periods 2018-2047 (the 2020s) and 2048-2077 (2050s). According to the projected climate data, the monthly minimum and maximum temperature are likely to have an increasing trend of +2.94°C and 2.25°C respectively. Regarding the rainfall change, under the RCP4.5 scenario, the study shows an annual average increment of 26.8% and 35.1% at near (2020) and mid-term (2050) respectively. The HBV Light hydrological model was successfully calibrated (2003-2012) and validated (2013-2017) using current climatic inputs and observed river flows. The overall performance of the model was good at the monthly time scale on calibration (R^2=0.87) and validation (R^2=0.85). Future discharge (2018-2077) was simulated using statistically downscaled 20 ensembles climate scenario data for both RCP4.5 and RCP8.5 scenarios. The average total annual flow at the outlet of the watershed might increase up to 7.3% for the RCP4.5 scenario and 7.0% for the RCP8.5 scenario for the 2018-2047 periods and for 2048-2077 periods it might increase up to 7.7% for RCP4.5 scenario and 7.9% for the RCP8.5 scenario. In conclusion increase in average total annual, seasonal and monthly flow volume is observed for periods which show a corresponding increase in mean annual, seasonal and monthly precipitation during scenario developments so that, future studies must recognize the over-all implication of climate change in the Awata watershed.

Keywords: Awata, Climate change, canESM2, HBV, SDSM, Ethiopia.

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INTRODUCTION

Climate change refers to a change in the state of the climate that can be recognized by changes in the mean and/or the inconsistency of its properties and that continues for a prolonged period, usually decade or more (IPCC, 2007). Nowadays the Intergovernmental Panel on Climate Change concluded that climate change is already happening with complicated effects on humans and the environment (IPCC, 2007) and its impacts have become major concerns of mankind. It is now widely acknowledged that climate change will have impacts on water resources availability and management throughout the world, in the near and longer terms. Some of the sectors under concern include urban water supply, irrigated agriculture, and hydropower production (Karsten *et al*., 2004; IPCC, 2007). Climate change and variability issues have therefore become a center of concern for scientists and policymakers around the world.

The use of GCM's in hydrologic models is a reasonable approach to assess possible future hydrologic changes in the basin. However, there have been some limitations due to the coarse spatial resolution of GCMs particularly estimating the hydrological runoff in the watershed scale. Many studies conducted downscaling methods to link GCMs output and hydrologic models at the watershed level (Fowler *et al.,* 2007).

Even though the fact that the impact of climate change is forecasted at a global scale, the type and magnitude of the impact at a watershed scale are not investigated in most parts of the world, Ethiopia's condition in particular. Understanding climate change and its impact on hydrological variability are important for water management, and thus has received attention from researchers in different parts of the world (e.g. Tekleab et al., 2013 and Zhao et al., 2015)

Awata watershed is under great pressure because of a growing population and increasing demand of water mainly for irrigation, which is not practiced well currently in the watershed, and also a great demand for domestic and livestock water consumption purposes. No Impact assessment of climate change study had been performed for the Awata watershed of the Genale Dawa basin, even though there have been studies conducted on another part of the Genale Dawa basin (e.g. Shanka, 2017 and Kassa, 2014), which indicates that with respect to future climate in Genale Dawa basin there is high confidence temperature will increase and leading to increasing evaporation. Therefore against this background, it is paramount to study climate change impacts on the water availability of Awata river watershed's to take the effect into account by the policy and decision-makers when planning water resource management. The objective of this study was to assess the impact of climate change on the water resource of the Awata River watershed.

MATERIALS AND METHODS

Study Area

Awata watershed which has a drainage area of 1513 km^2 is located in the Ganale Dawa River basin. Awata watershed geographically lies between coordinates of 5°30' to 6°30'N latitude and 38^{0}20' to 38^{0}60'E longitude with an approximation altitude range between 1650 and 3025m.a.s.l. as shown in Figure 1. The annual rainfall ranges between 820mm and 1350 mm. The monthly maximum temperature is between 19˚C and 24˚C, and the monthly minimum temperature is between 8˚C and 12˚C. The study area had been selected due to the reason that it is one of the major tributaries of Genale Dawa River and no impact assessment studies had been done on the watershed.

