JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Assessment of Climate Change Impact on stream flow of Baro-Akobo River Basin Case study of Baro Catchment

A thesis submitted to the School of Graduate Studies of Jimma University, Jimma institute of technology in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

Prepared By: Shimelash Molla

October, 2017

Jimma, Ethiopia

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ADVISOR: Tamene Adugna (Dr.Ing)
CO-ADVISOR: Tolera Abdisa (MSC)

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DECLARATION

I, the undersigned, declare that this thesis entitled "**Assessment of Climate Change Impact on Stream Flow of Baro-Akobo River Basin: Case Study of Baro-Catchment"** is my original work, and has not been presented for a degree in this or any other University.

Name: Shimelash Molla

Signature: _____________Date ___________

CERTIFICATION

I, the signers, confirm that I read and hereby recommend for the receipt by the Jimma University a paper entitled: "**Assessment of Climate Change Impact on Stream Flow of Baro-Akobo River Basin: Case Study of Baro-Catchment**" in Partial Fulfilment of the Requirements for the Degree of Masters of Science in Civil Engineering (Hydraulic Engineering).

Advisor: Tamene Adugna (Dr.Ing)

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Co-advisor: Tolera Abdisa (MSc)

Signature: ______________ Date ___________

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 provide the understanding of the direction of climate change impact 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 R^2 = 0.90 during calibration and R^2= 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 2^oC ,and 3^oC for the period of 2050s and from 3.5^oC to 6^oC at 1.5^oC 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 2^oC gives an increment of stream flow by around 11% .Beside this, for a constant precipitation of 0% and variation of temperature from 2^oC to 3^oC 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 6^oC Scenarios (i.e. the worst scenarios) .

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

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ACRONYMS

DEM	Digital Elevation Model
GCM	Geographic Information System
GIS	Geographic Information System
HRU	Hydrologic Response Unit
IPCC	International Panel on Climate Change
NCEP	National Centre for Environmental Prediction.
PET	Potential Evapo transpiration
RCP	Representative Concentration Pathways
SDSM	Statistical Downscaling Model
SRES	Special Report on Emission Scenarios
SWAT	Soil and Water Assessment Tool
SWATCUP	Soil and Water Assessment Tool- Calibration and Uncertainty Program
WMO	World Meteorological Organisation

1. INTRODUCTION

1.1. 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 have 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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1.2. 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, in which Baro river is the major one. 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.

1.3. Objectives

1.3.1. General Objective

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

1.3.2. 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 possible effects of climate change on the hydrology of the catchment based on synthetic scenarios set by IPCC 5th assessment report.

2. LITERATURE REVIEW

2.1. Climate Change

2.1.1. Definition of Climate Change

Climate changes refer to a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate changes may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014).

2.1.2. Global Climate Change

Future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability. The global mean surface temperature change for the period 2016–2035 relative to 1986–2005 is similar for the four Representative Concentration Pathways (RCPs) and will likely be in the range 0.3°C to 0.7°C (medium confidence). This assumes that there will be no major volcanic eruptions or changes in some natural sources (e.g., CH4 and N2O), or unexpected changes in total solar irradiance. By mid-21st century, the magnitude of the projected climate change is substantially affected by the choice of emissions scenario. 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 for RCP4.5, RCP6.0 and RCP8.5 (high confidence). Warming is likely to exceed 2°C for RCP6.0 and RCP8.5 (high confidence), more likely than not to exceed 2°C for RCP4.5 (medium confidence), but unlikely to exceed 2°C for RCP2.6 (medium confidence). The increase of global mean surface temperature by the end of the 21st century (2081–2100) relative to 1986–2005 is likely to be 0.3°C to 1.7°C under RCP2.6, 1.1°C to 2.6°C under RCP4.5, 1.4°C to 3.1°C under RCP6.0 and 2.6°C to 4.8°C under RCP8.59 (IPCC, 2014).

Over the next decades, it is predicted that billions of people, particularly those in developing countries, face shortages of water and food and greater risks to health and life as a result of climate change .Concerted global action is needed to enable developing countries to adapt to the effects of climate change that are heppening now and will worsen in the future.

Africa may be the most vulnarable continent to climate variablity and change because of multiple existing stresses and low adaptive capacity. Existing stressess include poverty, food insecurity, political conflicts, and ecosystem degradation. By 2050, between 350 million and 600 million people are projected to experience increased water stress due to climate change. urban population is also projected to triple, increasing by 800 million people, compliacting urban poverty and access to basic services.(United States Environment Protection Agency, 2017)

2.2. The Impacts of climate change in Ethiopia

Climate change is already taking place now, thus past and presesnt changes help to indicate possible future changes. Over the last decades, the temprature in Ethiopia increased at about $0.2^{o}C$ per decade. The increase in minimum temprature is more pronounced with roughly $0.4^{o}C$ per decade. Precipitation, on the otherhand, remained fairly stable over the last 50 years when averaged over the country.(Keller, 2009)

The Baro-Akobo, Alwero,Gilo, Birbir and Sor together discharge an estimated $11.81bm^3$ of water annually. Accoding to water sector development program (2002-2016) water reources program, the long term mean annual flow of Gambella flood plain is estimated to $23.6bm^3$ but at the outlet of the basin it is only $11.8bm^3$. The diffrence of $11.8bm^3$ is lost through evaporation and overflows. (Berhane, 2013)

The mean temperature range in the area is about $27.5^{o}C$ below 500m on the flood plain to about $17.5^{o}C$ at 2,500m in the highland. The range in the mean maximum temperature is 35 to $24^{o}C$ and in mean minimum temperature from 20 to $10^{o}C$. Temperature peaks during February and March on the flood plain but high values extend into April in the highlands. Below about 700m elevation mean maximum temperature values exceed $38^{o}C$ for two to three months. in contrast to the low land, the area above about 2,000m is remarkdly cooler, with the maximum temperature in the hottest period not exceeding $28^{o}C$ and generally being in the range $21\text{-}26^{o}C$. The precipitation within the Bar-Akobo is formed under the influence of the south-eastern monsoons from the Indian Ocean. Like in the other parts of the country, the precipitation is strongly influenced by altitude. The annual rainfall is in the range of 900mm to 1500mm in areas with an altitude range between 400m and 500m, and in the range of 1900mm to 2400mm in areas with an elevation of 500m to 2000m.(Kassa, 2013)

2.3. Causes of Climate Change

Anthropogenic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever. This has led to atmospheric concentrations of carbon dioxide, methane and nitrous oxide that are unprecedented in at least the last 800,000 years. Their effects, together with those of other anthropogenic drivers, have been detected throughout the climate system and are extremely likely to have been the dominant cause of the observed warming since the mid-20th century.(IPCC, 2014a)

Continued emission of greenhouse gases will cause further warming and long-lasting 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 substantial and sustained reductions in greenhouse gas emissions which, together with adaptation, can limit climate change risks. Cumulative emissions of CO2 largely determine global mean surface warming by the late 21st century and beyond. Projections of greenhouse gas emissions vary a wide range, depending on both socio-economic development and climate policy.(IPCC, 2014a)

2.4. Climate Scenarios

2.4.1. Conditions for selecting climate change scenarios

Climate change scenarios selected for impact assessment should meet the following four conditions (Ian Burton, 1998):

Condition 1. The scenarios should be consistent with the broad range of global warming projections based on increased atmospheric concentrations of greenhouse gases,(Houghton, 1996).Regional changes in climate variables may be outside the range of global average changes, but should be consistent with what climate change theory and models conclude may happen.

Condition 2. The scenarios should be physically plausible; that is, they should not violate the basic laws of physics. It is not plausible, for example, to assume that a country with as large an area as Russia or Brazil would have a uniform increase or decrease in precipitation. However, such a scenario could be plausible for smaller areas. In addition, changes in variables need to be physically consistent with each other. For example, days with increased precipitation will most likely have increased cloudiness (Ian et al., 1998).

Condition 3. The scenarios should estimate a sufficient number of variables on a spatial and temporal scale that allows for impacts assessment. Many impacts models need scenario data for a number of meteorological variables such as temperature, precipitation, solar radiation, humidity, and winds. In addition, daily or more frequent information may be needed for some studies.

Condition 4. The scenarios should, to a reasonable extent, reflect the potential range of future regional climate change. For example, a set of scenarios that examines only a relatively large or small amount of warming, or only wet or dry conditions, will not help identify the full range of sensitivities to climate change.

In assessing options for creating climate change scenarios, it is important to meet as many of these conditions as possible. Where conditions are not met, the shortcoming should be acknowledged in reporting the results of analyses that use the scenarios.

2.4.2. Generic types of climate change scenarios

There are three generic types of climate change scenarios: scenarios based on outputs from GCMs, synthetic scenarios, and analogue scenarios. All three types have been used in climate change impacts research; although probably a majority of impacts studies have used scenarios based on GCMs. This section briefly describes each type of scenario and its relative advantages and disadvantages (Ian et al., 1998).

i). General Circulation Models (GCM)

GCMs are mathematical representations of atmosphere, ocean, ice cap, and land surface processes based on physical laws and physically-based empirical relationships. Such models have been used to examine the impact of increased greenhouse gas concentrations on future climate. GCMs estimate changes for dozens of meteorological variables for grid boxes that are typically 250 kilometres in width and 600 kilometres in length. Their resolution is therefore quite coarse. The most advanced GCMs couple atmosphere and ocean models and are referred to as coupled ocean- atmosphere GCMs (Gate at al., 1996) for an evaluation of coupled GCMs.

Two types of GCM runs can be useful for impact assessments. Almost all GCMs have been used to simulate both current (1HCO2) and future (2HCO2 or occasionally 4HCO2) climates. The difference between these simulated climates is a scenario of how climate may change with an effective doubling (or quadrupling) of atmospheric CO2 concentrations. These are referred to as equilibrium experiments since both the current and future climates are assumed by modellers to be in equilibrium (i.e., stationary). GCMs used for equilibrium experiments generally have only a very simple representation of the oceans.

To be sure, climate is never in equilibrium. Greenhouse gas concentrations are not held constant, because of human activities or other reasons. The assumption of a stable climate makes it easier, however, for climate modellers to estimate the effect of increased greenhouse gases on climate and for impact assessors to examine potential impacts.

The second type of experiment is called a transient experiment. Here, a coupled GCM is used to simulate current (1HCO2) climate and then future climate as it responds to a steady increase in greenhouse gas concentrations beyond 1HCO2 concentrations (e.g., (Manabe, 1995).

A typical forcing scenario in a transient experiment is a 1 percent per year increase in CO2 concentration, but many different forcing scenarios could in principle be used. The model is typically run for 100 years or more into the future.

An important limitation of many transient scenarios from GCMs is the so-called "cold start" problem (Hasselmann, 1993).This occurs when a transient GCM simulation fails to reflect the climate change that arises because of historical greenhouse gas emissions (Kattenberg, 1996). When this occurs, GCMs usually underestimate the change in climate in the first few decades beyond the present. More recently, a few "warm start" transient experiments have been successfully completed in which historical emissions of greenhouse gases back to the nineteenth century have been used to force the model (Mitchell, 1997). Many impact assessment studies have used GCMs as the basis for creating scenarios (Parry, 1988). These studies combined average monthly changes between 2HCO2 and 1HCO2 climates from equilibrium GCM experiments with 30 years of observed climate data. The use of the observed climate data provides greater spatial, and sometimes temporal, variability than can be provided by the GCM (thus helping meet Condition 3), although it assumes that these aspects of climate do not change from current conditions.

ii). Synthetic scenarios

Synthetic scenarios, sometimes referred to as arbitrary scenarios, are based on incremental changes in such meteorological variables as temperature and precipitation. For example, temperature changes of +2^{o}C and +4^{o}C can be combined with precipitation changes of 10 % or 20 % or no change in precipitation to create a synthetic scenario (Poiani, 1993).

Synthetic scenarios usually assume a uniform annual change in temperature and other variables over a study area, although some studies have introduced temporal and spatial variability to synthetic scenarios. (Rosenthal, 1995), used different uniform changes in winter and summer temperature across climate zones of the United States. Thus, they included some temporal and spatial variability. All three studies based the selection of synthetic scenarios on outputs from GCMs.

The main advantages of synthetic scenarios are their ease of use and transparency to policy makers and other readers of impacts studies. In addition, synthetic scenarios can capture a wide range of potential climate changes (Condition 4). One can examine small changes in climate (e.g., 1^{o}C) up to large changes in climate (e.g., 5^{o}C to 6^{o}C), and one can examine increased and decreased precipitation scenarios. In addition, because individual variables can be changed independently of each other, synthetic scenarios also help identify the relative sensitivities of sectors to changes in specific meteorological variables. A further advantage of synthetic scenarios is that different studies can use the same synthetic scenarios to compare sensitivities (although assuming the same synthetic scenario across different sites may well violate Condition 2, internal consistency). Synthetic scenarios are inexpensive, are quick and easy to construct, and generally require few computing resources.

A major disadvantage of synthetic scenarios is that they may not be physically plausible (Condition 2), particularly if uniform changes are applied over a very large area or if assumed changes in variables are not physically consistent with each other. As noted above, uniform changes in temperature, and particularly precipitation, are not plausible over large areas. It is important to not arbitrarily select changes in variables such as temperature, precipitation, wind, clouds, and humidity that are not internally consistent with each other. Synthetic scenarios may not be consistent with estimates of changes in average global climate (Condition 1). This last limitation can be overcome by using the outputs of GCMs to guide the development of synthetic scenarios, as was done in each of the three studies cited above.

iii). Analogue scenarios

Analogue scenarios involve the use of past warm climates as a scenario of future climate (temporal analogue scenario), or the use of current climate in another (usually warmer) location as a scenario of future climate in the study area (spatial analogue scenario).

iv). Combinations of Options

None of the above options fully satisfies all four scenario selection conditions. (Sulzman, 1995), therefore recommend using a combination of scenarios based on outputs from GCMs and synthetic scenarios. They advocate using GCM-based scenarios because they are the only ones explicitly based on changes in greenhouse gas concentrations. Synthetic scenarios complement GCM scenarios because they allow for a wider range of potential climate change at the regional level and are easier to construct and apply.

2.5. Future Climate Scenarios

A climate scenario is a reasonable representation of future climate conditions (temperature, precipitation and other climatological phenomenon) that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change (Houghton.J.T., 2001). Climate change scenarios are developed to give coherent, internally consistent and plausible descriptions of future state of the world. The climate change scenarios should be assessed according to consistency with global projections, physical plausibility, applicability in impact assessments and representatively (Abera, 2011).

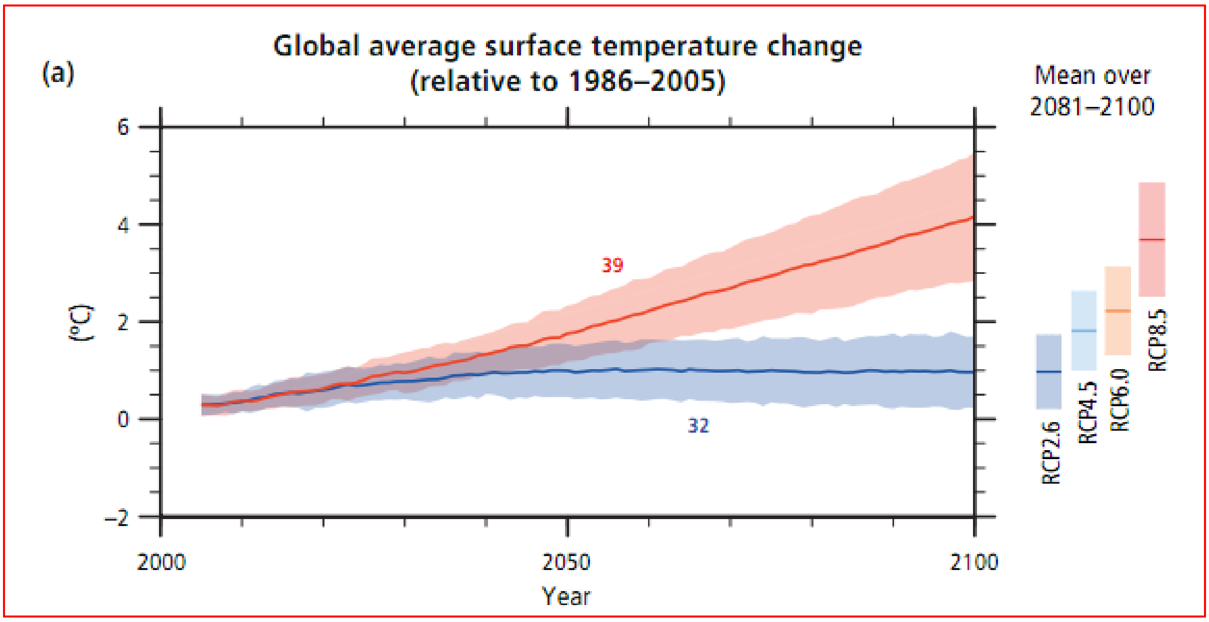
Representative Concentration Pathways (RCPs) are the four new greenhouse gas concentration trajectories included by the IPCC, 2014 in its fifth Assessment Report (AR5). These define four likely climate futures in the coming years which are considered potential depending on the amount of emitted greenhouse gases. These pathways are applied in climate modelling and research and replace the projections on Special Report on Emission Scenarios (SRES) published in 2000 (Moss et al., 2008). The RCPs include a stringent mitigation scenario (RCP2.6), two intermediate scenarios (RCP4.5 and RCP6.0) and one scenario with very high GHG emissions (RCP8.5) (IPCC, 2014). They are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values (+2.6, +4.5, +6.0, and +8.5 W/m^2, respectively).

