Journal of
Earth Science & Climatic Change

Review Article Open Access

Evaluation of Climate Change Impacts on Runoff in the Gidabo River

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Abstract

Climate change significantly affects many hydrological systems, which in turn affects the runoff and the flow of rivers in Gidabo river basin. Therefore, the aim of this research was taken as to investigate the impacts of possible future climate change scenarios on the runoff in the catchment area of Gidabo River. Statistical Downscaling Model version 4.2 was used to downscale the daily precipitation, daily maximum and minimum temperature in the basin of the study area. The large-scale climate variables for the A2a and B2a scenarios obtained from the Hadley Centre Coupled Model version 3 were used to show future scenario. After the calibration of the model and testing of the downscaling procedure, the hydrological model was run for the three future periods: 2011-2040, 2041-2070, and 2071-2099. The meteorological variables such as, precipitation, minimum and maximum temperature that were downscaled from SDSM were used as input to the SWAT hydrological model which was calibrated (R=0.77) and validated (R=0.81) with meteorological and hydrological historical data (1980-2006) to examine the possible impact of climate change on the runoff of the catchment. The results obtained from this study indicate that there is significant variation in the monthly, seasonal and annual runoff. The SWAT simulation of future average seasonal runoff shows increasing pattern during February to May and June to September for both A2a and B2a scenarios in all time periods. The change in climate variables such as increase in precipitation and temperature thereby which is very sensitive parameter that can be affected by changing climate than any other hydrological component are likely to have significant impact on runoff.

Keywords: Climate change; Gidabo river basin; Statistical Downscaling Model (SDSM); Stream flow

Introduction

The effect of climate change is a major issue in the environmental discussion on both global and local scale. The effect on river runoff due to changes in precipitation, evapo-transpiration and temperature, is an important factor in environmental (transport of nutrients, sediment and habitats of flora and fauna), agricultural (drainage and flooding) and economical applications (e.g. water supply, flooding, engineering, and agro economics). Therefore, good estimates of future runoff are an important input to the discussion of the effects of climate change [1].

The effect of climate change on river runoff varies in different ways, on different spatial scales and for time series of different lengths in various periods. Modeling the effect of climate change on river runoff is usually achieved either by direct use of climate model data in hydrological models or by changing existing climate data series with expected changes.

Understanding the climate change impact on the hydrologic cycle evolution is one of the major challenges in the context of water resources management. GCMs have become a main tool in addressing the climate change impact studies in environmental and water resources and are coupled with atmospheric, oceanic, land surface and sea ice models [1]. The use of GCMs in hydrologic models is a reasonable approach to assess possible future hydrologic changes of basins. However, there have been some limitations due to coarse spatial resolution of GCMs particularly estimating the hydrological parameters such as runoff in the watershed scale. Many studies conducted downscaling methods to make a link between GCMs output and hydrologic models at watershed scale. The Intergovernmental Panel on Climate Change (IPCC 2007) stated that it is evident by now that recent climate changes have had serious impacts on the river runoff in many regions of the world. Precipitation is considered as an essential parameter in climate change through the studies. Forecasting runoff trend might affect the developmental plan for an area due to changing energy demand and water consumption in different sectors. Runoff forecasting is one of the significant components in hydrological models, which play an important role in water resources management. The changes are predicted in river runoff patterns in future according to the IPCC scenarios. In most of the studies, a historical climate data (1980-2006) as a base period is entered into hydrological models to make a long time series of hydrological data, and then the hydrological model is calibrated against the base period data to verify the considered hydrological model in the scope of study [2]. Finally, runoff value can be estimated by driving a future climate series projected according to the IPCC scenarios.

Description of study area

The Gidabo Basin is located in the Abaya-Chamo sub-basin of the Rift Valley Basin situated in the southern part of Ethiopia. It is found with in the Southern Main Ethiopian Rift valley System, Northeast of Lake Abaya in Southern Nations Nationalities and Peoples Regional State (SNNPRS) [2]. The absolute geographical location of the area is between 6.09 and 6.60 N latitude, and 38.0 and 38.38 E longitudes with an area and perimeter of 3342.37 square kilometers and 305.25 kilometers respectively.