METHODOLOGY

In this study, the output variables from canESM2 (second generation of the Earth System Model) for both emission scenarios of RCP4.5 and RCP8.5 were statistically downscaled by with Statistical Downscaling Model (SDSM) version 5.1.1. The HBV-Light hydrological model was calibrated and validated using historical climate data of three stations (Hagere Selam, Kibremengist, and Yirba Muda) and observed discharge data of Awata River. The downscaled future scenario 20 ensembles data of both RCP4.5 and RCP8.5 scenarios were used as an input for the HBV-Light model to assess watershed hydrological response to climate change.

Data Types and Sources

Meteorological Data

The required meteorological data of the study area were collected from the Ethiopian National Meteorology Agency (NMA). The long-term records daily meteorological data for 30 years (1988-2017) were obtained from three meteorological stations (Hagere Selam, Kibremengist, and Yirba Muda) located in and nearby of the study area. Meteorological data collected included variables such as precipitation, minimum and maximum temperature. All stations listed above contain daily rainfall and temperature data for at least 30 years. Therefore all stations were used for hydrological model development.

Hydrological Data

Streamflow data of Awata River was required for

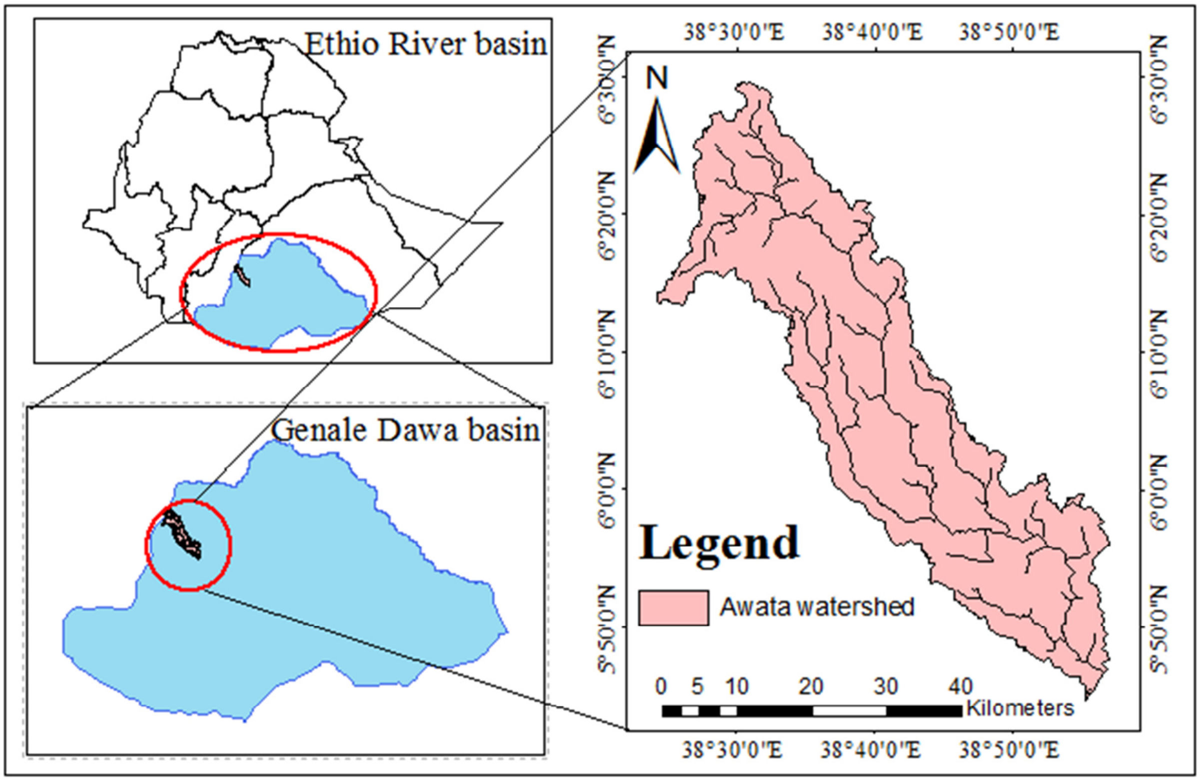

Figure 1. Location map of Awata watershed.

calibrating and validating of the HBV light model simulation. There is one main gauging station at the outlet of the Awata River at Shakiso. Daily and average monthly based Stream flow Discharge data for the years 1988-2007 which have continuous record was collected from the Hydrology Department of Ministry of water irrigation and electricity of Ethiopia (MoWIE).

