doi:10.20944/preprints202009.0621.v1

Article

Change in Stream Flow of Gumara Watershed, Upper Blue Nile Basin, Ethiopia under Representative Concentration Pathway Climate Change Scenario

Gashaw Chakilu *, Szegedi Sandor and Turi Zoltan

Doctoral School of Earth Science, University of Debrecen, Debrecen; szegedi.sandor@science.unideb.hu (S.S.); turi.zoltan@science.unideb.hu (T.Z.)

* Correspondence: ggismu@yahoo.com; Tele: +36204038176

Abstract: Climate change plays a pivotal role in the hydrology of tributaries in the upper Blue Nile basin. This study was designed to reveal the extent to which climate change impacts on stream flow of the Gumara watershed under the Representative Concentration Pathway (RCP) climate change scenario. The study considered the RCP 2.6, RCP 4.5 and RCP 8.5 scenarios using the second generation Canadian Earth System Model (CanESM2). The Statistical Downscaling Model (SDSM) was used for calibration and projection of future climatic data of the study area. Soil and Water Assessment Tool (SWAT) model was used for simulation of the future stream flow of the watershed. Result showed that the average temperature will be increasing by 0.84°C, 2.6°C and 4.1°C in the end of this century under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios respectively. The change in monthly rainfall amount showed a fluctuating trend in all scenarios but the overall annual rainfall amount is projected to increase by 8.6%, 5.2% and 7.3% in RCP 2.6, RCP 4.5, and RCP 8.5 respectively. Overall, this study revealed that, due to climate change, the stream flow of the watershed is found to be increasing by 4.06%, 3.26%, and 3.67% under RCP 2.6, RCP 4.5 and RCP 8.5 scenarios respectively.

Keywords: climate change; stream flow; SWAT; Gumara watershed; Blue Nile

---

1. Introduction

Globally, there has been a considerable increase in emissions of greenhouse gas following the pre-industrial era, driven largely by economic and population growth and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years[1]. The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986 2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.5[2]. The global ocean will continue to warm during the 21st century, with the strongest warming projected for the surface in tropical and Northern Hemisphere subtropical regions[3].

In Ethiopia it is strongly evident that the climate has been changing all over the country because of global warming. The average temperature is expected to increase by 3.8°C by 2080 and annual average minimum temperature has showed an increasing trend between 1951-2006 by at least 0.37°C in every decades [4]. Studies revealed that increment of temperature is more prominent in the main rainy season. The rate of increase in minimum temperature is higher than in maximum temperature over the decadal periods. According to [5] minimum and maximum temperature has increased by 0.1oc and 0.15oc per decade respectively over the 33% of the upper Blue Nile basin in the west part of the country.

Historically changes in the amount of rainfall is not showing consistent trend spatially and temporally across Ethiopia. Similar observations have been made in other parts of the world [6]

According to the result revealed by [7], the rainfall in the season referred to as Belg (April–May) has not showed statistically significance change trend between 1960-2006. However according to [8], the Intergovernmental Panel on Climate Change (IPCC) forecast on the amount of precipitation has showed a long-term increase in rainfall in Ethiopia despite the short and medium term observation of frequent dry periods with extreme rainfall levels. Regardless of the seasonal inconsistent variation, in terms of the annual scale of rainfall, the increasing trend is shown in the western parts of Ethiopia [9]. The study conducted by [10] has revealed that based on climate model projections the monthly rainfall amount will increase during the last two months of kiremt (rainy season) and immediately after the kiremt in the Upper Blue Nile basin, Ethiopia.

Climate change significantly affects the state of the hydrological cycle. According to [11] the hydrology of headwater catchments of the Upper Blue Nile basin has been influenced by climate change. Gilgel Abay is one of the adjacent watersheds of the study area found in Upper Blue Nile basin; its flow has been affected by climate change. Especially, in terms of the seasonal influence, the effect of climate change on the stream flow of this watershed is more prominent in kiremt (rainy season) and belg (small rainy season) than the dry season flow nature [12]. The study area of this research is one of the tributaries feeding the Lake Tana which is the source of Blue Nile River where the Grand Ethiopian Renaissance Dam is being constructed. The flow of this catchment prominently plays at role on water balance of the Lake Tana and the newly constructed dam as well. Therefore, this study has been designed to reveal the impact of future climate change on the stream flow nature of Gumara watershed under Representative Concentration Pathway (RCP) climate scenario.

2. Data and Methodology

2.1. Study Area Description

The Gumara River is found in Lake Tana basin and upper Blue Nile basin; it is located to the east of the Lake Tana and extends between latitudes of 11° 35′ and 11° 55′ N and longitudes 37° 40′ and 38° 10′ E. The Gumara catchement has a total drainage area of 12718.6 km^2 up to the gauging station (near Woreta), a head of 25 km before it joins the lake. The total main stream length from its origin (Guna Mountain) is approximately 132.5 km before the river joins Lake Tana (figure 1). Gumara watershed is found in between dega and woina dega climate zones; the upper part of the catchment has dega and the lower part has woina dega climate zone and the average annual rainfall is 1455.66mm.

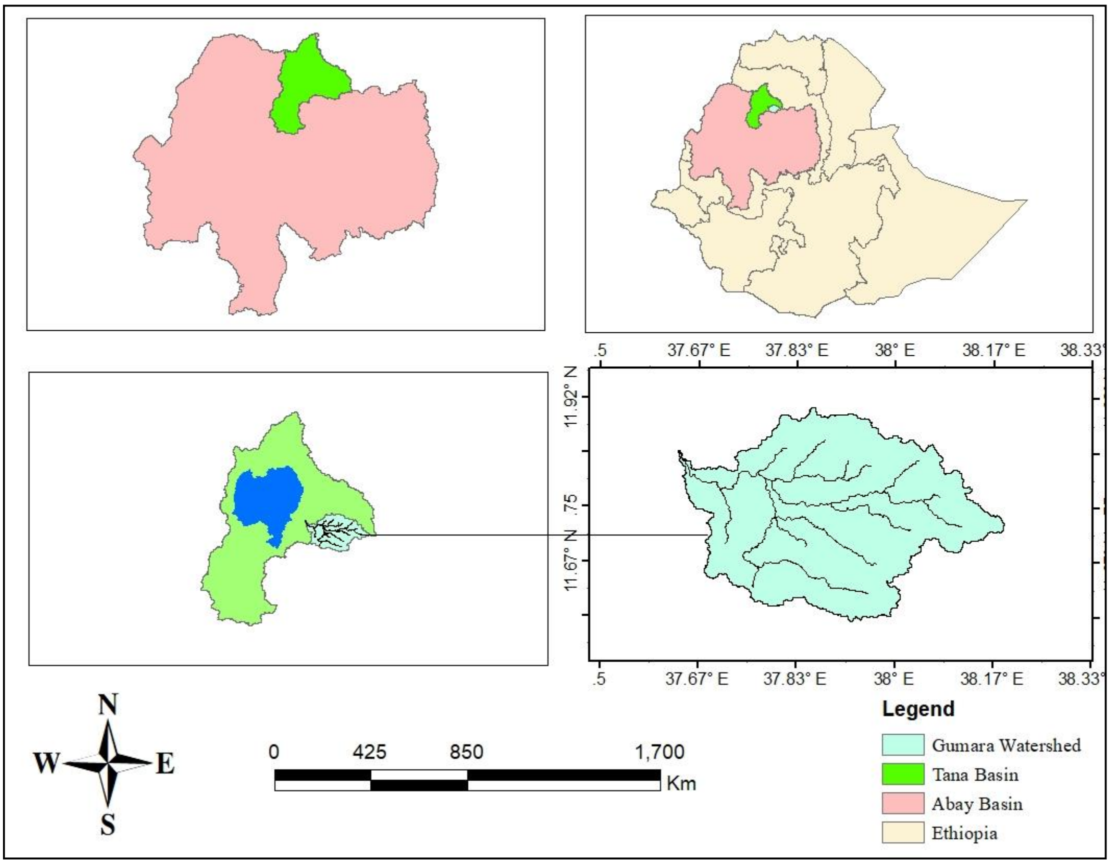


Figure 1. Location map of study area.