Materials and Methods

This study concerns the evaluation of climate change impact on runoff with the application of a semi-distributed physically based watershed model SWAT in the Gidabo river basin. Statistical Downscaling Model (SDSM) was used for future climate generation [3]. The method consists of using climatic output data from General Circulation Models (GCMs) to retrieve climate scenarios. The weather generator was then used to produce daily temperature and precipitation data to serve as an input data for the SWAT hydrological model to simulate runoff and stream flow. The future simulated results were then compared with the base line period as a means of obtaining the change

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Received date: February 12, 2021; **Accepted date:** February 26, 2021; **Published date:** March 05, 2021

Citation: Shalishe A (2021) Evaluation of Climate Change Impacts on Runoff in the Gidabo River. J Earth Sci Clim Change 12: 535.

caused by climate change. The historical climate data and stream flow data have been collected from National metrological Agency and ministry of water irrigation energy and electricity that used to calibrate and validate SWAT model. Watershed parameters are taken from the output of the Digital Elevation Model (DEM) that has been processed by GIS. Taking these watershed parameters, the historical climate and flow data calibration has been taken to determine the model parameters [3,4]. Model calibration is change of model parameters based on checking results against observations to ensure similar response over time. This consists of comparing the model outputs, generated with the use of historic meteorological observations, to recorded stream flows. In this process, model parameters varied until recorded flow patterns are accurately simulated. The manual calibration of this study was done based on the procedures recommended in SWAT user manual. In order to apply the calibrated model for estimating the future flow and runoff, the model tested against an independent established of measured data. This testing of a model on an independent established of data set is commonly referred to as model validation [4]. As the model prognostic capability was demonstrated as being reasonable in the calibration and validation periods, then the model was used for future predictions under different future running scenarios. Instead the coarser climate data (GCM) are downscaled in to finer spatial resolution regional climate data and these regional climate data are further downscaled in to station level by using Statistical Downscaling Model (SDSM 4.2.2), these downscaled data have been taken directly as an input of the model to evaluate the future climate change impact on Gidabo River basin [5].

Results and Discussion

Scenarios developed for baseline period

One of the criteria commonly used in the measuring the performance of any useful downscaling method is whether the historic condition can be simulated or not [6], It is therefore imperative that the method used for transferring the results of climate models to meteorological stations generate precipitation and temperature time series have the same statistical properties as observed meteorological data that is used for hydrological modeling. Downscaled base-line daily maximum and minimum temperature data shows good agreement with observation for both calibration and validation periods with R 0.61 and 0.63 respectively. In the case of daily precipitation even though there were little variations in individual months the performances of the model, overall shows a good agreement between the observed and calibrated for almost all months of the year with R=0.52.

Precipitation: SDSM model performs reasonably well in assessing the mean daily precipitation at Gidabo catchment in many months. The simulated SDSM output indicates reasonable agreement with observed mean daily precipitation. With respect to daily precipitation at Dilla station, the SDSM model slightly overestimates for some months such as May, June and September but in some months such as January, February and august there is underestimation of the model [7]. In other months the downscaled daily precipitation shows better agreement with observed values.

Maximum temperature: The projected maximum temperature for baseline period shows good agreement between observed and downscaled values. With respect to monthly maximum temperature at Dilla station, the SDSM model slightly underestimates for some months such as January, May and June but in some months such as February and august there is overestimation of the model. In other months the downscaled maximum temperature shows better agreement with observed values [7].

Minimum temperature: According to monthly minimum temperature at Dilla station, the SDSM model slightly underestimates for months June, October, November and December and there is overestimation for the months April, May and August. In the other months the downscaled minimum temperature shows good agreement with the observed values.

Scenario developed for future time period

Precipitation: The precipitation projection points to increase in mean annual precipitation by 3.75% for the HadCM3 A2a scenario and by 3.61% for the HadCM3 B2a scenario. The mean annual precipitation is expected to increase by 2.9% for both HadCMA2a and HadCM3 B2a scenarios in the period 2011-2040. In the 2041-2070 periods the mean annual precipitation is expected to increase by 3.35% and 3.3% and for the 2071-2099 periods by 6.15 and 4.56% for HadCM3 A2a and B2a scenarios respectively. Both A2a and B2a scenarios indicates a monthly mean precipitation increase in February, march, April, Jun, July, august and September and a decrease in other months for all time periods. It is observed that the change of precipitation shows similar trend irrespective of the magnitude for both climate change scenarios. However, the downscaling of precipitation is highly uncertain due to the influence of the seasonal cycle of temperature and precipitation [1,3].