Climate Model and Downscaling

For this study, the climate scenario data (RCP4.5 and RCP8.5) were extracted from the canESM2 model based on longitude and latitude that had a grid resolution of 2.5° latitude by 3.75° longitude. The coarser climate data (canESM2 output) further downscaled into station level by using a statistical downscaling model (SDSM version 5.1.1) and these downscaled data were taken directly as an input to the hydrological model to assess the future climate change impact on the hydrology of the watershed.

Statistical Downscaling Model

According to Wilby *et al.* (2007), empirical downscaling includes developing a numerical relationship between large-scale atmospheric variables (predictors) and local surface variables (predictands). For this study, the canESM2 data were taken as predictors and the station data were taken as predictands. The baseline data for the base period were from 3 stations in and around the Awata watershed within the range of 30 years (1988-2017). The first 20 (1988-2007) years of data were considered for calibrating SDSM while the remaining 10 (2008-2017) years were used for validation. After calibrating the SDSM model, the future climate scenarios (2018-2077) were generated based on the calibrated parameter and large scale predictor (canESM2 predictor) based on the mean of 20 ensembles for both RCP4.5 and RCP8.5 scenarios.

Data Quality Checking and Control

Consistency test of Precipitation data

Consistency of time series data was analyzed based on the theory that a plot of two cumulative quantities that are measured for the same period should be a straight line and their proportionality unchanged, which is represented by the slope. Therefore, the inconsistency of the record was done by the double-mass curve technique. This technique is based on the principle that when each recorded data comes from the parent population, they are consistent. The double mass curve technique was plotted by using the annual cumulative total rainfall of the station under the study as ordinate (Y-axis) and the average annual cumulative total of neighboring stations as abscissa (X-axis). The significant change observed in the system of the curve was, corrected by following equation 1:

$$P'_x = P_x * \frac{M'}{M}$$
(1)

where: - P'_x = Corrected precipitation at station x
P_x = Original recorded precipitation at station x
M' = Corrected slope of the double mass curve
M = Original slope of the double mass curve

Homogeneity test

The second step of the quality control process involved a homogeneity analysis. In this particular study, due to its lower demands in application and interpretation, the homogeneity of annual rainfall was tested using XLSTAT.

The bias correction method of downscaled climate data

Bias correction compensates for any tendency to over or underestimates the mean of the conditional process by the downscaling model. This parameter is set to 1 (default value) for maximum and minimum temperature since the process is non-conditional whereas for precipitation this parameter can be adjusted to match the mean of the conditional process and was set to 0.96

Data preparation for model input

HVB Light model requires observed daily input data of rainfall, air temperature, monthly potential evapotranspiration, streamflow (for calibration) and catchment characteristics of the study area. The average areal rainfall was estimated by multiplying the rainfall amount of each station with its area of polygon and the sum of these products was divided by the total area of the catchment (i.e., Thiessen polygon involves by assigning relative weights to the rainfall stations to compute the areal depth of rainfall over the watershed).

Hydrological Modeling

To simulate the streamflow of the watershed, the HBV-Light model was used. The HBV (Hydrologiska Byran's Vattenbalansavdelning)-Light hydrology model is a widely used conceptual model Seibert (2005). It computes runoff from observed daily rainfall, daily temperature, long-term monthly potential evapotranspiration, and runoff data. The daily areal rainfall (2003-2017) was calculated by the Thiessen polygon method. Potential evapotranspiration for the study area was estimated by the FAO Penman-Monteith method. The total period of the data that was used for this specific study was 15 years. From this period by using a split sample technique 2/3rd of the data (2003-2012) were used for calibration and the remaining 1/3rd of the data (2013-2017) were applied for validation.

Model Performance Criteria

For this particular study, two model simulation performance criteria namely Nash and Sutcliffe efficiency (NSE) and Coefficient of determination (R^2) were used. The Nash-Sutcliffe coefficient of efficiency (NSE) and the coefficient of determination R^2 are estimated by:

Nash-Sutcliffe efficiency(Reff)
$$1 - \frac{\sum(Q_{obs} - Q_{sim})^2}{\sum(Q_{obs} - \overline{Q_{obs}})^2} \quad (2)$$

Coefficient of Determination (R^2)
$$\frac{(\sum(Q_{obs} - \overline{Q_{obs}})(Q_{sim} - \overline{Q_{sim}}))^2}{\sum(Q_{obs} - \overline{Q_{obs}})^2 \sum(Q_{sim} - \overline{Q_{sim}})^2} \quad (3)$$

Where: = observed runoff; =simulated runoff; $\overline{Q_{obs}}$, $\overline{Q_{sim}}$= mean observed and simulated runoff.