The RCPs are comprised of extensive variety of possible changes of anthropogenic (i.e., human) Greenhouse Gases (GHG) emissions in the future (Ebi et al., 2014). The global annual emissions of GHGs from 2010-2020 (as per CO2-equivalents) will peak with a substantial decline of emissions thereafter is assumed in the RCP2.6 (IPCC, 2014).

Emissions peak around 2040 in the RCP 4.5 and then decline (IPCC, 2014). Around 2080 there is a peak in the emissions in RCP6.0 and then decline and in RCP8.5, continuous rise of emissions throughout the 21st century (IPCC, 2014). 2046-2065 and 2081-2100 are the mid and late 21st century averages respectively and projections established on the RCPs 21st century. The global mean sea level rise and global warming projections from the IPCC AR5 relative to sea levels and temperatures in late 20th to early 21st centuries are shown below.

Table 2.1. AR5 global warming projections (Source: IPCC, 2014)

AR5 global warming rise (^{o}C) projections		
	2046 to 2065	2081 to 2100
Scenario	Possible range and average	Possible range and average
RCP2.6	1.0 (0.4-1.6)°C	(0.3-1.7)1.0°C
RCP4.5	(0.9-2.0)1.4°C	(1.1-2.6)1.8°C
RCP6.0	(0.8-1.8) 1.3°C	(1.4-3.1)2.2°C
RCP8.5	(1.4-2.6)2.0°C	(2.6-4.8)3.7°C



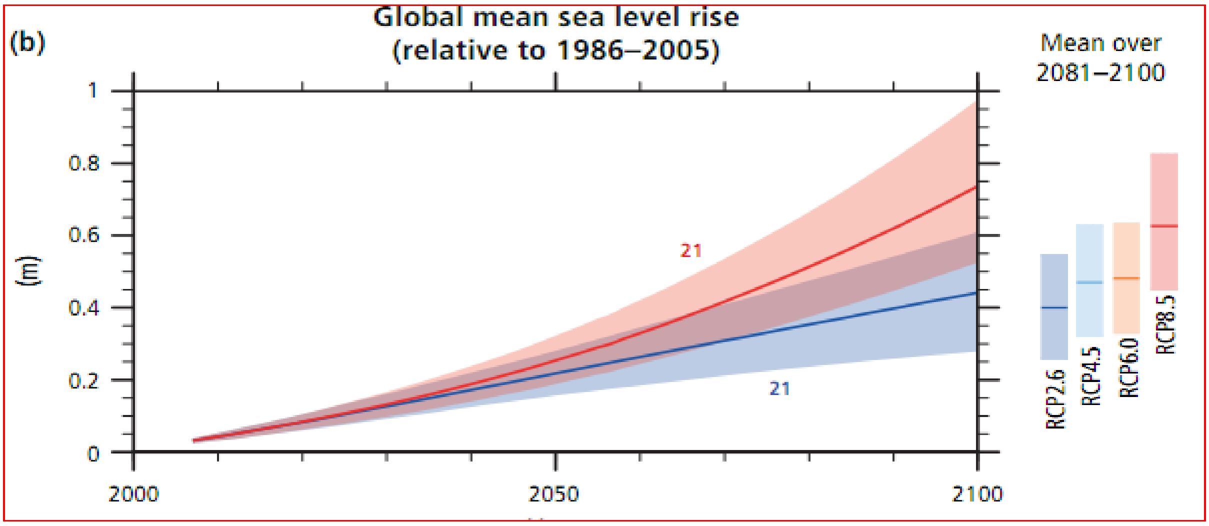


Figure 2.1. Global average surface temperature change (a) and global mean sea level rise (b).

2.6. Defining the Baseline Climate

The baseline (or reference) is the state against which change is measured. In the context of transformation pathways, the term baseline scenarios refers to scenarios that are based on the assumption that no mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. Baseline scenarios are not intended to be predictions of the future, but rather counterfactual constructions that can serve to highlight the level of emissions that would occur without further policy effort (IPCC, 2014).

Baseline climate information is important to characterize the prevailing conditions and its thorough analysis is valuable to examine the possible impacts of climate change on a particular exposure unit. It can also be used as a reference with which the results of any climate change studies can be compared. The choice of baseline period has often been governed by availability of the required climate data. According to World Meteorological Organisation (WMO), the baseline period also called reference period generally corresponds to the current 30 years normal period. A 30-year period is used by WMO to define the average climate of a site or region, and scenarios of climate change are also generally based on 30-year means.

2.7. Emission Scenarios

Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might clarify. A set of scenario assists in the assessment of future developments in complex systems that are either inherently unpredictable, or that have high scientific uncertainties (Shimelis etal., 2011).

To determine how the composition of the atmosphere, and consequently how climate may change in the future, it is necessary to construct scenarios of greenhouse gas and sulphat aerosol emissions for the next 100 years and beyond. This requires assumptions to be made about how society will involve in the future (Taddele, 2009). Four different narrative storylines were developed to describe the relationship between emission driving forces and their evolution. Each storyline represents different demographic, socio-economic, technological and environmental developments. The four qualitative storylines yield four sets of scenarios called families (A1, A2, B1, and B2). The four scenario families give 40 SRES scenarios which are all equally valid with no assigned probabilities of occurrence. According to the special report on emission scenarios (IPCC, 2000) the associated storylines are summarized below.

I. The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

II. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological changes are more fragmented and slower than in other storylines.

III. The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

IV. The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels.

All of these scenarios do not include climate initiatives of the United Nations Framework Convention on Climate Change (UNFCCC) or the emission targets of the Kyoto Protocol. The Kyoto Protocol is an international treaty which extends the 1992 United Nations Framework Convention on Climate Change (UNFCC) that commits State Parties to reduce greenhouse gas emissions, based on the promise that (a) global warming exists (b) human-made CO_2 emissions have caused it.

However, non-climatic change policies designed for a wide range of other purposes influence the GHG emission drivers such as demographic change, social and economic development, technological change and pollution management. This influence is reflected in the storylines and resultant scenarios.

2.8. Uncertainties in climate change studies

There are several sources of uncertainty in the generation of climate change information. There is uncertainty associated with alternative scenarios of future emissions and their radioactive effects. Uncertainties in the climate effects of manmade aerosols (liquid and solid particles suspended in the atmosphere) constitute a major hesitation in quantitative studies. Uncertainties related to clouds increase the difficulty in simulating the climatic effects of aerosols, since these aerosols are known to interact with clouds and potentially can change cloud radiative properties and cloud cover. The numerical models introduce uncertainties because of the finite approximation to the continuous equations.

2.9. Hydrological Models

Hydrological models are simplified, conceptual representations of a part of the hydrologic, or water cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. Two major types of hydrologic models can be distinguished:

1. Stochastic Models. These models are black box systems, based on data and using mathematical and statistical concepts to link a certain input (for instance rainfall) to the model output (for instance runoff). Commonly used techniques are regression, transfer functions, neural networks and system identification. These models are known as stochastic hydrology models.
2. Process-Based Models. These models try to represent the physical processes observed in the real world. Typically, such models contain representations of surface runoff, subsurface flow, evapo-transpiration, and channel flow, but they can be far more complicated. These models are known as deterministic hydrology models. Deterministic hydrology models can be subdivided into single-event models and continuous simulation models.

2.9.1. Hydrologic Model Selection

There are a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. (Baven K., 2001), suggested four criterions for selecting model structures as below.

1. Consider models which are readily available and whose investment of time and money appeared worthwhile.

2. Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.

3. Prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes.

4. Make a list of the inputs required by the model and decide whether all the information required by the model can be provided within the time and cost constraints of the project.

Therefore, by considering the factors listed above a semi distributed physically based hydrological model SWAT is selected for this particular study.

2.9.2. The Soil and Water Assessment Tool (SWAT)

SWAT is a physically based, continuous time and computationally efficient hydrological/water quality model, which uses readily available inputs. As physically-based model, SWAT use hydrologic response units (HRUs) to describe spatial heterogeneity in terms of land cover, soil type and slope within the watershed. The SWAT system is embedded within a geographic information system (GIS) that can integrate various spatial environmental data including soil, land cover, climate and topographic features. It was developed to forecast 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. It enables users to study long term impacts and hence is being used extensively in the U.S. and other parts of the world to assess the impact of global climate change and water quality.

SWAT is a theoretical model that operates on a daily time step. In order to adequately simulate hydrologic processes in a basin, the basin is divided into sub basins through which streams are routed. The subunits of the sub basins are referred to as hydrologic response units (HRU"s) which are the unique combination of soil and land use characteristics and are considered hydrological homogeneous. The model calculations are performed on a HRU basis and flow and water quality variables are routed from HRU to sub basin and subsequently to the watershed outlet (Muhammed, 2016). The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. Soil water balance is the primary considerations by the model in each HRU, which is represented as (Arnold, 1998):

$$SWt = \text{SWo} + \sum_{i=1}^{t}(\text{Rday} - \text{Qsurf} - \text{Ea} - \text{Wseep} - \text{Qgw}) \quad \text{--------------------------------2.1.}$$

Where, SW_t is the final soil water content (mm),

SW_o is the initial soil water content on day i (mm), t is the time (days),

R_{day} is the amount of precipitation on day i (mm),

Q_{surf} is the amount of surface runoff on day i (mm),

E_a is the amount of evapotranspiration on day i (mm),

W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm), and Qgw is the amount of return flow on day i (mm).

The subdivision of the watershed enables the model to reflect differences in evapotranspiration for various crops and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases accuracy and gives a much better physical description of the water balance.Brief description of some of the key model components are provided in this study. More detailed descriptions of the different model components are listed in SWAT user‟s manual (Neitsch et, 2005).

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter. When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will start. Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (USDA-SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911; as cited in Neitsch et al., 2005). Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is (SCS, 1972):

$$\text{Qsurf} = \frac{(Rday - 0.2S)^2}{(Rday + 0.8S)} \ldots\ldots\ldots\ldots\ldots\ldots \text{2.2.}$$

Where, Q surf is the accumulated runoff or rainfall excess (mm), R day is the rainfall depth for the day (mm); S is the retention parameter (mm).

The retention parameter is defined by the following equation:

$$S = 25.4\left(\frac{1000}{\text{CN}} - 10\right) \ldots\ldots\ldots\ldots\ldots\ldots \text{2.3.}$$

Where CN is the curve number

2.9.3. SWAT-CUP

Based on previous studies it was found that SUFI2 has better performances in calibrating SWAT quickly in a computationally less expensive method and also with less no of iterations (Alam, 2015).so, SUFI2 has been used to perform the calibration of SWAT at selected calibration points of the Baro watershed.

In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). As all the processes and model inputs such as rainfall and temperature distributions are correctly manifested in the model output (which is measured with some error) - the degree to which we cannot account for the measurements - the model is in error; hence uncertain in its prediction. Therefore, the percentage of data captured (bracketed) by the prediction uncertainty is a good measure to assess the strength of our uncertainty analysis. The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, disallowing 5% of the very bad simulations. As all forms of uncertainties are reflected in the measured variables (e.g., discharge), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is highly interesting, but quite difficult to do, and as far as the author is aware, no reliable procedure yet exists.

Another measure quantifying the strength of a calibration/uncertainty analysis is the R factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data with the smallest possible uncertainty band. As parameter uncertainty increases, the output uncertainty also increases (not necessarily linearly). Hence, SUFI-2 starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially falls within the 95PPU, then decreases this uncertainty in steps while monitoring the P-factor and the R-factor. In each step, previous parameter ranges are updated by calculating the sensitivity matrix (equivalent to Jacobian), and equivalent of a Hessian matrix, followed by the calculation of covariance matrix, 95% confidence 21 intervals of the parameters, and correlation matrix. Parameters are then updated in such a way that the new ranges are always smaller than the previous ranges, and are centred around the best simulation (Abbaspour et al., 2007).

The goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the above two measures. Theoretically, the value for P factor ranges between 0 and 100%, while that of R-factor ranges between 0 and infinity. A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data. The degree to which we are away from these numbers can be used to judge the strength of our calibration. A larger P-factor can be achieved at the expense of a larger R-factor. Hence, often a balance must be reached between the two. When acceptable values of R factor and P-factor are reached, then the parameter uncertainties are the desired parameter ranges. Further goodness of fit can be quantified by the R^2 and/or Nash-Sutcliff (NS) coefficient between the observations and the final "best" simulation. It should be noted that we do not seek the "best simulation" as in such a stochastic procedure the "best solution" is actually the final parameter ranges. If initially we set parameter ranges equal to the maximum physically meaningful ranges and still cannot find a 95PPU that brackets any or most of the data.

2.10. Previous studies in the Baro-Akobo River basin

Of the climate change impacts that have been studied on Baro-Akobo river basin at different times by different researchers let see some of them as below.

According to (Taye et al., 2016b) in the past few decades Baro-Akobo river basin has gone through various dynamic processes. Population increase and realted anthropogenic pressure and possible climatic variablity have brought visible changes to the ecosystem of the basin. Since 1984, widespread drought has brougt thousands of settlers and related activities to the basin. In addition to the local settlers, this area remained to be home to hundreds of thousands of south sudanese refugees for decades and continued in a larger scale at present. More pressure is coming to the basin in a from of large scale commercial farming.Resettlement is also going on but with less magnitude. Baro-River used to be navigable to connect Southern Sudan with Ethiopia (Taye et al., 2016b).He states that there is clearly noticeable and measurebale climate change in the basin. Incraese in temprature, particularly the mean temprature, erratic nature of the rainfall and its changing patterns are creating negative impacts at micro watersheds and basin level. increase in temprature increased evapo-transpiration from the subsurface soil creating moisture stress to the plants(Taye Alemayehu, 2016b).

3. METHODS AND MATERIALS

3.1. 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-Ghibe 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.

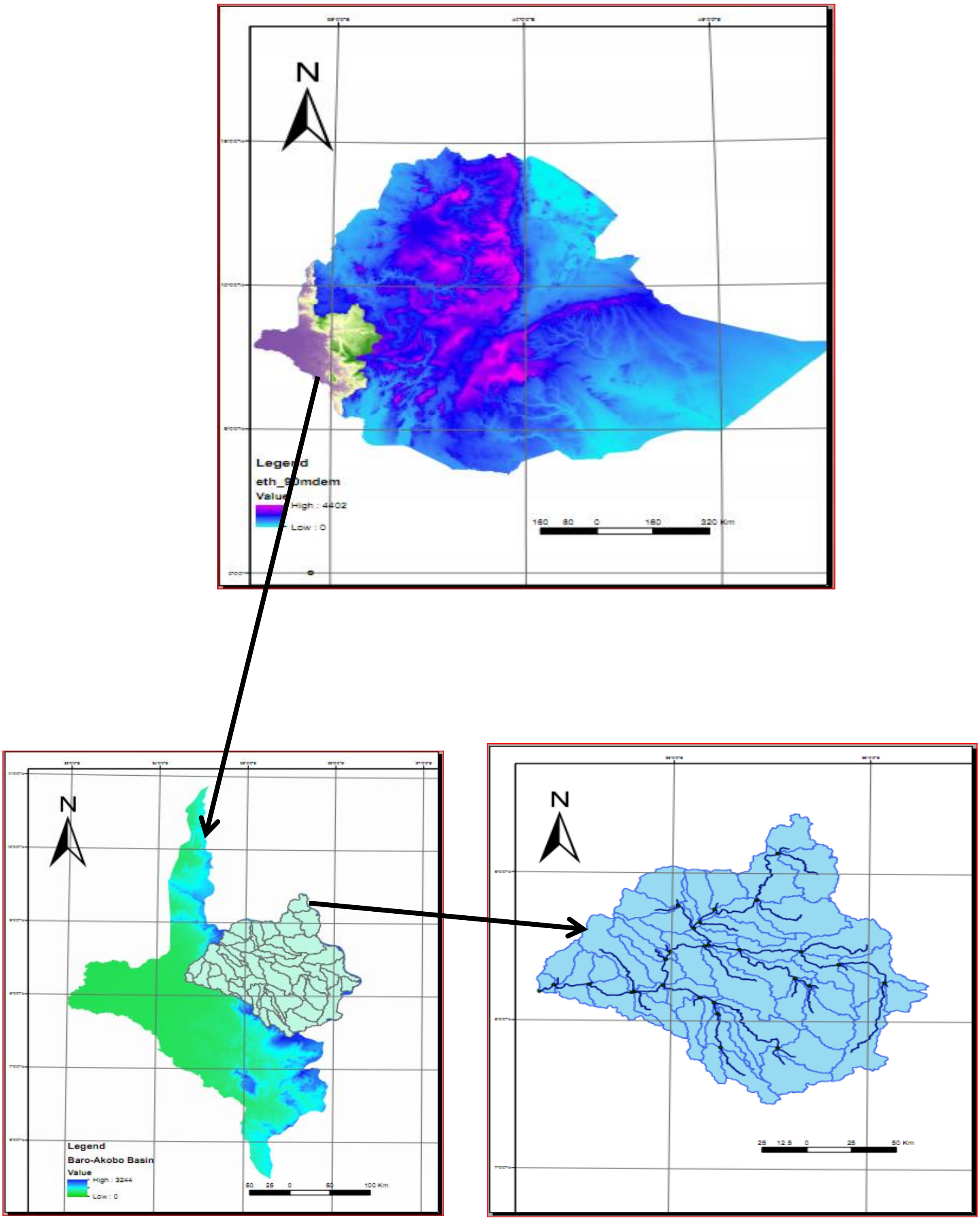


Figure. 3.1. Location of Baro Watershed

3.2. 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.