Maximum temperature: The projected annual maximum temperature in 2020s indicated that maximum temperature expected to increase by 0.22 C for A2a and 0.25 C for B2a scenario. In 2050s the increment will be 0.65 C and 0.53 C for A2a and B2a scenarios, respectively. Whereas, in 2080s the maximum temperature will be increased by 1.1 C and 0.9 C for A2a and B2a scenarios, respectively. This shows that the future period will experience increasing trend in maximum temperature for both A2a and B2a scenarios. However, the change will be more for A2a scenario relative to B2a scenario. This is due to the fact that A2a represents medium high scenario which causes more Carbon dioxide as compared to B2a scenario which is medium low scenario.

Minimum temperature: Similar to the precipitation and maximum temperature scenarios, the average monthly minimum temperature also indicates that there is an increasing trend from the base period. But there is a significant decrease in April, September, October and November during the entire time period for both HadCM3 A2a and B2a scenarios [4,6]. In the month of February for Hadcm3 A2a and Hadcm3 B2a scenario the change in minimum temperature slightly increases 2050s and decreases for the other two time periods. In the month of January for HadCM3 B2a scenario, the mean monthly minimum temperature change is expected to decrease for the time period 2020s and increase for the time periods of 2050s and 2080s. The projected annual minimum temperature in 2020s indicated that maximum temperature expected to increase by 0.17 C for both A2a and B2a scenario. In 2050s the increment will be 0.4 C and 0.3 C for A2a and B2a scenarios, respectively. Whereas, in 2080s the maximum temperature will be increased by 0.6 C and 0.5 C for A2a and B2a scenarios.

Hydrological model results

6.3.1 Sensitivity analysis: The sensitivity analysis was performed for 27 parameters that may have a potential to influence Gidabo river flow. Even though 27 parameters were considered for the sensitivity analysis, only 6 of them are effective for monthly flow simulation analysis. The first six parameters showed a relatively higher sensitivity, being the curve number parameter being the most sensitive of all. The six most sensitive parameters controlling the surface runoff in the watershed are curve number (CN2), the soil evaporation compensation factor

(ESCO), Soil depth (SOL_Z), the threshold water depth in the shallow aquifer for flow (GWQMN), the soil available water capacity (SOL_AWC) and Average slope steepness (SLOPE).The ranges of variation of these parameters are based on a listing provided in the SWAT2009 manual and are sampled by considering a uniform distribution [2,5].

Sensitivity analysis: The SWAT model was calibrated and validated using measured stream flow data collected from stream gauging station located on the Gidabo River at Aposto. The coefficient of determination (R) and Nash-Sutcliffe simulation efficiency (NSE) were used to evaluate the model performance for both calibration and validation time periods. Calibration was performed for five years period from 1999 to 2003. The R value indicates the strength of relationship between the observed and simulated values. The NSE value indicates how appropriate the plot of the observed versus the simulated values fits the 1:1 line. If the R and E values are less than or very close to 0, the model prediction is considered unacceptable. If the value approaches to 1, the model predictions are considered perfect. The calibration results are good agreement between the simulated and observed monthly flows at the out let of the watershed. This is proved by the correlation coefficient R=0.77 and the Nash-Suttcliffe simulation efficiency (NSE)=0.6 during calibration period. The results fulfilled the requirements for R >0.6 and E >0.5. As exemplary hydrographic, observed vs simulated discharge at Gidabo gauging station are the model underestimates the peaks in most years of calibration period, in which the peak is nearly captured. The main reason for the underestimation of the peak may be due to many missed measured rainfall data used in calibration period. Validation demonstrates the performance of the model for simulated flows in periods different from the calibration periods, but without any further adjustment in the calibrated parameters. Consequently, validation was performed for three years period from 2004 to 2006. When analyzing the performance on a monthly time scale, the verification period shows that the model performed well. The correlation coefficient (R=0.81) and the Nash-Suttcliffe simulation efficiency (NSE=0.65) shows good agreement between observed and simulated values. Both values fulfilled the requirement of R >0.6 and NSE > 0.5. The model over estimated some stream flow events during validation period, the high intensity, short duration rainfall events and rainfall variability over the precipitation gauging station might have caused the over estimation of the stream flow events. In general most of stream flow events are well represented by the calibrated model. This may indicate that the spatial distribution of precipitation with in the watershed is accurately represented by the available rain gauge as model input.