RESULTS AND DISCUSSION

CanESM2 output Downscaling for the Future Climate Scenarios

Climate scenarios for future periods (2018-2047) and (2048-2077) have been developed for two emission scenarios of canESM2 RCP4.5 and RCP8.5 based on the mean of 20 ensembles.

Minimum temperature

As shown in Figure (2), the projected average monthly minimum temperature result implies an increasing trend under both the RCP scenario for the future period (2018-2047) and (2048-2077). The RCP4.5 scenario suggests there is an increment of the minimum temperature from 1.05°C to 1.82°C for near-term (2020) and 1.06°C - 2.30°C for mid-term (2050) from the baseline period. And under RCP8.5 scenario shows from baseline period the minimum temperature expect to increase from 1.51°C – 2.3°C for near-term and 1.64°C – 2.94°C for mid-term respectively.

Maximum temperature

As is shown in Figure 3, the mean monthly maximum temperature shown generally an increasing trend for a

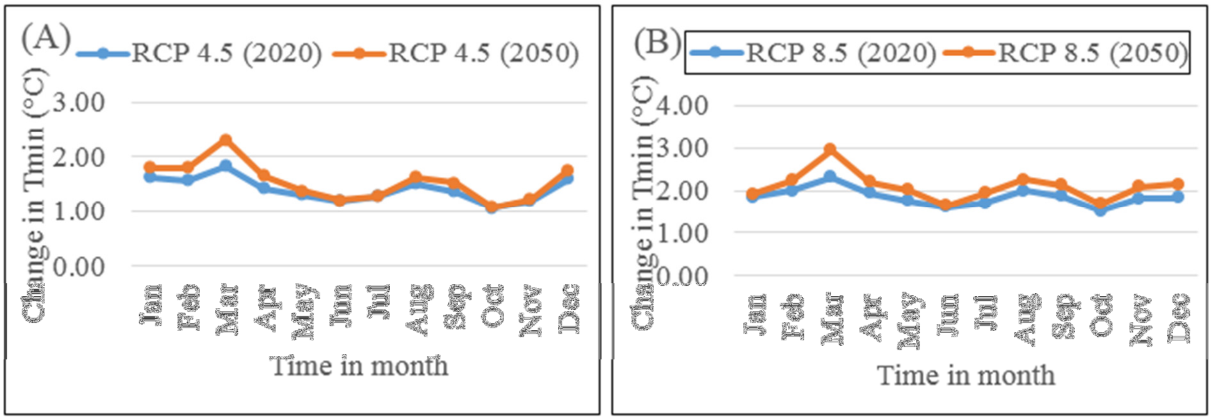

Figure 2. Projected changes in average monthly minimum temperature for near-term scenario (2018-2047) and mid-term scenario (2048-2077) under RCP 4.5 (A) and RCP 8.5 (B) respectively

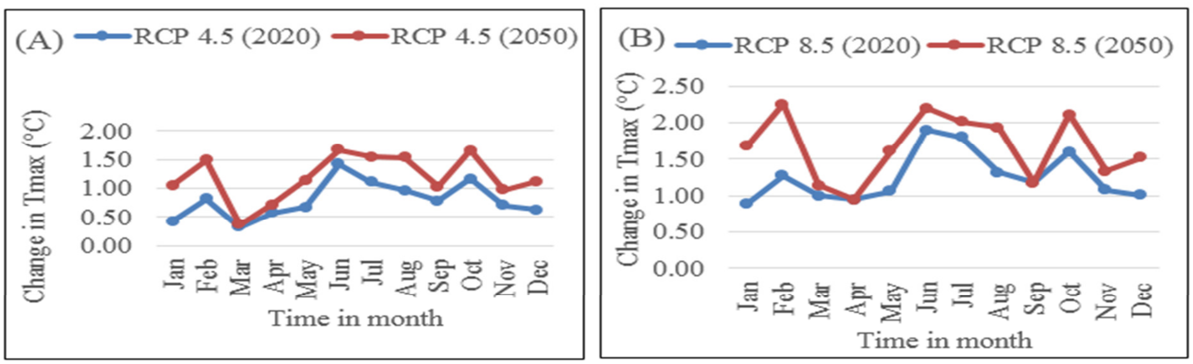

Figure 3. Projected changes in average monthly maximum temperature for near-term scenario (2018-2047) and mid-term scenario (2048-2077) under RCP 4.5 (A) and RCP 8.5 (B) respectively.

future period (2018-2047) and (2048-2077) under both RCP4.5 and RCP8.5 scenarios. The RCP4.5 scenario suggests the monthly maximum temperature will increases from 0.32°C to 1.41°C for near-term (2020) and 0.37°C – 1.66°C for mid-term (2050) from the baseline period. And also RCP8.5 scenario shows from baseline period the monthly maximum temperature will increases from 0.89°C– 1.90°C for near-term and 1.17°C – 2.25°C for mid-term respectively.

