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INVESTIGATING CLIMATE CHANGE IMPACT ON STREAM FLOW OF BARO-AKOBO RIVER BASIN CASE STUDY OF BARO CATCHMENT.

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ABSTRACT

In recent decades changes in climate have caused impacts on natural and human systems on all continents and across the oceans. Impacts are due to observed climate change, irrespective of its cause, indicating the sensitivity of natural and human systems to changing climate. One of the direct impacts of this climate change is on water resources development and indirectly for agricultural production, environmental quality and economic development which will lead again to difficult conditions for Human to live in. The objective of this thesis is to assess the impact of climate change on the stream flow of Baro watershed which is the major tributary of Baro-Akobo basin, Ethiopia. The soil and water assessment tool (SWAT) model was used to simulate the stream flow using the meteorological data of thirty one years from 1986 to 2016. The model was calibrated for a period of sixteen years from 1990-2005 and validated for the observed data for eleven years from 2006-2015 and shows a good agreement with R2 = 0.90 during calibration and R2= 0.93 during validation whereas NSE=0.66 during calibration and 0.61 during validation. Hypothetical climate change scenarios of precipitation from -20% to +20% at 10% interval and temperature change from 2oC ,and 3oC for the period of 2050s and from 3.5oC to 6oC at 1.5oC interval for the period of 2080s under RCPs 8.5 was taken based on the IPCC 5th assessment set for African countries. Results of this procedure show the sensitivity of stream flow to climate variability. For example, a change of precipitation from -20% to +20% for constant temperature of 2oC gives a reduction of stream flow by around 11% .Beside this, for a constant precipitation of 0% and variation of temperature from 2oC to 3oC there is reduction of stream flow by average of 12.7%. This shows that the Baro Catchment will be more sensitive to the average increase in temperature than to the average decrease in rainfall, which shows the role of evapotranspiration in the water cycle. Overall, the result suggest, a decrease in stream flow of 12.73% for the period of 2050s (i.e.2046-2065) and 15.56% by the end of the 21st century (2080s) as a consequence of decreasing rainfall of -20% and increasing temperature of 6oC Scenarios (i.e. the worst scenarios) .

Key words: Baro Watershed, Synthetic scenario, RCP, Climate, SWAT, SWAT-CUP

1. INTRODUCTION

Background

Evidence of observed climate change impacts is strongest and most comprehensive for natural systems. Changing of precipitation or melting snow and ice are changing hydrological systems in many regions, affecting water resources in terms of quantity and quality. Many terrestrial, fresh water, and marine species have shifted their geomorphic ranges , seasonal activities, migration patterns, abundances, and species interactions in response to ongoing climate change (IPCC, 2014) .Some impacts on human systems have also been attributed to climate change, with a major or minor contribution of climate change distinguished from other influences. The negative impacts change on crop yields has been more common than positive impacts according to the assessments of many studies covering a wide range of regions and crops.

Climate changes have had observable impacts on the natural systems. Climate change is expected to worsen current stresses on water resources availability from population growth, urbanization and land-use change (Liben, 2011). A major effect of climate change is likely to be interchanges in hydrologic cycles and changes in water availability. Increased evaporation, combined with changes in precipitation, has the potential to affect runoff, the frequency and intensity of floods and droughts, soil moisture and available water for irrigation and hydroelectric power generation.

The global increase in water resources demand due to lifestyle change and population growth is affected by freshwater scarcity throughout the planet. Meanwhile, the potential effects of climate change on water resources availability increase further challenges on the sustainability of this insufficient yet life-dependent substance; this is in addition to the complexity of the prospect of climate's natural variability and its eventual reserved effect on the water balance cycle (Ramadan, 2012). As this is a decades old subject of on-going discussion in the global scientific community, the Intergovernmental Panel for Climate Change (IPCC) recently emphasized the need for directing climate variability and change impacts on water resources studies toward regional and local dimensions. To be consistent with local population demands and priorities this allows for the creation of competent mitigation solutions. Continued emission of greenhouse gases will cause further warming and on-going changes in all components of the climate system, increasing the likelihood of severe, pervasive and irreversible impacts for people and ecosystems. Limiting climate change would require considerable and continual reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks.

According to IPCC 2014 Surface temperature is projected to rise over the 21st century under all assessed emission scenarios. It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions. The ocean will continue to warm and acidify, and global mean sea level to rise. Accordingly to this report (IPCC, 2014),the global mean surface temperature change for the period 2016-2035 will likely be in the range 0.3°C-0.7°C (medium confidence). Relative to 1850-1900, global surface temperature change for the end of the 21st century (2081-2100) is projected to likely exceed 1.5°C (high confidence). It is virtually certain that there will be more frequent hot and fewer cold temperature extremes over most land areas on daily and seasonal timescales, as global mean surface temperature increases (Allen et al., 2014).

Developing countries in general and least developed countries like Ethiopia in particular are more exposed to the adverse impacts of climate variability and change. This is due to their low adaptive capacity and high sensitivity of their socio-economic systems to climate variability and change (Elshamy, 2010).

From the point of view of the design and management of water resource systems, hydrologists are required to make accurate predictions of the impacts of climate change on the intensity, amount, and spatial and temporal variability of rainfall. Furthermore, and possibly most important, they also must examine how the stream flow regime (e.g., stream flow hydrographs, peak flow ,etc.) at different spatial and temporal scales is affected by rainfall variability and by the expected changes in that variability as a result of climate change (Ramirez et al., 2007).

One of the most important impacts on society of future climatic changes will be changes in regional water availability (Chong-yu Xu, 1999). Such hydrologic changes will affect nearly every aspect of human well-being, from agricultural productivity and energy use to flood control, municipal and industrial water supply, and fish and wildlife management. The great importance of water in both society and nature underscores the necessity of understanding how a change in global climate could affect regional water supplies.

According to the Intergovernmental Panel on Climate Change (IPCC) 5th assessment report (Isabelle, 2014) global average surface temperature would likely rise between 3°C to 6°C by 2100 with the RCPs of 8.5 and rise by 2^{o}c to 3^{o}c with the RCPs of 4.5. With respect to precipitation, the results are different for different regions; the report also indicates that an increase in mean annual rainfall in East Africa is likely. The minimum temperature over Ethiopia show an increase of about 0.37°C per decade, which indicates the signal of warming over the period of the analysis 1957-2005 (Di Baldassarre, 2011). Previous studies in Nile basin provide different indication regarding long term rainfall trends; (Elshamy ME, 2009) reported future precipitation change in the Blue Nile is uncertain in their assessment of climate change on stream flow of the Blue Nile for 2081-2098 period using 17 GCMs. (Wing H, 2008) showed that there are no significant changes or trends in annual rainfall at the national or watershed level in Ethiopia.

The successful realisation of any water resources activity is important to a country like Ethiopia for the growth of the national economy. Among the twelve river basins in Ethiopia, the Baro-Akobo basin has abundant water resources which up to now have not been developed to any significant level. The Baro-Akobo basin has of great unrealized potential, under populated by Ethiopian standard, and with plenty of land and water. The abundance of water combined with the relief of the basin, from the high plateau at above 2,500m elevation down to the Gambella plain at an altitude of 430m provides favourable conditions for hydropower in this region. The river Baro-Akobo is used for water supply for domestic and industrial uses, irrigation, hydropower generation and navigation.

Of the tributaries of the Basin, Baro-river is the major one. The Baro River is created by the confluence of the Birbir and Gebba Rivers, east of Metu in the Illubabor Zone of the Oromia Region. From its source in the Ethiopian Highlands it flows west for 306 kilometres (190 mi) to join the Pibor River. The Baro-Pibor confluence marks the beginning of the Sobat River, a tributary of the White Nile.

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Statement of the problem

By 2025, it is estimated that around 5 billion people, out of a total population of around 8 billion, will be living in countries suffering water shortage (using more than 20% of their available resources) (Arnell, 1999).

Climate warming observed over the past several decades is consistently associated with changes in a number of components of the hydrological cycle and hydrological systems such as: changing precipitation patterns, intensity and extremes; widespread melting of snow and ice; increasing atmospheric water vapour; increasing evaporation; and changes in soil moisture and runoff (Abera, 2011).

There is abundant evidence from observational records and climate projections that freshwater resources are susceptible and have the potential to be strongly impacted by climate change. However, the ability to quantify future changes in hydrological variables, and their impacts on systems and sectors, is limited by uncertainty at all stages of the assessment process. Uncertainty comes from the range of socio-economic development scenarios, the downscaling of climate effects to local/regional scales, impact assessments, and feedbacks from adaptation and mitigation activities. Decision making needs to operate in the context of this uncertainty. Robust methods to assess risks based on these uncertainties are at an early stage of development (Bates, 2008)).

This impact of climate change affects more developing countries in general and least developing countries like Ethiopia in particular, due to their low adaptive capacity and high sensitivity of their socio-economic systems to climate variability and change. Current climate variability is already imposing a significant challenge to Ethiopia by affecting food security, water and energy supply, poverty reduction and sustainable development efforts, as well as by causing natural resource degradation and natural disasters (Abebe, 2007).

Among the river basins of Ethiopia which are affected by climate change Baro-Akobo river basin is one of them (Kebede, 2013), in which Baro river is the major tributary. Therefore in this study the impact of climate changes on the Baro-River was assessed. This is used to have a good in sight for checking the possible impact of climate change in the basin in the future.

Objectives

1.1.1. General Objective

The general obvective of this study is to assess the impact of climate change on streamflow of the Baro river by taking different scenarios.

1.1.2. Specific Objective

The following specific objectives are set in order to come to the main objective.

- To develop hydrologic SWAT model for the Baro-Watershed.
- To assess the impact of precipitation and temprature for the future period as compared to the baseline period based on the synthetic scenarios.
- To quantify the possible impacts of climate change on the hydrology of the catchment based on synthetic scenarios set by IPCC 5th assessment report.

