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# Modelling the Impacts of Climate Change on Surface Runoff in Finchaa Sub-basin, Ethiopia

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## Abstract

Climate change is possible to affect the water resources availability and hydrology of Finchaa Sub-basin. Climate change impacts are the main concern for sustainability of water management, water use activities and agricultural production throughout the world. Climate changes alter regional hydrologic conditions and results in a variety of impacts on water resource systems. The objective of this study is to assess the impact of climate change on the surface runoff of Finchaa sub-basin located in upper Blue Nile Basin of Ethiopia. The General Circulation Model (GCM) derived scenarios (HadCM3 A2a & B2a SRES emission scenarios) were used for the climate projection. The statistical Downscaling Model (SDSM) was used to generate future possible local meteorological variables in the study area. The down-scaled data were then used as input to the Soil and Water Assessment Tool (SWAT) model to simulate the corresponding future surface runoff in of Finchaa sub-basin. The time series generated by GCM of HadCM3 A2a and B2a and Statistical Downscaling Model (SDSM) indicate a significant increasing trend in maximum and minimum temperature values and a slight decreasing trend in precipitation for both A2a and B2a emission scenarios in sub-basin for all three bench mark periods. The result reveal that, average annual rainfall in the watershed might reduce up to 9.84%, 23.29% and 41.51% and 9.27 %, 20.71% and 35.37% in 2020s, 2050s, and 2080s for A2a and B2a emission scenarios, respectively. The average annual maximum temperature might increase by 0.25$^0$C, 0.60$^0$C and 1.09$^0$C and 0.50$^0$C, 0.26$^0$C and 0.86$^0$C in 2020s, 2050s and 2080s for A2a and B2a emission scenario respectively. The average annual minimum temperature might increase by 0.3$^0$C, 0.80$^0$C and 0.92$^0$C and 0.40 $^0$C, 0.66 $^0$C and 1.1$^0$C in 2020s, 2050s and 2080s for A2a and B2a emission scenario respectively. Impact analysis was made with the downscaled temperature and rainfall time series as input to the SWAT model for the future three benchmark periods. As a result, at the outlet of the watershed the projected on average annual runoff reduced by 4.29%, 10.62%, 18.07% and 8.27%, 8.58%, 16.69% for the 2020s,2050s and 2080s for both A2a and B2a emissions scenarios respectively. This report includes strategy recommendations to communities, policy and decision makers for measuring and enhancing effective adaptation option for future climate change impacts on surface runoff. Such study provides appropriate insights into future surface water resources, to develop effective eco-environment management plans and strategies in the face of climate change.

## Keywords

A2a, B2a, climate change, impact, Finchaa sub-basin, GCM, SDSM, SWAT, Surface runoff.

## 1. Introduction

Water resource is now changing around the world, being redistributed more erratically due to the impact of climate change [1, 2]. There are serious concerns on the potential impacts of climate change on water resources [3, 4]. This is particularly prominent in semi-arid and arid regions, because in these regions water resources, primarily stream flow, are highly sensitive to climate change; a small change in climate variables may result in significant variations of hydrological cycles and subsequence changes of regional water resources [5, 6, 7, 8]. Climate change will have a profound impact on natural resources, of which water is one of the most important. With climate change the amount of rainfall in many parts of Africa is expected to decline while variability may increase dramatically [9]. With climate change and increases in climate variability, the need for managing water resources requires immediate action or attention. Climate change has the potential to reduce water resource availability in the Nile basin countries in the forthcoming decades [10]. According to the study report by [11], the change in climate variables such as reduce in precipitation and increase in temperature thereby increase in evapotranspiration which is very sensitive parameter that can be affected by changing climate than any other hydrological component are likely to have significant impact on stream flow.

Water availability and quality will be the main pressures on, and issues for, societies and the environment under climate change. Climate change is likely to exacerbate water availability and quality, which will have wide range of implications for business [9].

Many studies have been undertaken to investigate climate change impacts on water resource in different basin of Ethiopia using different models and emission scenarios [12, 13, 14, 15, 16, 17, 18, 19, 20], showed that the water resource is very sensitive to climate change and climate variability. To better plan water management adaptation strategies, more information is necessary on the potential changes in climate conditions. However, these studies were only based on hypothetical precipitation and temperature change, which of course didn‘t take into consideration the Regional Climate Model (RCMs). Because of fast growing population rates, increasing resources and industrial development, water is becoming a very scarce and valuable resource [21].

Finchaa sub-basin is normally endowed with land features that are characterized by large upstream water potential sites, intensive downstream irrigable lands and high head hydropower plant at the foot almost vertical canyons. In the sub basin there is a project called Finchaa, Amerti and Neshe multipurpose project. Finchaa and Amerti dams and reservoirs are the earliest in the Blue Nile basin and constructed in 1968 and 1984 respectively, whereas the construction of Neshe reservoir completed in 2011.The project comprises big irrigation for sugar factory and hydropower projects including the community water supply. The Finchaa system was expanded in 1980 by diverting Amerti flows into the Finchaa reservoir by construction a 20m high earth and rock fill dam on Amerti river and a 1.57 km long diversion tunnel. As a result, the capacity was upgraded to 134 MW by an additional turbine unit. Finchaa sugar plantation and its processing facility were developed in late 1990’s and the Factory was inaugurated in 1999. The plantation is located downstream of the Finchaa power plant and it takes advantage of regulated flows provided by Finchaa reservoirs. Since the construction of the Finchaa, Amerti and Neshe multipurpose, downstream irrigation in the area has been expanding starting from 1968. The main sources of water for this all activities are the three reservoirs i.e. Finchaa, Amerti and Nesh reservoirs. There is an increasing demand for water which leads to competition for water among different sectors. Therefore because of this big project expansion in the watershed there is highly increase in deforestation that lead increase in temperature and decrease in precipitation [22] in the Finchaa sub-basin.

Therefore, it is good to understand the impact of climate change on the hydrological variables essentially involves taking projections of climatic variables (e.g. precipitation and temperature) at a global scale; downscaling these global-scale climatic variables to local-scale hydrologic variables, and computing hydrological components for hydro meteorological variability and hydrological impact in the future; to adapt to climate change. The objective of this study is to assess the impacts of climate change on surface runoff of Finchaa sub-basin located in upper Blue Nile Basin of Ethiopia.

**Study Area, Dataset and Methods Description of the Study area**

Finchaa sub-basin lies between $9^0$10’ to $10^0$00’N and $37^0$ 00’ and $37^0$ 30’E. The sub-basin is located around 315 km north-west of Addis Abeba, in Blue Nile river basin. Finchaa sub-basin is a part of Abbay river basin which contains three watersheds (Finchaa, Amerti and Nesh watershed).The sub-basin has an area of 4089 km2.