3.2.1 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:

$$St = \mathrm{So} + \sum_{i=1}^{t}(\mathrm{Rday} - \mathrm{Qsurf} - \mathrm{Ea} - \mathrm{wseep} - Qgw) \text{---} 3.1$$

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:

$$\mathrm{Qsurf} = \frac{(Rday - 0.2S)^2}{(Rday + 0.2S)} \text{--} 3.2.$$

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:

$$S = 25.4\left(\frac{100}{CN} - 10\right) \text{--} 3.3.$$

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).

3.3. 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.

3.3.1. 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.

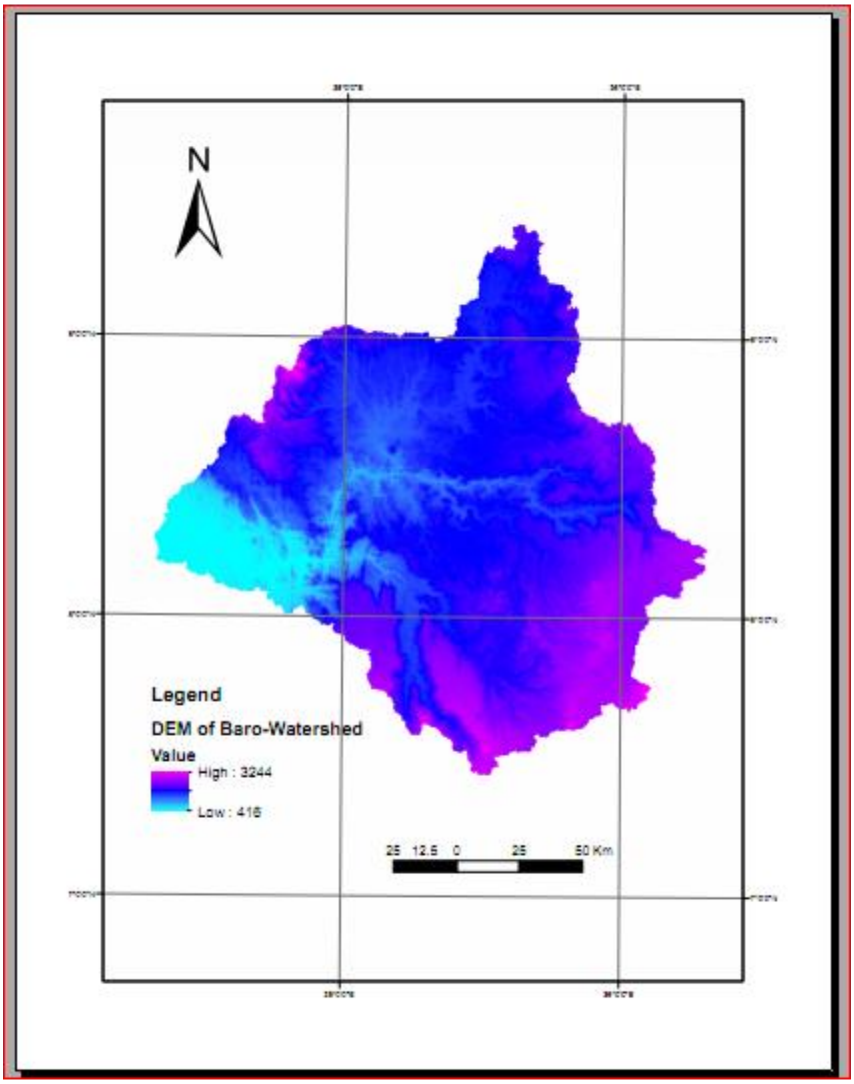


Figure 3.2. Digital elevation model for Baro River extracted from Ethio- DEM.

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.

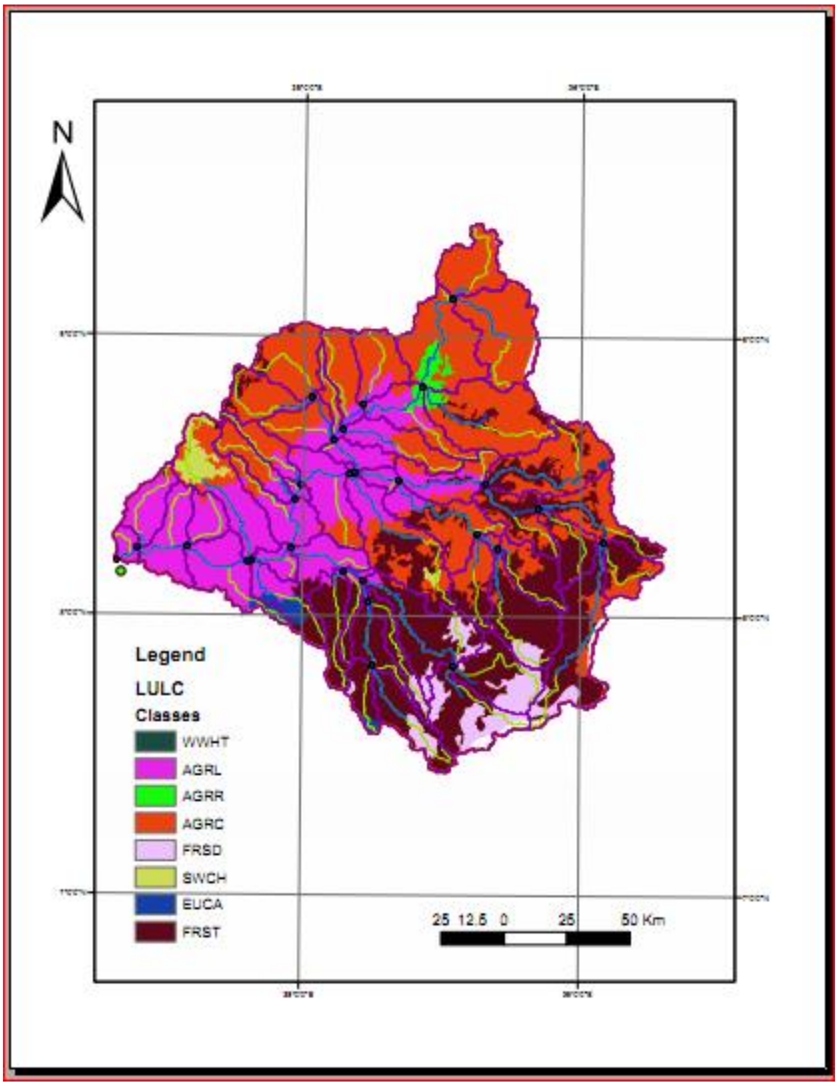


Figure.3.3. Land use/cover of Baro Watershed

Table 3.1. 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

3.3.3. 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.

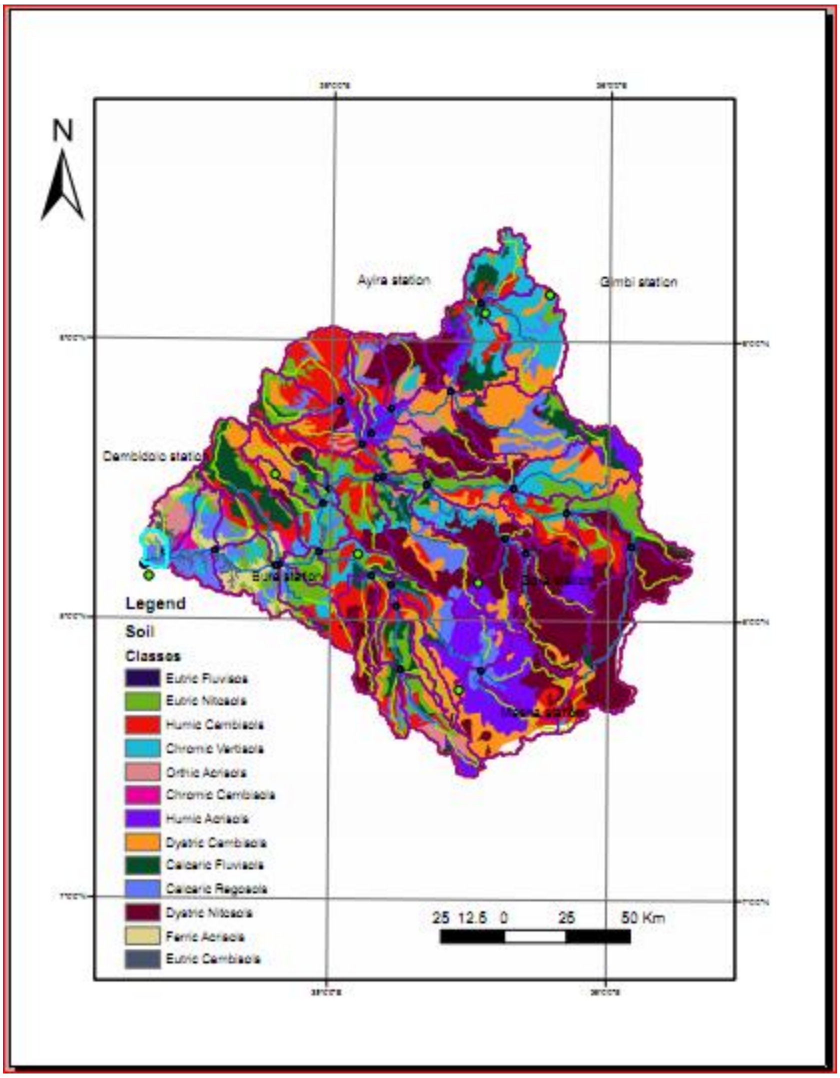


Figure 3.4. Soil map of the Baro watershed

Table 3.2.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

3.3.4. 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.

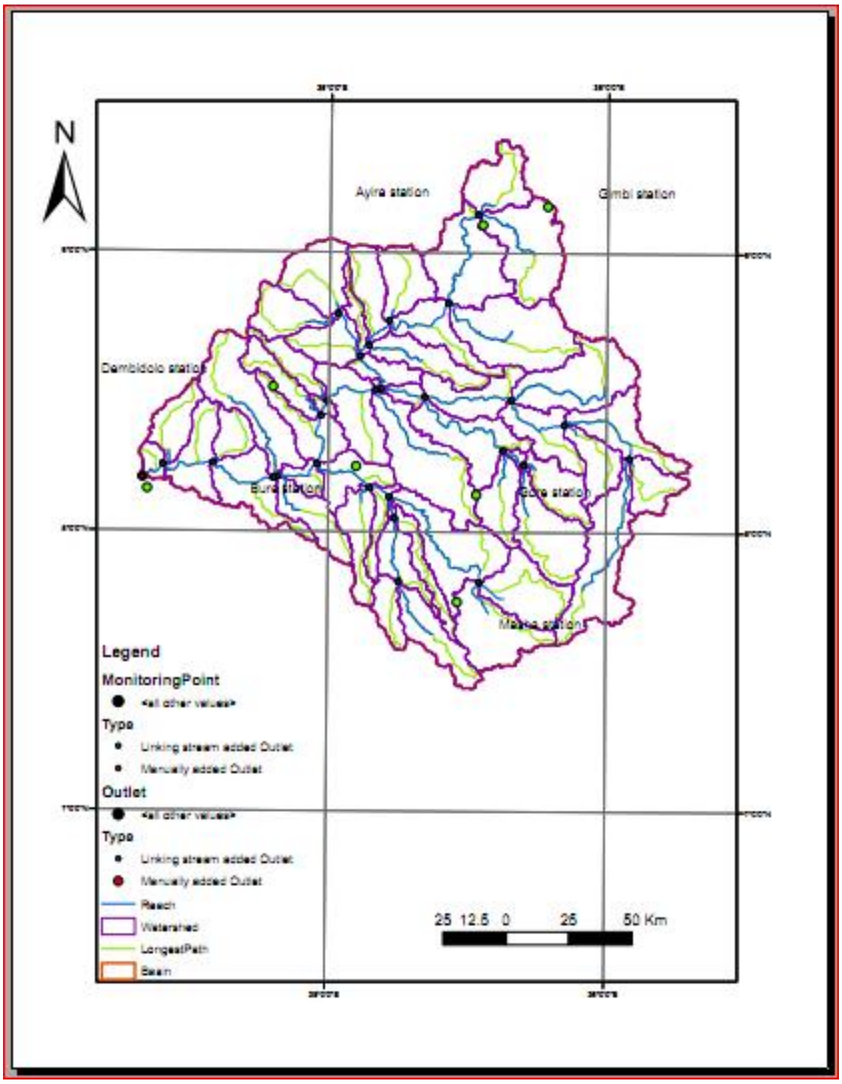


Figure 3.5. Delineated Watershed of Baro Watershed

Table 3.3. List of station name, location and meteorological variables

No	Station name	Latitude (Degree)	Longitude (degree)	Elevation (m)	Rainfall	Max Temp	Min Temp	Start year	End year
1	Gore	8.1333	35.5333	2033	√	√	√	1986	2016
2	Bure	8.2333	35.1	1750	√	√	√	1986	2016
3	Masha	7.75	35.4667	2282	√	√	√	1986	2016
4	Dembidolo	8.5167	34.8	1850	√	√	√	1986	2016
5	Gimbi	9.1667	35.7833	1970	√	√	√	1986	2016
7	Ayira	9.1	35.55	1555	√	√	√	1986	2016

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.

3.4 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.

3.5 Hydro-Meteorological Data Analysis

3.5.1. 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.

3.5.2. 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.

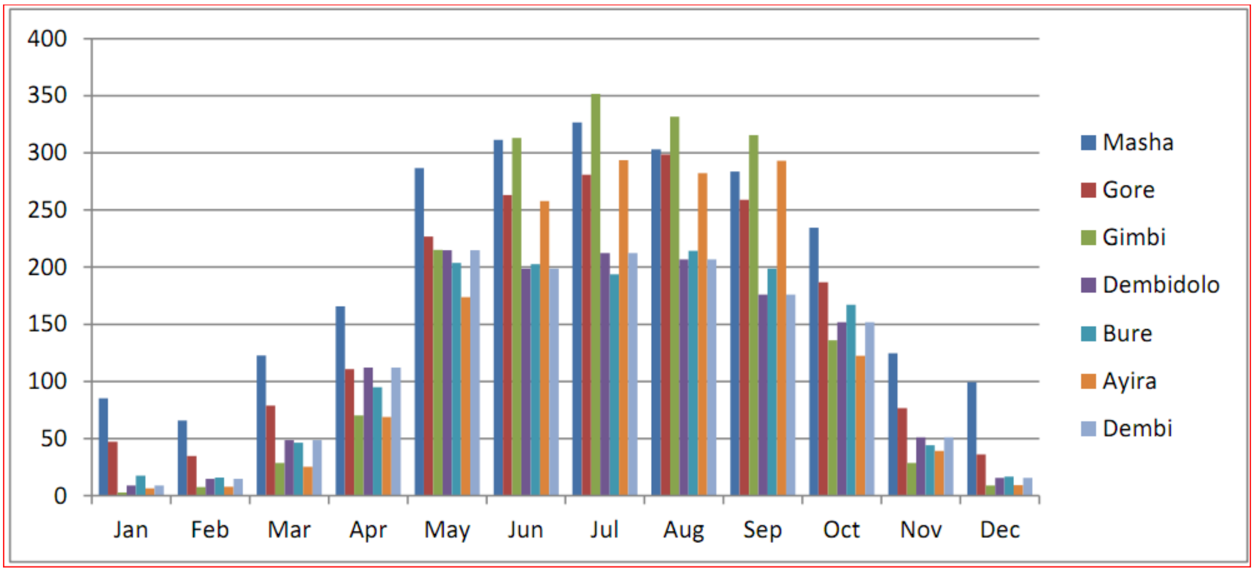


Figure 3.6. Average Monthly Rainfall data series (1986-2016)

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.

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

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.

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

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 stream flow 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.

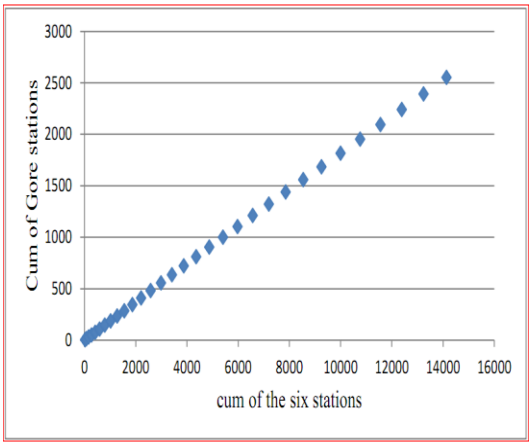
Table 3.4. Regression equations for metrological stations missed data filling.