2. Method and Materials

2.1. Description of the Study Area

Baro-Akobo Basin lies in the southwest of Ethiopia between latitudes of 5° 31` and 10° 54` N, and longitudes of 33° 0` and 36° 17` E. The basin area is about 76,000 km^2 and is bordered by the Sudan in the West, northwest and southwest, Abbay and Omo-Gibe Basins in the east. The major rivers within the Baro-Akobo basin are Baro and its tributaries Alwero, Gilo and the Akobo. These rivers, which arise in the eastern part of the highlands, flow westward to join the White Nile in Sudan. The mean annual runoff of the basin is estimated to be about 23 km^3 as gauged at Gambella station. Elevation of the study area varies between 440 and 3000 m a.m.s.l. The higher elevation ranges are located in the North East and Eastern part of the basin while the remaining part of the basin is found in lower elevation. In the study area, there is high variability in temperature with large differences between the daily maximum and minimum temperatures.

One of the tributaries of the Baro River is a river in southwestern Ethiopia, which defines part of Ethiopia's border with South Sudan. The Baro River is created by the confluence of the Birbir and Gebba

Rivers, east of Metu in the Illubabor Zone of the Oromia Region. From its source in the Ethiopian Highlands it flows west for 306 kilometers (190 mi) to join the Pibor River. The Baro-Pibor confluence marks the beginning of the Sobat River, a tributary of the White Nile. The Baro and its tributaries drain a watershed 41,400 km^2 (16,000 sq. mi) in size. The river's mean annual discharge at its mouth is 241 m^3/s (8,510 ft^3/s).In this thesis the impact of climate change on this river is going to be assessed which will be a representative of the basin since it covers most of the area of the basin.

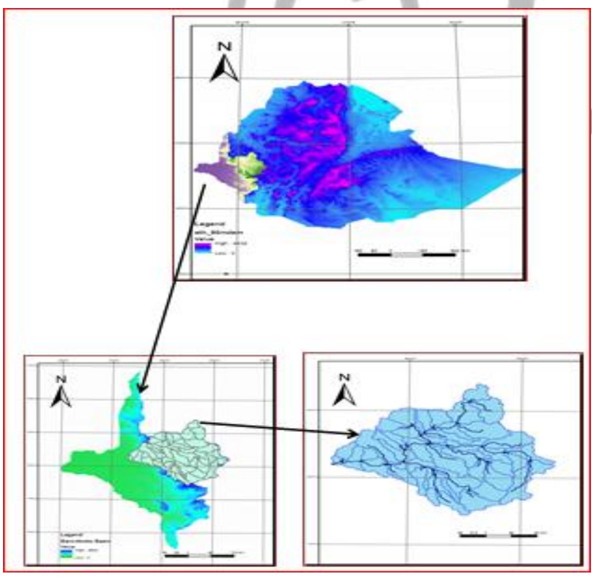

Figure. 2.1. Location of Baro Watershed

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2.2. Hydrologic Modeling

A physically based hydrological model was used for the Baro catchment to assess the impact of climate change on the area. Soil and Water Assessment tool (SWAT) was selected as the best modeling tool owing to many reasons. First and for most it is a public domain model and it is used for free. Secondly in countries like Ethiopia, there is a shortage of long term observational data series to use sophisticated models; however, SWAT is computationally efficient and requires minimum data. Besides SWAT was checked in the highlands of Ethiopia and gave satisfactory results (Setegn Shimelsi, 2008). SWAT model was developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields. However, this study concentrated on the hydrological aspect of the basin. The description of the model, model inputs and model setup are discussed in detail in the subsequent sections.

2.2.1 Soil and Water Assessment Tool (SWAT) Background

SWAT is a river basin scale model developed to quantify the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time. The main components of SWAT include weather, surface runoff, return flow, percolation, evapotranspiration, transmission losses, pond & reservoir storage, crop growth & irrigation, groundwater flow, reach routing, nutrient & pesticide loading, and water transfer. It is a public domain model actively supported by the USDA Agricultural Research Service at the Grassland, Soil and Water Research Laboratory in Temple, Texas.

SWAT requires specific information about weather, soil properties, topography, vegetation, and land management practices occurring in the watershed. The minimum data required to make a run are commonly available from government agencies. From this a number of output files are generated by SWAT. These files can be grouped by the type of data stored in the file as standard output file (.std), the Hydrologic Response Units (HRU) output file (.sbs), the sub-basin output file (.bsb), and the main channel or reach output file (.rch).

In order to setup the model, the digital elevation model, land use/land cover and soil map were projected into common projection system. Model has capability to delineate the DEM into watershed or basin and divided into sub-basin. The layers of land use/land cover, soil, map and slopes categories were overlaid and reclassified into hydrological response unit (HRUs). Hydrologic response units (HRUs) have been defined as the unique combination of specific land use, soil and slope characteristics (Arnold, 1998).The model estimates the hydrologic components such as evapotranspiration, surface runoff, peak rate of runoff and other components on the basis of each HRUs unit. Water is then routed from HRUs to sub-basin and sub-basin to watershed (Tripathi.M.P, 2003). The equation of mass balance performed at the HRU level is given as follows:

$$St = \mathrm{So} + \sum_{i=1}^{t}(\mathrm{Rday} - \mathrm{Qsurf} - \mathrm{Ea} - \mathrm{wseep} - Qgw) \quad \text{--2.1}$$

Where St is the final storage (mm), S_o is the initial storage in day i (mm), t is the time (days), R_{day} is the rainfall (mm/day), Qsurf is the surface runoff (mm/day), Ea is evapotranspiration (mm/day), W_{seep} is seepage rate (mm/day) and Q_{gw} is return flow (mm/day).

In order to estimate the surface runoff, there were two methods available: SCS curve number (Soil Conservation Service) and Green and Ampt infiltration method. In this study, the SCS curve number method was used to estimate surface runoff. The SCS curve number is described by the following equation:

$$Qsurf = \frac{(Rday - 0.2S)^2}{(Rday + 0.2S)} \text{----------------------2.2.}$$

Where Qsurf is accumulated runoff or rainfall excess (mm/day), Rday is the rainfall depth (mm/day) and S is the retention parameter (mm). The retention parameter is defined by the following equation:

$$S = 25.4\left(\frac{100}{CN} - 10\right) \text{----------------------2.3.}$$

SWAT provides three methods that can be used to calculate potential evaporation (PET). These are the Penman-Monteith method, the priestly-Taylor method and the Hargreaves method. The model can also read in daily PET values if the user prefers to apply a different potential evapotranspiration method. The three PET methods vary in the amount of required inputs. The Penman-Monteith method requires solar radiation, air temperature, relative humidity and wind speed. The Priestley-Taylor method requires solar radiation, air temperature and relative humidity. The Hargreaves method requires air temperature only. In this study, among the three methods, Penman-Monteith Method was used to estimate PET values (Neitsch S.L., 2005).

2.3. SWAT Model Inputs Data

The SWAT Model requires input data's such as DEM of the study area, topography, soil, land use and meteorological data including daily rainfall, minimum and maximum temperature, relative humidity, solar radiation and wind speed for the analysis of the watershed.

2.3.1. Digital Elevation Model

The Digital Elevation Model (DEM) is any digital representation of a topographic surface and specifically to a raster or regular grid of spot heights. It is the basic input of SWAT hydrologic model to delineate watersheds and River networks.

The first step in creating the model input is the watershed delineation accomplished using digital elevation data. DEM is the first input of SWAT model for delineating the watershed to be modeled. Based on threshold specifications and the DEM, the SWAT Arc View interface was used to delineate the watershed into sub basins and subsequently, sub basins were divided into Hydrologic Response Units (HRU)

The DEM was also used to analyze the drainage patterns of the land surface terrain. Sub basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width were derived from the DEM.

The catchment physiographic data were generally collected from topographic maps and 90mx90m resolution DEM. This DEM data was obtained from GIS data that found in Ministry of Water and Energy directorate of GIS. This DEM data was basic input for the water shed delineation and slope calculation of the basin in the SWAT model processing.

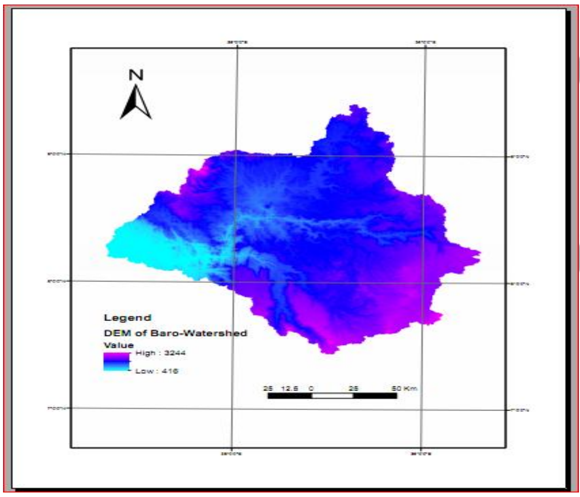


Figure 2.2. Digital elevation model for Baro River extracted from Ethio- DEM.

3.3.2. Land Use Land Cover Data

SWAT requires the land use land cover data to define the Hydrological Responses Units (HRU). The land use land cover map of the study area was obtained from the ministry of water resources GIS department. Based on these data the SWAT major land use land cover map was produced by overlying the land use shape files. Then after the major land use land cover classification were sub divided into sub classes mainly based on dominant crops for cultivated lands. Then SWAT calculated the area covered by each land use. The different land use/land cover types are presented in table 3.1.

