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

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Abstract

This research was conducted to study impacts of climate change on water resource of 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 (2020s) and 2048-2077 (2050s). According to the projected climate data, the monthly minimum and maximum temperature are likely to have an increasing trend +2.94°C and 2.25°C respectively. Regarding the rainfall change, under the RCP4.5 scenario the study shows annual average increment of by 26.8% and 35.1% at near (2020) and mid-term (2050) respectively. On monthly bases rainfall shows there is incensement in some months and decrease in some months. 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 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. Over the two projected periods (2018-2047 and 2048-2077) under both RCP4.5 and RCP8.5 scenario HBV-Light model simulation results showed that the mean annual discharge will significantly increase related to the baseline periods (1988-2017). The average total annual flow at outlet of the watershed might increase up to 7.3% for RCP4.5 scenario and 7.0% for 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 RCP8.5 scenario.

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

1. 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 aprolonged period, usually decade or more [2].Nowadays the Intergovernmental Panel on Climate Change concluded that climate change is already happening with complicated effects on humans and the environment [2]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 [2][3]. Climate change and variability issues have therefore become a center of concern for scientists and policy makers 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 coarse spatial resolution of GCMs particularly estimating the hydrological runoff in the watershed scale. Many studies conducted downscaling methods to make a link between GCMs output and hydrologic models at watershed level [1].

Even though the fact that the impact of climate change is forecasted at the global scale, the type and magnitude of the impact at a watershed scale is not investigated in most part of the world, the Ethiopia's condition in particular. Measureable estimates of hydrologic effects of climate change are essential for understanding and solving the potential water resource management problems associated with water supply for domestic and industrial water use, power generation, and agriculture as well as for future water resource planning, reservoir design and management, and protection of the natural environment [5].

Awata watershed is under great pressure because of 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 other part of the Genale dawa basin [4] and[7], which indicates that with respect to future climate in Genale Dawa basin there is high confidence temperature will increase and leading to increase evaporation. Therefore against to this background, it is paramount to study the climate change impacts on the water availability of Awata river watershed's in order to take the effect in to 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 *Awata River watershed*.

2. MATERIALS AND METHODS

A.Study Area

Awata watershed which has a drainage area of 1513 km² is located in Ganale Dawa River basin. Awata watershed is 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 it 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.



Figure 1. Location map of Awata watershed.

B. 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. HBV-Light hydrological model was calibrated and validated using historical climate data of threestations (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 scenario were used as an input for HBV-Light model to assess watershed hydrological response to climate change.

C. Data Types and Sources

1) Meteorological Data: The required meteorological data of the study area was collected from the Ethiopian National Meteorology Agency (NMA). The long-term records daily meteorological data for 30 years (1988-2017) was obtained from three meteorological stations (Hagere selam, Kibremengist and Yirba muda) located in and nearby of the study area. Meteorological data collected were includes 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.

2)Hydrological Data:Stream flow data of Awata River was required for calibrating and validating of the HBV light model simulation. There is one main gauging station at the outlet

of 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)

D. Climate Model and Downscaling

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

1) Statistical Downscaling Model: According to [8]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 takes as predictors and the station data were taken as predictands. The base line 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 SDSM model, the future climate scenarios (2018-2077) was 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.

E. Data Quality Checking and Control

1) 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 time period should be a straight line and their proportionality unchanged, which is represented by 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). Significant change observed in the system of the curve was, corrected by following equation 1:

$$P'_{\chi} = P_{\chi} * \frac{M}{M} \qquad (1)$$

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

2) 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.

3) **Bias correctionmethod of downscaled climate data:** Bias correction compensates for any tendency to over or under estimates 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 in order to match the mean of the conditional process and was set to 0.96

F. Data preparation for model input

HVB Light model requires observed daily input data of rainfall, air temperature, monthly potential evapotranspiration, stream flow (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).

G. Hydrological Modeling

To simulate the stream flow of the watershed, HBV-Light model was used. The HBV (Hydrologiska Byrans Vattenbalansavdelning)-Light hydrology model is a widely used conceptual model [6]. 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 Thiessen polygon method. Potential evapotranspiration for the study area was estimated by the FAO Penman-Monteithmethod. The total period of the data that was used for this specific study was 15 years. From this period by using 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.