2.2. Hydro-Climatic and Spatial Datasets

Historical observed climate data of stations in and near the study area were collected from NMA (National Meteorological Agency) of Ethiopia. The maximum temperature, minimum temperature and precipitation which were basically needed for both climate and hydrological models were collected in all stations, whereas the other meteorological data like wind speed, relative humidity, and sunshine hour were available in only two stations. As other parts of the country, meteorological stations are sparsely distributed across the study area. Climate model variables or predictors were obtained from the Canadian Climate data and scenario website (http://climate-scenarios.canada.ca/?page=main).

Recorded stream flow data of Gumara River was collected from Ministry of Water Irrigation and Energy (MoWIE) of Ethiopia. The time series of collected stream flow data was 1985 – 2008 (24 years).

Both Digital Elevation Model (DEM), Shuttle Radar Topography Mission (SRTM) (30m X 30m resolution) and Land use/cover data were taken from USGS Earth explorer website (https://earthexplorer.usgs.gov/). The Land use coverage was extracted for the study area which is having 73.33% and 88.33% of Kappa statistic and overall classification accuracy respectively. The other important input for flow simulation model was soil data obtained from the Ministry of Water, Irrigation and Energy (MoWIE) of Ethiopia.

2.3. Data preparation and bias correction

Prior to analysis, the collected raw data was prepared to eliminate errors and biases. There were some missing values in all stations and these were replaced by -99 which are compatible for SDSM model which was used for climate projection, and SWAT model for simulation of future stream flow. The raw data was arranged in monthly bases and it has been stacked to daily annual time

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

series base so as to make it well suited for climate statistical downscaling and hydrological simulation models.

Predictor variables had been calibrated by observed station data which are referred to as Predictands through statistically adjusting the value of parameters. This statistical correlation of parameters and predictands was done using SDSM model. This model has also produced the future projected data of maximum temperature, minimum temperature, and precipitation of the stations based on the calibrated parameters. Both the temperature and rainfall change evaluated comparatively between the historical data (1961-1990) which was considered as baseline data with future three 30 year time series datasets represented as 2020s (2011-2040), 2050s (2041-2070), and 2080s (2071-2100).

2.4. SWAT model setup, calibration and Validation

Like climate data, the raw data of stream flow had also been prepared to make it compatible with the SWAT model for simulation of stream flow in ArcGIS 10.1 software. SWAT model passes the process through six important steps in simulation of the stream flow. The six steps of modeling are: 1) delineation of the basin and river network extraction, 2) Hydrological Response Unit (HRU) definition and analysis; 3) climate station and weather generation formation 4) sensitivity analysis of parameters 5) model calibration, and 6) model validation.

The basin is delineated into 24 sub basins with river network merged into the SRTM DEM using the "burn in" method. Sub basins of the catchment were further divided into 184 Hydrological Response Units (HRUs) using the land use, soil and slope distribution process.

The observed 10 years of stream flow data (1985-1994) was used for model calibration; and verification of calibrated parameters are tested by 1995-2000 (six) years of stream flow data. The proportion of data sets used for calibration and validation of model parameters is nearly similar with the recommended on which is 70% of data set should taken for calibration and 30% for validation [13]. The calibration process was carried out using SWATCUP12 software. Using this software has processed the calibration was run with 2000 iterations through automatically adjusting of values of selected parameters within the range of adjustment domain. Sensitive parameters which have significant influence on stream flow simulated by SWAT model were selected by sensitivity analysis process. Selected parameters are similar with the previous study done by [14]. The model efficiency was evaluated by using statistical variables determining the fitness of simulated stream flow with observed data. Those statistical variables NS (Nash-Sutcliffe efficiency) and RVE (Relative Volume Error) are shown in equation 1 and equation 2 respectively.

$$NS = 1 - \frac{\sum_{i=1}^{n}\left(Q_{sim(i)} - Q_{obs(i)}\right)^2}{\sum_{i=1}^{n}\left(Q_{obs(i)} - \overline{Q}_{obs}\right)^2} \tag{1}$$

where Q_{sim} and Q_{obs} represent the simulated and observed daily flows respectively, n refers to the number of days in the simulated or observed time series period. The overbar symbol indicates the mean value. The range of NS lies between 1 and -∞; 1 indicates that the best fit of the model or the model generates similar values of flow with the measured values. To accept the model, the NS values should be more than 0.5.

$$RVe = \frac{\sum_{i=1}^{n}\left(Q_{sim(i)} - Q_{obs(i)}\right)}{\sum_{i=1}^{n} Q_{obs(i)}} \tag{2}$$

RVe determines the ratios of differences of total simulated and total observed value of flow; it doesn't show us the difference of values within that corresponding time of measured and simulated discharge values.

2.5. Comparison of stream flow under RCP scenarios

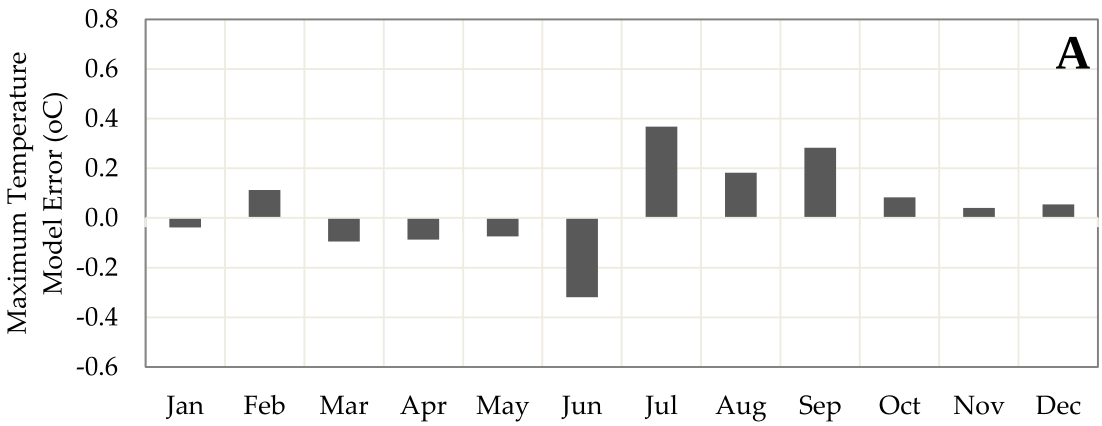
Once the model has been calibrated by selected parameters and validation was carried out in the watershed, stream flow was simulated using those selected parameters and automatically adjusted values of parameters. Stream flow was simulated using historical climate data and projected climate data under RCP2.6, RCP4.5, and RCP8.5 scenarios separately.

The impact of climate change on stream flow of the catchment under RCP2.6, RCP4.5 and RCP8.5 was evaluated by comparing the flow generated by projected climate data under those scenarios in 2020s, 2050s, and 2080s with the baseline period (1961-1990). The land use characteristics of the watershed is the other determinant factor for simulation of stream flow; but since the study is designed to indentify the impact of climate change alone, the same land use cover data with the baseline period was taken.