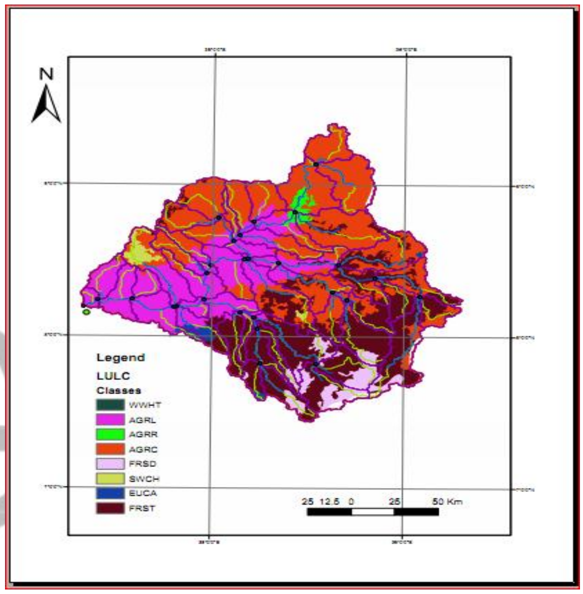


Figure.2.3. Land use/cover of Baro Watershed

Table 2.1. SWAT Major Land Use Classes, Codes and Areal Coverage of Baro Watershed

Land use	SWAT code	Area(km^2)	%watershed area
Agricultural Land - Generic	AGRL	5073.82	21.24
Agricultural Land-Row Crops	AGRR	208.64	0.87
Agricultural Land-Close-grown	AGRC	9489.46	39.73
Forest - Deciduous	FRSD	940.81	3.94
Alamo – Switch grass	SWCH	263.05	1.10
Eucalyptus	EUCA	169.75	0.71
Forest-Mixed	FRST	7738.3	32.40

2.3.3. Soil Data

Nature and conditions soils affect how river basin responds to a certain rainfall event greatly (Shrestha et al., 2013).soil properties such as the hydraulic conductivity, moisture content availability, physical properties , bulk density, chemical composition, organic carbon content and texture, for the different layers of each specific soil type are required by SWAT model (Setegn et al ., 2008). This soil data required by SWAT's for soil data base as per FAO soil group is obtained from the ministry of water resource GIS department. Eutric Fluvisols, Humic Cambisols, Chromic Vertisiols, Orthic Acrisols, Humic Cambisols, Humic Cambisols, Acrisols, Dystric Nitosols, Chromic Luvisols are the major soils in the study area.

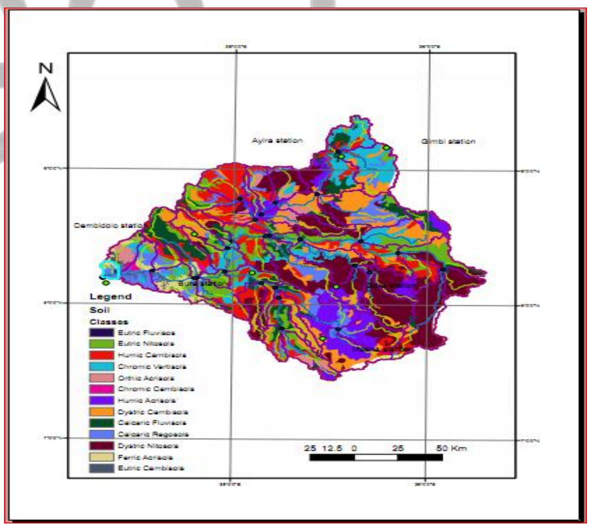


Figure 2.4. Soil map of the Baro watershed

Table 2.2.The SWAT result for the soils area coverage in the watershed is shown below.

Soil types	Area (km2)	% of total area
Humic Cambisols	2685.46	11.24
Eutric Nitosols	1765.49	7.39
Orthic cambisols	380.51	1.59
Chromic vertisols	2392.12	10.02
Eutric Cambisols	3940.13	8.58
Eutric Fluvisols	1218.29	5.10
Orthic Acrisols	2225.57	9.32
Chromic Cambisols	4121.89	17.26
Dystric Nitosols	7564.57	31.67
Ferric Acrisols	530.44	2.22

2.3.4. Meteorological Data

To simulate the hydrological conditions of the Basin meteorological data is needed by the SWAT model. This meteorological data required for the study were collected from the Ethiopian National Meteorological Services Agency (NMSA). The meteorological data collected were Precipitation, maximum and minimum temperature, relative humidity, wind speed and Sunshine hours. Data from twelve stations, which are within and around the study area, were collected. However, most of the stations have short length of record periods. Six of the stations have records within the range of 1986-2016 but most of them have missing data. The other problem in the weather data was inconsistency in the data record. In some periods there is a record for precipitation but there will be a missing data for temperature, and vice versa.

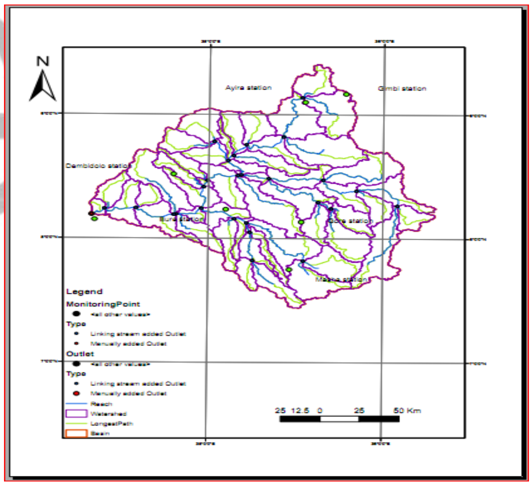


Figure 2.5. Delineated Watershed of Baro Watershed

Only Gore and Masha stations have data for relative humidity, sunshine hours and wind speed with short period of record. All stations listed above contain daily rainfall and temperature data for at least fifteen years. Therefore all stations were used for hydrological model development.

2.4 Hydrological data

The hydrological data was required for performing sensitivity analysis, calibration and Uncertainty analysis and validation of the model. The hydrological data was also collected from the Ethiopian Ministry of Water, Irrigation and Electricity of hydrological section. Even if the hydrological data of daily flow was collected for the rivers in the basin, due to time limitation to accomplish sensitivity analysis and calibration for the entire basin, it was decided to concentrate on the largest river Baro for modelling and climate impact analysis. Hence, it was only the hydrological data of the Baro used for sensitivity analysis, calibration and validation.

2.5 Hydro-Meteorological Data Analysis

2.5.1. General

Hydrological modelling requires a hydro-meteorological data (precipitation, temperature, relative humidity and sunshine hours) and hydrological (i.e stream flow) data for analysis. But the Reliability of the collected raw hydro-meteorological and hydrological data significantly affects quality of the model input data and as a result, the model simulation. Therefore the quality of the data is directly proportional to the output of the model at the of processing.

2.5.2. Missing Data Completion

Missing data is a common problem in the hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data is very important. The missing data can be completed using metrological and /or hydrological stations located in the nearby, provided that the stations are located in hydrological homogeneous region.

- **Rainfall Data screening**

Rough rainfall data screening of the six meteorological stations in the study area was first done by visual inspection of monthly rainfall data. Because of long braking in rainfall records of some stations and absence of lengthy overlapping period of record this inspection was done in the record of the hydrologic years of 1986 to 2016 for thirty one years. Graphical comparison of the rainfall data done by creating time series plotting of monthly rainfall data showed that the six stations show similar periodic pattern.

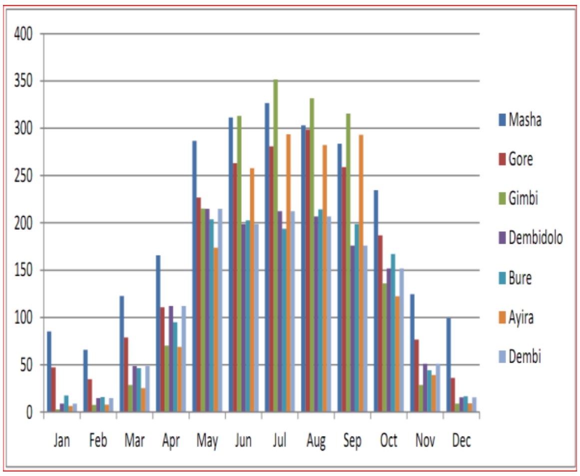


Figure 2.6. Average Monthly Rainfall data series (1986-2016)

When undertaking an analysis of precipitation data from gauges where daily observations are made, it is often to find days when no observations are recorded at one or more gauges. These missing days may be isolated occurrences or extended over long periods. In order to compute precipitation totals and averages, one must estimate the missing values. Several approaches are used to estimate the missing values. Station Average, Normal Ratio, Inverse Distance Weighting, and Regression methods are commonly used to fill the missing records. In Station Average Method, the missing record is computed as the simple average of the values at the nearby gauges. (Mc Cuen, 1998) recommends using this method only when the annual precipitation value at each of the neighbouring gauges differs by less than 10% from that for the gauge with missing data.

$$\mathrm{Px} = \frac{1}{\mathrm{M}}[P1 + P2 + \cdots + Pn] \text{……….3.4.}$$

Where:

P_x= the missing precipitation record

P_1, P_2,…….., P_m= precipitation records at the neighbouring stations

M= Number of neighbouring stations

If the annual precipitations vary considerably by more than 10 %, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighbouring stations by the ratios of normal annual precipitations.

$$\mathrm{Px} = \frac{Nx}{M}\left[\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pm}{Nm}\right] \text{………3.5.}$$

Where:

N_x= Annual-average precipitation at the gage with missing values

N_1, N_2,…….., N_m= Annual average precipitation at neighbouring gauges.

In this research because of the shortage of the total annual rainfall and normal rainfall, which is necessary conditions for the normal ratio and station average methods, the regression was good methods of estimation to fill the gaps.