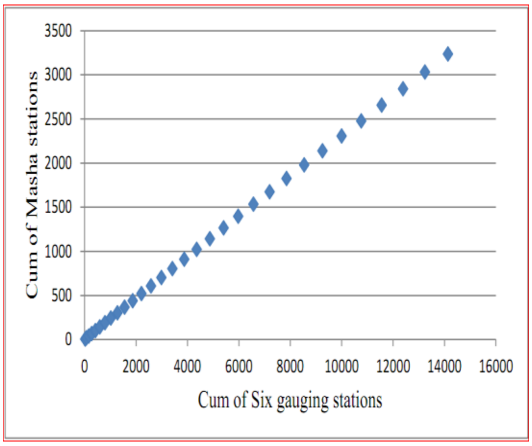
Station	R2	Coefficient a	Coefficient b	Regression equation
Dembi dolo	0.657	1.223	-0.83	Y= 1.223(Bure)-0.83
Gimbi	0.709	1.163	1.085	Y=1.163(Ayira)+1.085
Masha	0.609	0.624	2.414	Y=0.624(Mizan Teferi)+2.414
Gore	0.648	0.767	-0.723	Y=0.767(Masha)-0.723

3.5.3. 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.∑Px) and the accumulated values of the average of the group of base stations (i.e.∑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.





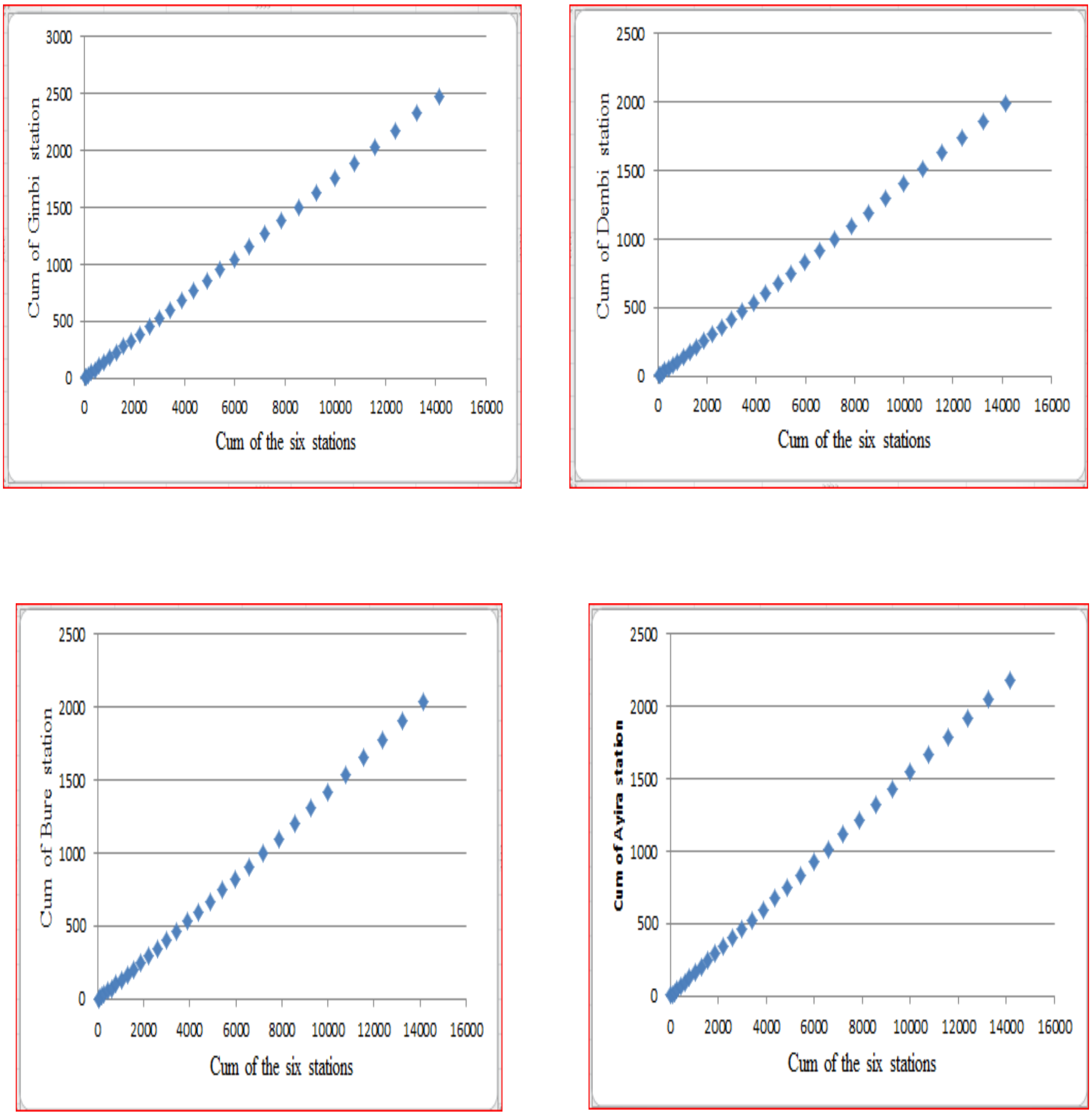


Figure 3.7. Double mass curve of gauging stations

3.6. Model set up

3.6.1. 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.

3.6.2. 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.

3.6.3. 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.

3.6.4. 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).

3.6.5. 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.

3.6.6. 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	$0.75 < NSE \leq 1.00$
Good	$0.65 < NSE \leq 0.75$
Satisfactory	$0.50 < NSE \leq 0.65$
Unsatisfactory	$NSE \leq 0.50$

3.7. 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.

3.7.1. 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).

4. Result and Discussion

4.1. SWAT Hydrological Model Results

4.1.1. 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 508.2 mm and lateral soil flow is 58.7 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 4.1 Average annual basin values.

AVERAGE ANNUAL BASIN VALUE	
Precipitation	2156.8mm
Surface runoff Q	508.20mm
Lateral Soil Q	58.7mm
Ground water (shal AQ) Q	609.06mm
Groundwater (Deep AQ)Q	47.1mm
Revap (Shal AQ ⟹ soil/plants)	24.1mm
Deep AQ recharge	47.72mm
Total AQ recharge	954.36
Total water yield	1223.06mm
Percolation out of soil	955.17mm
ET	633.7mm

PET	1204.9mm

Table 4.2. 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	102.89	2.06	2.46	15.13	72.56	121.06
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.

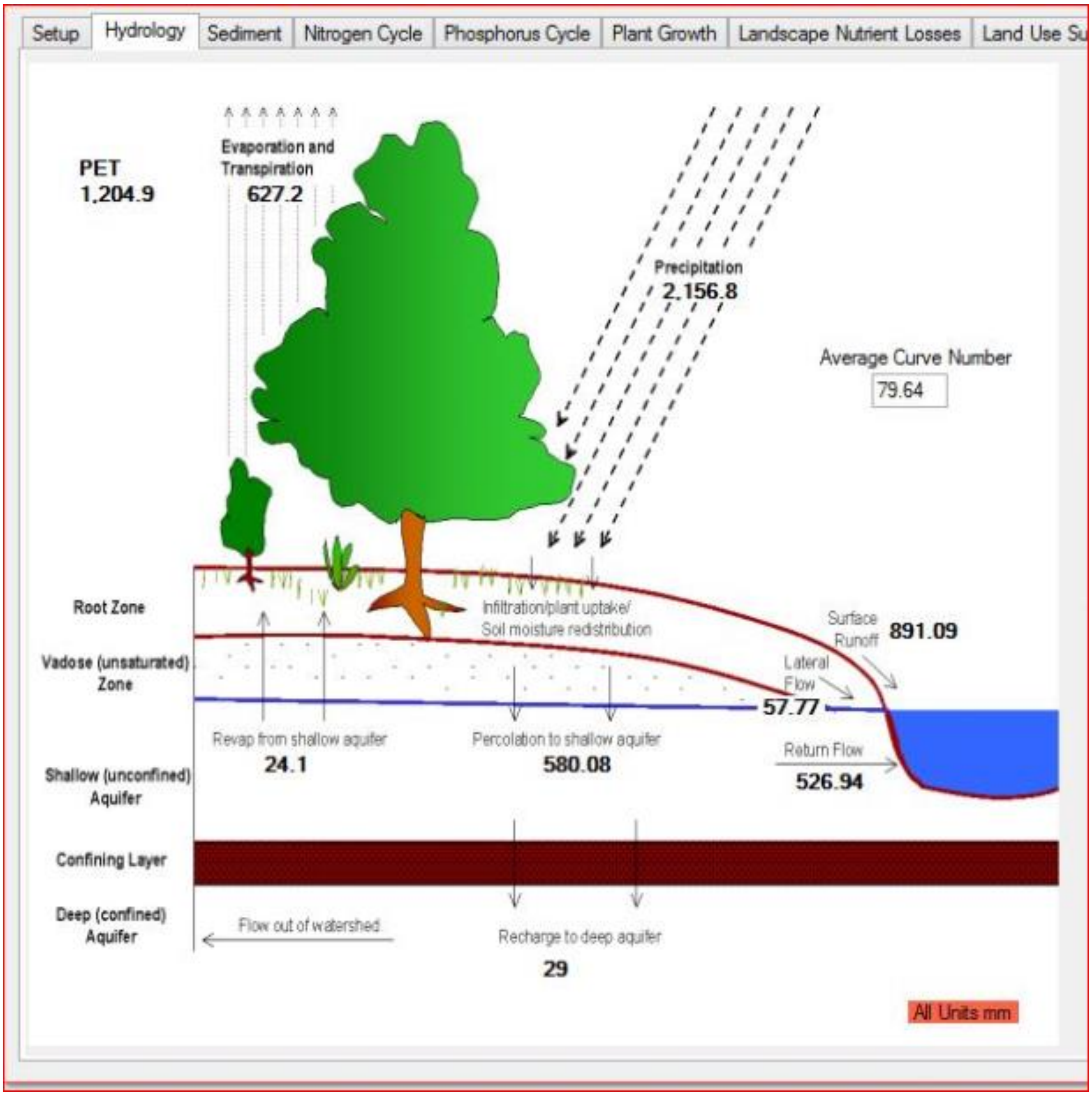


Figure 4.1. General SWAT model result Baro Watershed

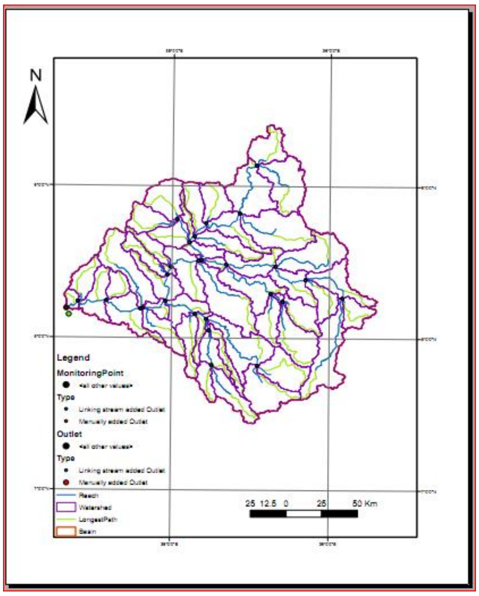
4.1.2. Determination of Hydrologic Response Units

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

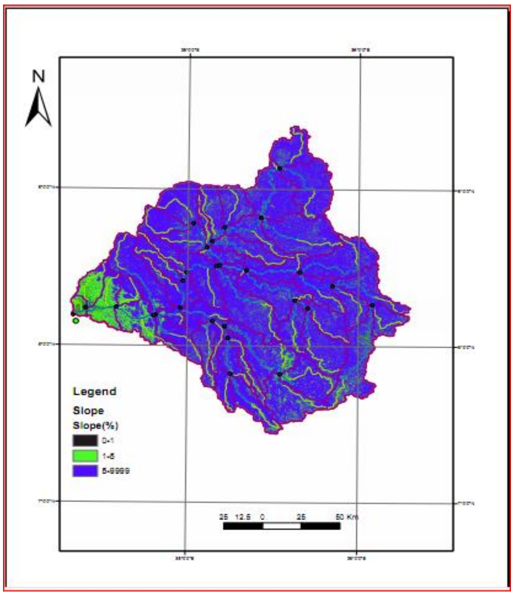
The overall watershed delineation and HRU definition simulation in the watershed gave a watershed area of 24563.64 km^2 which resulted in 53 sub-basins and 201 HRUs. The watershed delineation of the area gave minimum, maximum and mean elevations in the basin of 416, 3244, and 1678.39 masl respectively.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

Table 4.3. Area covered by Land Use, Soil and Slope

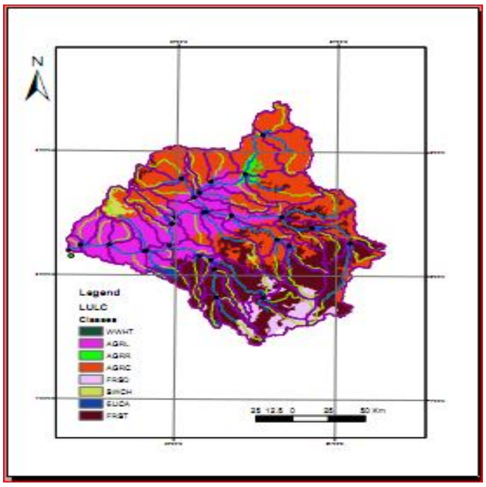
	Area [ha]	Area[acres]	%Wat.Area
Watershed	2456364.6900	6069799.9672	
LANDUSE:			
Agricultural Land-Close-grown --> AGRC	938359.2276	2318732.5694	38.20
Agricultural Land-Row Crops --> AGRR	25820.3866	63803.4662	1.05
Forest-Mixed --> FRST	757145.6978	1870944.8764	30.82
Agricultural Land-Generic --> AGRL	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



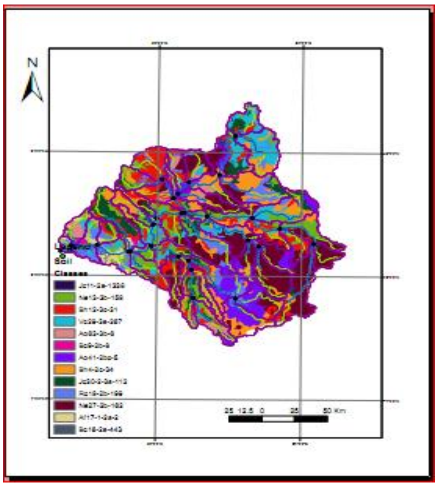
a). Delineated Watershed map



b). slope map



a) Land use map



d) soil map

Figure 4.2. The delineated sub basins, land use, slope, and soil map of the Baro-Watershed

4.2. Performance Evaluation of the Hydrologic Model

4.2.1. 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 5.5 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 4.4. 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).

4.2.2. 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 4.5. Model efficiencies parameters in calibration and validation periods

Sub basin number	Simulation period	Parameter	period	values
6 gauging stations	1990-2005	R2	Calibration	0.9
		NS	Calibration	0.66
		R2	Validation	0.93
		NS	Validation	0.61

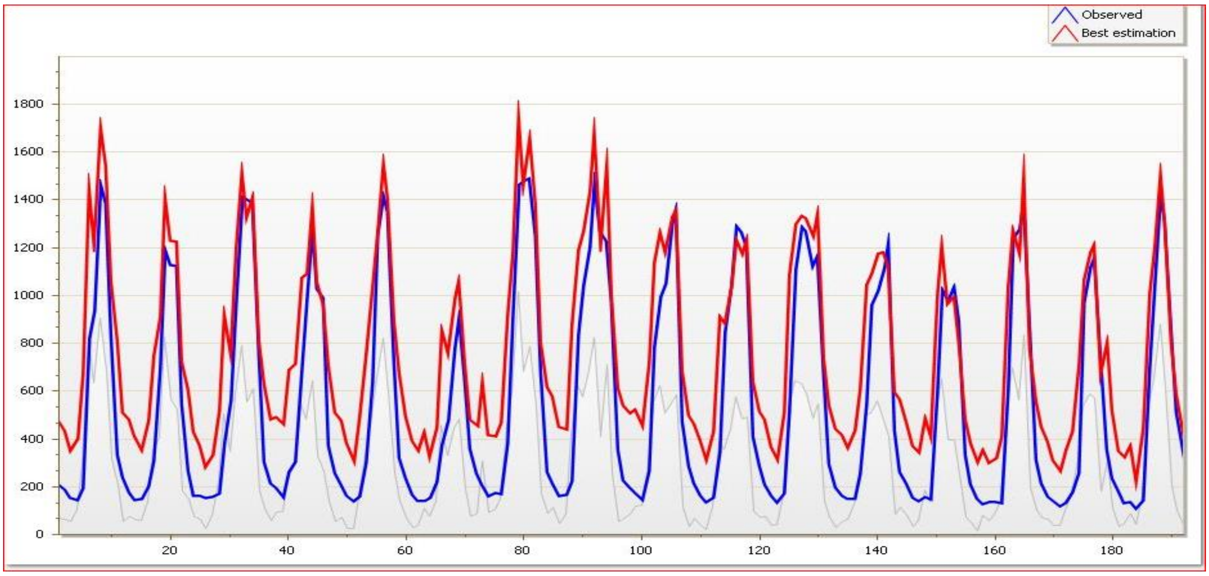


Figure 4.3. Calibration results of average monthly simulated and observed flows of Baro River at Gambella station (1990-2005)

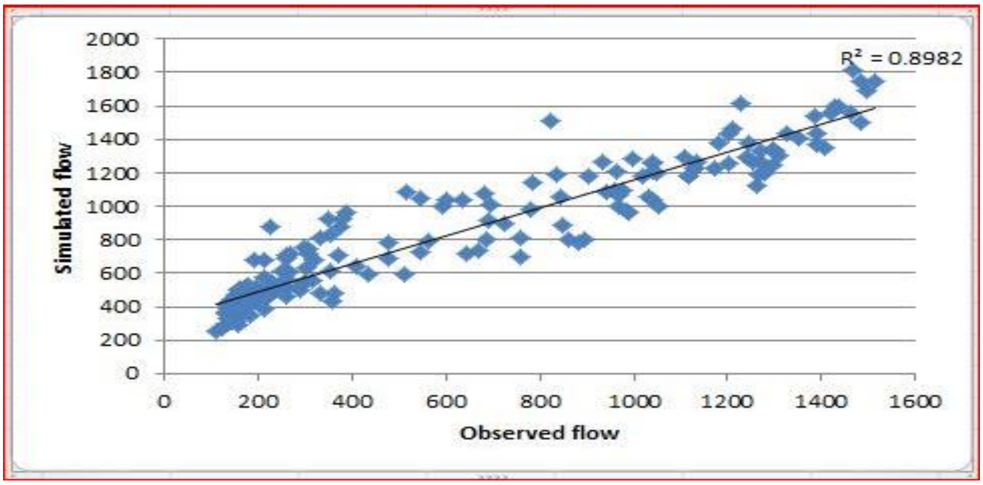


Figure 4.4. Simulated and observed flows during the calibration period using scatter plot (1990-2005)

4.2.3. 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.