Areal precipitation

As is depicted in Figure 4, the mean monthly precipitation shows both increasing and decreasing trend for both RCP4.5 and RCP8.5 scenarios for a future period (2018-2077).

Under RCP4.5 the monthly precipitation decreases pattern indicates in January, May, October, November, and December up to (9.1% -34.4%) and (12.4% -33.2%) in near (2018-2047) and mid-term (2048-2077) respectively.

As shown in Figure 4, under RCP8.5 the projected change shows mean monthly precipitation increasing pattern principally from February-May and June-September in between (2.9–101.3%) in near-term and (5.1–99.7%) in mid-term scenarios. Nevertheless under RCP8.5 monthly precipitation distribution indicates a decreasing pattern in January, May, October, November, and December up to (11.6–37.8%) in the near-term and (16.3–39.8%) in mid-term future times.

Hydrological Model Calibration and Validation

The calibration and validation of the HBV-Light model were implemented by using a split-sample technique (2003-2012) data for calibration and the remaining (2013-2017) data for validation. Calibration was done manually by optimizing the model parameters in each subroutine that have a significant effect on the performance of the model using observed stream flow. Based on this, several runs were made to select the most optimum parameter set to match the observed discharge with

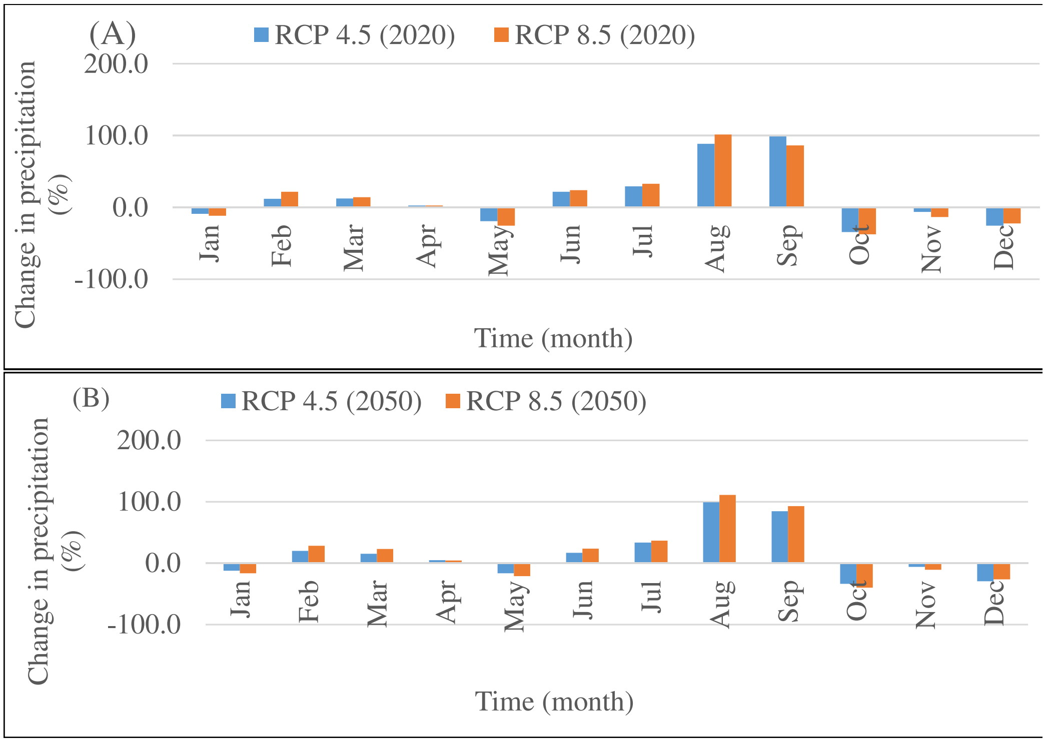

Figure 4. Projected change of average monthly precipitation distribution for near-term (A) and mid-term (B) under RCP 4.5 and RCP 8.5 respectively