3. Results and Discussion

3.1. Simulation, bias correction and future climate data projection

Statistically downscaled climate data was compared with the observed data. The efficiency of SDSM model was evaluated and the difference of simulated and observed maximum and minimum temperature is shown in figure 2(A) and (B), respectively. The difference between observed and simulated maximum temperature in the baseline period is more prominent in the wet season (June-September); whereas the difference on the remaining months is insignificant. The maximum variation is shown on June which is 0.36^{o}C. The minimum temperature of downscaled data showed positive difference in all months except August, October and November. The maximum difference is 0.32^{o}C observed on March. Both the maximum and minimum temperature model error are indicated in (**Error! Reference source not found.** A and B respectively).



Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

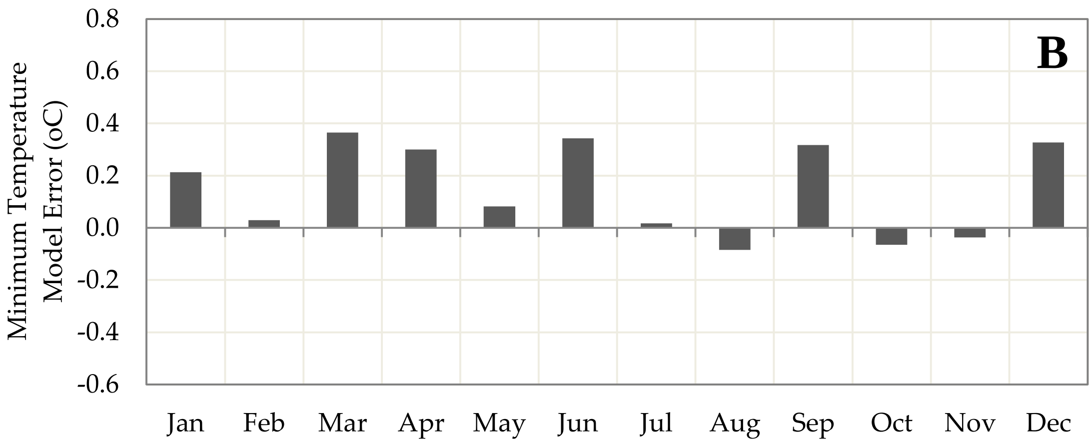


Figure 2. CanESM2 model error of maximum temperature and minimum temperature for the baseline period (1961-1990). (A) Average monthly maximum temperature difference between observed and downscaled data for the baseline period, and (B) Average minimum temperature difference between observed and downscaled for the baseline period.

The model cannot reasonably capture the observed rainfall of the baseline period in rainy season (June-September). Indeed, the change is significant in summer (rainy) season because rain is not common in the winter seasons in the study area. The change is negative at the beginning of the rainy season and it is positive in the last two months of the season. The overall average difference between observed and downscaled rainfall data of the study area is 0.58mm/day (**Error! Reference source not found.**). Statistical Down Scaling Model (SDSM) for CanESM2 climate model in RCP scenarios has been used by other researchers in the region and it has good fitness with the real data[15].

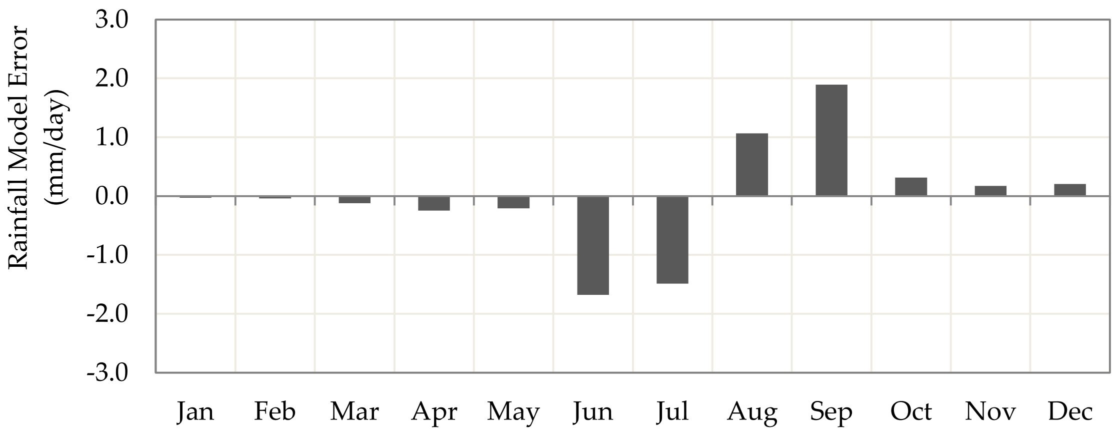


Figure 3. Model error of rainfall between observed and downscaled data of the baseline period (1961-1990).

3.2. Calibration and validation of SWAT model

The tream flow of the watershed was simulated using the SWAT hydrological model. Based on the sensitivity analysis which was conducted to determine parameters affecting the stream flow, 11 sensitive parameters were selected. Among these sensitive parameters V_ALPHA_BF (base flow), and CN2 (curve number) were found to be the most sensitive parameters. The calibration process was carried out using the SWAT CUP 2012 software. The model was calibrated by model parameters and those parameters with fixed value have also been validated. The efficiency is measured by NS and RVe and the values of those statistical variables are 0.66 and 0.72% respectively. This fitness was

 doi:10.20944/preprints202009.0621.v1

also verified and it gives NS (0.63%) and RVe (1.24%). Thus, based on the values of those efficiency determinant variables, the model showed consistency with those optimized values of parameters on the study area and it is possible to say that these parameter values are representative of the Gumara watershed (**Error! Reference source not found.**).

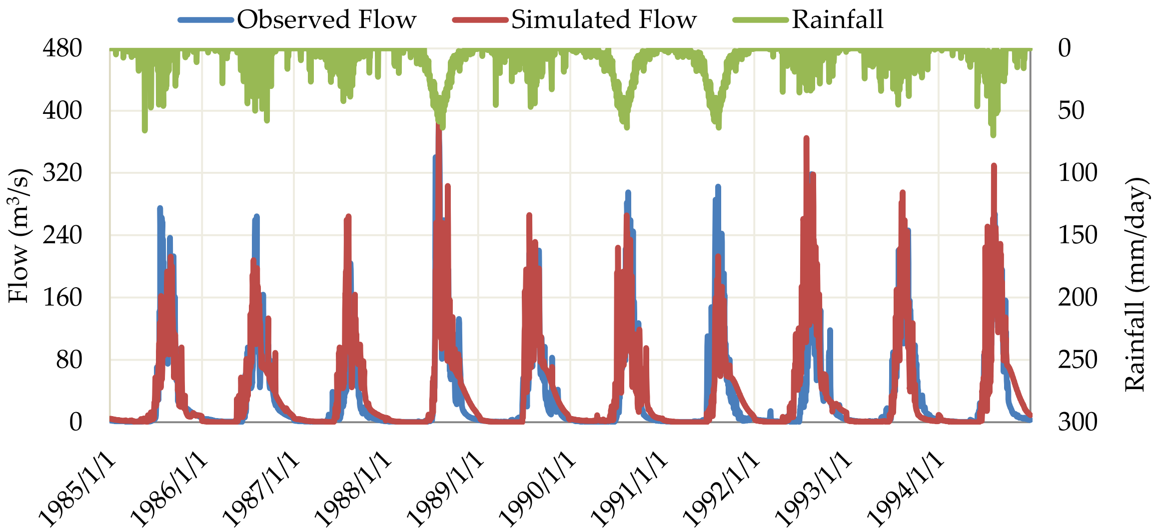


Figure 4. Comparison of simulated and observed flow for the calibration period (1985-1994).