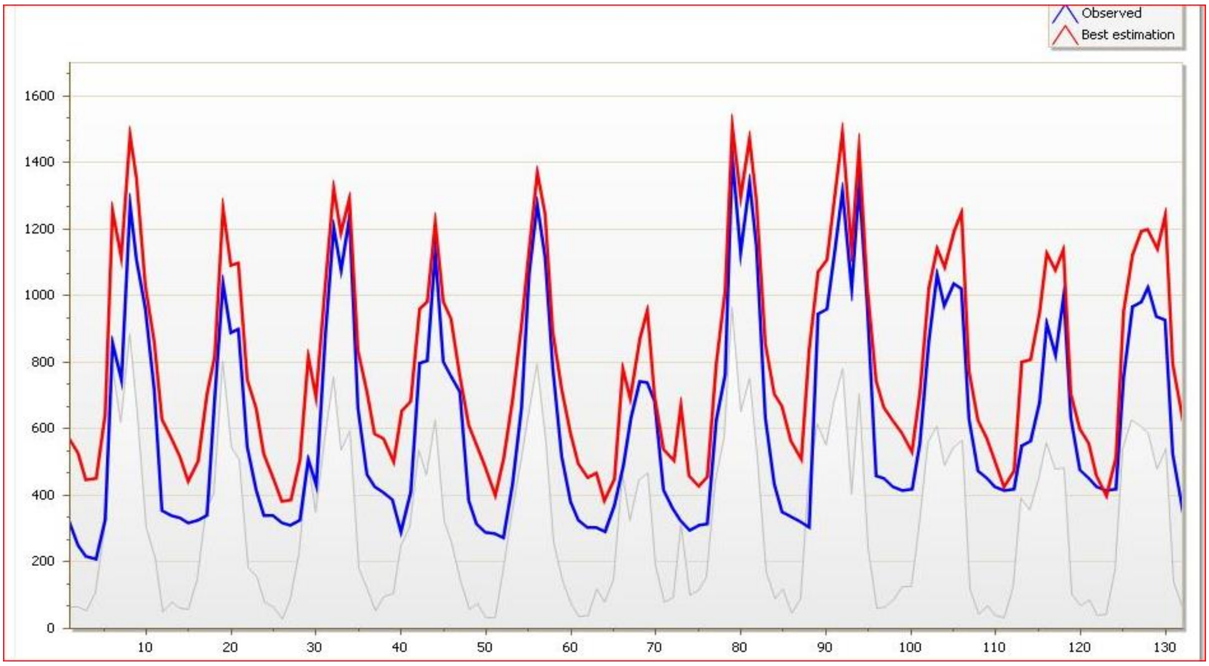


Figure 4.5. Validation results of average monthly flows of Baro at Gambella station (2006-2016).

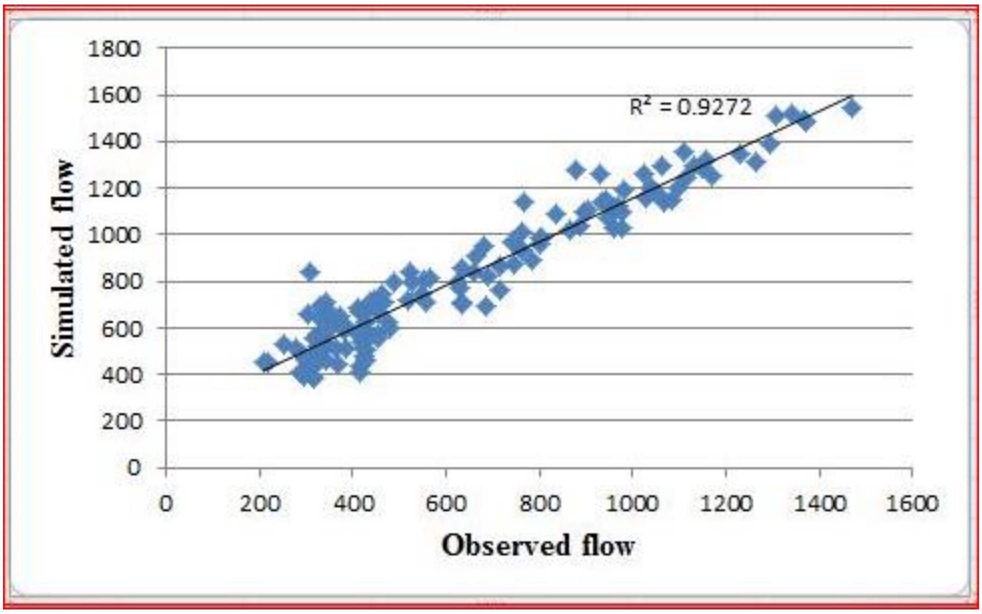


Figure 4.6. Observed vs simulated flow for validation (2006-2016).

4.3. 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^{o}C, +3^{o}C, +4^{o}C, +5^{o}C and +6^{o}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^{o}C, 2^{o}C, 3^{o}C and for 2080s with temperature change of 4^{o}C, 5^{o}C and 6^{o}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^oC 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 4.6. Total annual water yield for the 2050s and 2080s

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

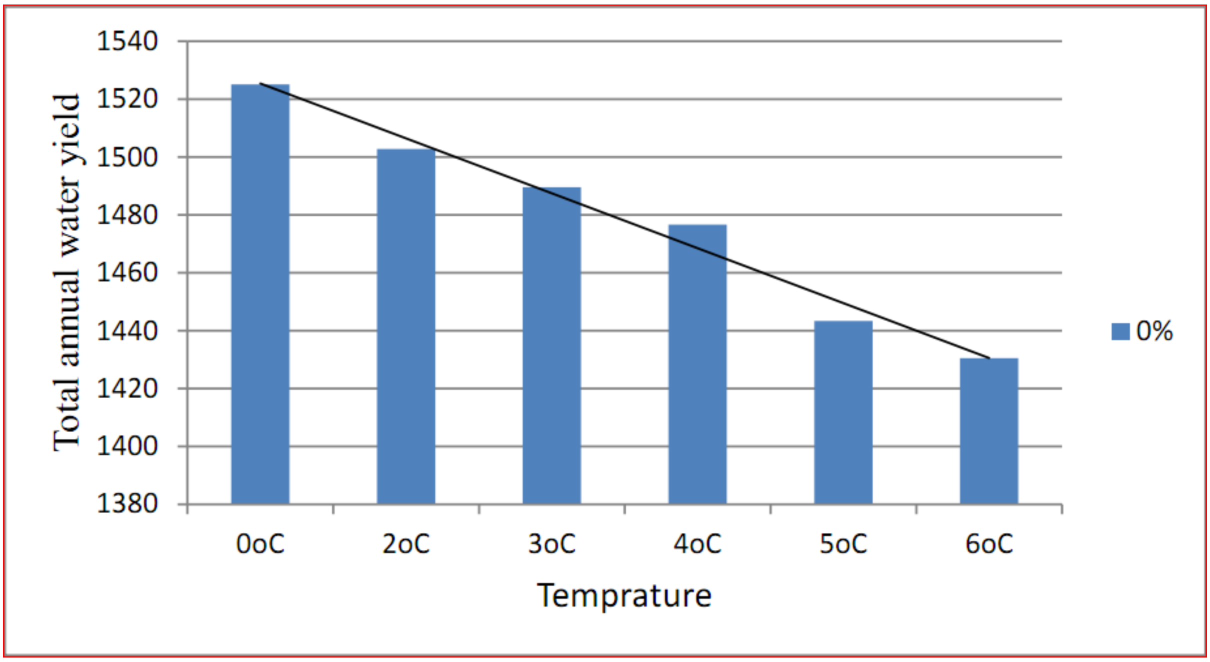


Figure 4.7: Trend which shows the variation of total annual water yield for constant precipitation but with varying temperature

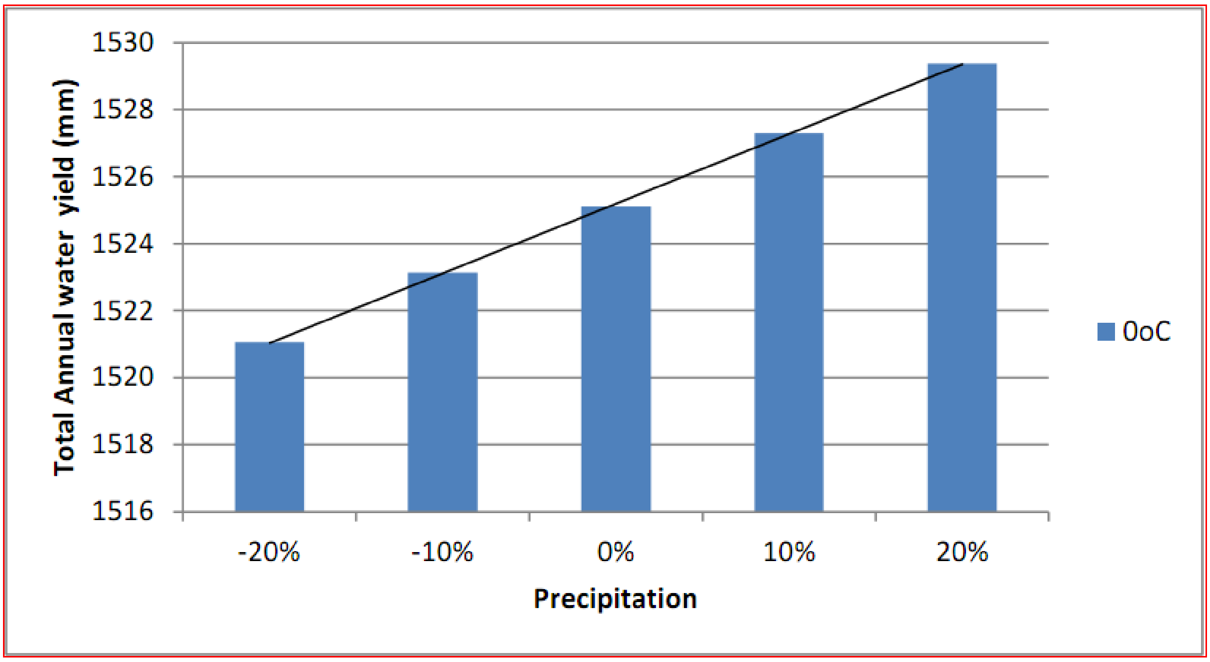


Figure 4.8: Trend which shows the variation of total annual water yield for constant precipitation but with varying temperature

4.3.1. 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°C, 2°C and 3°C for the period of 2050s according to IPCC Fifth Assessment report set for Africa and 4°C, 5°C and 6°C 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 4.7. 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°C	45041	45107	45175	45241	45308
3°C	44785	44852	44918	44985	45051

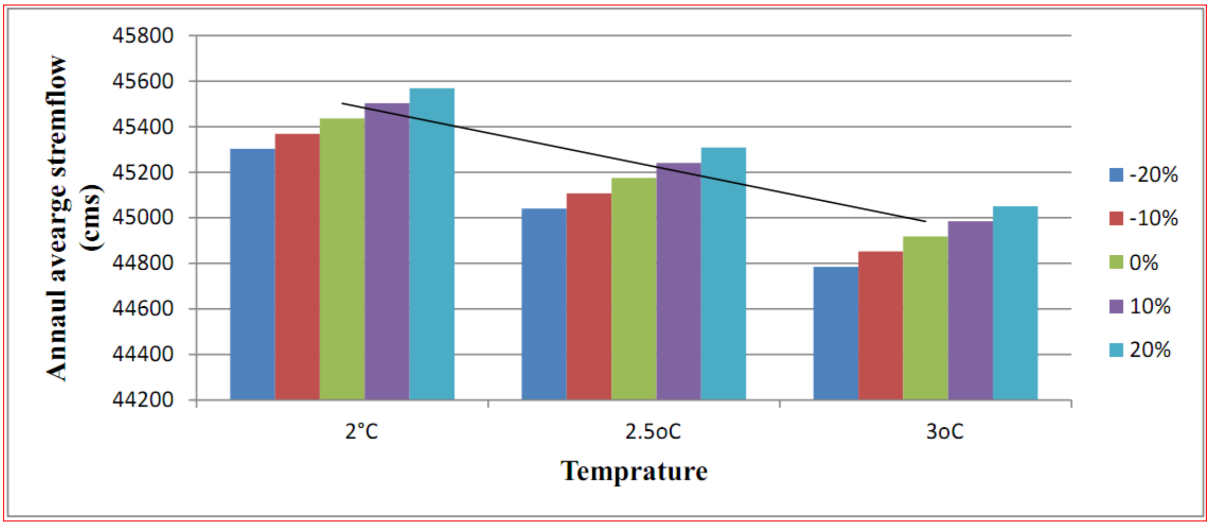


Figure 4.9: Mean annual discharge (cms) due to the changes in temperature for the period of 2050s using Bar-Chart.

Table 4.8. 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°C	44024	44090	44156	44223	44288
6°C	43242	43337	43403	43469	43534

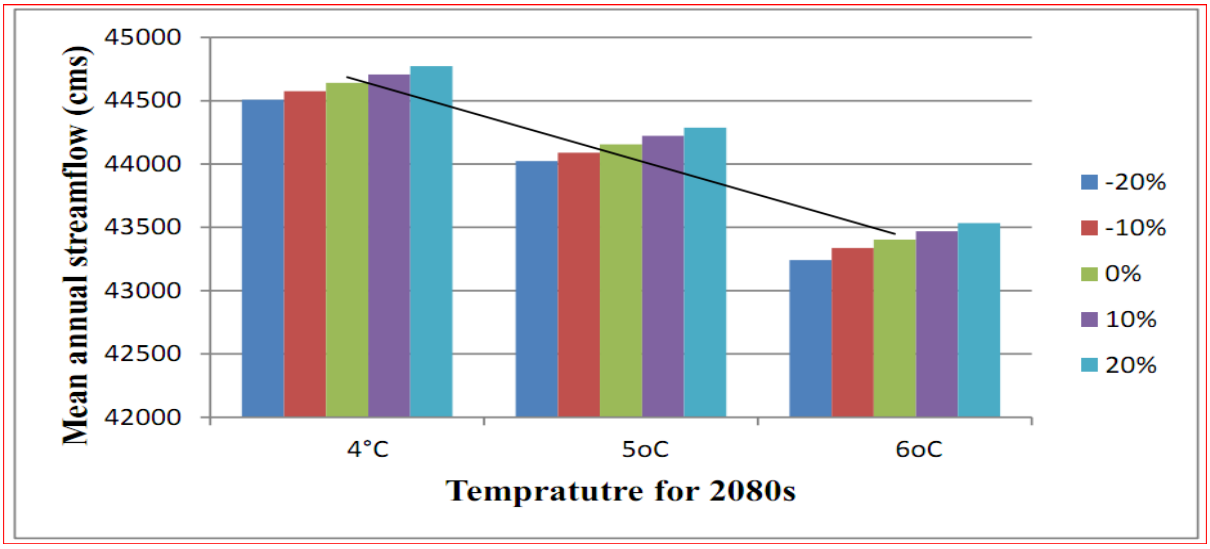


Figure 4.10: Mean annual discharge (cms) due to the changes in temperature precipitation for the period of 2080s using Bar-Chart.