Method based on regression analysis

Assume that two precipitation gages Y and X have long records of annual precipitation, i.e.Y_1, Y_2,………,Y_N and X_1, X_2,……X_N. The precipitation Y_t is missing. We will fill in the missing data based on a simple linear regression model. The model can be written as:

Y_t = a+bX_t

Then R^2 indicates the relationship between the two variables. The higher the value of R^2 indicates the best fit of the regression equation. Thus based on this for this estimation different R-values are calculated and the best fit selected for each station. Based on this method all the stations were filled and the regression equations with basic parameters are shown below.

- **Filling in Missing of Rainfall data**

A number of stations in the basin have incomplete records. Such gaps in the record are filled by developing correlations between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods.

Table 2.4. Regression equations for metrological stations missed data filling.

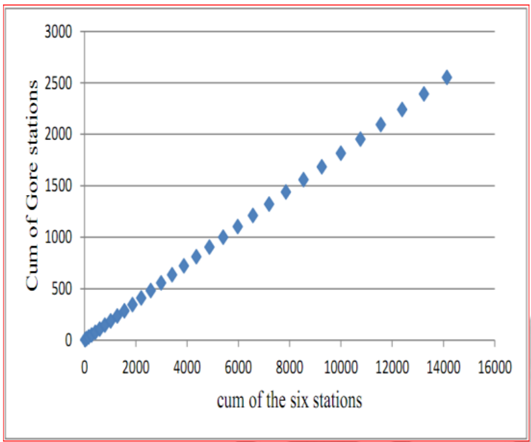
Station	R2	Coefficient a	Coefficient b	Regression equation
Dembidolo	0.657	1.223	-0.83	Y= 1.223(Bure)-0.83
Gimbi	0.709	1.163	1.085	Y=1.163(Ayira)+1.085
Masha	0.609	0.624	2.414	Y=0.624(Mizan Teferi)+2.414
Gore	0.648	0.767	-0.723	Y=0.767(Masha)-0.723

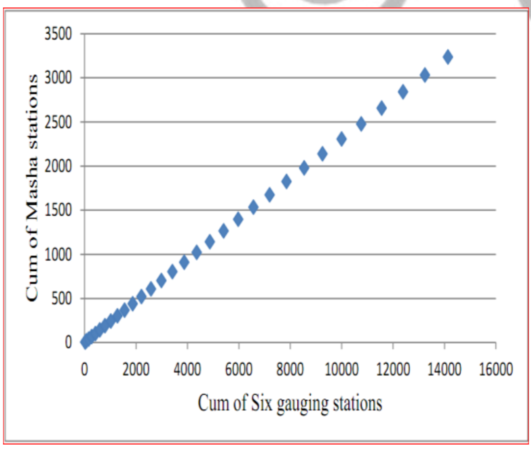
2.5.3. Consistency of Recording Stations

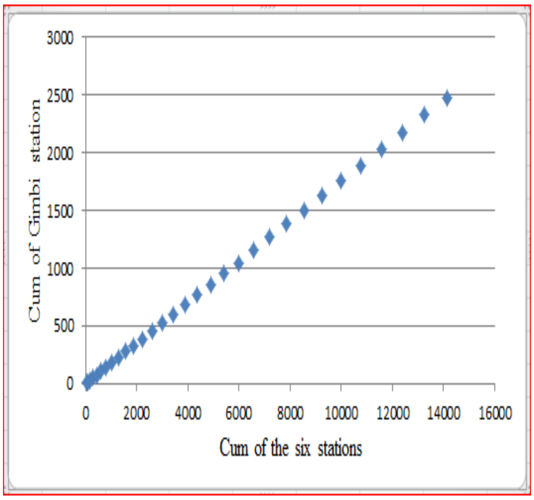
If the conditions relevant to the recording of a rain gauge stations have undergone a significant change during the period of record, inconsistency would rise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. Some of the common causes for inconsistency of record are :i) shifting of a rain gauge station to a new location, (ii) the neighbourhood of the station undergoing a marked change, (iii) change in the ecosystem due to calamities, such as forest fires, landslides, and (iv) occurrence of observational error from a certain date. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent(Subramanya, 2008).

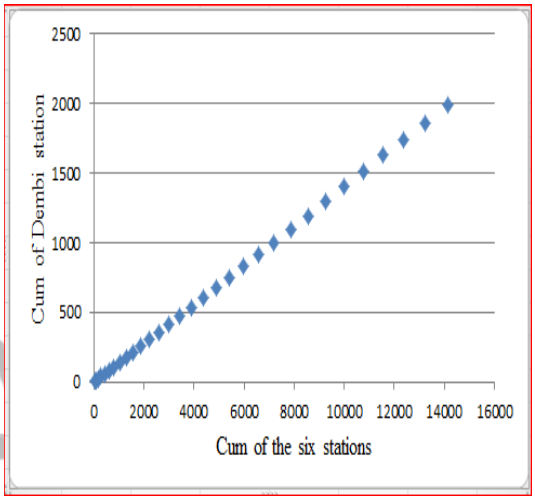
A group of 5 to 10 base stations in the neighbourhood of the problem station X is selected. The data of the annual (or monthly mean) rainfall of the station X and also the average rainfall of the group of base stations covering a long period is arranged in the reverse chronological order. The accumulated precipitation of the station X (i.e.$\sum Px$) and the accumulated values of the average of the group of base stations (i.e.$\sum Pav$) (i.e, Masha, Gore, Bure, Ayira, Gimbi and

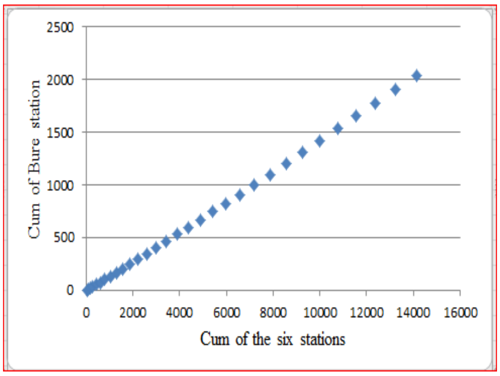
Dembi dolo stations) are calculated starting from the latest record. Values of ∑Px are plotted against ∑Pav for various consecutive time periods. If a decided change in the regime of curve is observed it should be corrected. However, as all the selected stations in this study were consistent as shown below by the double mass curve there is no need of further correction.











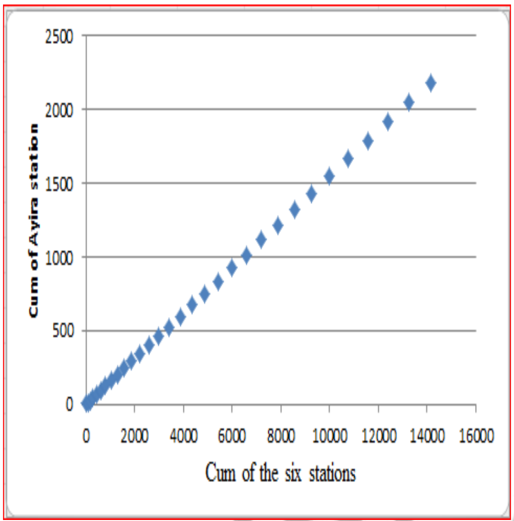


Figure 2.7. Double mass curve of gauging stations

2.6. Model set up

2.6.1. Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 37N, which is a projection parameters for Ethiopia. A watershed was partitioned into a number of sub-basins, for modelling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold based stream definition option was used to define the minimum size of the sub-basins.

2.6.2. Hydrological Response Units (HRUs)

The land area in a sub-basin was divided into HRUs. The HRU analysis tool in Arc-SWAT helped to load land use, soil layers and slope map to the project. The delineated Watershed by Arc SWAT and the prepared land use and soil layers were overlapped 100%. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected. The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. For this specific study a 5% threshold value for land use, 20% for soil and 20% for slope were used. The HRU distribution in this study was determined by assigning multiple HRU to each sub-basin.

2.6.3. Weather Generation

The swat model has an automatic weather data generator. However it needs some input data to run the model. Input data required are daily values of precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity. But, in many areas such data are either incomplete or records may not have sufficient length, which is the case in this study. If no data are available at the same time for all stations, the model can generate all the remaining data from daily precipitation and temperature data. In this research of the six stations which were used in order to run the SWAT model only two stations have full data. These stations are Masha and Gore meteorological stations. Using these two stations the SWAT model generates representative weather variables for Baro watershed. In this research, six stations were used to run the swat model for estimation of surface runoff. From this six stations only two of them are with full of data (i.e Gore and Masha stations) .Therefore from this two stations weather is generated for the rest of missing stations using the automatic weather data generator.

2.6.4. Sensitivity analysis

Sensitivity analysis is a technique of identifying the responsiveness of different parameter involving in the simulation of a hydrological process. For big hydrological models like SWAT, which involves a wide range of data and parameters in the simulation process, calibration is quite a bulky task. Even though, it is quite clear that the flow is largely affected by curve number, for example in the case of SCS curve number method, this is not sufficient enough to make calibration as little change in other parameters could also change the volumetric, spatial, and temporal trend of the simulated flow. Hence, sensitivity analysis is a method of minimizing the number of parameters to be used in the calibration step by making use of the most sensitive parameters largely controlling the behaviour of the simulated process (Zeray., 2006). This appreciably eases the overall calibration and validation process as well as reduces the time required for it.

After a thorough pre-processing of the required input for SWAT 2012 model, flow simulation was performed for a thirty one years of recording periods starting from 1986 through 2016.The first four years of which was used as a warm up period and the simulation was then used for sensitivity analysis of hydrologic parameters and for calibration of the model. Sensitivity analysis was performed on 19 SWAT parameters and the most sensitive parameters were identified using Global sensitivity analysis method in SWAT-CUP SUFI12. (Griensven.A, 2005).

2.6.5. Calibration and Validation of SWAT Model

SWAT-CUP

SWAT-CUP is an interface that was developed for SWAT. Using this generic interface, any calibration/uncertainty or sensitivity program can easily be liked to SWAT.