The simulation flow in calibration period captures the peak flow in some years and it follows similar patterns, although in some years the simulated peak flow is above the peak values of observed stream flow and vice versa. In dry season the simulated flow did not best captured the line; for example there is a light shifting to the right which shows that it is a little bit over estimated. In the calibration process, the model had good efficiency and the simulated flow closely followed the pattern of observed stream flow. The single peaked high stream flows are often associated with extremely high rainfall events and perhaps occur at a time scale smaller than the daily time step of the simulation period. Only three meteorological stations were used to represent the basin for this study; one of which is located out of the watershed, and besides the altitudinal variation of the study area is also very high. For this reason, the rainfall is extremely variable in terms of the spatial distribution within this area [16], and [17], and the rainfall data used for the study may not be fully representative of the study area. Therefore, this may have increased the spatial variability of runoff in the catchment and hence some variations in peak flows of the simulated and observed flow was shown.

The calibrated parameters of the study area have been verified to measure their level of consistency by using six years of meteorological data (1995-2000). The simulated flow reasonably captured the peaks but also showed modest variation in dry season flows (Figure 1).

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

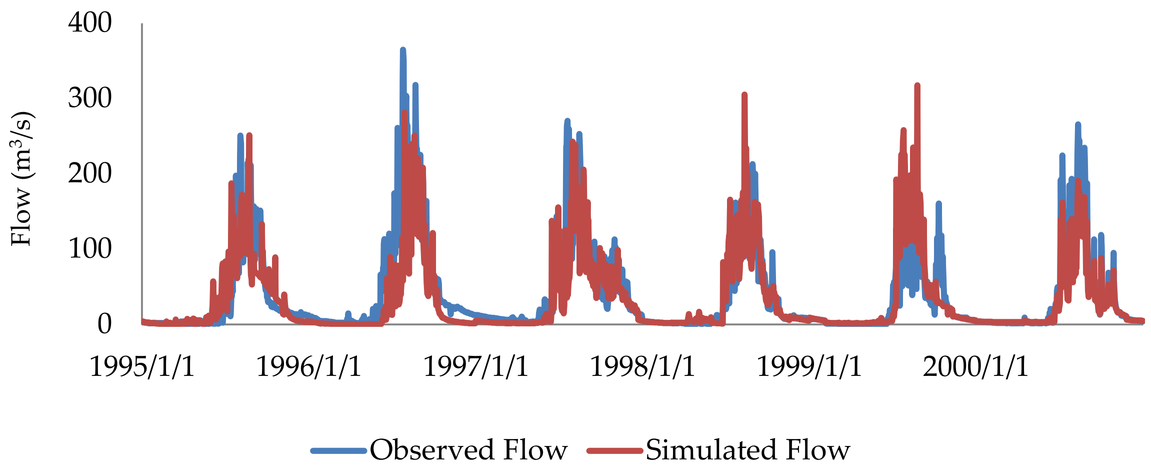


Figure 6. Comparison of simulated flow and observed flow for the validation period (1995-2000).

3.3. Changes of climate under RCP scenarios

The change of rainfall, maximum temperature, and minimum temperature based on RCP2.6, RCP4.5, and RCP 8.5 scenarios analyzed in terms of monthly bases, because it is designed to reveal seasonal variation. The change was shown between the three phases of the whole period (2020s, 2050s, and 2070s) in which thirty years of time series is contained, compared with the base line period (1961-1990).

3.3.1. Change in Rainfall

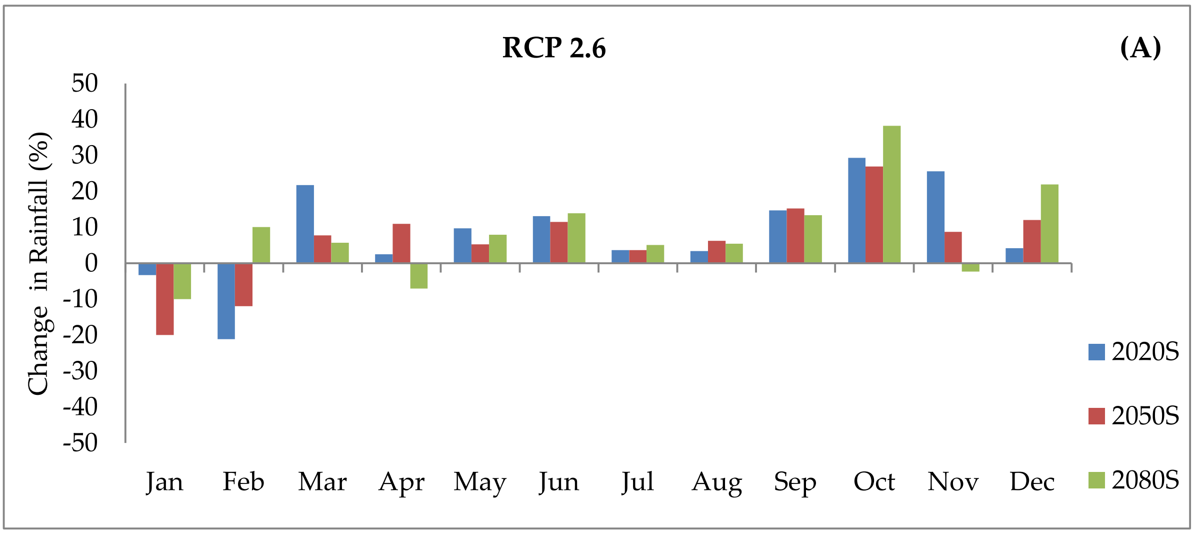
The average monthly rainfall in the study area for the whole period of this century has been forecasted under RCP 2.6, RCP 4.5 and RCP 8.5 climate scenarios. Under RCP 2.6 scenario, the maximum change of monthly average rainfall showed increment of 38.21% in October and the minimum change is -2.30% in November by 2080s period and the variability of changes are observed within this range. Under this climate scenario, almost all months, except two consecutive months (January and February), recorded an increase in rainfall amount. The rainfall change under RCP 4.5 scenario ranges from 0.61% to 42.11% in both increasing and decreasing values, where the minimum is observed in March within 2050s, and the maximum change is also in March but in the middle of 21th century (2050s). In RCP 4.5 scenario, there is an increment in three consecutive months (August - November), whereas in the remaining months (e.g. December, May, June and July) the change is not considerable. Like in RCP 4.5, the rainfall trend in RCP 8.5 exhibited similar pattern, namely fluctuating pattern in monthly bases even though both the upward and downward maximum change is relatively small compared to the RCP 4.5. The range of change was between 0.64% and 33.08% in increasing and decreasing values. The maximum change is observed in February within 2080s. Even though different models were used, the result of this study is consistent with finding of other studies near to Gumara watershed [18], [19] and out of the region [20]. Moreover, the change in annual average rainfall in percent for the future time periods was found to be increasing for all scenarios, but when we compare the change between the three scenarios, the variation is not that much considerable. The change in monthly average rainfall under the three scenarios is shown in (**Error! Reference source not found.** A, B and C).