Impact of climate change on future runoff

Impacts on monthly runoff: The impact of climate change was analyzed taking the 1980-2006 flow as the baseline flow compared with the future flows for the 2020s, 2050s and 2080s. Precipitation, minimum and maximum temperature were the climate change drivers considered for the impact assessment. The monthly percentage change in runoff in both scenarios for the period 2020s, 2050s and 2080s. In the 2020s, 2050s and 2080s for the A2a and B2a scenarios, the runoff showed a decreasing trend for the Months January, May, October, November and December, and increasing trend for the month February, march, April, Jun, July, august and September. In 2050s for both scenarios a decrease in runoff exhibited, this might shows a monthly increase up to 15.5 % and 13.4% and monthly decrease up to 20.3% and 12% for HadCM3 A2a and HadCM3 B2a scenarios respectively. In 2080s increasing trend will expect for both the scenarios in all the months except January, May, October, November and December. In monthly basis the A2a scenario will expect to increase up to 17% and decrease up to 13.9%. However, in 2080s B2a scenario, the pattern of monthly runoff change may be increase up to 9.5% and decrease up to 6.5 % [8].

Impact on seasonal and annual runoff: For this specific study, seasonal analysis was taken for three seasons i.e. ONDJ (October, November, December and January), FMAM (February, March, April and May) and JJAS (June, July, august and September). During ONDJ season total average seasonal runoff showed decrease in all horizons both HadCM3A2a and HadCM3B2a scenarios. Furthermore Percentage decrement will be high displaying 8.8% in 2020s, 8% in 2050s and 11.2 in 2080s for HadCM3A2a scenario and 9.3 % in 2020s, 9 % in 2050s and 3.0% in 2080s for HadCM3B2a scenario during ONDJ season. In general the average total seasonal runoff decreasing pattern in month of October to January for both A2a and B2a scenarios. In months of February to May and Jun to September there might be increasing pattern of average total seasonal runoff in both the scenarios. In 2020s, 2050s and 2080s, the total average annual runoff in Gidabo river basin is increasing of up to 3.4%, 2.9 and 6.8% for HadCM3A2a and 5.1 %, 5.6 and 5.8 % for HadCM3B2a scenarios respectively. A change in temperature and precipitation due to climate change has significant impacts on the amount of runoff. Generally, future average seasonal and annual runoff comparison showed that, runoff increases in magnitude in both future periods as compare to the base period (1980-2006). High amount of increase in average seasonal runoff exhibited during summer season (JJAS) and high amount of decrease in magnitude Bega season (ONDJ) [8].

Conclusion

Soil and Water Assessment Tool (SWAT) was successfully used to simulate, the impact of climate change on the Runoff of Gidabo river basin were assessed based on projected climate conditions by using GCM out puts of HadCM3 SRES A2a and B2a emissions scenarios with Statistical Downscaling (SDSM) modeling approach . This is proved during calibration and validation period of the model performance criterion such as regression coefficient and Nash-Sutcliffe used to evaluate the model. The SDSM simulated maximum and minimum temperature more accurately than that of the precipitation. This is due to the fact that the maximum and minimum temperatures are highly affected by large scale variables. Accordingly, the major large scale predictors highly affect local maximum temperature. The precipitation projection points to increase in mean annual precipitation by 3.75% for the HadCM3 A2a scenario and by 3.61% for the HadCM3 B2a scenario. The change in climate variables such as increase in precipitation and temperature thereby which is very sensitive parameter that can be affected by changing climate than any other hydrological component are likely to have significant impact on runoff. This in combination of the future climate change impact on increase of precipitation in the watershed causes an increase of annual runoff around the watershed. As hydro meteorological data is very important for water resources, infrastructure construction and other studies, a gauging station in this area is essential. So it suggested that at least a few gauging stations may be installed by the relevant Government organization in this sub basin.

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