4.3.2. 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^{o}C 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 4.9 Changes in mean annual discharge (%) due to changes in temperature and precipitation in 2050s and 2080s.

ΔP	-20%	-10%	0%	10%	20%
ΔT 2^{o}C	11.7	11.6	11.46	11.3	11.2
ΔT 3^{o}C	12.73	12.6	12.45	12.3	12.2
ΔT 3.5^{o}C	13.27	13.13	13.00	12.878	12.75
ΔT 4.5^{o}C	14.2	14.08	13.95	13.82	13.69
ΔT 6^{o}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.

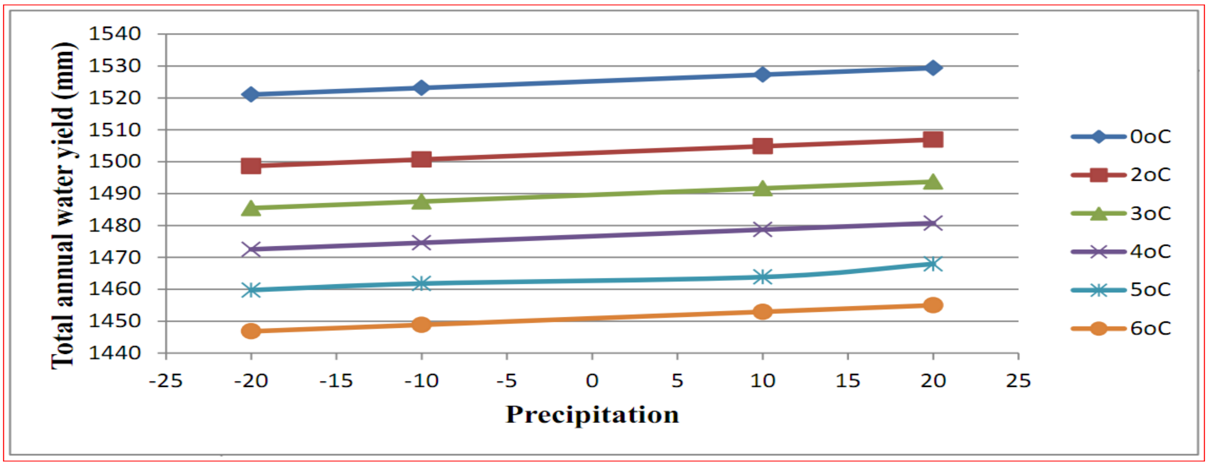


Figure 4.11 Increasing trend of annual water yield with increase of precipitation (2050s, 2080s).

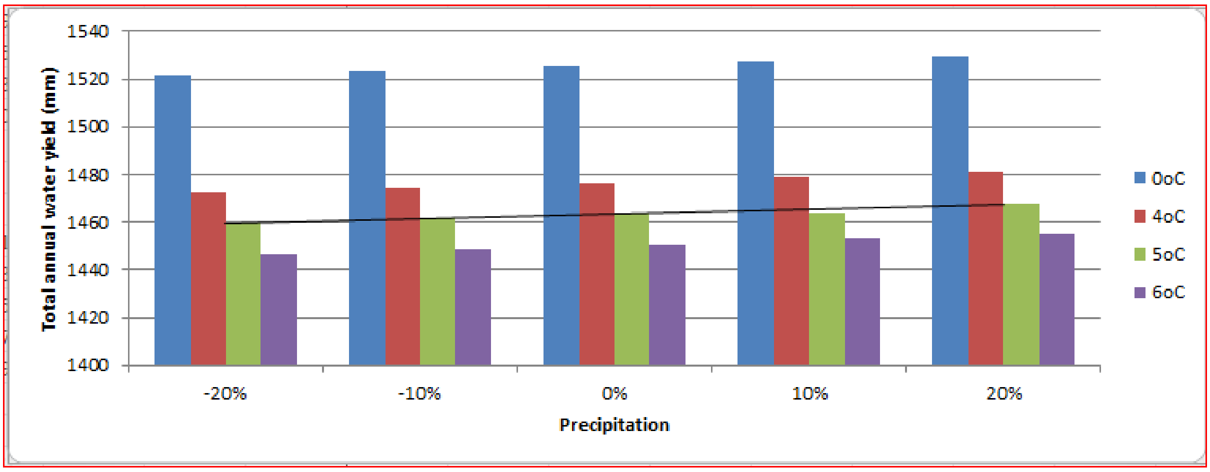


Figure 4.12: Total annual water yield (mm) due to the changes in precipitation for the period of 2080s using Bar-Chart.

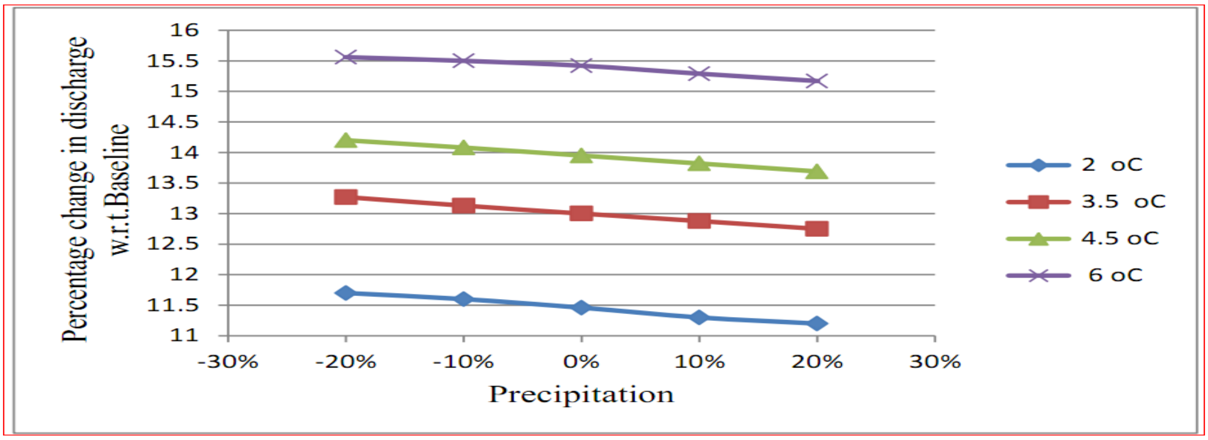


Figure 4.13. Changes in annual mean stream flow (%) at Gambella station with respect to baseline (%).

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.

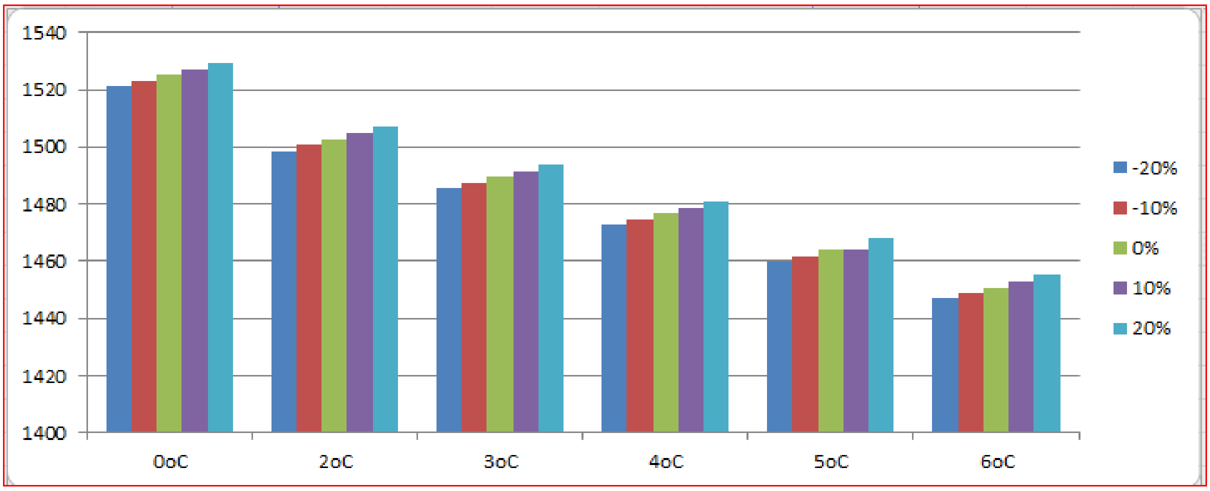


Figure 4.14. Effect of temperature keeping precipitation constant

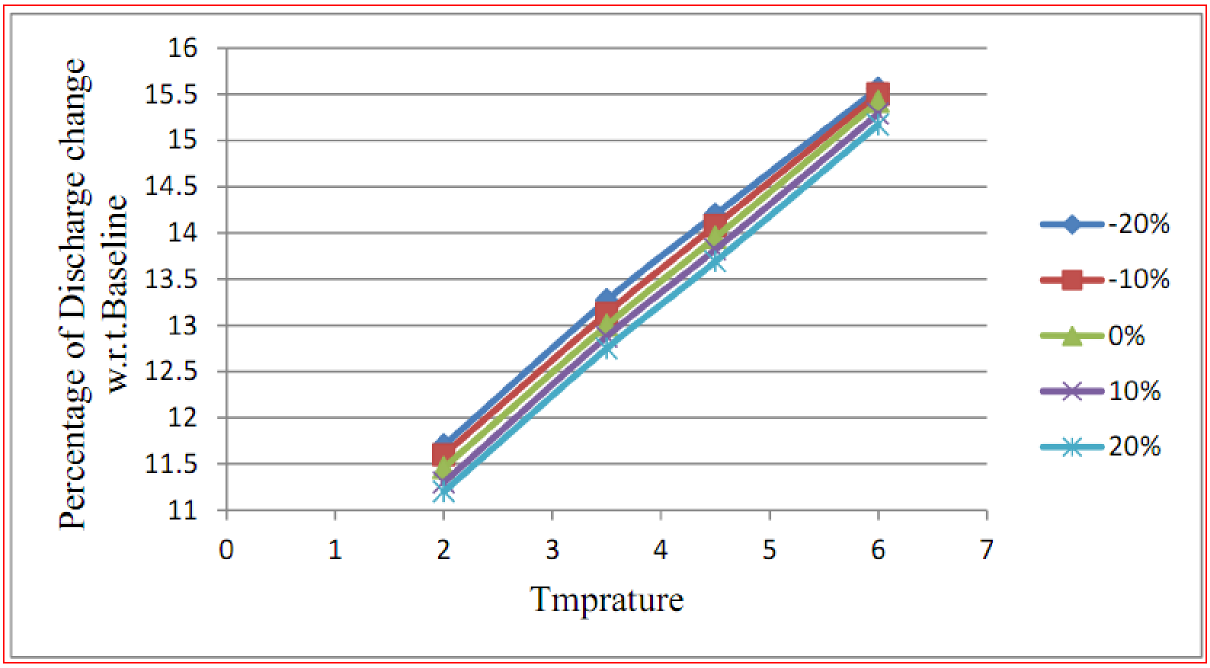


Figure 4.15 Changes in Annual Average Discharge (%) at Gambella station with respect to baseline.

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^{o}C, 3^{o}C, 4.5^{o}C and 6^{o}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^{o}C and 20% precipitation increase there is a reduction of 11.2% in stream flow, whereas a 3^{o}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.

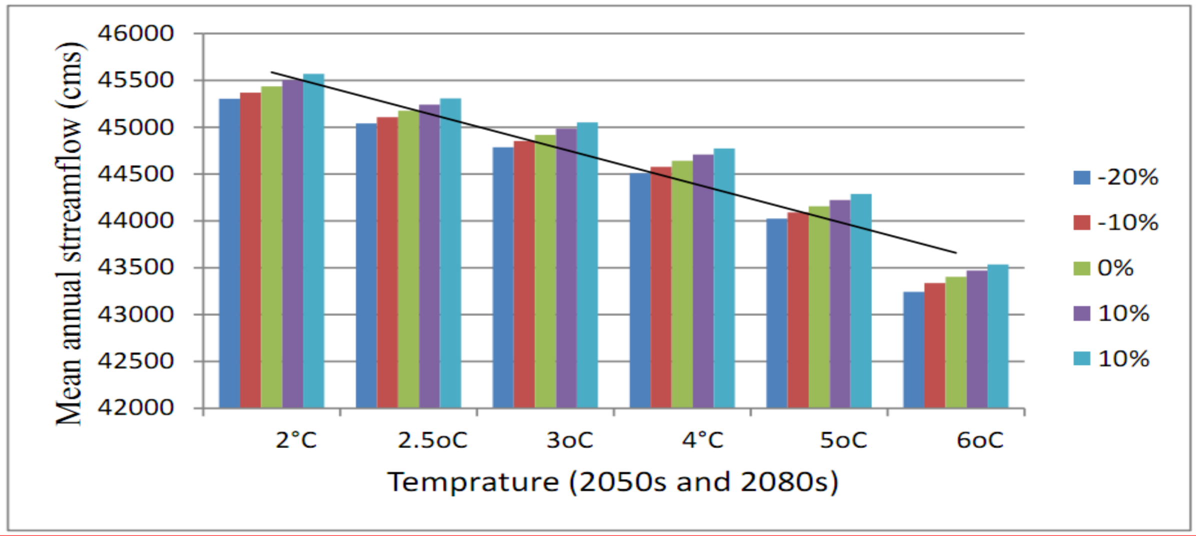


Figure 4.16 Combined effect of climate change and temperature over average annual stream flow

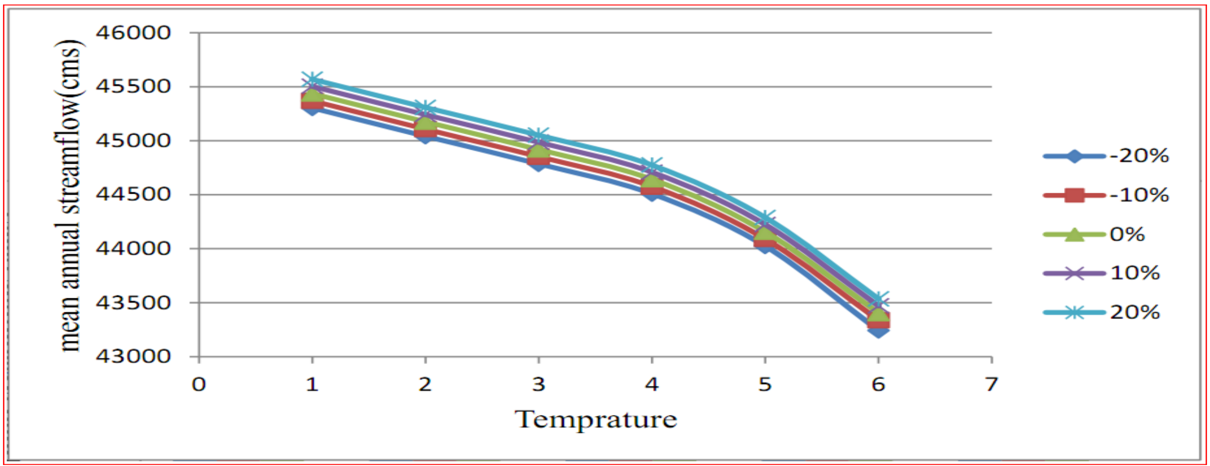


Figure 4.17 Combined effects of climate change and temperature over average annual stream flow.

5. Conclusion and Recommendation

5.1. 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.