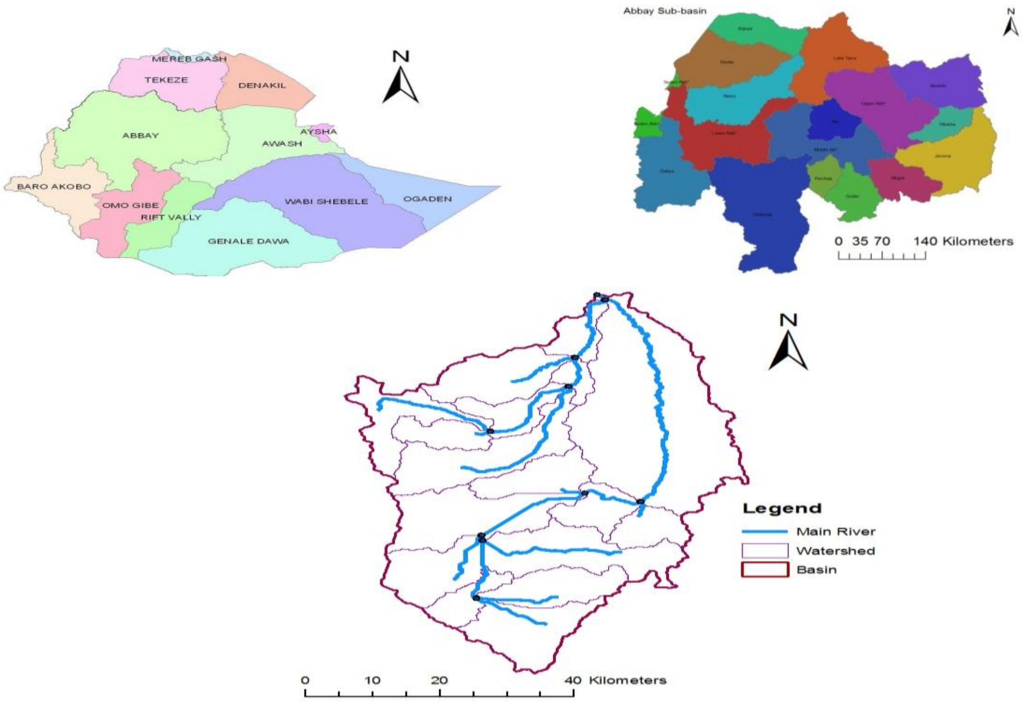



**Figure 1: Location of the study area (Finchaa Sub-basin).**

## 2. Dataset and Methods

The historical climate data and stream flow data have been collected from National Metrological Agency (NMA) and Ministry of Water Resources (MoWR) that used to calibrate and validate SWAT model. Before the calibration has been taken for the given model, watershed parameters are needed, these watershed parameters were watershed area, mean elevation, land use and the shape of the watershed. These parameters are taken from the output of the digital elevation model (DEM) that has been processed by GIS. Taking these watershed parameters, the historical flow and climate data calibration has been taken to determine the model parameters. Model calibration is tuning of model parameters based on checking results against observations to ensure similar response over time. This involves 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 [23]: first calibration of the water balance followed by that of temporal flow.

### Modeling Approach

This study concerns the assessment of climate change impact on hydrology with the application of a semi-distributed physically based watershed model SWAT in the Finchaa sub basin. Statistical downscaling model (SDSM) was used for future climate generation. The procedure consists of using climatic output data from General Circulation Models (GCMs) to retrieve climate scenarios [24]. 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 stream flow. The future simulated results were then compared with the base line period as a means of obtaining the change caused by climate change.

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model was tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenarios. On the other hand, the coarser climate data (GCM) are downscaled in to finer spatial resolution regional climate data (RCM) and these regional climate data are further downscaled in to station level by using statistical downscaling model SDSM [25], these downscaled data have been taken directly as an input of the model to assess the future climate change impact on hydro-climatology of the sub-basin.

**Arc SWAT model approach**

Watersheds can be subdivided into sub watersheds and further into hydrologic response units (HRUs) to account for differences in soils, land use, crops, topography, weather, etc. The model has a weather generator sub routine that generates daily values of precipitation, air temperature, solar radiation, wind speed, and relative humidity from statistical parameters derived from average monthly values. The model computes surface runoff volume either by using modified SCS curve number method or the Green & Ampt infiltration method. Flow is routed through the channel using a variable storage coefficient method or the Muskingum routing method. SWAT has three options for estimating potential evapotranspiration: Hargreaves, Priestley-Taylor, and Penman-Monteith. The model also includes controlled reservoir operation and groundwater flow model. The important equations used by the model are discussed below in detail. The detailed and complete descriptions are given in the SWAT theoretical documentation [23]. SWAT splits hydrological simulations of a watershed into two major phases: the land phase and the routing phase. The difference between the two lies on the fact that water storage and its influence on flow rates is considered in channelized flow [23].
The land phase of the hydrologic processes is simulated based on the following water balance Equation:

$$SW_t = SW_o + \sum_{t=1}^{t}\left(R_{day} - Q_{surf} - E_a - \omega_{sweep} - Q_{gw}\right) \quad (1)$$

Where, $SW_t$ is the final soil water content (mm), $SW_o$ is the initial soil water content (mm), t is the time (days), $R_{day}$ is the amount of precipitation on day *i* (mm), $Q_{sur}$ is the amount of surface runoff on day *i* (mm), $E_a$ is the amount of evapotranspiration on day *i* (mm), $w_{sweep}$ is the amount of water entering the vadose zone from the soil profile on day *i* (mm) and $Q_{gw}$ is the amount of return flow on day *i* (mm).

**Surface Runoff Simulation**

For the surface runoff process, it occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure and the Green & Ampt infiltration method. Here is a brief description to both methods. The SCS curve number procedure is a function of the soil's permeability, land use and antecedent soil water conditions. Where the SCS runoff equation is an empirical model that came into common use in the 1950s.This equation is:

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (2)$$

Where $Q_{suf}$ The accumulated runoff or rainfall excess (mm), $R_{day}$: the rainfall depth for the day (mm), $I_a$: the initial abstractions (surface storage, canopy interception, infiltration prior to runoff) (mm), and *S*: the retention parameter.
Therefore, runoff will only occur only when $R_{day} > I_a$. Retention parameter *S* is defined as:

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \quad (3)$$

Where CN is the curve number for the day and the initial abstractions, $I_a$, is commonly approximated as 0.2S, then Equation 2 and 3 becomes:

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (4)$$

SWAT calculates CN using soil classes and land uses classifications data.

**Peak runoff rate assessment**

The peak runoff rate is the maximum runoff flow rate that occurs with a given rainfall event. The peak runoff rate is an indicator of the erosive power of a storm and is used to predict sediment loss. SWAT calculates the peak runoff rate with a modified rational method.

$$q_{peak} = \frac{\alpha_{tc} \cdot Q_{surf} \cdot Area}{3.6 \cdot t_{conc}} \quad (5)$$

Where $q_{peak}$ is the peak runoff rate (m3/s), $\alpha_{tc}$ is the fraction of daily rainfall that occurs during the time of concentration, $Q_{suf}$ is the surface runoff (mm), Area is the sub basin area (km2), $t_{conc}$ is the time of concentration for the sub basin (hr) and 3.6 is a unit conversion factor.

SWAT estimates the value of α using the following equation:

$$\alpha_{tc} = 1 - \exp\left[2.t_{conc}.\ln\left(1-\alpha_{0.5}\right)\right] \quad (6)$$

Where: $t_{conc}$ is the time of concentration (h), and $\alpha_{0.5}$ is the fraction of daily rain falling in the half-hour highest intensity rainfall.

**Sensitivity analysis**

A sensitivity analysis was performed on the model to select the most sensitive parameters, out of the total of 27 flow parameters that are included in SWAT, for calibration. The model incorporates Automated Latin Hypercube One-factor-At-a-Time (LH-OAT) global sensitivity analysis procedure [26], which was used for the sensitivity analysis of the parameters following the initial parameterization.