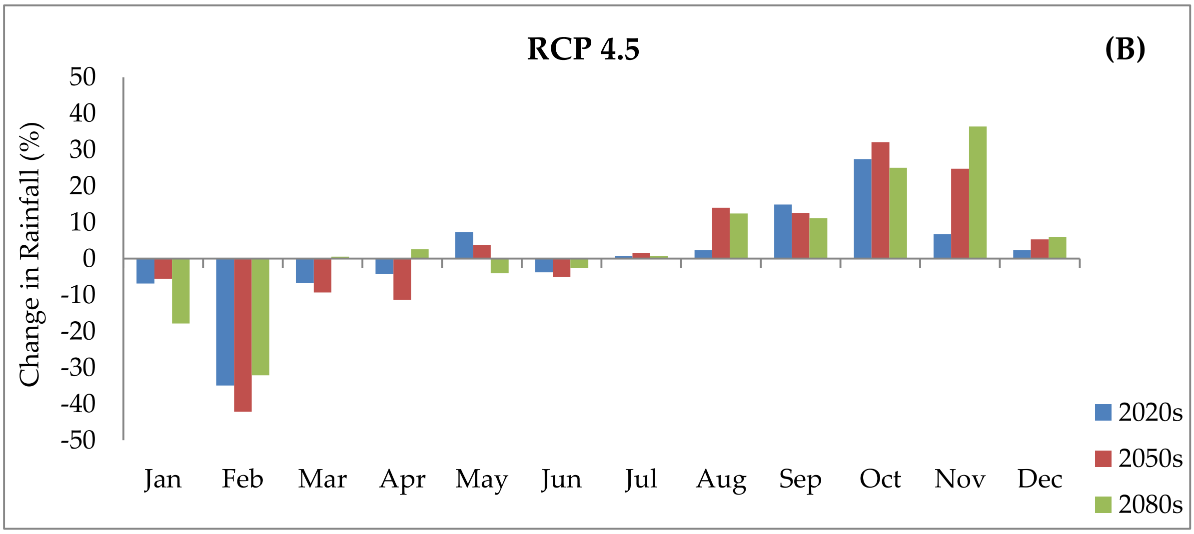
3.3.2. Change in Maximum and Minimum Temperature

In this study, the change in the projected maximum temperature and minimum temperature of the three time frames compared to the baseline (1961-1990) period in all RCP scenarios was revealed. The change of maximum temperature in monthly average bases under the RCP 2.6 scenario varied between 0.26^{o}c and 1.66^{o}c in 2020s and 2080s respectively. In this scenario, the maximum change in

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

minimum temperature is 1.19°c observed in October 2080s. In RCP 4.5 scenario, the change in monthly average maximum temperature and minimum temperature ranged from 0.51°c (December) to 3.38°c (July) and 0.14°c (August) to 2.67°c (October) (**Error! Reference source not found.** and **Error! Reference source not found.**). The change in average maximum and minimum temperature under RCP 4.5 in 2080s is 2.6°c and 1.69°c respectively. The change in both maximum and minimum temperature under RCP 8.5 was found to be increasing prominently compared to the other scenarios; the change in monthly average maximum temperature ranged from 0.42°c in August to 4.96°c in April Under RCP8.5 scenario, the average minimum temperature increased by 4.02 °C whereas the maximum temperature increased by 3.8°C. Climate Scenarios in RCP 2.6, RCP 4.5, and RCP 8.5 are developed with assumptions of having 2.6W/m², 4.5W/m², and 8.5W/m² radiative forcing respectively. Because of these concentrations of radiative forces, these scenarios are also assumed to be the cause for the increment in average temperature by 1.5°C (RCP2.6), 2.4°C (RCP4.5) and 4.9°C (RCP8.5) [21], and the results of this study are consistent with this assumption. Moreover the result of this study regarding to the change in maximum and minimum temperature matches with that of other previous studies [22] near to the study area, and [23] and [24] out of the region.





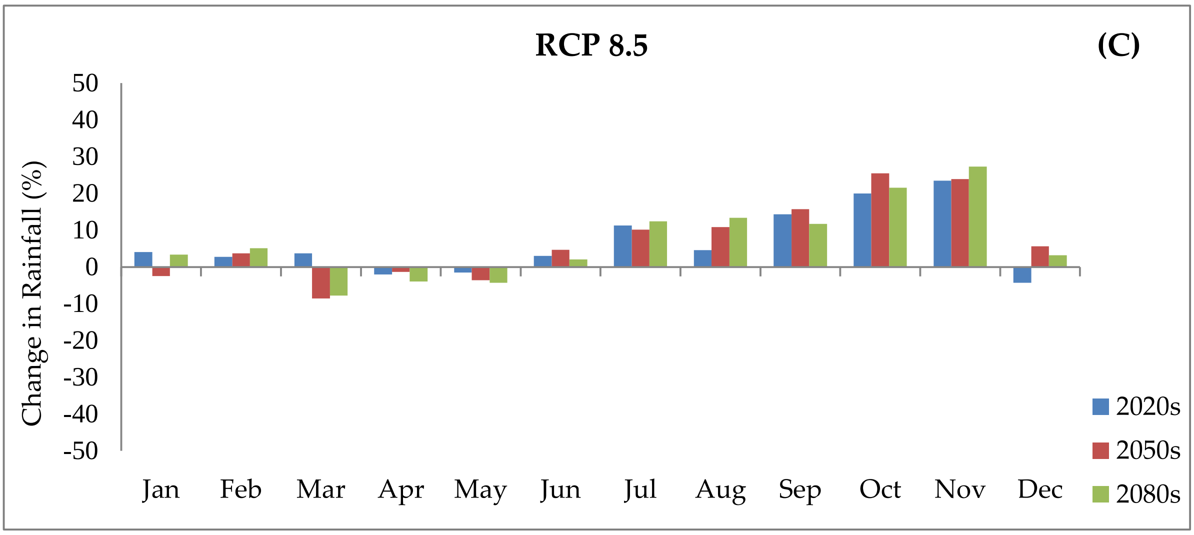
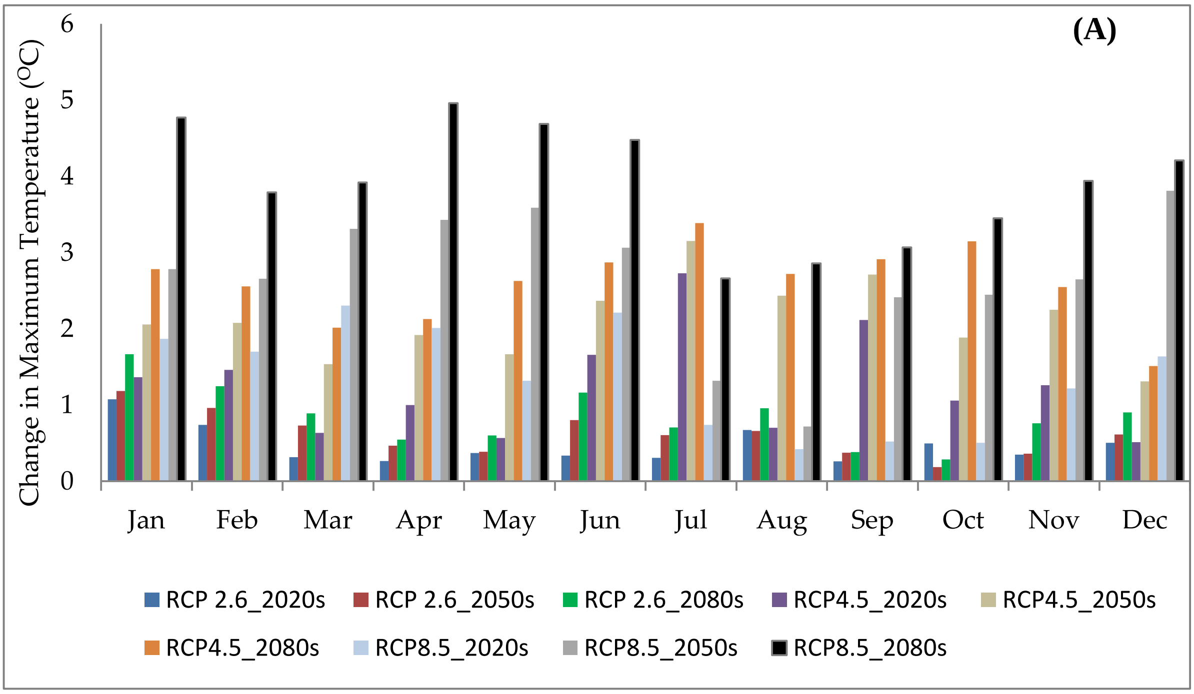


Figure 7. Change in rainfall produced by RCP scenarios compared to the baseline (1961-1990). A) Change in rainfall by RCP 2.6; B) Change in rainfall by RCP 4.5; and C) Change in rainfall by RCP 8.5.



Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

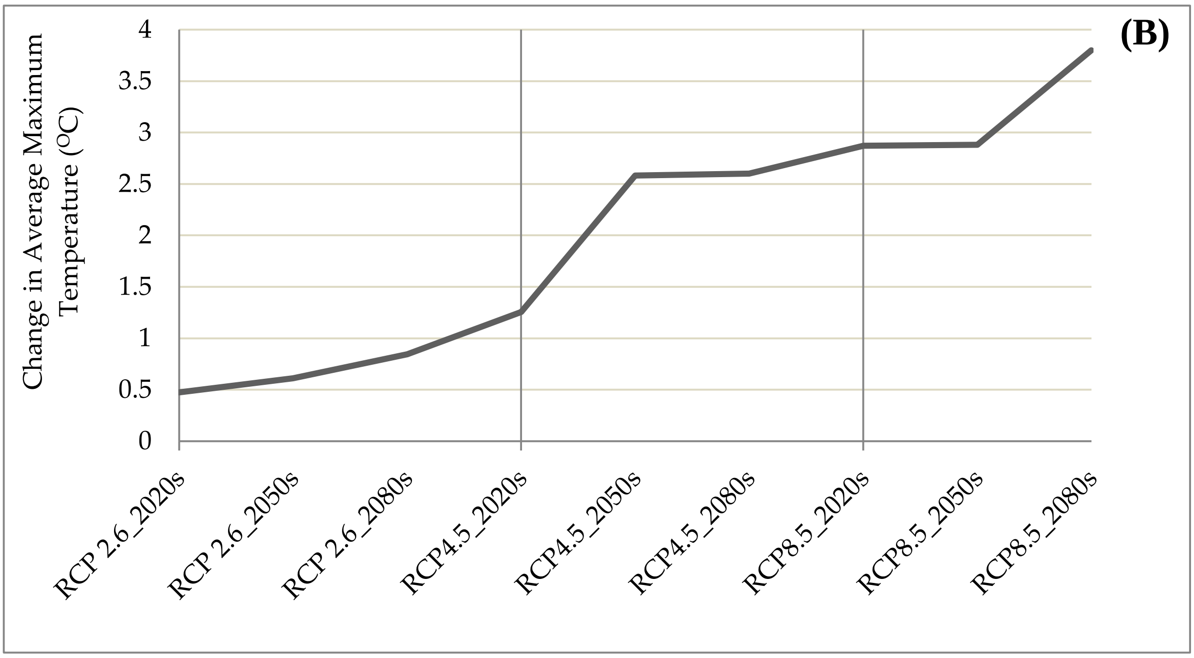
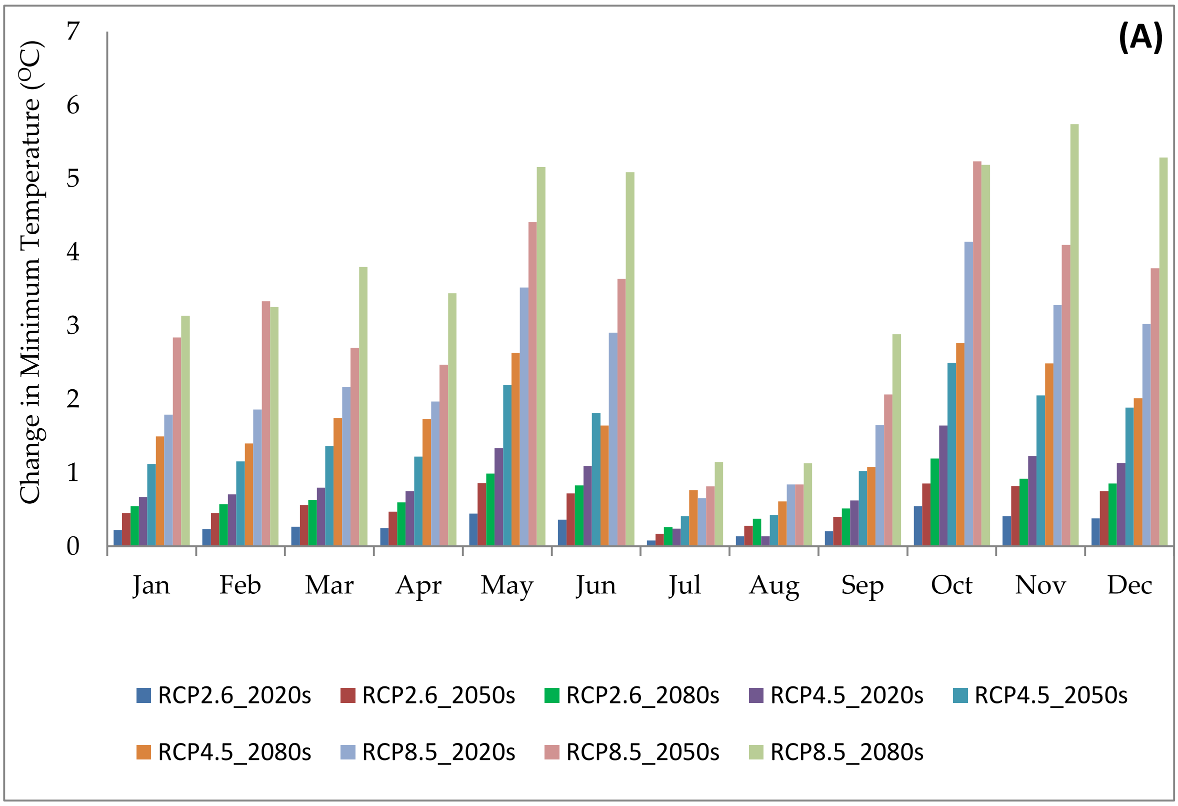


Figure 8. Change in maximum temperature compared to the baseline period: A) Change in monthly average maximum temperature; B) Change in Annual average maximum temperature.



Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1

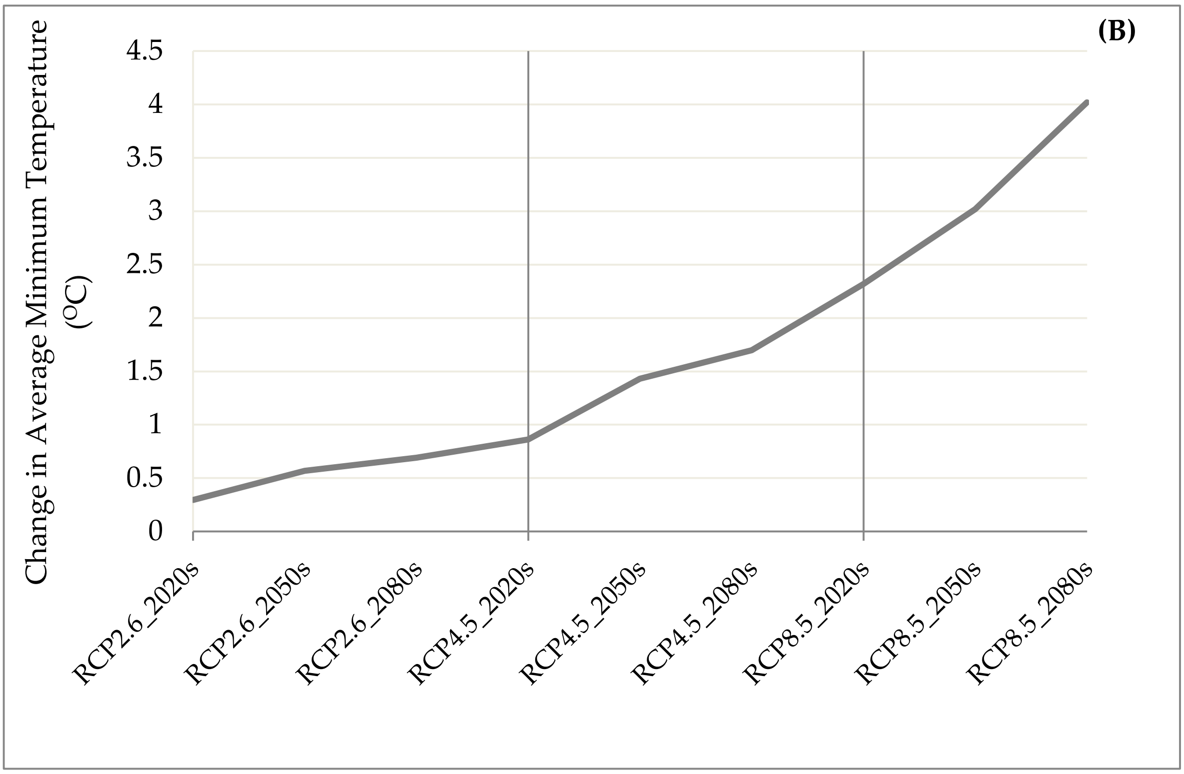
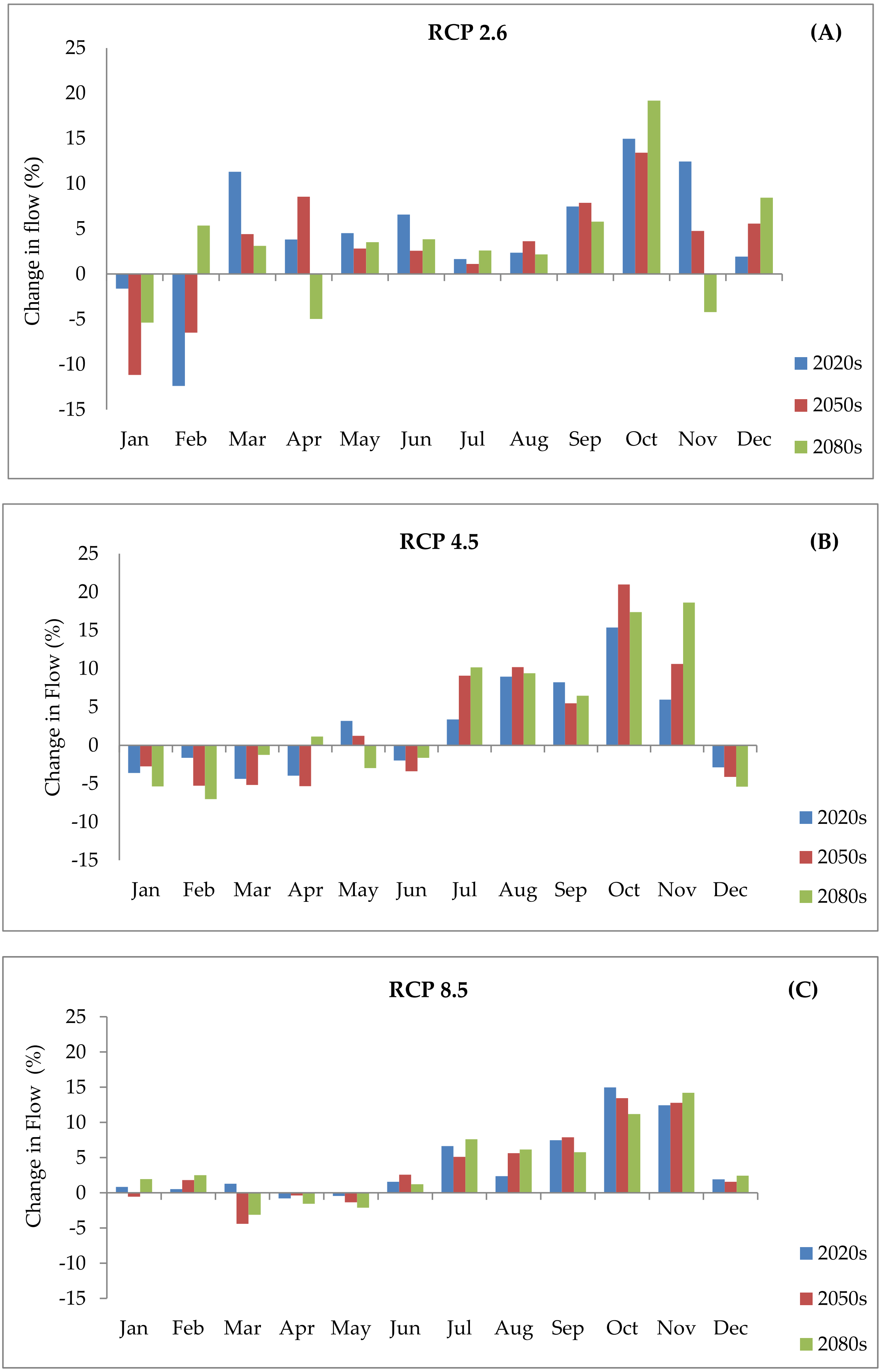


Figure 9. Change in minimum temperature compared to the baseline period: A) Change in monthly average maximum temperature; B) Change in annual average minimum temperature.

3.4. Evaluating impact of climate change on stream flow

The change in stream flow of Gumara watershed under RCP 2.6, RCP 4.5, and RCP 8.5 scenarios showed increasing trend in monthly average values in some months and years of but decreasing trend was also observed in some years of studied period. In RCP 2.6 scenario, the change in stream flow was found to be increasing in almost all months other than January and February with some exceptions in 2080s. The change under this scenario ranged from 1.11% in July 2020s to 19.18% in August 2080s (**Error! Reference source not found.** A). In RCP 2.6 scenario, the average stream flow recorded an increment of 4.43% in 2020s, 3.09% in 2050s, and 3.29% in 2080s; but the change is decreased between these three time frames. However, when considered on a monthly basis, the change in stream flow showed consistent increase under RCP 4.5 scenario. For example the stream flow change increased in five consecutive months (July – November), whereas in the other months it showed increasing with a little bit increment exception in May. The change ranged from 1.21% in May (period) to 20.97% in August (2080s). Even though there is high variability between months, in RCP 4.5 scenario, the change in average stream flow is not considerable, it is 2.21%, 2.45%, and 2.53 % in 2020s, 2050s, and 2080s respectively (**Error! Reference source not found.** B). Under RCP 8.5 scenario, the change in stream flow indicated insignificant increase in dry seasons but decreased in the pre summer months and it is decreasing in the pre summer (rainy season). The change in stream flow under all scenarios showed significant increase in post summer season (September - November) (**Error! Reference source not found.**). Moreover the average stream flow change in RCP 8.5 scenario is indicating 4.06%, 3.26%, and 3.67% in 2020s, 2050s and 2080s respectively (**Error! Reference source not found.** C). The result of this study showed somehow consistency with previous results of research works conducted using different climate models and scenarios in the adjacent watersheds [25], [26], and [22]. Soil and water conservation, and other watershed management practices should be carried out so as to maintain the overall health of natural resources [27] in this watershed as well as the whole basin of blue Nile.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 26 September 2020 doi:10.20944/preprints202009.0621.v1



 doi:10.20944/preprints202009.0621.v1

Figure 10. Change in stream flow under RCP scenarios compared to the baseline period (1961-1990): A) change in stream flow under RCP 2.6 scenario; B) Change in stream flow under RCP 4.5 scenario; and B) change in stream flow under RCP 8.5 scenario.