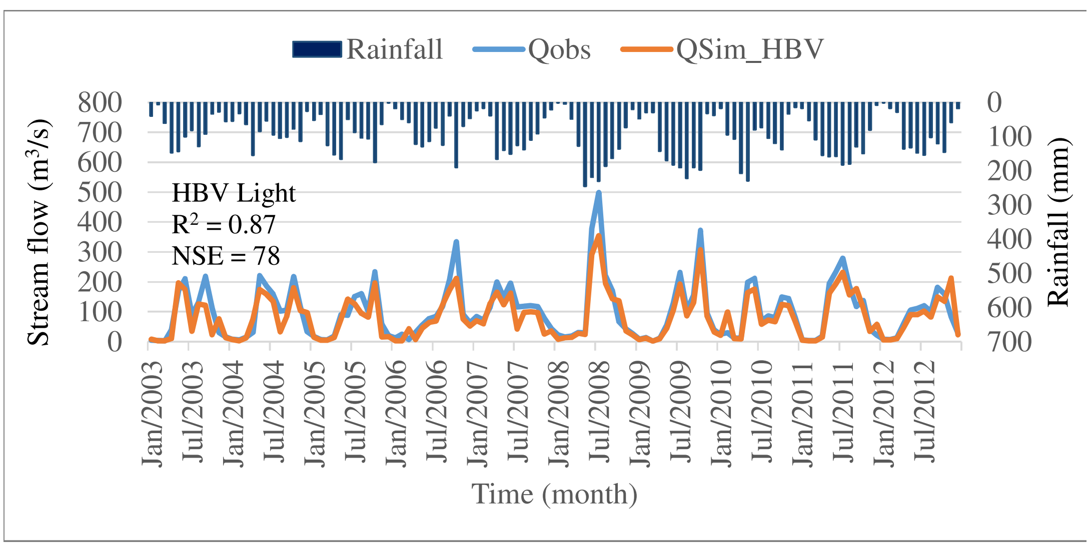

Figure 5. Monthly observed vs. simulated discharge hydrograph of Awata watershed during the calibration period (2003-2012).

simulate discharge.

The result of each run was evaluated in different ways including visually inspecting and comparing the calculated and observed hydrograph. The statistical criteria selected for showed good performance for daily and monthly calibration (with R^2 = 0.87 and NSE = 0.78 for monthly simulation). Besides, the models were validated using an independent data set, which shows good agreement for both daily and monthly simulation results (with R^2= 0.85 and NSE = 0.82 for monthly simulation). Generally speaking, the results show that the HBV-Light model can reproduce historical daily discharge with acceptable accuracy. The calibration and validation result of the HBVLight model are shown in Figure 5 and Figure 6. NSE and R^2 were calculated from simulated discharge values and the available observed runoff for the simulation period.

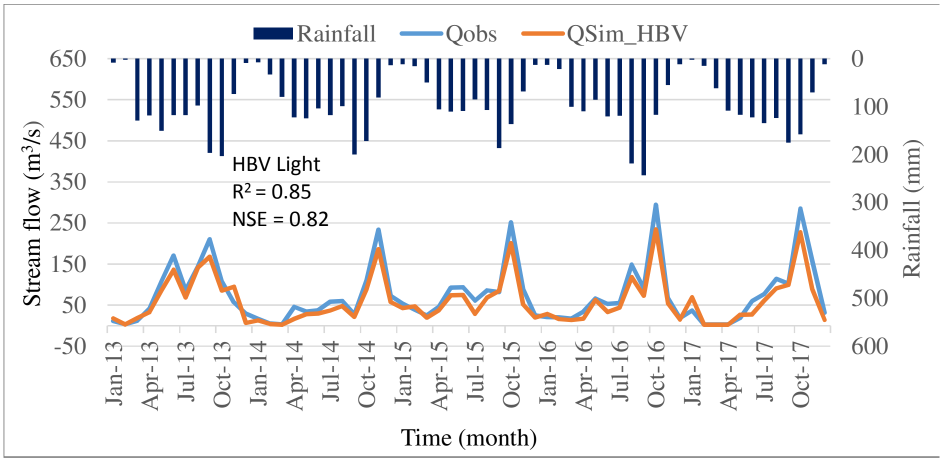

Figure 6. Monthly observed vs. simulated discharge hydrograph of Awata watershed during the validation period (2013-2017).