Calibration of Model

Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two. Automated model calibration requires that the uncertain model parameters are systematically changed, the model is run, and the required outputs (corresponding to measured data) are extracted from the model output files.

The main function of an interface is to provide a link between the input/output of a calibration program and the model. The simplest way of handling the file exchange is through text file formats.

The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman, 2005) presented nearly 20 different statistical tests that can be used for evaluating SWAT stream flow output during a manual calibration process. They recommended using the Nash-Suttcliffe simulation efficiency ENS and regression coefficients R^2 for analysing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed.

Validation of Model

Calibrated model parameters can result in simulations that satisfy goodness-of fit criteria, but parameter values may not have any hydrological meaning. Values of model parameters will be a result of curve fitting. This is also reflected in having different sets of parameter values producing simulations, which satisfy these criteria. It is necessary to test if parameter values reflect the underlying hydrological processes, and are not a result of curve fitting. Therefore; to conduct appropriate model validation results, it is necessary to carry out split sample test. The split-sample test involves splitting the available time series into two parts. One part is used to calibrate the model, and the second part is used for testing (validating) if calibrated parameters can produce simulations, which satisfy goodness-of-fit tests.

The spilt sample test is suitable for catchments with long time series, and it is applied in this catchment since it has thirty one years of data. For this catchment, the available record is split into two equal parts that is from 1990-2005 for calibration and 2006-2016 for validation.

2.6.6. SWAT-Model Performance Assessment

To evaluate the model performance a coefficient of determination (R^2), Nash-Sutcliffe (NSE), and root mean square error (RMSE) are applied. The accuracy of the simulated value when compared with the observed value is evaluated by R^2, whereas the NSE measures the goodness of fit and describes the variance between the simulated and observed values. It depicts the strength between the simulated and observed data and the direction of the linear relation. (X.Zhang, 2007). Generally, the calibration and validation of the SWAT model are considered to be acceptable or satisfactory performance when NSE is within the range of 0.5 and 0.65, considered satisfactory when the range is between 0.65 and 0.75.The NSE value between 0.75 and 1.00 indicate a very good performance. Lastly, RMSE was used to assess the validity of the model in this study. The desired value for RMSE is 0, which depicts a perfect simulation, with lower values representing better performance.

Table 3.5. General Performance rating for the recommended statistics

Performance Rating	NSE
Very good	0.75<NSE≤1.00
Good	0.65<NSE≤0.75
Satisfactory	0.50<NSE≤0.65
Unsatisfactory	NSE≤ 0.50

2.7. Climate Change Scenarios

When attempting to evaluate the response or sensitivity of any physical (or biological) system to climate change, one of the largest uncertainties introduced is our current level of understanding (or lack thereof) of the magnitude, or even the direction of future climate change. Even if global climate change could be modeled using today's general circulation models (GCMs), much climatic variation takes place at regional and smaller scales that are unresolved and will remain so for the foreseeable future. Because of this, studies of the effects of climate change on hydrologic systems are limited to the use of climate change scenarios that may or may not match future climate realities. However, these scenarios are useful for investigating the response of hydrologic systems to climate change and variability since they are easily constructed and employed as inputs to other models.

A number of different approaches to developing climate change scenarios have been devised in recent years. These include GCM output, analog climates (historical, paleoclimatic or spatial), synthesis scenarios ("scenarios by committee"), arbitrary change scenarios, or scenarios based on physical or statistical arguments (WMO, 1987) . While GCM output can provide some indication of the direction as well as the possible magnitude of a climate change associated with some forcing (e.g., doubled CO2), the uncertainties associated with GCMs, as well as their poor spatial resolution, reduce their usefulness for studies of regional hydrologic consequences of climate change. Although resource managers and planners may desire indications of climate change direction and magnitude, GCM output must be used cautiously. Hypothetical, arbitrary climate change scenarios can be developed at much lower cost than GCM scenarios, and can provide useful information on the response of hydrologic systems to plausible levels of climate change and variability.

Only two climatic inputs (temperature and precipitation) were used to compute the climate change impact on the Hydrology of the Baro Catchment. Scenarios with mean annual temperature changes of 0^oC, 2^oC, 3.5^oC, 4.5^oC, 6^oC and annual total precipitation changes from -20% to +20% at 10% interval were constructed with the assumption that all months experienced the same change (i.e constant temperature change or precipitation change.

2.7.1. Impact of climate change on Water yields

By adjusting the climatic inputs in the SWAT model, impact assessment of climate change on water yields can be accomplished. Simulated water yields under the High future scenarios RCP8.5 were evaluated relative to the observed monthly discharge for the gauge station Baro watershed. This was done through graphical methods. Regression graphs of the annual totals of the observed for the period 1986- 2016 were compared with those of the simulated water yields for the 2050s and 2080s from the two climate change scenarios (i.e. precipitation and temperature change scenarios).

3. Result and Discussion

3.1. SWAT Hydrological Model Results

3.1.1. Watershed Delineation

The Arc SWAT interface proposes the minimum, maximum, and suggested size of the sub basin area (in hectare) to define the minimum drainage area required to form the origin of a stream. Generally, the smaller the threshold area, the more detailed are the drainage networks, and the larger are the number of sub-basins and HRUs. However, this needs more processing time and space. As a result, an optimum size of a watershed that compromises both was selected. (Dilnesaw, 2006) did a sensitivity analysis of the threshold area on SWAT model performance and found that the optimum threshold area that can be used for the delineation procedure is ±1/3 of the suggested threshold area. Therefore, a threshold area of -1/3 of that suggested by the model was used.

After running the SWAT model to find the climate impact on the Baro River and SWAT-CUP for calibration of the model, the following results were found. The average annual rainfall of the basin is 2156.8 mm and surface water runoff of 891.09 mm and lateral soil flow is 57.77 mm. The entire model output types, which have monthly and annual values is shown in table 5.1. The total runoff found by the model in the Catchment area of 24563.64 km^2.

Table 3.1 Average annual basin values.

AVERAGE ANNUAL BASIN VALUE	
Precipitation	2156.8mm
Surface runoff Q	891.09mm
Lateral Soil Q	57.77mm
Ground water (shal AQ) Q	580.08mm
Groundwater (Deep AQ)Q	47.1mm
Revap (Shal AQ ⟹ soil/plants)	24.1mm
Deep AQ recharge	29.00mm
Total AQ recharge	954.36
Total water yield	1223.06mm
Percolation out of soil	935.17mm
ET	627.2mm
PET	1204.9mm

Table 3.2. Average Monthly Basin Values .

MON	RAIN	SURF Q	LAT Q	Water Yiled	ET	PET
mm	mm	mm	mm	mm	mm	mm
1	29.54	0.59	1.31	17.93	24.14	115.77
2	25.26	0.42	1.01	11.6	39.2	121.99
3	130.53	55.33	1.47	63.51	71.23	133.59
4	102	2.0	2.4	15.13	72.	121

	.89	6	6		56	.06
5	299.46	89.86	4.65	114.08	68.78	102.46
6	240.79	8.64	7.05	85.81	61.06	76.08
7	370.29	119.97	8.59	218.2	56.85	70.74
8	414.63	157.83	9.4	290.12	58.62	76.63
9	280.07	52.44	8.86	176.61	57.01	81.18
10	174.73	17.95	7.6	125.97	54.64	96.52
11	61.67	2.36	4.14	69.28	41.35	99.99
12	27.4	0.72	2.18	35.05	29.28	112.04

The water balance in SWAT considers precipitation as inflow to the watershed unit, evapotranspiration and deep percolation as loss and surface runoff and lateral flow as the outflow.

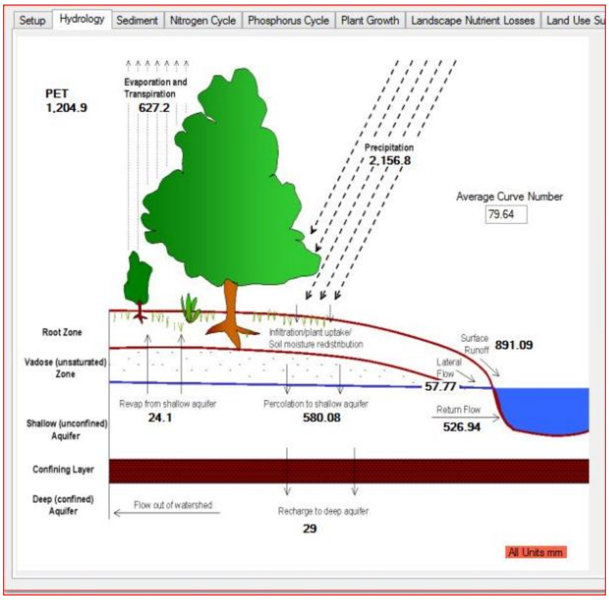


Figure 3.1. General SWAT model result Baro Watershed

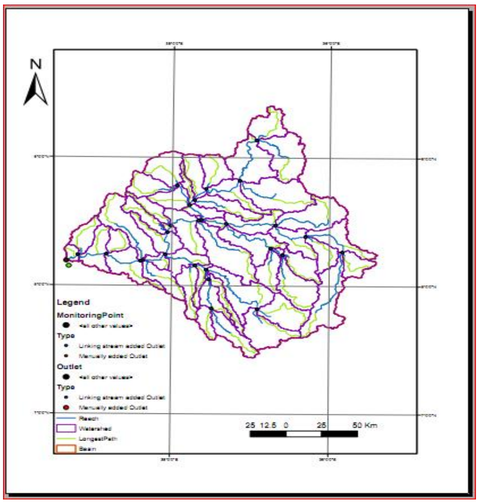
3.1.2. Determination of Hydrologic Response Units