**Model Calibration, Validation and Performance**

Model calibration is tuning of model parameters based on checking results against observations to ensure similar response over time. This involves 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.

In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model tested against an independent set of measured data. This testing of a model on an independent set of data set is commonly referred to as model validation. As the model predictive capability was demonstrated as being reasonable in both the calibration and validation phases, the model was used for future predictions under different management scenarios.

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination ($R^2$) and Nash-Sutcliffe simulation efficiency ($E_{NS}$) were the goodness of fit measures used to evaluate model prediction. The $R^2$ value is an indicator of strength of relationship between the observed and simulated values. The Nash-Sutcliffe simulation efficiency ($E_{NS}$) indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, $E_{NS}$ is 1. If the $E_{NS}$ is between 0 and 1, it indicates deviations between measured and predicted values. If $E_{NS}$ is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction [27]. The $R^2$ and $E_{NS}$ values are explained in Eq. 7 and 8 respectively.

$$R^2 = \left[\frac{\sum_{i=i}^{N}(o_i - \bar{o})(p_i - \bar{p})}{\left[\sum_{i=1}^{N}(o_i - \bar{o})^2\right]\left[\sum_{i=1}^{N}(p_i - \bar{p})^{0.5}\right]}\right] \quad (7)$$

$$E_{NS} = 1 - \frac{\sum_{i=1}^{N}(o_i - p_i)^2)}{\sum_{i=1}^{N}(o_i - \bar{o})^2} \quad (8)$$

Where: N-number of compared values ∞

$O_i$ - observed data O- observed mean $P_i$: - simulated data - simulated mean

ENS can have values ranging from -∞to 1. If the simulation is accurate, $E_{NS}$ is equal to one. If the accuracy of the simulation results is smaller than the average value of the measured variables, then $E_{NS}$ will have a negative value. The disadvantage of this evaluation tool appears in cases of extreme events; as such events have strong weights [28].

**Determination of Impacted surface runoff**

The sub-basin values of monthly temperature changes and the monthly precipitation change factors (precipitation multipliers) found as an output from the GCM model and downscaled by the

SDSM model were given as an input to the SWAT model. The remaining climatic and all other land use and soil hydrologic parameters used in model development under current climate conditions were assumed to be constant and remain valid under conditions of climate change.
The model calculates the impacted daily precipitation by simply multiplying the daily precipitation multiplier by the corresponding baseline daily precipitation values; whereas the impacted daily temperatures are calculated by adding the average daily delta values of the maximum and minimum daily temperature to the corresponding average baseline daily temperature.

$$\mathrm{R_{day}} = \mathrm{R_{day}}.\left(1 + \frac{\mathrm{adj_{pcp}}}{100}\right) \tag{9}$$

Where: $R_{day}$ is the precipitation falling in the sub-basin on a given day (mm H2O), and $ad_{jpcp}$ is the percentage change in rainfall.

$$T = T + adj_{tmp} \tag{10}$$

Where: $T$ is the daily temperature (℃); $adj_{tmp}$ is the change in temperature (℃).
In order to simulate the seasonal variations in the climate conditions, the monthly delta and precipitation multiplier values were used and applied evenly on all the days of the month.

## 3. Results and discussion

### Climate change model results

*Selected of predictor variables*

The selection of appropriate predictors is one of the most important steps in a downscaling exercise. The best correlated predictor variables selected for minimum temperature, maximum temperature and precipitation for Finchaa, Shambu and Neshe meteorological stations. For Shambu and Neshe meteorological stations the strongest correlation was obtained between the predictands and each predictor for each month. The correlation of maximum temperature with the predictor variables was exceptionally strong for all the selected predictors.

**Table 1: Selected predictor variables for the predictands for shambu, Neshe and Finchaa stations**

| Station | Predictor | Symbol | Predictand | | |
|---|---|---|---|---|---|
| | | | TMAX | TMIN | PRCP |
| | 500hpa zonal velocity | ncepp5_uaf | | ✓ | |
| Shambu | 850hpa divergence | ncepp8zhaf | ✓ | | |
| | 500hpa geopotential height | ncepp500af | ✓ | ✓ | ✓ |
| | 850hpameridional velocity | ncepp8_vaf | | | ✓ |
| | 850hpa geopotential height | ncepp850af | | | ✓ |
| | Surface specific humidity | ncepshumaf | ✓ | ✓ | ✓ |
| | Mean temperature at 2m | nceptempaf | ✓ | | ✓ |
| | Mean sea level pressure | Ncepmaslpaf | ✓ | ✓ | |
| Neshe | 500hpa geopotential height | ncepp500af | | ✓ | ✓ |
| | 500hpa zonal velocity | ncepp5_uaf | ✓ | | ✓ |
| | Surface wind direction | ncep_thaf | ✓ | | ✓ |
| Fincha | Surface divergence | ncep_zhaf | | ✓ | ✓ |
| | 500hpa geopotential height | ncepp500af | ✓ | ✓ | ✓ |
| | 850hpameridional velocity | ncepp8_vaf | ✓ | | ✓ |
| | relativehumidity at 850hpa | ncepp850af | ✓ | ✓ | ✓ |
| | Mean temperature at 2m | nceptempaf | ✓ | | ✓ |

## SDSM Model Calibration and Validation

The calibration was carried out from 1971-1985 for 15 years and the withheld data from 1986-2000 were used for model verification. Twenty mean ensembles of synthetic daily weather series generated using NCEP-reanalysis data for the verification of the calibrated model. The mean of the 20 ensembles of maximum temperature and minimum temperature values gave a better $R^2$ values ($R^2$=0.72 and $R^2$ =0.68 respectively), inferring that future projections would also be well replicated. The model develops a better multiple regression equation parameters for the maximum and minimum temperature than the precipitation ($R^2$ =0.46). These calibration results show that the simulated maximum and minimum temperature has better agreement with the observed results than the precipitation variables.

Validation was done based on 14 years simulation from 1986 to 2000. Twenty (20) ensembles (runs) of daily values were generated and the average of these ensembles was taken for comparison. During validation maximum temperature and minimum temperature values gave a better $R^2$ values ($R^2$=0.85 and $R^2$ =0.78 respectively) and for precipitation ($R^2$ =0.56). The downscaled model showed good performance during validation period in the cases of minimum and maximum temperatures and correlation coefficients that were found during the calibration step are more or less maintained.