5.2. 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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Appendix A

Summary of Average Monthly Meteorological variables from 1986-2016 for principal stations considered in the Modeling Work

i). Average monthly precipitation

1. Gore Station

Year	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1986	0.18	0.33	1.97	3.02	4.02	6.75	9.48	10.96	11.01	3.76	1.01	0.09
1987	0.88	1.19	2.23	2.57	4.49	9.04	12.16	10.62	10.56	5.67	2.04	1.01
1988	2.66	3.76	1.42	0.11	7.98	8.83	3.95	13.45	11.79	12.72	2.72	0.76
1989	0.84	0.78	5.60	2.52	7.65	8.82	10.15	8.86	8.54	5.07	1.90	3.30
1990	1.18	0.61	1.30	3.55	5.40	13.46	7.91	12.08	11.05	4.78	4.29	0.65
1991	1.40	0.64	1.57	4.67	5.66	7.94	10.59	8.58	8.65	3.46	2.68	0.56
1992	1.36	0.22	2.51	3.90	8.52	6.49	11.05	10.47	6.98	8.96	6.06	0.53
1993	0.56	1.79	4.55	5.47	4.64	8.96	8.43	11.34	7.16	5.83	2.72	0.02
1994	2.26	0.05	0.47	4.35	6.56	9.51	8.51	13.73	9.08	2.70	3.19	0.60
1995	0.01	1.01	4.85	2.03	5.03	7.31	8.34	9.55	7.81	5.40	2.14	2.87
1996	5.96	1.93	4.73	4.56	10.52	8.65	14.30	11.83	12.50	6.89	3.02	3.10
1997	2.04	0.40	1.71	9.28	9.41	10.74	10.64	13.09	7.99	9.49	3.40	0.31
1998	0.79	1.24	3.46	2.97	6.12	8.21	9.82	6.83	8.59	8.65	0.78	0.25
1999	0.83	0.51	0.00	4.26	11.32	6.31	7.59	6.54	7.79	6.55	1.04	1.13
2000	0.94	0.20	0.98	3.45	11.13	8.83	7.53	9.66	8.58	8.19	1.85	0.69
2001	0.06	1.59	1.09	3.96	5.81	9.27	7.38	8.50	8.61	7.07	0.91	1.46
2002	1.27	0.53	2.74	4.00	3.47	7.83	8.67	7.82	6.72	4.81	0.78	0.82
2003	0.08	2.27	1.52	2.48	4.58	11.70	6.51	8.66	9.89	3.07	1.97	1.19
2004	0.36	1.09	1.07	2.83	3.87	8.38	7.78	6.84	5.73	3.63	4.21	1.43
2005	0.51	0.13	3.86	1.55	3.32	7.77	7.85	15.48	8.44	6.30	2.52	0.09
2006	0.18	0.91	1.48	0.40	7.19	8.09	9.36	8.84	9.30	7.05	2.77	3.50
2007	0.43	2.04	1.25	4.86	5.96	9.28	7.56	8.60	8.40	2.66	2.04	0.33
2008	2.25	0.57	0.87	4.22	9.13	12.00	6.34	5.36	6.08	4.77	1.88	1.76
2009	1.11	2.13	3.13	7.94	2.82	6.55	8.62	9.29	7.57	6.02	0.95	0.65
2010	2.21	0.52	1.00	1.03	7.09	6.90	6.92	6.57	8.03	5.91	3.06	1.22
2011	0.35	0.38	0.74	3.42	9.24	11.17	14.24	12.41	9.45	4.00	2.23	0.54

2012	0.34	0.36	1.64	1.21	7.34	8.67	9.00	13.48	9.74	4.56	4.11	2.45
2013	0.44	1.01	1.63	1.42	12.69	8.88	8.54	5.05	6.33	6.79	3.86	0.47
2014	0.49	0.96	3.14	8.45	12.11	10.38	8.47	8.80	8.09	2.81	3.92	0.28
2015	0.23	0.00	1.31	1.44	8.83	7.05	8.45	7.66	9.86	6.01	3.58	2.87
2016	14.94	8.63	15.00	8.48	14.73	8.00	14.63	7.74	7.21	13.07	1.61	1.06

2. Masha Station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0.75	3.18	3.20	3.42	5.31	11.52	10.59	12.10	7.50	4.51	3.65	2.86
1987	1.93	0.53	5.77	4.69	6.32	10.73	10.73	10.03	8.72	10.76	3.34	2.42
1988	4.72	5.58	3.11	1.06	19.16	24.76	9.49	10.34	14.10	8.22	2.92	1.54
1989	2.58	2.48	7.19	2.70	7.69	13.65	12.14	9.66	9.97	6.74	3.69	4.48
1990	2.74	3.20	4.08	4.39	6.55	7.73	7.87	13.57	12.21	6.45	4.90	1.19
1991	1.49	3.43	4.73	7.62	9.37	8.59	9.10	11.29	7.70	5.73	3.24	3.13
1992	3.72	1.72	3.26	5.30	11.15	10.48	11.71	9.69	6.90	12.87	5.29	2.99
1993	1.34	4.28	4.16	4.71	6.71	8.18	10.88	8.18	11.00	6.39	2.62	1.40
1994	1.91	0.41	1.21	3.86	10.59	12.05	8.84	5.04	9.16	4.04	1.85	3.91
1995	0.20	2.32	3.10	1.92	9.36	9.64	7.12	11.98	8.13	4.53	4.72	5.13
1996	4.27	1.74	5.12	7.24	7.71	5.95	19.82	16.92	17.79	10.47	5.43	5.54
1997	4.15	2.02	3.72	13.59	13.76	7.97	9.81	8.50	9.64	11.44	3.81	2.71
1998	1.50	0.23	7.30	4.28	4.86	10.75	11.02	8.90	10.05	13.45	1.55	1.51
1999	1.90	0.46	0.13	10.02	11.92	10.36	10.56	7.71	9.53	7.53	3.73	3.32
2000	2.59	0.82	1.92	9.20	10.87	9.68	12.10	12.07	8.62	9.35	5.74	3.10
2001	0.73	1.78	1.60	5.96	10.11	8.62	14.27	6.74	8.62	9.84	3.84	5.47
2002	2.53	0.95	4.44	9.18	5.49	11.21	7.71	11.30	5.68	6.10	2.33	2.15
2003	0.88	1.26	1.64	6.49	7.51	9.62	10.55	6.45	9.87	1.96	5.13	3.61
2004	2.83	0.47	3.16	4.61	5.50	7.25	11.68	9.85	7.72	4.08	5.08	3.54
2005	1.40	2.48	4.42	3.70	4.52	9.11	9.58	9.88	13.05	5.15	4.15	2.01
2006	1.52	1.91	3.38	2.04	9.29	11.02	13.10	8.45	12.04	7.70	3.89	6.12
2007	2.60	3.21	3.31	6.93	6.25	9.69	7.36	9.82	8.30	3.91	3.53	1.09
2008	3.78	3.13	2.17	7.33	9.96	9.16	10.34	9.61	8.73	7.00	3.39	3.31
2009	0.62	4.92	5.01	9.66	5.05	8.66	8.63	10.85	7.83	7.14	3.74	2.88
2010	3.45	2.55	2.39	2.00	10.61	11.83	6.95	7.17	6.95	6.82	5.59	3.97
2011	3.45	2.55	2.39	2.00	10.61	11.83	6.95	7.17	6.95	6.82	5.59	3.97
2012	2.01	0.10	1.72	0.97	7.61	7.50	6.52	10.83	9.46	3.22	3.29	3.30
2013	0.89	0.82	2.59	4.60	13.23	10.67	6.71	9.42	8.97	11.03	8.17	2.54
2014	1.41	1.31	4.78	8.67	10.39	11.15	12.82	12.47	8.47	4.12	5.87	3.27
2015	0.02	0.00	0.44	1.17	8.65	10.52	10.95	5.32	8.48	9.31	5.31	4.32
2016	20.35	12.07	20.50	11.85	20.69	11.77	20.57	11.20	10.79	18.49	2.94	1.71

ii). Average monthly Maximum Temperature

1. Gore station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	25.19	25.78	25.43	25.28	25.87	21.22	20.35	20.92	21.34	22.80	23.49	24.34
1987	25.49	26.94	26.00	25.81	23.11	20.59	21.39	21.47	22.39	22.36	22.91	24.43
1988	24.86	25.21	24.59	27.34	23.64	21.49	20.31	20.64	21.08	22.48	23.39	24.07
1989	24.95	25.12	24.70	24.74	23.11	22.04	20.99	21.10	21.77	22.99	23.14	22.50
1990	24.86	24.30	25.57	25.91	25.08	23.82	22.96	23.52	23.83	24.71	24.79	25.34
1991	25.75	27.21	26.68	24.43	24.09	23.07	19.51	21.50	22.98	23.52	24.05	24.44
1992	25.04	25.64	26.75	25.75	24.15	22.70	20.87	20.66	22.28	22.56	23.33	24.31
1993	24.79	25.25	26.49	24.54	23.66	23.07	21.59	22.13	22.63	23.98	24.81	25.66
1994	26.36	27.68	28.46	26.56	24.29	22.01	20.90	21.01	22.08	24.44	24.24	25.05
1995	26.97	26.64	26.93	26.12	23.16	23.71	21.30	22.24	21.97	24.12	24.90	23.80
1996	25.09	25.97	25.59	25.64	23.09	22.21	21.50	21.47	22.06	24.02	25.32	24.50
1997	24.19	25.10	25.70	23.81	22.74	21.92	20.62	21.45	22.87	22.97	22.79	24.04
1998	25.30	26.98	26.16	27.48	24.35	22.64	21.02	20.75	22.02	22.45	24.03	25.56
1999	25.54	27.80	28.40	26.67	23.21	21.98	20.45	20.77	22.02	21.74	24.48	24.82
2000	25.87	27.28	28.51	25.10	23.97	22.23	21.26	20.89	22.22	22.35	23.77	24.71
2001	25.34	27.28	26.14	26.86	24.15	21.77	21.38	21.70	22.51	23.34	23.82	24.70
2002	24.68	26.90	26.22	26.14	25.06	21.64	22.27	21.67	22.54	23.28	24.07	23.93
2003	26.03	27.39	27.12	26.40	26.51	24.05	22.96	23.51	24.21	25.58	25.26	25.42
2004	25.98	27.03	27.54	26.07	25.19	21.89	21.40	22.08	22.30	23.84	23.89	24.74
2005	25.59	28.80	27.58	26.81	25.08	22.11	21.05	21.98	22.35	22.97	23.97	25.59
2006	27.07	28.22	27.75	27.95	23.87	25.15	21.66	21.48	21.89	23.69	23.67	23.96
2007	24.80	25.84	27.53	25.98	24.51	22.80	21.43	21.50	22.42	24.52	24.56	25.60
2008	25.59	26.75	27.71	24.77	23.64	22.46	20.80	21.12	22.55	24.70	23.83	24.08
2009	25.28	25.85	26.54	25.79	24.86	23.58	21.71	21.48	22.32	23.65	24.27	24.15
2010	25.88	26.40	27.59	27.89	24.12	22.89	21.07	21.76	21.93	23.82	23.56	23.59
2011	24.79	27.28	26.92	27.02	24.40	22.35	22.27	21.52	22.57	24.76	24.23	25.00
2012	26.27	28.55	28.14	27.66	25.30	23.14	21.63	21.80	22.66	25.25	24.66	25.53
2013	26.49	28.02	27.98	29.03	24.65	23.04	21.48	21.69	23.30	23.56	24.49	25.16
2014	25.81	27.65	26.81	25.24	23.71	23.31	21.98	21.83	22.22	29.86	27.21	24.89
2015	26.56	30.64	27.75	26.99	24.39	22.89	22.59	22.87	23.68	24.71	24.00	24.50
2016	30.76	30.76	30.73	23.15	22.87	23.10	22.72	24.36	23.33	22.61	25.16	26.99

2. Masha station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	20.89	21.40	21.29	21.15	21.00	20.27	16.13	16.82	17.36	19.26	21.39	22.95
1987	24.04	24.97	24.17	23.76	22.86	22.57	21.65	20.82	22.11	22.22	22.25	22.40
1988	22.85	22.68	23.97	24.35	22.54	21.79	20.83	19.17	19.21	20.47	21.82	22.51
1989	22.05	22.46	21.99	22.20	21.38	20.16	18.37	19.59	19.93	21.07	21.60	20.97
1990	21.92	21.20	22.84	23.29	22.21	20.57	19.45	20.18	20.59	21.73	21.83	22.40
1991	22.63	23.79	23.15	22.02	21.79	20.43	17.37	17.54	20.77	21.66	21.14	21.36
1992	21.39	22.52	24.04	23.11	22.14	20.40	18.19	19.26	20.14	19.97	21.15	21.66
1993	21.85	22.44	24.06	21.52	20.38	19.61	17.69	18.38	19.04	20.80	21.87	22.97
1994	23.88	25.59	26.62	24.15	21.19	18.24	16.79	16.94	18.32	21.39	21.12	22.18
1995	24.68	24.24	24.62	23.57	20.12	21.50	19.35	20.26	21.01	21.88	22.23	20.59
1996	22.23	23.38	22.21	22.96	21.82	20.33	17.55	17.53	18.30	20.84	22.53	21.47
1997	21.14	22.24	23.03	20.57	19.18	21.36	19.69	20.45	21.79	21.85	21.36	21.96
1998	22.86	24.65	23.61	24.61	23.57	21.95	19.86	19.96	20.37	21.32	22.93	23.30
1999	23.13	25.75	26.03	24.17	22.66	21.95	19.63	18.29	19.66	17.96	21.44	21.88
2000	23.24	25.08	26.68	22.24	20.78	18.52	17.26	16.77	18.51	18.68	20.51	21.74
2001	22.55	25.08	23.59	24.53	21.01	17.91	17.41	17.83	18.88	19.96	20.58	21.72
2002	21.70	24.59	23.70	23.60	22.20	17.75	18.57	17.79	18.92	19.89	20.90	20.72
2003	24.06	25.20	24.86	23.93	24.06	20.87	19.45	20.17	21.08	22.85	22.45	22.71
2004	23.57	23.12	23.60	22.90	22.25	20.14	19.24	19.55	19.90	20.45	20.11	21.77
2005	22.91	27.14	25.42	24.10	22.89	21.24	20.27	20.60	21.07	21.82	22.71	23.26
2006	23.88	24.64	24.08	24.20	22.29	22.15	20.16	20.17	20.65	21.87	21.86	20.83
2007	22.27	23.12	24.22	23.40	22.43	20.81	19.67	19.79	20.88	22.77	22.44	22.95
2008	22.91	23.64	24.15	22.15	22.20	20.46	19.70	19.98	21.47	21.83	22.19	22.64
2009	24.01	23.64	23.89	23.49	23.20	22.36	20.65	20.45	21.52	22.18	22.89	22.03
2010	23.49	23.91	24.55	24.89	23.02	21.91	19.93	20.39	21.29	22.69	22.79	22.19
2011	22.49	24.76	23.82	24.07	23.00	21.71	21.78	20.50	21.83	23.17	22.13	23.82
2012	24.00	25.76	25.12	25.15	23.43	21.32	20.77	20.67	21.23	23.54	23.05	22.89
2013	23.63	24.75	24.52	25.59	23.44	21.99	21.59	21.73	21.57	23.14	24.96	24.53
2014	23.17	25.42	24.47	24.85	23.91	23.86	18.19	17.99	21.74	28.42	24.98	24.40
2015	24.34	29.43	31.97	24.79	23.71	23.80	22.62	21.83	20.40	21.74	20.81	21.11
2016	29.58	29.59	29.55	19.70	19.35	19.65	19.14	21.28	19.94	19.08	22.32	24.69