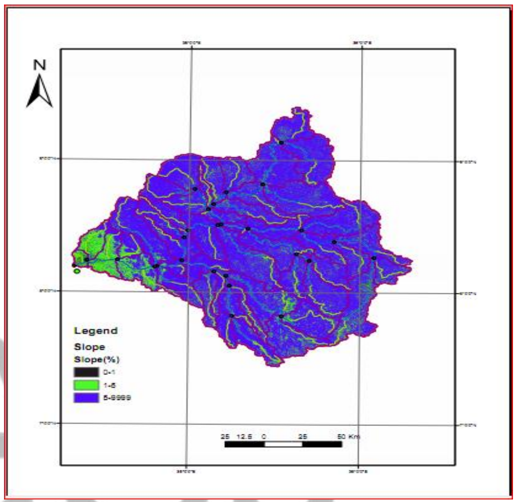
After the delineation of the catchment is completed determination of HRU follows. The HRUs were determined by assigning one HRU for each sub basin considering the dominant soil/land use combinations, which makes the automatic calibration easy. After mapping the basins for terrain, land use and soil, each of the basins has been simulated for the given hydrologic response units and sub-basins

The overall watershed delineation and HRU definition simulation in the watershed gave a watershed area of 24563.64 km^2 which resulted in 53 sub-basins and 201 HRUs. The watershed delineation of the area gave minimum, maximum and mean elevations in the basin of 416, 3244, and 1678.39 masl respectively. The area covered by each land use type is presented below in table 4.3

Table 3.3. Area covered by Land Use, Soil and Slope

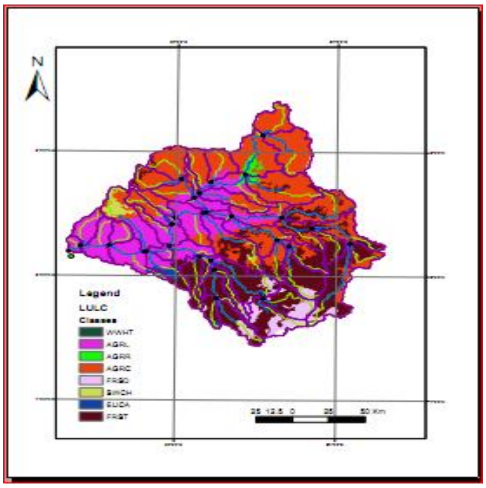
	Area [ha]	Area[acres]	
Watershed	2456364.6900	6069799.9672	
	Area [ha]	Area[acres]	%Wat.Area
LANDUSE:			
Agricultural Land-Close-grown --> AGRC	938359.2276	2318732.5694	38.20
Agricultural Land-Row Crops --> AGRR	25820.3866	63803.4662	1.05
Forest-Mixed --> FRST	757145.6978	1870944.8764	30.82
Agricultural Land-Generic --> AGRL	573655.5007	1417531.4250	23.35
Alamo Switchgrass --> SWCH	26298.6990	64985.4001	1.07
Eucalyptus --> EUCA	21200.4888	52387.4679	0.86
Forest-Deciduous --> FRSD	113884.6896	281414.7622	4.64
SOILS:			
Vc29-3a-267	246152.4545	608255.0228	10.02
Bh4-2c-34	333904.6192	825095.0093	13.59
Ao41-2bc-5	215618.2617	532803.5056	8.78
Jc30-2-3a-112	115820.5106	286198.2727	4.72
Ne27-2b-162	612020.1332	1512332.3502	24.92
Bh12-3c-31	366971.7361	906805.5084	14.94
Ne13-3b-158	284063.5214	701935.1646	11.56
Ao63-3b-6	78408.6991	193751.8160	3.19
Rc18-2b-199	172814.4438	427033.1314	7.04
Af17-1-2a-2	30590.3103	75590.1862	1.25
SLOPE:			
5-9999	2284538.6676	5645209.2745	93.00
1-5	168602.9178	416626.2399	6.86
0-1	3223.1047	7964.4528	0.13

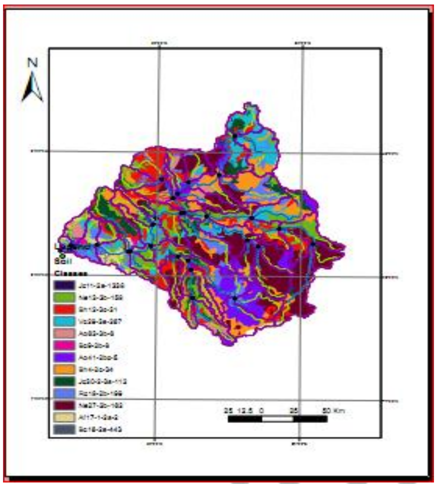




a). Delineated Watershed map

b). slope map





a) Land use map
d) soil map

Figure 3.2. The delineated sub basins, land use, slope, and soil map of the Baro-Watershed

3.2. Performance Evaluation of the Hydrologic Model

3.2.1. Sensitivity Analysis

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or on model predictions. Even though 19 parameters were used for the sensitivity analysis, all of them have no meaningful effect on the daily flow of the Baro River. Table 4.5 below shows the rank of sensitive parameters according to their effect on the catchment.

Nineteen hydrological model parameters of the SWAT model underwent sensitivity and uncertainty analyses using Global sensitivity analysis method in SWAT-CUP SUFI2. The top 12 parameters having sensitivity indices greater than or equal to 0.05 were then selected, as shown in table below.

- moisture condition II (CN2)
- base flow alpha factor (Alpha_Bf)
- Available water capacity of the soil layer (SOL-AWC)
- Groundwater “revap” coefficient, (GW-REVAP)
- Manning’s n value for main channel (CH-N2)
- Threshold depth of water in the shallow aquifer for return flow to occur (mm) (GWQMN)

- Surface Runoff Lag time (SURLAG)
- Plant uptake compensation factor (EPCO)
- Depth from soil surface to bottom of layer (SOL_Z)
- Channel effective hydraulic conductivity (CH_K2)
- Soil Evaporation compensation factor (ESCO)
- Manning’s “n” value for overland flow (OV_N)
- Threshold depth of water in the shallow aquifer required for return flow to occur (mm)

A t-test and P-values

The t-stat is the coefficient of a parameter divided by its standard error. It is a measure of the

Precision with which the regression coefficient is measured. If a coefficient is “large” compared to its standard error, then it is probably different from 0 and the parameter is sensitive (Alkasim, 2016).

The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05) indicates that you can reject the null hypothesis. In other words, a predictor that has a low p-value is likely to be a meaningful addition to your model because changes in the predictor's value are related to changes in the response variable. Conversely, a larger p-value suggests that changes in the predictor are not associated with changes in the response.

So that parameter is not very sensitive. A *p-value* of < 0.05 is the generally accepted point at which to reject the null hypothesis (i.e., the coefficient of that parameter is different from 0). With a *p-value* of 0.05, there is only a 5% chance that results you are seeing would have come up in a random distribution, so you can say with a 95% probability of being correct that the variable is having some effect.

Table 3.4. Most sensitive Parameters

Parameter	t-stat	P-Value
13:R__HRU_SLP.hru	0.005011466	0.996034622
3:V__GW_DELAY.gw	-0.056035604	0.955684988
15:R__RCHRG_DP.gw	-0.107576382	0.915047972
11:R__CANMX.hru	-0.266652553	0.791561055
10:R__SOL_K .sol	0.274031596	0.7859384
12:R__SLSUBBSN.hru	-0.31337519	0.75616411
17:R__REVAPMN.gw	0.430910091	0.669614185
14:R__OV_N.hru	-0.448327991	0.657137873
6:R__ESCO.hru	0.44999772	0.655947043
8:R__CH_K2.rte	0.541203652	0.592363812
19:R__SOL_Z.sol	-0.726318754	0.47327262
18:R__EPCO.hru	0.778468395	0.442390054
16:R__SURLAG.bsn	1.025567806	0.313294157
4:V__GWQMN.gw	1.157089578	0.256366197
7:R__CH_N2.rte	1.586534098	0.123103846
5:R__GW_REVAP.gw	2.107911079	0.043501032
9:R__SOL_AWC.sol	2.452444939	0.020223274
2:V__ALPHA_BF.gw	-3.401778911	0.001914614

1:R__CN2.mgt	5.151955794	0.000015167

Based on A *t*-test that was used to identify the relative significance of each parameter that was a value larger in absolute value was most significant and p-value the significance of the sensitivity, a value close to zero is more significant. From the model output, the first two most sensitive parameters are SCS runoff curve number f (CN2) and base flow alpha factor (Alpha_Bf).

3.2.2. Model Calibration

The calibration of the model was performed for 16 years (1990 to 2005) using Baro River flow data at Gambella gauging station. Taking the first four years as a warm up period, the flow was simulated for 16 years from January 1st 1990 to December 31st 2005.

The automatic calibration SUFI-2 was used to calibrate the model using the observed stream flow. Observed daily stream flows were adjusted on the monthly basis and simulations run were conducted on monthly basis to compare the modeling output with the measured daily discharge at the outlet of Baro watershed.