## Downscaling the GCM for the Baseline Period

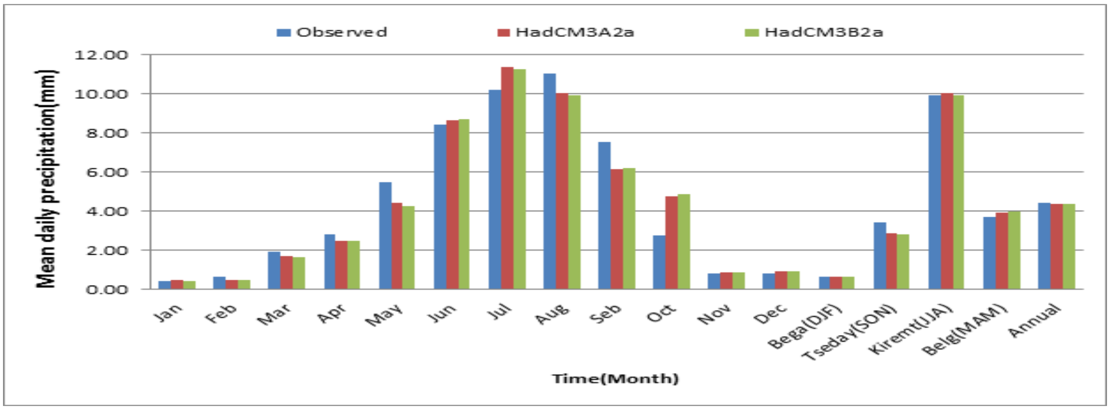
The downscaled HadCM3 for the base period with two emission scenarios (A2a and B2a) and some of the statistical properties of the downscaled data were compared with observed data. The climatological base line period used for the impact assessment was between 1971-2000 for Finchaa, Shambu and Neshe stations. This base line period is also used to compare with future scenarios generated. The future scenarios were developed by dividing the future time series in to three equal periods of 30 years: 2011-2040, 2041-2070, 2071-2099.

## Scenarios developed for base period

Baseline scenarios, which reflect current conditions, were initially executed prior to performing the scenario simulations. Accordingly 30-year period from1972-2001 was selected for Finchaa, Shambu and Neshe stations to represent baseline.

## Precipitation

The SDSM model performs reasonably well in estimating the mean daily precipitation Shambu and Neshe meteorological stations. The monthly precipitation downscaled for the baseline period for A2a and B2a emission scenarios is shown in (Figure 2).



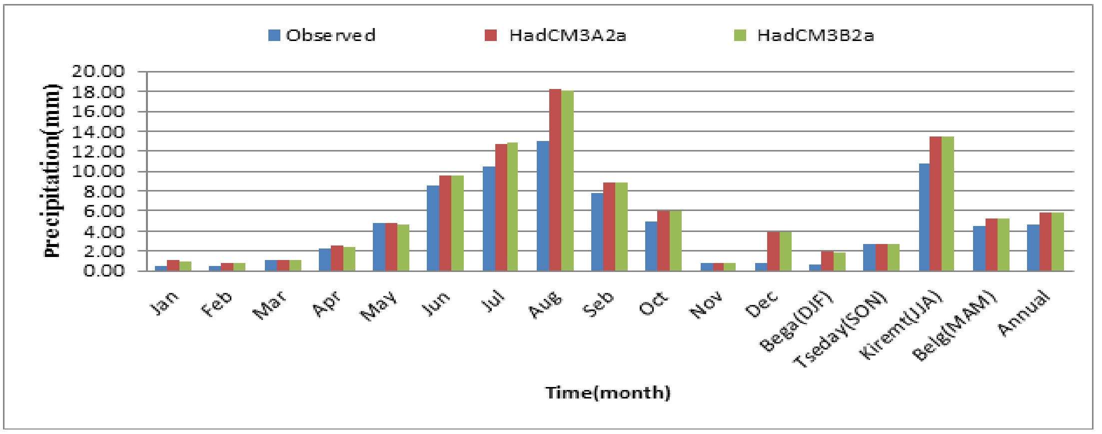



**Figure 2: Mean daily observed and downscaled precipitations for the baseline period of Shambu and Nesherespectively**

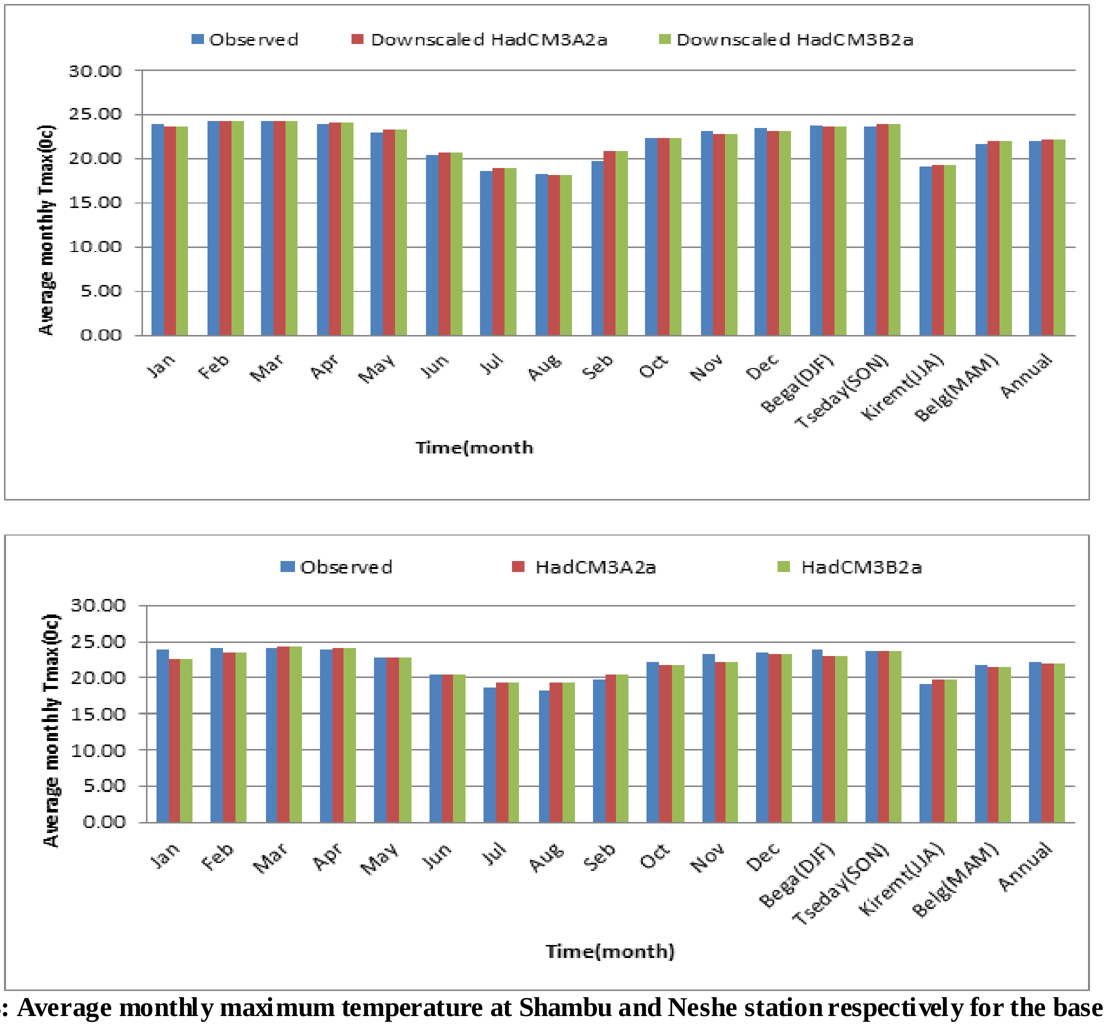



**Figure 3: Average monthly maximum temperature at Shambu and Neshe station respectively for the base period (1971-2000).**

## Maximum Temperature

The downscaled monthly mean maximum temperature reveals strong relations with the observed temperature for the baseline period (1971-2000) of both in A2a and B2a emission scenarios. The downscaled monthly mean maximum temperature reveals good relations with the observed temperature at Shambu and Neshe stations for the baseline period of both in A2a and B2a emission scenarios.