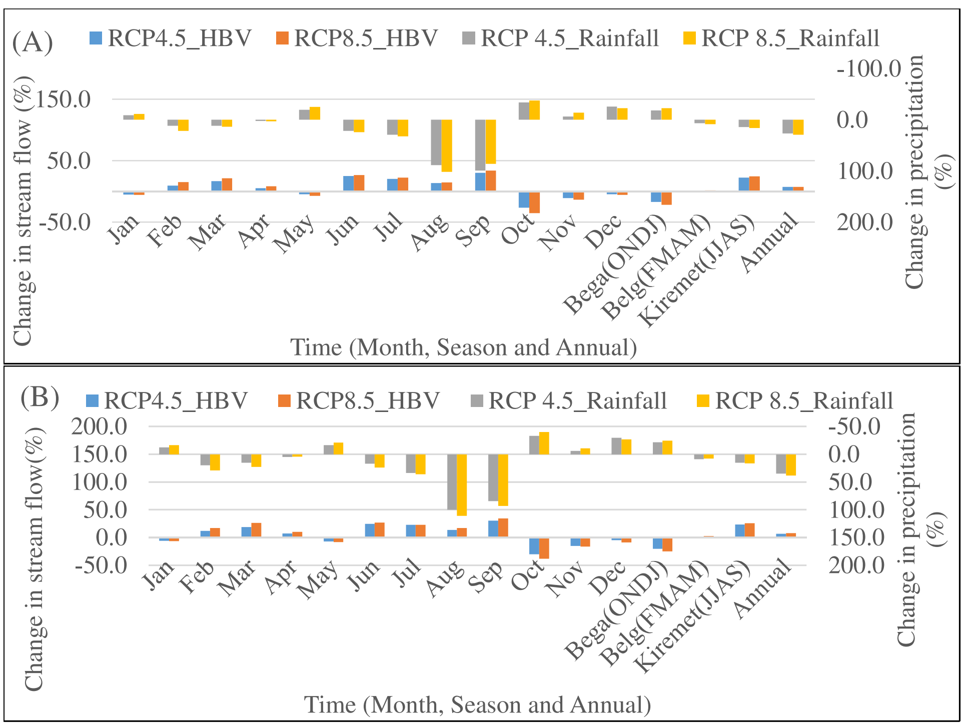

Figure 7. Projected change of mean monthly Streamflow in near-term (2018-2047) (A), and mid-term (2048-2077) (B) from the baseline period (2003-2017) in Awata watershed

Impact of Climate Change on Stream Flow under Future Scenarios

The impacts of climate change were analyzed taking the 2003-2017 flow as the baseline flow compared with the future flows for the 2020s(2018-2047) and 2050s(2048-2077). Based on this, the hydrological impact of the Awata watershed was analyzed with HBV light using the data concerning two 30 years of future time series from 2018-2047 and 2048-2077 for RCP 4.5 and RCP 8.5.

The output obtained from HBV light model was helpful to identify the possible trend of the simulated river flow. HBV light indicates the percentage increment of total average annual flow volume 7.3% (2018-2047) and 7.0% (2048-2077) for RCP 4.5 scenario, and For RCP 8.5 scenario, the increment ranges between 7.7% (2018-2047) to 7.9% (2048-2077) as shown in (Figure 7) (A) and (B). An increase in average total annual flow volume is observed for periods that show a corresponding increase in mean annual precipitation during scenario developments.

Seasonally, the model indicates the average total flow volume increases in *Kiremet* season (June- September) and decrease in *Bega* season (October- January) for future two-time horizon comparing with the base period. The percentage change of ranges between +24.7% (2018-2047) to +25.6% (2048-2077) for simulation with the HBV model in *Kiremet* season under RCP8.5.

On monthly basis, the model indicates decrease trend in months of January, May, October and December; and increased trend in months of February, March, April, June, July, August and September throughout the future two time horizon for both RCP4.5 and RCP8.5 scenarios as compared with base period (Figure 7)(A) and (B).

According to Figure 7 (A), in 2020s, HBV light model indicates a monthly decrease up to -4.7% to -26.6% and increase up to +5.7% to +30.5% for RCP4.5 and likely for RCP8.5 scenarios, a monthly decrease up to -5.9% to -35.1% and increase up to +8.3% to +33.9%.