4. Conclusion

The future climate and its impact on the stream flow under Representative Concentration Pathway scenarios in the sub basin of Upper blue Nile basin (Gumara watershed) are evaluated using CanESM2 climate model and statistically downscaling model. Stream flow of the study area was simulated by using SWAT model. The findings revealed that there is an increment in both maximum and minimum temperature under all scenarios in 2020s, 2050s, and 2080s with a higher rate of increase towards the end of the century. Even though there was no significant difference in the range and average change in rainfall between the three scenarios, the range of change in monthly average rainfall is somewhat higher under RCP 2.6 scenario than in other scenarios. The results of this study suggest that the change in climate under RCP 2.6, RCP4.5 and RCP8.5 scenarios had a strong bearing on the rate of the annual average stream flow increased by 4.06%, 3.26%, and 3.67% respectively.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix: Representative Concentration Pathway (RCP) Scenarios

RCP2.6: Was developed by the IMAGE modeling team of the PBL Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels. It is a "peak-and-decline" scenario; its radiative forcing level first reaches a value of around 3.1 W/m^2 by mid-century, and returns to 2.6 W/m^2 by 2100. Clearly, emissions would need to decline substantially in order to reach a level of 2.6 W/m^2 by the end of the century. The cumulative emission reduction over the century amounts to about 70% and the emission reduction in 2100 to more than 95% compared to baseline. In order to reach such radiative forcing levels, greenhouse gas emissions (and indirectly emissions of air pollutants) are reduced substantially, over time [28]

RCP4.5: was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level. Radiative forcing is expected to be 4.5W/m^2 at the end of 2100 [29].

RCP 8.5: was developed using the MESSAGE model and the IIASA Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels. Rising radiative forcing pathway is leading to 8.5W/m^2 by the end of 2100 [30].

References

1. Change, I.C., Mitigation of climate change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 2014. 1454.
2. Hegerl, G.C., et al. Good practice guidance paper on detection and attribution related to anthropogenic climate change. in Meeting report of the intergovernmental panel on climate change expert meeting on detection and attribution of anthropogenic climate change. 2010. IPCC Working Group I Technical Support Unit, University of Bern, Bern ….
3. Pachauri, R.K., et al., Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change. 2014: Ipcc.
4. Tadege, A., Climate change national adaptation program of action (NAPA) of Ethiopia. National Meteorological Agency, Addis Ababa, 2007.

 doi:10.20944/preprints202009.0621.v1

5. Mengistu, D., W. Bewket, and R. Lal, Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. International Journal of Climatology, 2014. 34(7): p. 2278-2292.
6. Phinzi, K. and N.S. Ngetar, Land use/land cover dynamics and soil erosion in the Umzintlava catchment (T32E), Eastern Cape, South Africa. Transactions of the Royal Society of South Africa, 2019. 74(3): p. 223-237.
7. Cheung, W.H., G.B. Senay, and A. Singh, Trends and spatial distribution of annual and seasonal rainfall in Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society, 2008. 28(13): p. 1723-1734.
8. EEA, J., WHO (2008): Impacts of Europe's changing climate-2008 indicator-based assessment. European Environment Agency, Copenhagen, 2008.
9. Bekele, L., Indications of the changing nature of rainfall in Ethiopia: The example of the 1 st decade of 21 st century. African Journal of Environmental Science and Technology, 2015. 9(2): p. 104-110.
10. Haile, A.T., et al., Changes in water availability in the Upper Blue Nile basin under the representative concentration pathways scenario. Hydrological sciences journal, 2017. 62(13): p. 2139-2149.
11. Worqlul, A.W., et al., Impact of climate change on streamflow hydrology in headwater catchments of the Upper Blue Nile Basin, Ethiopia. Water, 2018. 10(2): p. 120.
12. Dile, Y.T., R. Berndtsson, and S.G. Setegn, Hydrological response to climate change for gilgel abay river, in the lake tana basin-upper blue Nile basin of Ethiopia. PloS one, 2013. 8(10): p. e79296.
13. Klemeš, V., Operational testing of hydrological simulation models. Hydrological Sciences Journal, 1986. 31(1): p. 13-24.
14. Chakilu, G. and M. Moges, Assessing the land use/cover dynamics and its impact on the low flow of Gumara watershed, Upper Blue Nile Basin, Ethiopia. Hydrology: Current Research, 2017. 8: p. 1-6.
15. Fenta Mekonnen, D. and M. Disse, Analyzing the future climate change of Upper Blue Nile River basin using statistical downscaling techniques. Hydrology and Earth System Sciences, 2018. 22(4): p. 2391-2408.
16. Tilahun, K., Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century. Journal of Arid Environments, 2006. 64(3): p. 474-487.
17. Worqlul, A.W., et al., Evaluation of CFSR, TMPA 3B42 and ground-based rainfall data as input for hydrological models, in data-scarce regions: The upper Blue Nile Basin, Ethiopia. Catena, 2017. 152: p. 242-251.
18. Taye, M.T., et al., Assessment of climate change impact on hydrological extremes in two source regions of the Nile River Basin. Hydrology and Earth System Sciences, 2011. 15(1): p. 209.
19. Seleshi, Y. and U. Zanke, Recent changes in rainfall and rainy days in Ethiopia. International Journal of Climatology: A Journal of the Royal Meteorological Society, 2004. 24(8): p. 973-983.
20. Tahir, T., A. Hashim, and K. Yusof. Statistical downscaling of rainfall under transitional climate in Limbang River Basin by using SDSM. in IOP Conf. Ser. Earth Environ. Sci. 2018.
21. Wayne, G., The beginner's guide to representative concentration pathways. skeptical science, 2013. 25.
22. Kim, U., J.J. Kaluarachchi, and V.U. Smakhtin, Climate change impacts on hydrology and water resources of the Upper Blue Nile River Basin, Ethiopia. Vol. 126. 2008: Iwmi.
23. Tan, M.L., et al., Climate change impacts under CMIP5 RCP scenarios on water resources of the Kelantan River Basin, Malaysia. Atmospheric Research, 2017. 189: p. 1-10.
24. Mishra, V. and R. Lilhare, Hydrologic sensitivity of Indian sub-continental river basins to climate change. Global and Planetary Change, 2016. 139: p. 78-96.
25. Adem, A.A., et al., Climate change impact on stream flow in the upper Gilgel Abay Catchment, Blue Nile Basin, Ethiopia, in Landscape Dynamics, Soils and Hydrological Processes in Varied Climates. 2016, Springer. p. 645-673.
26. Enyew, B., H. Van Lanen, and A. Van Loon, Assessment of the impact of climate change on hydrological drought in Lake Tana catchment, Blue Nile basin, Ethiopia. J. Geol. Geosci, 2014. 3: p. 174.
27. Mena, M.M., et al., Community Adoption of Watershed Management Practices at Kindo Didaye District, Southern Ethiopia. International Journal of Environmental Sciences & Natural Resources, 2018. 14(3): p. 32-39.
28. Van Vuuren, D.P., et al., RCP2. 6: exploring the possibility to keep global mean temperature increase below 2 C. Climatic Change, 2011. 109(1-2): p. 95.
29. Thomson, A.M., et al., RCP4. 5: a pathway for stabilization of radiative forcing by 2100. Climatic change, 2011. 109(1-2): p. 77.
30. Moss, R.H., et al., The next generation of scenarios for climate change research and assessment. Nature, 2010. 463(7282): p. 747-756.