**Minimum temperature**

The monthly minimum temperature downscaled for A2a and B2a emission scenarios in the baseline period show a reasonably good agreement with the observed minimum temperature as shown in Figure 4.

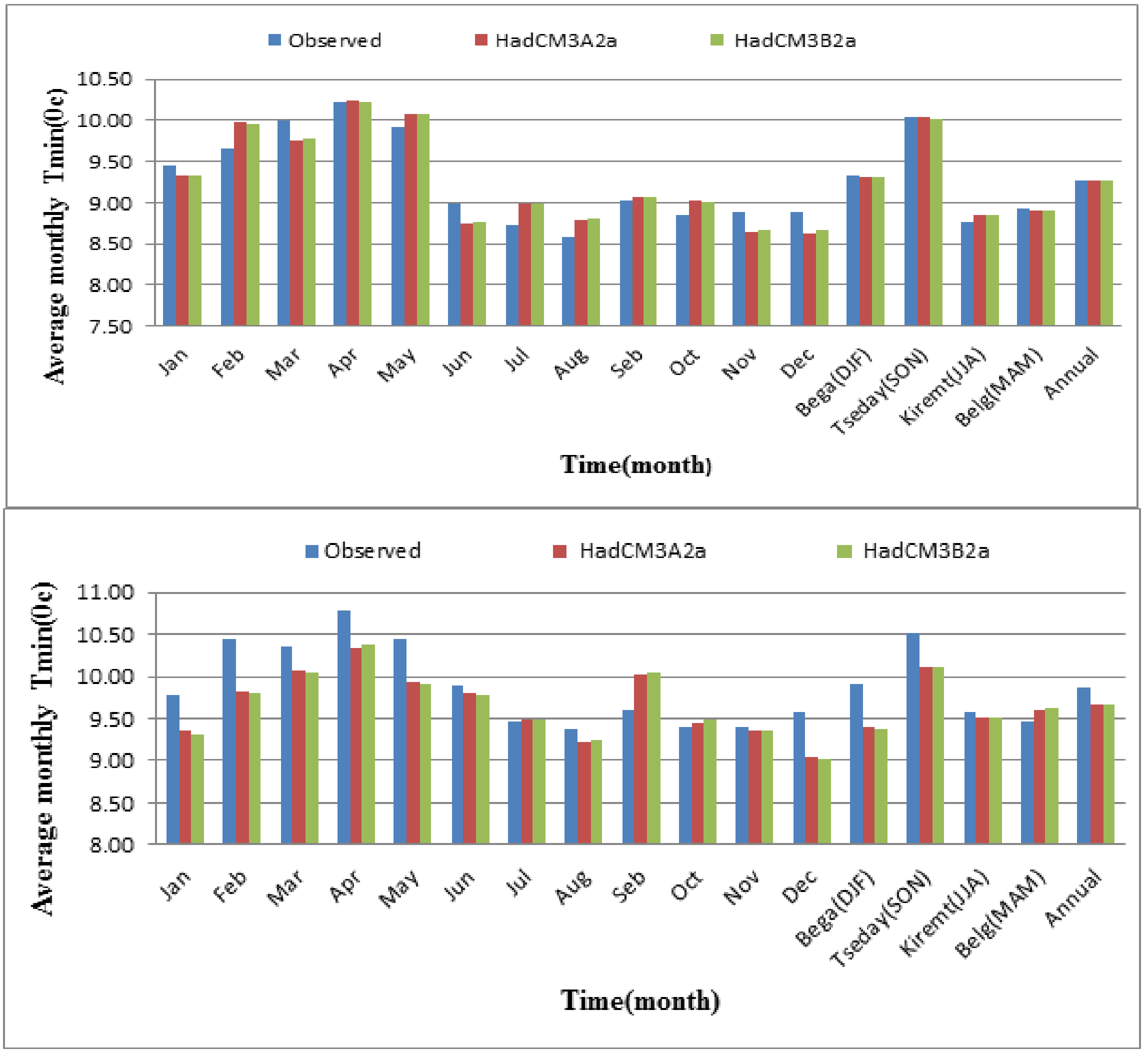



**Figure 4: Observed and downscaled monthly mean Tmin at Shambu and Neshe respectively for the baseline period.**

**Scenarios developed for the future period (2011-2099)**

The climate scenario for future period was developed from statistical downscaling using the GCM predictor variables for the two SRES emission scenarios (HadCM3A2a and HadCM3B2a) for 90 years based on the mean of 20 ensembles and the analysis was done based on three 30-year periods centered on the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2099).The generated future scenarios for precipitation decreasing trend and those for maximum and minimum temperature show an increasing trend with respect to the base period for the sub-basin.