ii).Average Monthly value of Minimum Temperature

1. Gore

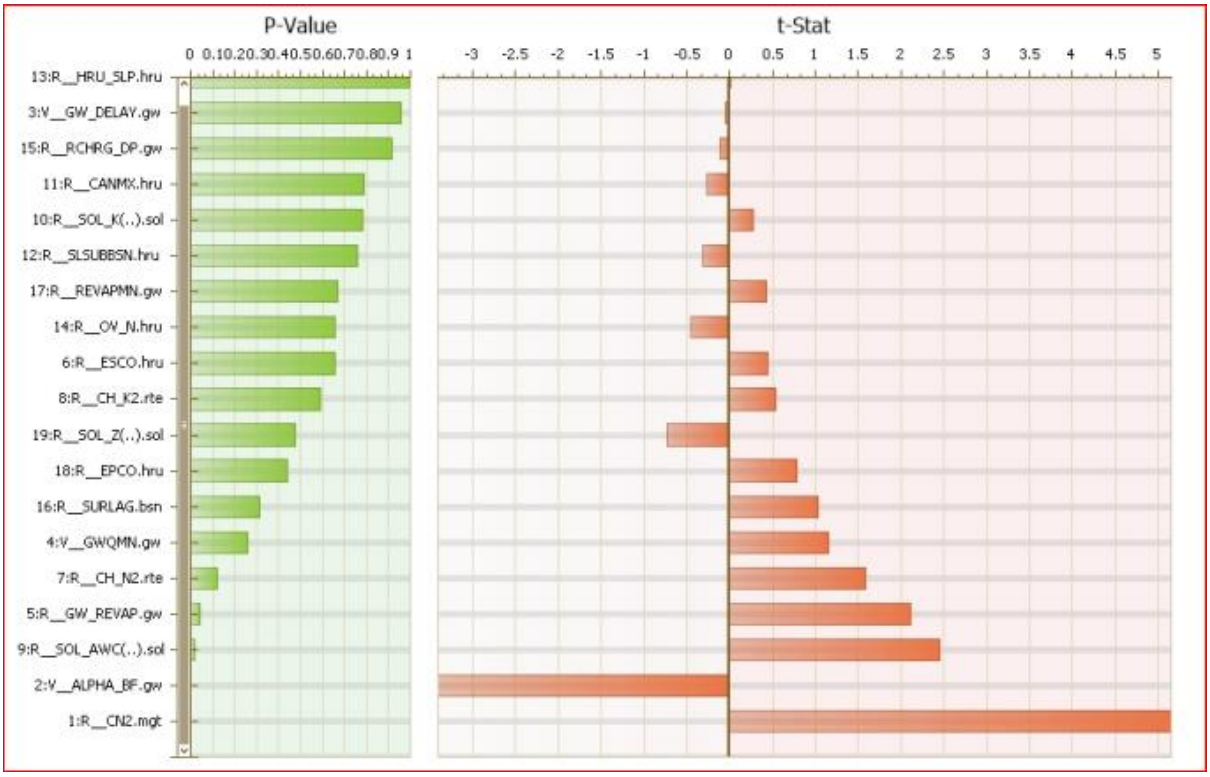
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	15.09	14.03	14.66	14.90	15.31	13.43	13.00	13.09	13.20	13.64	14.45	14.45
1987	14.89	15.58	15.24	14.89	15.02	12.62	13.33	13.57	13.48	14.01	14.71	14.84
1988	14.58	14.34	15.36	16.53	13.79	12.99	13.28	12.92	13.02	13.11	13.52	12.99
1989	11.69	12.37	13.15	14.06	13.25	12.83	12.66	12.52	12.33	12.94	13.67	12.76
1990	9.67	10.24	10.51	10.87	10.86	10.44	10.08	10.16	9.99	9.73	9.91	14.60
1991	13.65	14.81	14.71	13.83	14.07	13.03	12.86	12.66	12.91	12.71	13.43	13.29
1992	13.05	13.16	14.44	14.36	13.81	13.05	13.02	13.12	12.70	13.06	13.19	12.99
1993	12.89	13.33	13.87	13.65	13.91	12.93	12.55	12.56	12.44	12.92	13.84	13.96
1994	14.13	14.26	14.65	13.32	12.75	12.39	12.94	13.23	13.39	13.81	13.84	13.58
1995	14.30	14.34	14.09	14.81	14.18	13.49	12.88	13.11	13.02	13.41	13.81	13.35
1996	12.95	14.41	14.41	14.88	13.94	13.28	13.17	13.23	13.28	13.20	12.38	13.47
1997	13.92	14.27	14.66	14.28	13.75	13.21	13.37	13.29	13.29	13.53	13.98	13.98
1998	14.19	14.86	15.22	16.32	14.84	13.14	13.71	13.84	13.45	13.87	13.96	14.11
1999	14.49	15.50	15.35	13.87	11.95	12.21	12.14	12.36	12.38	12.77	13.15	13.22
2000	14.24	15.07	14.97	13.62	12.61	12.39	12.67	12.63	13.43	13.42	14.11	14.49
2001	13.86	14.68	15.12	15.12	14.31	13.07	13.24	13.44	13.02	13.31	13.96	14.51
2002	14.21	15.60	15.05	15.77	15.04	13.46	14.21	14.28	14.13	14.38	15.32	14.58
2003	15.46	15.51	15.37	15.29	15.53	12.83	13.36	13.58	13.19	14.10	14.66	14.27
2004	15.20	14.96	16.10	15.45	14.40	13.30	13.11	13.56	13.13	14.11	14.19	14.50
2005	14.39	17.43	15.21	16.87	15.05	13.49	13.47	13.44	13.41	13.52	14.18	15.14
2006	15.77	15.95	15.81	15.84	13.53	13.07	13.44	13.64	13.37	13.60	13.90	13.44
2007	14.04	14.53	15.35	14.67	13.79	13.25	13.34	13.25	13.17	13.65	14.04	14.35
2008	14.16	14.93	15.59	13.59	13.35	13.25	13.10	13.45	13.55	12.38	14.06	14.23
2009	14.75	14.96	14.41	14.60	14.69	13.60	13.74	13.67	13.81	14.26	14.70	14.47
2010	15.14	15.90	16.18	16.79	14.95	13.65	13.79	13.80	13.31	13.59	14.28	14.29
2011	13.87	15.35	15.46	15.03	14.18	13.49	13.48	13.22	13.35	13.67	13.20	13.18
2012	13.99	16.08	15.44	15.50	12.88	12.76	13.27	13.38	13.05	13.72	13.78	13.11
2013	13.94	14.79	14.56	15.18	13.05	13.13	13.02	13.21	13.03	13.35	13.92	13.90
2014	14.80	14.24	14.79	13.84	14.27	13.85	13.37	13.54	13.51	14.11	13.55	14.22
2015	13.70	12.91	15.22	15.23	14.29	13.89	13.50	13.88	13.61	14.02	14.07	13.74
2016	14.32	14.01	14.36	14.02	14.32	14.05	14.07	14.91	13.53	13.55	14.51	16.71

2 .Masha

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	7.55	6.07	6.71	7.47	7.83	7.47	7.05	7.43	7.69	6.94	7.75	8.48
1987	8.49	9.96	11.13	12.90	12.33	11.14	11.41	11.34	11.39	11.45	10.77	10.59
1988	10.39	11.83	11.32	12.25	12.45	12.40	11.57	11.09	11.36	11.18	9.94	9.33
1989	10.69	9.75	11.04	11.74	11.42	10.74	10.85	10.84	10.96	10.59	10.68	10.91
1990	10.14	10.98	11.30	11.95	11.93	11.33	10.82	10.93	10.69	10.31	10.57	10.69
1991	10.62	11.00	11.59	11.75	12.05	11.56	10.69	10.79	11.15	10.08	10.54	9.88
1992	10.42	11.04	10.92	12.04	11.85	11.18	11.18	11.45	10.85	11.33	10.51	10.37
1993	11.53	11.84	12.21	12.06	12.24	11.56	11.29	11.30	11.21	11.55	12.19	12.27
1994	12.39	12.49	12.75	11.83	11.43	11.18	11.56	11.76	11.87	12.17	12.19	12.01
1995	12.51	12.54	12.36	12.87	12.29	11.68	11.40	11.50	11.64	11.18	10.92	10.74
1996	10.31	11.39	11.79	12.55	12.07	12.05	11.70	11.76	11.80	11.74	11.17	11.93
1997	12.25	12.49	12.76	12.50	12.13	12.12	11.70	11.61	11.30	11.96	12.35	11.68
1998	11.81	11.61	13.13	13.75	13.43	12.39	12.02	11.95	11.94	11.90	11.21	10.06
1999	10.53	11.41	11.50	12.29	11.36	11.20	11.07	10.98	11.15	11.44	9.98	10.45
2000	10.32	10.92	11.81	12.03	11.85	11.23	11.08	11.21	11.45	11.56	10.36	10.02
2001	9.60	11.28	11.83	12.35	12.17	11.39	10.95	11.44	11.12	11.37	10.62	10.53
2002	10.83	11.21	11.97	12.10	12.35	11.63	12.02	11.25	11.16	11.13	11.03	10.68
2003	10.63	11.48	12.63	12.21	12.49	11.71	11.80	11.77	11.48	10.98	10.91	9.84
2004	11.32	10.63	12.61	12.55	12.12	11.89	11.33	11.59	11.46	11.03	11.14	11.26
2005	9.88	12.04	12.05	13.12	12.30	12.23	11.76	11.55	11.99	11.09	10.51	9.22
2006	11.05	11.65	11.94	12.22	12.21	11.63	12.03	11.72	11.93	11.81	11.72	11.89
2007	10.90	11.10	12.14	12.39	12.65	11.77	11.99	11.54	11.87	10.70	10.48	10.04
2008	10.85	11.04	11.73	11.96	11.83	11.71	10.65	11.21	11.22	11.16	10.06	9.51
2009	14.14	10.85	11.62	11.78	11.43	11.11	11.32	10.98	11.77	11.15	10.18	10.78
2010	10.03	10.94	11.44	12.43	12.27	11.84	11.48	11.40	11.62	11.17	10.60	10.10
2011	9.85	9.66	10.67	11.55	11.52	11.54	11.08	11.32	11.21	10.95	10.88	9.96
2012	9.56	10.55	11.26	11.89	11.24	10.79	10.05	9.80	10.15	9.90	10.03	9.40
2013	9.47	9.95	10.98	10.44	10.82	10.72	11.58	11.75	11.62	11.84	12.24	10.75
2014	12.74	10.22	12.76	10.33	10.73	11.30	11.80	11.98	10.55	12.31	11.99	10.18
2015	9.40	11.37	10.49	11.24	11.40	11.21	11.39	11.47	11.43	12.33	12.35	12.12
2016	12.52	12.31	12.55	12.32	12.52	12.34	12.35	12.94	11.97	11.99	12.66	14.19

Appendix B

Graphical view of sensitive parameters generated from SWAT-CUP SUFI-2.



Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	0.091381	-0.090668	0.128668
2:V__ALPHA_BF.gw	-0.031253	-0.369241	0.544241
3:V__GW_DELAY.gw	276.404633	194.159286	523.140686
4:V__GWQMN.gw	408.406555	-2408.261963	2533.261963
5:R__GW_REVAP.gw	0.119687	0.067168	0.201832
6:R__ESCO.hru	0.884473	0.748672	0.916328
7:R__CH_N2.rte	0.123224	-0.063498	0.178998
8:R__CH_K2.rte	61.043468	41.358387	114.26609
9:R__SOL_AWC .sol	0.124368	-0.380998	0.139998
10:R__SOL_K .sol	0.567762	-0.270625	0.790625
11:R__CANMX.hru	-13.409616	-27.916084	57.416084
12:R__SLSUBBSN.hru	71.635635	48.968178	127.131821
13:R__HRU_SLP.hru	0.336727	-0.144142	0.619142
14:R__OV_N.hru	4.472225	13.905633	0.619142
15:R__RCHRG_DP.gw	0.459174	0.305847	0.919153
16:R__SURLAG.bsn	11.818193	6.653592	19.89616
17:R__REVAPMN.gw	109.883316	-79.584114	307.084106
18:R__EPCO.hru	0.400977	-0.474137	0.509137

19:R__SOL_Z .sol	0.580847	-0.050008	1.985008

SWAT model results of average daily flows at the Baro River at Gambella station in a month (m3/s) at base line period (1990-2016)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1986	0.0	0.2	1645.9	166.4	8.8	24.7	707.3	285.0	1461.2	868.3	201.9	17.3
1987	16.8	16.0	17.1	17.8	24.8	40.5	69.9	69.2	70.4	64.1	44.5	37.4
1988	36.7	36.9	34.7	32.1	50.6	72.2	63.4	82.5	94.3	102.2	71.6	57.1
1989	54.3	54.8	57.0	55.8	69.6	78.8	97.0	101.8	98.6	87.2	77.3	72.8
1990	65.1	64.8	61.0	64.2	76.3	106.0	97.8	115.3	115.0	101.9	87.7	77.3
1991	74.5	74.0	71.5	77.0	88.2	97.2	108.5	111.7	112.3	92.6	86.9	79.4
1992	78.0	75.0	77.6	84.4	103.2	104.0	118.9	132.4	129.6	131.7	106.4	99.0
1993	92.8	94.0	89.8	101.1	102.5	118.0	127.4	141.2	127.3	124.0	110.3	101.3
1994	98.3	97.4	91.8	100.5	112.3	126.6	136.2	150.4	147.1	124.4	115.1	107.9
1995	102.3	104.3	104.1	102.9	109.7	123.0	125.6	130.7	137.0	125.6	112.9	109.5
1996	113.4	109.5	106.6	111.1	130.4	139.5	164.3	159.2	163.1	155.8	130.3	125.7
1997	121.8	119.5	115.6	128.3	147.4	158.2	160.6	176.6	163.5	162.2	150.3	130.7
1998	126.0	126.6	125.9	124.2	138.5	154.8	163.9	161.2	165.7	166.8	143.6	130.9
1999	128.2	130.1	123.8	127.8	153.1	155.0	157.7	166.1	165.5	168.6	143.8	136.0
2000	134.5	128.8	127.0	134.2	162.2	172.3	174.0	175.6	175.5	180.2	150.7	140.6
2001	136.2	138.9	133.1	136.2	146.4	164.5	168.0	167.8	175.0	173.0	149.1	142.9
2002	139.6	139.7	135.4	140.8	137.5	158.1	172.7	166.6	166.6	160.4	143.9	137.1
2003	133.6	137.2	133.1	132.5	136.9	163.5	175.3	174.2	187.6	161.1	145.2	141.4
2004	135.5	132.6	131.6	134.1	139.1	153.9	168.6	172.7	176.0	154.0	152.0	143.4
2005	134.8	136.5	135.9	131.6	138.6	161.7	174.5	186.3	177.4	164.1	151.1	140.1
2006	135.8	138.9	132.9	132.1	150.0	162.5	175.6	191.4	186.1	177.1	155.3	151.6
2007	141.7	145.8	141.9	145.9	155.7	169.7	167.5	176.9	194.3	175.7	153.1	144.5
2008	143.0	139.7	137.7	140.4	160.1	187.2	182.1	188.0	180.7	169.5	149.5	128.3
2009	125.6	127.4	121.2	137.9	131.6	156.1	1525.1	189.8	177.0	170.6	151.8	147.2
2010	146.3	146.8	136.6	134.7	155.5	165.2	170.5	168.5	180.4	187.7	160.5	146.9
2011	139.8	142.9	135.5	137.6	148.8	175.0	1384.9	194.9	202.4	186.4	160.9	152.0
2012	146.9	141.4	141.7	141.7	162.5	169.8	177.3	198.1	194.1	171.5	174.1	156.4
2013	147.2	149.2	144.1	142.0	175.3	179.6	183.0	179.6	174.6	173.3	161.5	148.2
2014	144.5	147.6	145.8	154.5	190.0	182.7	187.7	193.0	182.0	175.6	160.0	153.2
2015	148.9	150.3	146.3	149.7	166.9	177.2	178.4	7075.3	226.4	178.0	173.7	163.3
2016	178.1	173.4	182.7	181.3	4443.9	1272.3	213.6	200.8	196.7	210.6	180.9	172.0

Appendix C

Monthly Average stream flow at Gambella station due to constant ΔT= 2^{o}C and precipitation range from -20% to20%

Month	**ΔP=-20%**	**ΔP=-10%**	**ΔP=0%**	**ΔP=10%**	**ΔP=20%**
1	124.0450032	122.1432399	122.3469275	122.5483784	122.7446924
2	124.073504	122.1788277	122.3852367	122.5882818	122.7939646
3	121.0837697	119.2805427	119.4813929	119.6821836	119.87962
4	124.6916087	122.8803881	123.0851288	123.2883494	123.4974541
5	297.4159662	295.6218148	296.023066	296.446343	296.8292254
6	192.5172593	190.6783414	190.965351	191.2513446	191.5422158
7	256.1518986	254.7073865	255.0539646	255.4084171	255.757153
8	424.810182	423.0016892	423.5125942	424.0629678	424.5762576
9	167.5318663	165.3562013	165.6147778	165.8708035	166.1288631
10	157.5297939	155.4407729	155.6856103	155.9290709	156.1712544
11	140.4536586	138.4230064	138.6486135	138.8736602	139.1030274
12	131.1925362	129.2567504	129.4722979	129.6848599	129.9038889

Monthly Average stream flow at Gambella station due to constant ΔT= 3.5^{o}C and precipitation range from -20% to20%

Month	ΔP= -20%	ΔP= -10%	ΔP= 0%	ΔP = 10%	ΔP= 20%
1	120.8348	121.0393	121.2322	121.4568	121.6439
2	120.8815	121.0815	121.2892	121.494	121.691
3	118.0122	118.2116	118.4098	118.6075	118.8059
4	121.5889	121.7918	121.9988	122.2034	122.4063
5	294.0867	294.4989	294.8858	295.2761	295.6661
6	189.3135	189.5954	189.8872	190.1642	190.4567
7	253.2493	253.597	253.9492	254.2908	254.6371
8	421.1546	421.7169	422.2484	422.7746	423.3123
9	163.8391	164.09	164.3518	164.6001	164.8592
10	153.9692	154.2155	154.4622	154.7081	154.9525

11	137.0231	137.2461	137.4723	137.699	137.9289
12	127.876	128.1026	128.3015	128.5271	128.7439

Monthly Average stream flow at Gambella station due to constant ΔT= 4.5 ^{o}C and precipitation range from -20% to20%

Month	ΔP=-20%	ΔP=-10%	ΔP=0%	ΔP=10%	ΔP=20%
1	118.8674	119.0666	119.2866	119.4687	119.6733
2	118.9533	119.1556	119.3578	119.5598	119.7621
3	116.1272	116.3244	116.5235	116.722	116.9181
4	119.6888	119.8955	120.0976	120.2999	120.5033
5	292.1172	292.5167	292.8989	293.2846	293.7004
6	187.5062	187.7934	188.0675	188.3653	188.6538
7	251.2384	251.5796	251.9203	252.2766	252.625
8	418.9149	419.4469	419.9876	420.5178	421.0491
9	161.6509	161.9065	162.158	162.4192	162.6646
10	151.8148	152.0533	152.2991	152.5401	152.7882
11	134.9343	135.1589	135.3885	135.6094	135.8435
12	125.8323	126.0428	126.2594	126.4708	126.6782

Monthly Average stream flow at Gambella station due to constant ΔT= 6^{o}C and precipitation range from -20% to20%

Month	ΔP= - 20%	ΔP =- 10%	ΔP = 0%	ΔP =- 10%	ΔP = 20%
1	119.4861997	116.1666232	116.3584203	116.5505217	116.7509179
2	119.5786425	116.1513929	116.3551916	116.5518937	116.7551385
3	116.7437005	113.4047037	113.6001498	113.7977697	113.9919291
4	120.3305008	116.9688245	117.1711079	117.3698712	117.5726828
5	293.5227697	289.4959211	289.8969436	290.2838712	290.6786184
6	188.4650757	184.7736184	185.0636119	185.3522254	185.6349291
7	252.4247118	248.2299291	248.5810709	248.9284847	249.2659549
8	420.851211	416.0284477	416.5403961	417.0953607	417.6066264
9	162.4617681	158.5627842	158.807124	159.0651288	159.3115507
10	152.591132	148.7875137	149.0335652	149.2786248	149.5141401

11	135.6346345	131.9176071	132.1392609	132.3541288	132.5827118
12	126.4723623	122.8892093	123.0988502	123.3077552	123.5250145