Table 3.5. Model efficiencies parameters in calibration and validation periods

Sub basin No	Simulation period	Parameter	period	values
6 gauging stations	1990-2005	R2	Calibration	0.9
		NS	Calibration	0.66
	2006-2016	R2	Validation	0.93
		NS	Validation	0.61

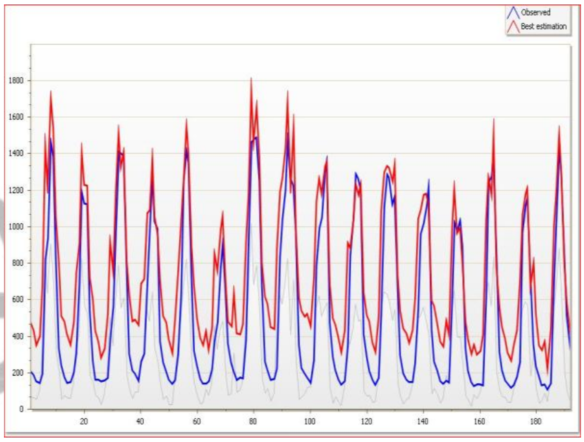


Figure 3.3. Calibration results of average monthly simulated and observed flows of Baro River at Gambella station (1990-2005)

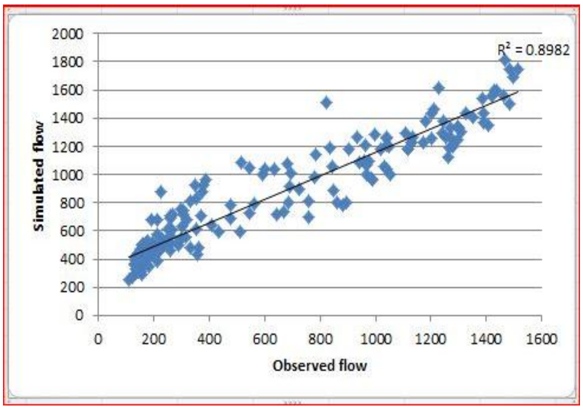


Figure 3.4. Simulated and observed flows during the calibration period using scatter plot (1990-2005)

3.2.3. Model Validation

Model validation was carried out over the period of 2006-2016. As it can be seen in figure below the model performance is improved, the coefficient of determination in this case is found to be R^2=0.93 and NSE=0.61. The observed and simulated flow hydrograph show well agreement. In general the model performed reasonably in simulating flows for periods outside of the calibration period, based on adjusted parameters during calibration.

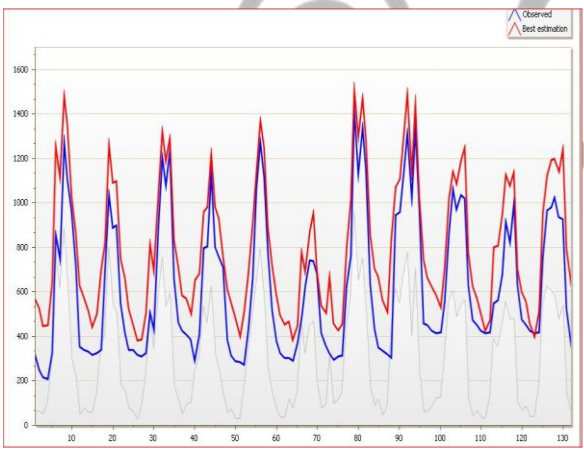


Figure 3.5. Validation results of average monthly flows of Baro at Gambella station (2006-2016).

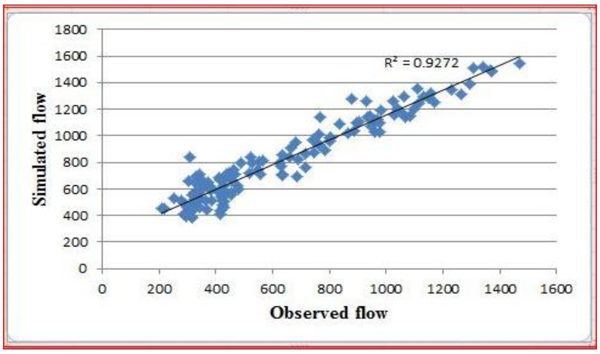


Figure 3.6. Observed vs simulated flow for validation (2006-2016).

3.3. Scenarios Developed for the Future

Warming projections under medium scenarios indicate that extensive areas of Africa will exceed 2^{o}C by the last two decades of this century relative to the late 20th century mean annual temperature and all of Africa under high emission scenarios (RCP 8.5 W/m^2) and reach between 3^{o}C and 6^{o}C by the end of this century (Niang, 2014).

Most of areas of the African continent lack sufficient observational data to draw conclusions about trends in annual precipitation over the past century. In addition to this, in many regions of the continent differences exist between different observed precipitation data sets (Nikilin, 2012). Therefore to check simply the effect of precipitation change on the stream flow, precipitation variation of from -20% to +20% was taken.

The changes in stream flow under the impact of climate change was investigated by using several hypothetical scenarios (synthetic approach) applied to the climate normal (1986-2016) meteorological data. Incremental climate change scenarios were applied with a hypothetical temperature increase (0, +2°C, +3°C, +4°C, +5°C and +6°C) and precipitation change from -20% to +20% at 10% interval were examined to check the impact of climate change in the stream flow. In this research the impact were analyzed for 2050s with temperature change of 0°C, 2°C, 3°C and for 2080s with temperature change of 4°C, 5°C and 6°C.

For a constant temperature the total annual water yield increases with the increment of Precipitation as it is shown in the Figure 4.10. On the other hand for constant precipitation the average water yield decreases with the increment of temperature in the stream flow for the period of 2050s and 2080s as shown in Figure 4.9. For example for temperature of 0°C but with increment of precipitation the average water yield will increase as shown below in the table below whereas for constant precipitation there is a reduction of total water yield.

Table 3.6. Total annual water yield for the 2050s and 2080s

ΔP		-20%	-10%	0%	10%	20%
ΔT	0°C	1521.05	1523.13	1525.11	1527.29	1529.37
	2°C	1498.63	1500.7	1502.77	1504.84	1506.91
	3°C	1485.46	1487.52	1489.59	1491.65	1493.71
	4°C	1472.52	1474.58	1476.63	1478.69	1480.74
	5°C	1459.75	1461.79	1463.84	1465.84	1467.94
	6°C	1446.82	1448.86	1450.49	1452.94	1454.98

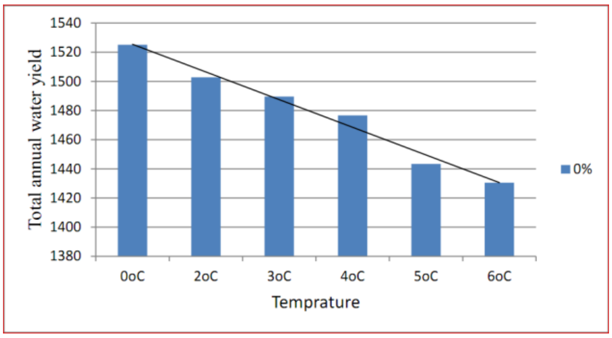


Figure 3.7: Trend which shows the variation of total annual water yield for constant precipitation but with varying temperature

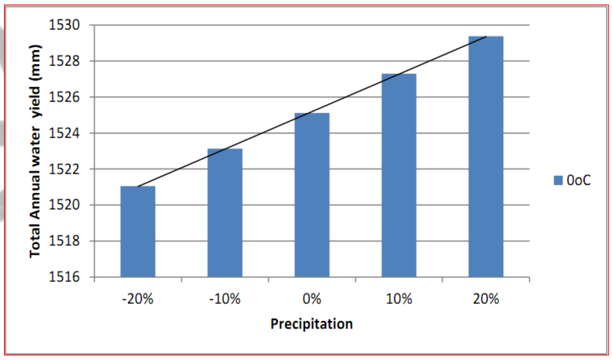


Figure 3.8: Trend which shows the variation of total annual water yield for constant precipitation but with varying temperature

3.3.1. Sensitivity Analysis

The changes in stream flow under the impact of climate change was investigated by using several hypothetical scenarios (synthetic approach) applied to the climate normal (1986-2016) meteorological data. Incremental climate change scenarios were applied with a hypothetical temperature increase of 0^oC, 2^oC and 3^oC for the period of 2050s according to IPCC Fifth Assessment report set for Africa and 4^oC, 5^oC and 6^oC for the period of 2080s. On the other hand taking the precipitation range from -20% to 20% at 10% interval the change of the flow is examined as shown below.

Table 3.7. Mean annual discharge (cms) due to the changes in temperature and precipitation for the period of 2050s.

ΔP	-20%	-10%	0%	10%	20%
ΔT 2°C	45303	45369	45436	45503	45569
2.5^o C	45041	45107	45175	45241	45308
3^oC	44785	44852	44918	44985	45051

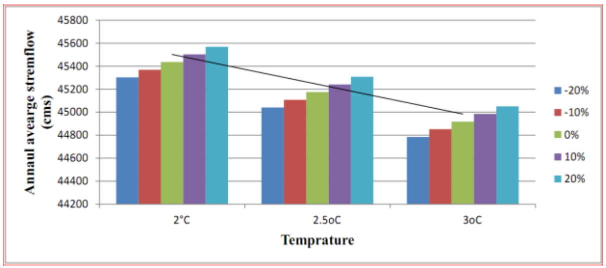


Figure 3.9: Mean annual discharge (cms) due to the changes in temperature for the period of 2050s using Bar-Chart.

Table 3.8. Mean annual discharge (cms) due to the changes in temperature and precipitation for the period of 2080s

ΔP	-20%	-10%	0%	10%	20%
ΔT 4° C	44508	44576	44642	44708	44774
5^o C	44024	44090	44156	44223	44288
6^o C	43242	43337	43403	43469	43534

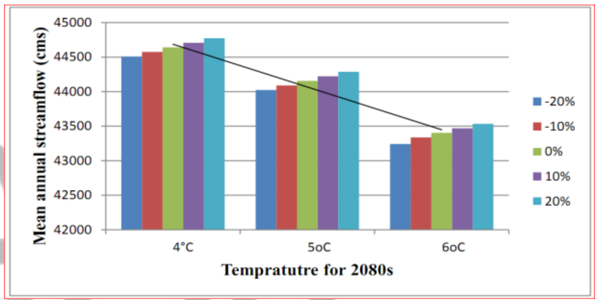


Figure 3.10: Mean annual discharge (cms) due to the changes in temperature precipitation for the period of 2080s using Bar-Chart.