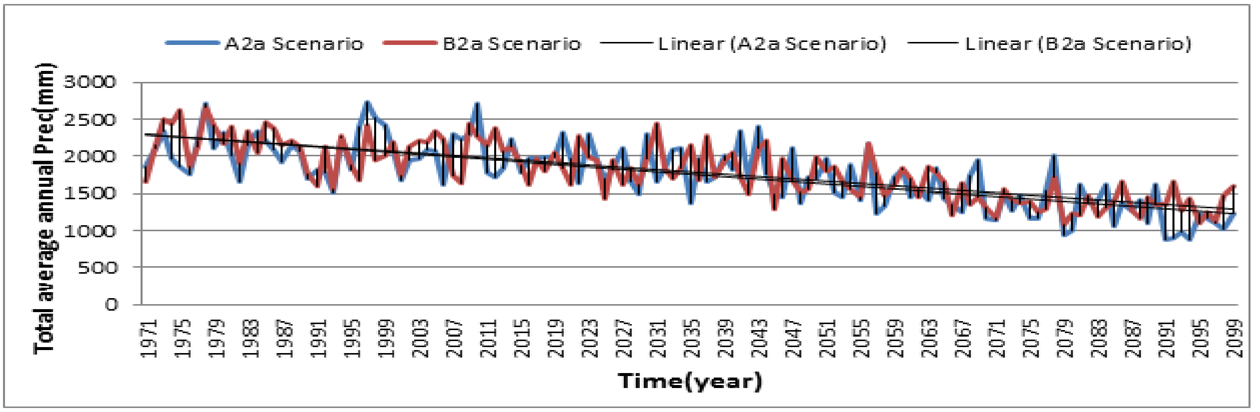



**Figure 5: Future pattern of annual precipitation of the sub-basin (1971-2099)**

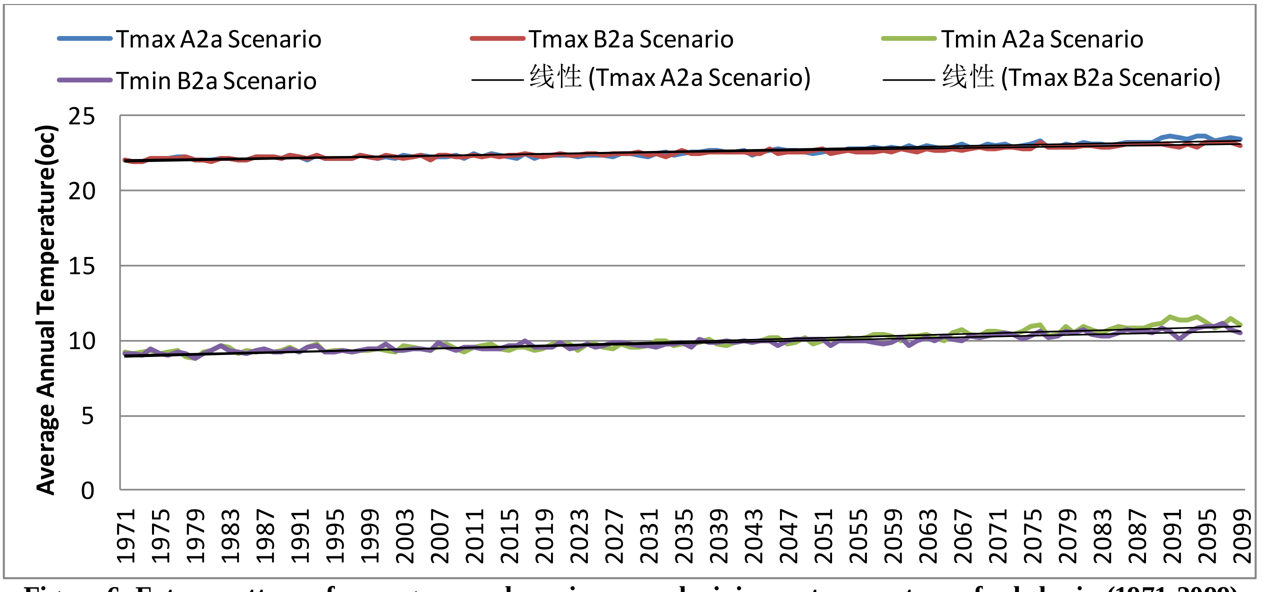



**Figure 6: Future pattern of average annual maximum and minimum temperature of sub-basin (1971-2099)**

In this study first the coarser climate data (GCM) are downscaled in to finer spatial resolution regional climate data (RCM) and these regional climate data are further downscaled in to station level by using statistical downscaling model (SDSM) and these downscaled data have been taken directly as an input of the model to assess the future climate change impact on hydrology of the sub-basin after calibration and validation done. The climate scenario for future period was developed from statistical downscaling using the HadCM GCM predictor variables for the two SRES emission scenarios (A2 and B2) for 90 years based on the mean of 20 ensembles and the analysis was done based on three 30-year periods centred on the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2099). The average annual precipitation in the watershed might reduce up to 9.84 %, 23.29 % and 41.51 % and 9.27 %, 20.71 % and 35.37 % in 2020s, 2050s, and 2080s for A2a and B2a emission scenarios, respectively as shown Figure 7 (a) and (b). This finding is not unique to this study [29] found out that the CCLM downscaling resulted in the upper Blue Nile were 1.8, -6.6 and -6.4% in 2020s, 2050s and 2080s respectively. The result of this analysis confirmed also with the [9] mid-range emission scenario show that compared to the (1961-1990) annual precipitation show a change of between 0.6 to 4.9% and 1.1 to 18.2% for 2030 and 2050 respectively.

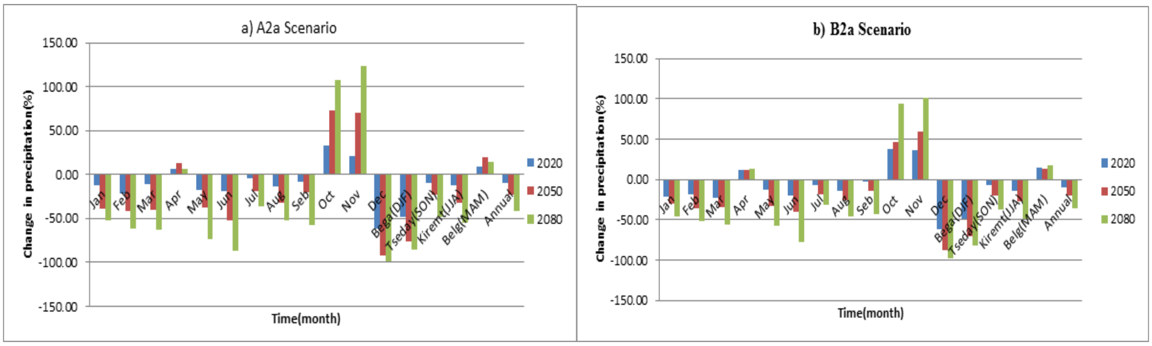



**Figure 7: (a) and (b) Change in average monthly, seasonal and precipitation for A2 and B2 emission Scenarios.**

Besides, as shown in Figure 8 (a) and (b) the average annual maximum temperature might increase by $0.25^0$C, $0.60^0$C and $1.09^0$C and $0.50^0$C, $0.26^0$C and $0.86^0$C in 2020s, 2050s and 2080s for A2a and B2a emission scenario respectively. The result of this analysis confirmed with [30, 31]findings.The Maximum temperature showed an increasing trend in three future time horizons.

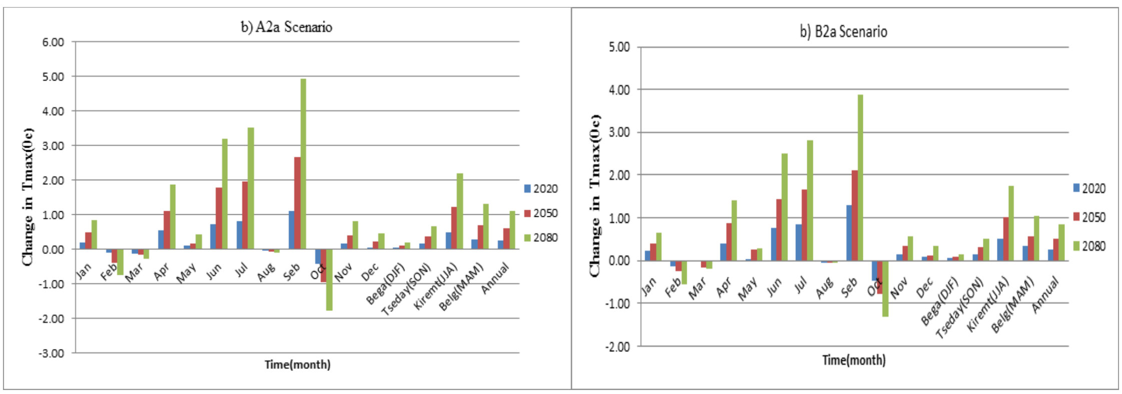



**Figure 8: (a) and (b) Change in average monthly, seasonal and annual maximum temperature for A2 and B2 emission Scenarios.**