As can be observed from Figure 7 (B), in the 2050s HBV light hydrological model exhibited a decrease and increase in monthly streamflow for both RCP 4.5 and RCP 8.5 scenarios. The model indicates a monthly decrease up to -6.0% to -30.0% and increase up to +10.4% to +31.9% for RCP4.5 and under RCP8.5 scenarios, a monthly decrease up to -6.2% to -38.3% and increase up to +10.2% to +34.4%.

Moreover, the model indicates the lowest percentage decrease in January and the highest percentage of decrease in October in the future near term and mid-term time horizon for both RCP 4.5 and RCP 8.5 scenario. On the other hand, the model indicates the lowest percentage of increase in February and the highest percentage of increase in September for both RCP 4.5 and RCP8.5 scenario. This is because of the corresponding lowest and the highest percentage increase in precipitation. These results agree with Shanka (2017) who researched the Gidabo River basin which is found in the Southern part of Ethiopia using GCM out including HadCM3. This finding is also harmonious with the findings of Kassa (2014).

CONCLUSION AND RECOMMENDATION

As the result indicates the mean monthly minimum temperature would increase in the range of +1.05°C to +1.82°C for near-term (2018-2047) and +1.06°C to +2.30°C for mid-term (2048-2077) from the baseline period under RCP4.5. Under RCP8.5 scenario also shows from baseline period the minimum temperature was increased in +1.51°C to +2.3°C for near-term and +1.64°C to +2.94°C for mid-term respectively. The mean monthly maximum temperature was also expected to increase in the range of +0.32°C to +1.41°C for near-term (2018-2047) and +0.37°C to 1.66°C for mid-term (2048-2077) from the baseline period for the RCP4.5 scenario. For RCP8.5 scenario shows from baseline period the maximum temperature was increased in the range of +0.89°C to +1.90°C for near-term and +1.17°C to +2.25°C for mid-term respectively.

The result of the Statistical Downscaling Model for the future scenario (RCP4.5 and RCP8.5) on a monthly and seasonal basis indicates that precipitation does not show a systematic increase or decrease. Precipitation increase in some months and decrease in other months for both RCP4.5 and RCP8.5 scenario simulated with HBV Light model in all future time horizon (2018-2077). However, in the main rainy season, *Kiremet* (June-September) revealed an increasing trend with the highest increased observed up to a maximum of 16.3% (2050) for the RCP 8.5 scenario and 15.3% (2050) for RCP 4.5 scenario. In *Bega* season both RCP4.5 and RCP8.5 scenarios indicate a decreasing pattern of precipitation in the two future time horizon compared with the base period with the maximum value of -21.4%(2050) and -24.7% (2050) for RCP4.5 and RCP8.5 respectively. Overall annual precipitation shows an increasing trend for both RCP4.5 and RCP8.5 scenario with the percent of increment up to 26.8% and 35.1% at near and mid-term respectively.

The conceptual hydrological model namely HBV light was selected and tested for the hydrological characteristics of Awata watershed. The model was run for calibration (2003-2012) and validation (2013-2017). On monthly based the results of HBV-Light shows that the model is able to reproduce discharge with good performance (R^2 = 0.87, NSE = 0.78) and (R^2 = 0.85, NSE = 0.82) during calibration and validation respectively.

The models and model output used in this study processed a certain level of uncertainty. Hence, the result of this research should be taken carefully and considered as an indicative prediction of the future and further researches should be expected by considering a land-use change in addition to climate change.

The result of this study is based on the output of single GCM and only two emission scenarios (RCP4.5 and RCP8.5). However, it is recommended to use the different GCM outputs and emission scenarios to compare the result of different models and explore a wide range of climate change scenarios that would result in different hydrological impacts. Meanwhile, the GCM was downscaled to a watershed level only using statistical downscaling models which is the regression-based model, even though other methods exist which are used for impact assessment. Thus, this study should be extended in the future considering other downscaling methods.

According to the study, there would be a reduction in precipitation in *the Bega* and an increment of precipitation in the major rainy season (*Kiremet*) which shows a corresponding decrease and an increase of stream flow of the watershed. Therefore, soil and water conservation activities should be adopted by the community as well as the water harvesting structure should be properly designed and applied to the watershed to compensate for this fluctuation of flow in the Awata River. The watershed water management system should be following the future trends of rainfall peaks as the temporal shift in peak rainfall showed a direct impact on the flow of Awata river watershed. When long records of rainfall and runoff are available, conceptual model HBV light can be successfully calibrated and used both for simulation and for real-time streamflow forecasting.

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