3.3.2. Change of annual mean discharge with respect to Baseline

The relative sensitivity of stream flow to the changes in precipitation, keeping the temperature unchanged, gives a moderate changes in stream flow as compare to the changes due to temperature for the river. Increasing temperature by 2 and 3^oC decreased stream flow rates by 11.7% and

12.73%, respectively, while 10% and 20% drop in rainfall resulted in a stream flow decrease of 11.6% and 11.7%. These result suggested that stream flow in the Baro Watershed will be more sensitive to the average increase in temperature than to the average decrease in rainfall, showing the role of evapotranspiration in the water cycle.

Table 3.9 Changes in mean annual discharge (%) due to changes in temperature and precipitation in 2050s and 2080s.

ΔP	-20%	-10%	0%	10%	20%
ΔT 2°C	11.7	11.6	11.46	11.3	11.2
ΔT 3°C	12.73	12.6	12.45	12.3	12.2
ΔT 3.5°C	13.27	13.13	13.00	12.878	12.75
ΔT 4.5°C	14.2	14.08	13.95	13.82	13.69
ΔT 6°C	15.56	15.5	15.42	15.29	15.17

Sensitivity to Precipitation Change:

For the Baro River, changes in average annual stream flow due to the changes in precipitation, keeping the temperature constant are shown in Figure 4.11. Various precipitation scenarios are analyzed which include -20%,-10%, 0%, 10%, and 20% changes with respect to the base period of 1986-2016. As a first approximation, a linear regression analysis of the stream flow responses for the various scenarios indicated that a 10 % change in precipitation would produce a 13 % change in stream flow for Baro River. Table 4.9 and Figure 4.10 shows that the Baro River is almost equally sensitive to a reduction and increase in precipitation.

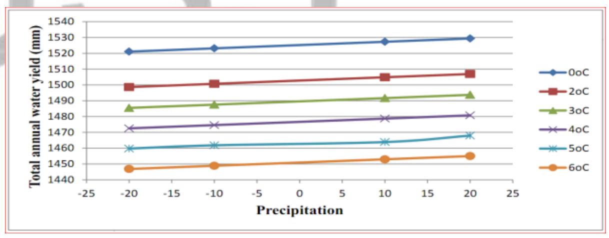


Figure 3.11 Increasing trend of annual water yield with increase of precipitation (2050s, 2080s).

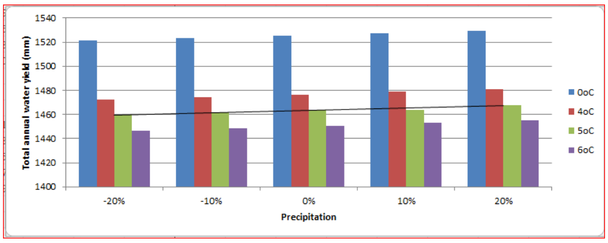


Figure 3.12: Total annual water yield (mm) due to the changes in precipitation for the period of 2080s using Bar-Chart.

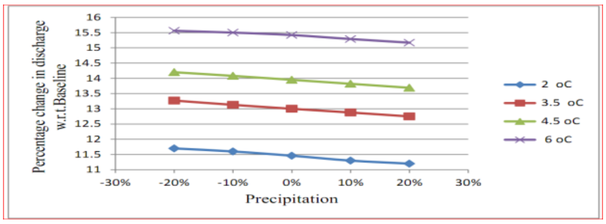


Figure 3.13. Changes in annual mean stream flow (%) at Gambella station with respect to baseline (%).

Sensitivity to Temperature Change:

The relative sensitivity of stream flow to the changes in temperature, keeping the precipitation unchanged, gives more changes in stream flow as compared to the changes due to precipitation for the watershed as shown in Table 4.10 above.

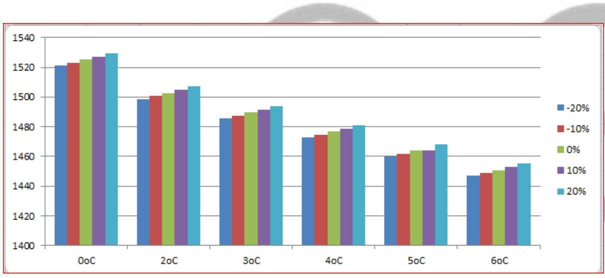


Figure 3.14. Effect of temperature keeping precipitation constant

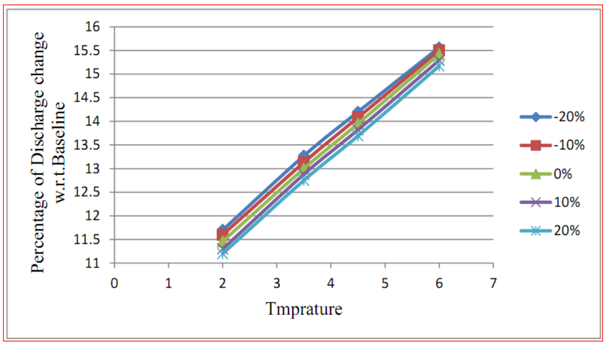


Figure 3.15 Changes in Annual Average Discharge (%) at Gambella station with respect to baseline.

Sensitivity to the Combined Effect of Temperature and Precipitation

Sensitivity of the flow when both temperature and precipitation changes are taken into account is analyzed. Combination of 2°C, 3°C, 4.5°C and 6°C with Precipitation ranging from -20% to +20% in the interval of 10% is analyzed here. Generally a change toward a warmer and drier climate would have the greatest effects on runoff. For example if we take a 2°C and 20% precipitation increase there is a reduction of 11.2% in stream flow, whereas a 3°C temperature increase with a 20% reduction of precipitation have a 12.73% reduction in stream flow. From this it can also be concluded that even with an increase in annual precipitation, increased evapotranspiration reduced net annual runoff.

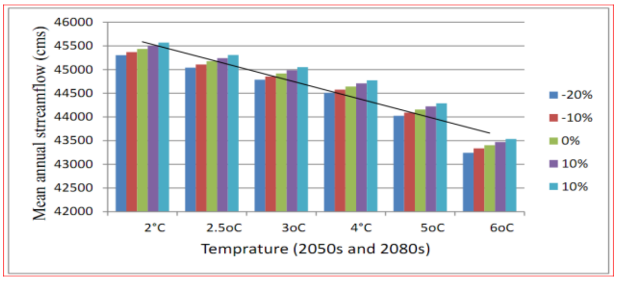


Figure 3.16 Combined effect of climate change and temperature over average annual stream flow

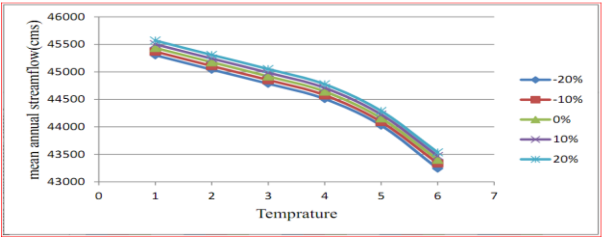


Figure 3.17 Combined effects of climate change and temperature over average annual stream flow.

4. Conclusion and Recommendation

4.1. Conclusion

In this study, potential impacts of climate change on the future stream flow of the Baro River has been assessed by using SWAT hydrological model on the basis of climate change forced by RCP 8.5 scenarios of IPCC 5th Assessment (AR5) report for 2050s and 2080s.

The SWAT model was used to create a hydrological model on the Baro watershed to investigate the effect of climate sensitivity on the stream flow based on the basis of climate change scenarios projected by IPCC 5th Assessment (AR5) report for 2050s and 2080s of the 21st century for African countries. This special Thesis focuses on the worst condition of RCP 8.5W/m^2 by taking the scenarios of temperature change and precipitation according to the IPC report set for African countries. For a region with critical water needs, understanding the possible consequences of climate change on stream flow is necessary to ensure adequate future supplies.

Initially the calibration and validation of the stream flow was made in which for the calibration the period from 1990-2005 was taken and for the validation process the period from 2005-2016 was taken. From the result a good performance was found with R^2 and NSE greater than 0.6 and 0.5 respectively. Following to the calibration and validation, the SWAT model was re-run using the temperature and precipitation scenarios to predict the impact of climate changes on the stream flow of the river. Then sensitivity of the flow to temperature and precipitation change at the Baro River in Gambella station was assessed.

This work demonstrated the high vulnerability of stream flow to changes in temperature and rainfall in the catchment. Generally, the decrease in rainfall was accompanied by a large increase in the evapotranspiration. The combination of this two trend is likely to result in decreased availability of water. A decrease in stream flow of 12.73% and 15.56% is expected for the period of 2050s and 2080s.

Precipitation scenarios yielded stream flow variations that correspond to the change of rainfall intensity and amount of rainfall, while scenarios with increased air temperature yielded a decrease in water level leading to a water shortage. Change in Temperature had a large effect on the magnitude of seasonal annual runoff than temperature.

4.2. Recommendation

The results of this study is a basis for informed decision in the water sector in terms of short and long term implementation of development projects and also strategic planning policies. These results can also be used in the water sector for water resources management and disaster risk reduction.

The results can be used by policy makers in understanding the vulnerability level of the Baro Catchment to climate change impacts; this will help in coming with suitable mitigation and adaptation approaches.

In the present research scenarios with mean annual temperature changes and annual total precipitation changes were constructed with the assumption that all months experienced the same change (i.e. constant temperature change or percentage precipitation change). While not all of the resulting scenarios are equally likely, and real climate changes will undoubtedly affect the seasonal cycle as well as the mean climate, these scenarios offer a simple basis on which to evaluate the impacts of climate change and variability on stream flow. Therefore it is recommended for the next researcher to include the seasonal effect of climate on the stream flow so that one can provide a good insight to the effect of climate change on the stream flow.

In the present study the land use was take for one year at the beginning of 21st century , for better approximation of future projected flow land use/land cover changes and population increase that cause difference in the water availability can be included in this model .

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