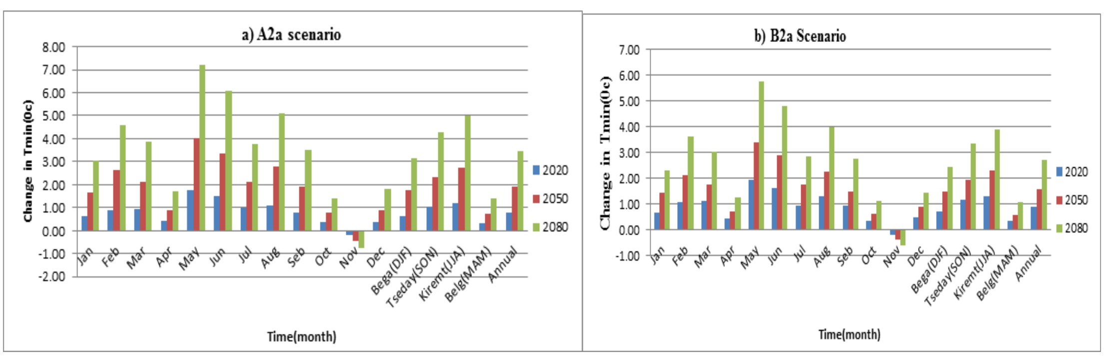
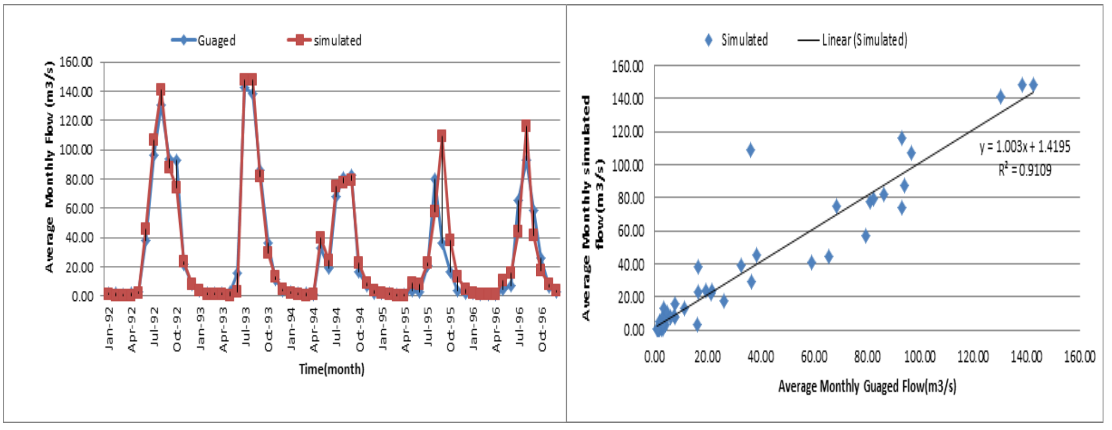



**Figure 9: (a) and (b) Change in average monthly, seasonal and annual minimum temperature for A2 and B2 emission Scenarios.**

The average annual minimum temperature might increase by $0.3^0$C, $0.80^0$C and $0.92^0$C and $0.40^0$C, $0.66^0$C and $1.1^0$C in 2020s, 2050s and 2080s for A2a and B2a emission scenario respectively. Generally, the temperature change projection for the catchment is in line with the range produced in by other researcher over the Blue Nile River basin [31, 32, 33, 34]. The projected minimum and maximum temperature in both future time horizons is within the range projected by [9] average temperature increases ranging from 1.4℃ to 5.8℃ towards the end of century.

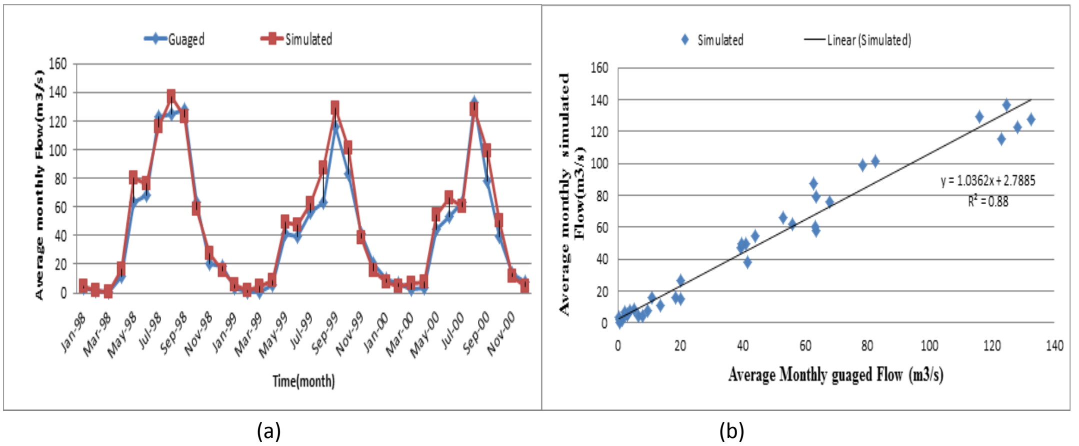
**SWAT Model Calibration and Validation**

The manual and automated calibration process was used to calibrate the model parameters using time series data from 1992 to 1996. Data from 1997 to 2000 were used to validate the model using the input parameter set. Time series plots and the statistical measures of coefficient of determination ($R^2$) and Nash-Sutcliffe efficiency ($E_{NS}$) were used to evaluate the performance of the model. The predicted and observed stream flow generally matched well. The results of the model calibration and validation showed reliable estimates of monthly stream flow with $R^2 = 0.92$ and $E_{NS} = 0.91$ during the calibration period (Figure 10) and $R^2 = 0.88$ and $E_{NS} = 0.86$ during the validation period (Figure 11).




(a) (b)

**Figure 10: Calibration result of average monthly simulated and gauged flows (a) and Scatter plot of monthly simulated versus gauged flow (b) at the outlet of the watershed**




(a) (b)

**Figure 11: Validation result of average monthly simulated and gauged flows (a) and Scatter plot of monthly simulated versus gauged flow (b) at the outlet of the watershed**

**Projected changes in the seasonal and mean annual surface runoff**

Precipitation, minimum and maximum temperature were the climate change drivers considered for the impact assessment. The seasonal percentage change in runoff in both scenarios for the period 2020s, 2050s and 2080s are

presented in (Figure 12 and 13).
Kiremt (JJAS) season is expected to show the larger share in decrease surface runoff. The decrease may reach up to 29.68% in 2080s for the A2a scenario and 25.32% in 2080s for the B2a scenario. In general, due to the projected increase in temperature and reduce in precipitation leads to reduction in future annual runoff as one goes from one period to the next.
The future scenario generated runoff shows a decreasing in the future time series for the three periods 2020s, 2050s and 2080s comparing with the base period 1990s for both emission scenarios. The maximum reduction in surface runoff in the Kiremt seasons by 29.68% and Belg 28.28% for the time period 2080s A2a emission scenarios (Figure12). In general, due to the projected increase in temperature and decreasing trend in precipitation the reduction in annual runoff by 4.29%, 10.62%, 18.07% and 8.27%, 8.58%, 16.69% for 2020s, 2050s and 2080s for both A2 and B2 emission scenarios respectively (Figure 13).