H. Model Performance Criteria

For this particular study, twomodel 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 coefficient of determination R^2 are estimated by:

Nash-Sutcliffe efficiency(Reff) $1 - \frac{\sum(Q_{obs} - Q_{sim})^{2}}{\sum(Q_{obs} - \overline{Q}_{obs})^{2}}$ (2) Coefficient of Determination (R²) $\frac{(\sum(Q_{obs} - \overline{Q}_{obs})(Q_{sim} - \overline{Q}_{sim}))^{2}}{\sum(Q_{obs} - \overline{Q}_{obs})^{2}\sum(Q_{sim} - \overline{Q}_{sim})^{2}}$ (3)

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

3. RESULTS AND DISCUSSION

A. 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. **1) Minimum temperature:** As shown in Figure (2), the projected average monthly minimum temperature result implies increasing trend under both 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.

2) Maximum temperature: As it shown in Figure 3, the mean monthly maximum temperature shown generally an increase trend for future period (2018-2047) and (2048-2077) under both RCP4.5 and RCP8.5 scenario. 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.

3) **Areal precipitation:** As it depicted in Figure 4, the mean monthly precipitation shows both increasing and decreasing trend for both RCP4.5 and RCP8.5 scenario for 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.



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.





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.

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 near-term and (16.3–39.8%) in mid-term future times.

B. Hydrological Model Calibration and Validation

The calibration and validation of the HBV-Light model were implemented by using 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 in order to match the observed discharge with 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's selected for showed good performance for daily and monthly calibration (with $R^2 = 0.87$ and NSE = 0.78 for monthly simulation). In addition, the models were validated using 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 an acceptable accuracy. The calibration and validation result of the HBVLight model is 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 time period.



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



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

C. Impact of Climate Change on Stream Flow under Future Scenarios

The impacts of climate change was 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 with respect to two 30 years 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 indicate 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). Increase in average total annual flow volume is observed for periods which 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 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 2050s HBV light hydrological model exhibited a decrease and increase in monthly stream flow 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 indicate the lowest percentage decrease in the month of January and the highest percentage of decrease in the month of October in 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 the month of February and the highest percentage of increase in September for both RCP 4.5 and RCP8.5 scenario. This is because of corresponding lowest and highest percentage increase of precipitation. These results agree with [7] who carried out research in Gidabo River basin which is found in Southern part of Ethiopia using GCM out including HadCM3. This finding is also harmonious with the findings of [4].



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

4. 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 (20482077) from the baseline period under RCP4.5. Under RCP8.5 scenario also shows from baseline period the minimum temperature was increased in $+1.51^{\circ}$ C to $+2.3^{\circ}$ C for near-term and $+1.64^{\circ}$ C to $+2.94^{\circ}$ C for mid-term respectively. The mean monthly maximum temperature was also expected to increase in the range of $+0.32^{\circ}$ C to $+1.41^{\circ}$ C for near-term (2018-2047) and $+0.37^{\circ}$ C to 1.66° C for mid-term (2048-2077) from the baseline period for RCP4.5 scenario. For RCP8.5 scenario shows from baseline period the maximum temperature was increased in the range of $+0.89^{\circ}$ C to $+1.90^{\circ}$ C for near-term and $+1.17^{\circ}$ C to $+2.25^{\circ}$ C for mid-term respectively.

The result of Statistical Downscaling Model for the future scenario (RCP4.5 and RCP8.5) on monthly and seasonal basis indicate that precipitation does not show 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 increased trend with highest increased observed up to a maximum of 16.3% (2050) for RCP 8.5 scenario and 15.3%

(2050) for RCP 4.5 scenario. In *Bega* season both RCP4.5 and RCP8.5 scenario indicate a decreasing pattern of precipitation in the two future time horizon comparing 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 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 scenario that would result 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 *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 water harvesting structure should be properly designed and applied on the watershed compensate this fluctuation of flow in the Awata River. The watershed water management system should be in accordance with 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 stream flow forecasting.

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