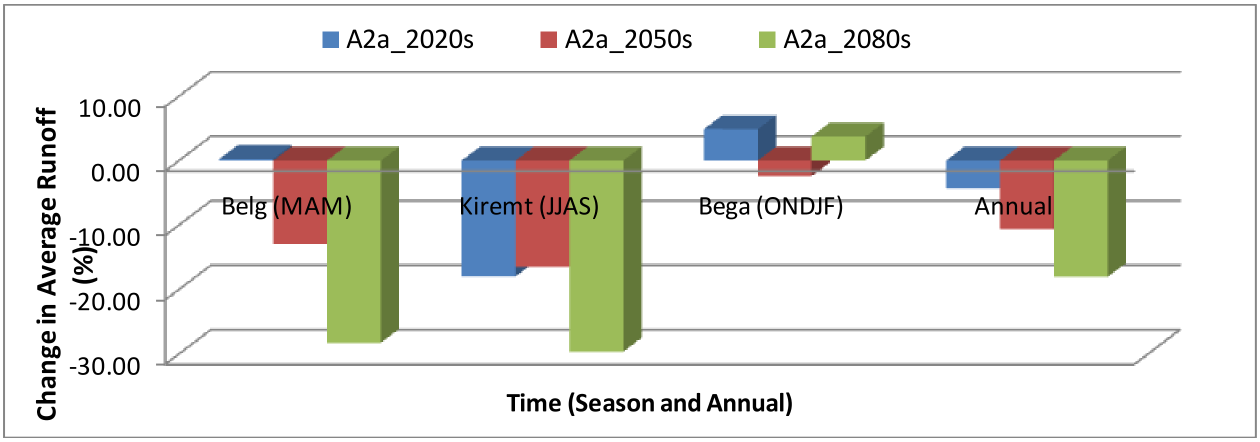



**Figure 12: Change in seasonal and annual surface runoff for A2 emission scenario**

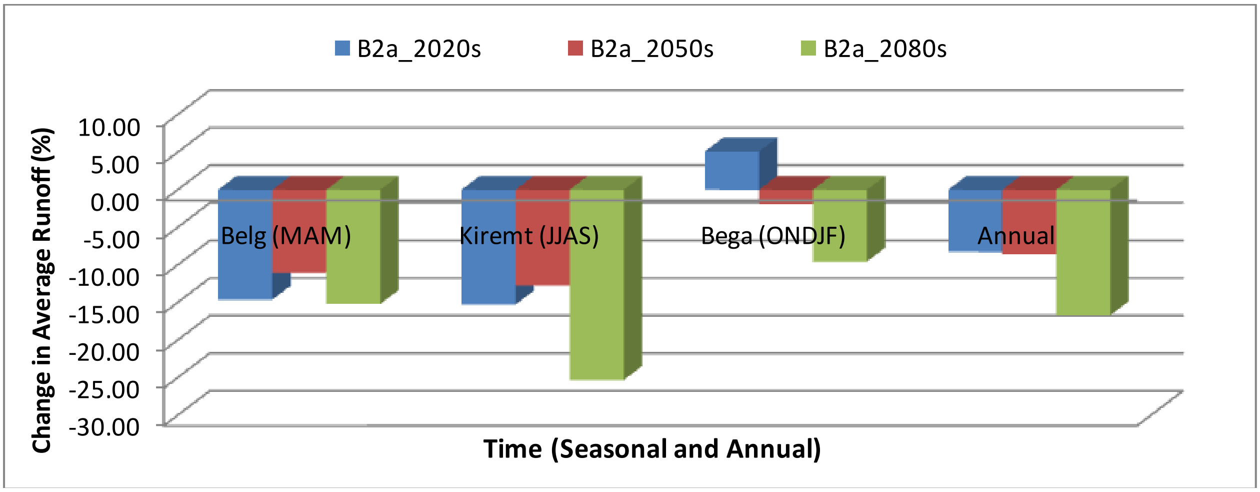



**Figure 13: Change in seasonal and annual surface runoff for B2 emission scenario**

## Adaptation Strategies

Adaptation to climate change can be the range of actions taken in response to changes in local and regional climatic conditions [35]. These responses include autonomous adaptation, like, actions taken by individual actors such as single farmers or agricultural organizations, as well as planned adaptation, i.e., climate-specific infrastructure development, regulations and incentives put in place by regional, national and international policies in order to complement, enhance and/or facilitate responses by farmers and organizations.

In general, adaptation to climate change problems causing reduction in the total surface runoff can be the range of actions taken in response to changes in local and regional climatic conditions.

Based on results of study surface runoff decreases for the future 2011-2099 periods. From the results, it can be concluded that the expected climate change will adversely impact the water resources in that watershed. To minimize these impacts a variety of adaptation methods have been proposed.

These include, development of watershed based integrated water resource management approach, introducing new farming techniques, in future project development like Finchaa sugar factory project consideration of future climate change and its impact at all levels of water resource are the most important one, crop calendar shift, constructing water storage structures to store excess water flowing during rainy season so as to use it for dry season, Growing drought-tolerant crops, development of appropriate irrigation water management practices of surface irrigation projects like sugar project and agricultural sector in study area, irrigation farming, awareness creating among the community of the future climate change in the watershed area and development of ground water and effective rainwater harvesting technologies.

## 4. Conclusions and Recommendations

The objective of this study is to assess the impacts of climate change on surface runoff of upper Awash River basin by using the General Circulation Model (GCM) out puts and Soil and Water Assessment Tool (SWAT) hydrology model.

The SWAT model is able to capture monthly and patterns which can be proven by the regression coefficient and the Nash-Sutcliffe simulation efficiency values obtained during calibration and validation periods. Hence, it can be concluded that SWAT is able to accurately explain the hydrological characteristic of the Finchaa sub-basin.

The result of climatic projections of SDSM model simulations revealed that the climatic variables generally follow the same trend with the observed meteorological data. The SDSM has good ability to replicate the historical maximum and minimum temperatures than rainfall. The mean of the 20 ensembles of maximum temperature and minimum temperature values gave a better $R^2$ values, inferring that future projections would also be well replicated. The model develops a better multiple regression equation parameters for the maximum and minimum temperature than the rainfall. This is mainly due to the conditional nature of rainfall.

The downscaled mean annual maximum and minimum temperature shows an increasing for all future time horizons for both A2a and B2a emission scenarios. Rainfall projection exhibited reducing in annual average rainfall for sub-basin all time horizons for both A2a and B2a emission scenarios.

The change in climate variables such as reduce in rainfall and increase in temperature; which is very sensitive parameter that can be affected by changing climate than any other hydrological component are likely to have significant impact on surface runoff.

Therefore, decrease in future projected average annual surface runoff leads to reduce in water resource availability of watershed. It is believed that the results of this study give a clue and increase awareness on the possible future risks of climate change.

In this study, the same land cover data as the present time were used and there is no consideration of changes in soil parameters, which could influence the soil properties of the watershed. This may explain the low response of soil moisture to the changes to climate in this study. Such a study should not be considered as a realistic actual scenario, because the latter would require including the impact of future land use change.

Downscaling of the large scale variables by using SDSM was done at three meteorological stations, and it was assumed that this change will be applicable to other stations as well. However, it is recommendable if climate change assessment will be done downscaling large scale variables at each station found in the study area.

In addition to fluctuations on temperature and precipitation, non-climatic factors such as population growth, and changes in per capita and agricultural water demand, deforestation and are among current trends over the sub- basin and can play a more relevant role on the water resources of the upper Awash sub-basin. Hence, it is strongly recommend a thorough investigation of the combined effect of climate, non-climatic factors, and land use or land cover change on the surface runoff, which are so important for the economy and livelihoods of people in the study area.

Hence, such studies should continue on different Ethiopian basins for better awareness in the future. This will contribute partly to the sustainability if impacts of climate change are considered at all levels (from planning to execution and management) of water resource development projects of study area.

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