EVALUATION OF CLIMATE CHANGE IMPACTS ON STREAM FLOW OF MODJO RIVER WATERSHED IN THE UPPER AWASH RIVER BASIN, ETHIOPIA

By

Tesfaye Muse Ekule

A Thesis Submitted to the Department of Water Resources Engineering, School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

July, 2021

Adama, Ethiopia

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Tesfaye Muse Ekule

ID No. Pge/18880/11

Major Advisor: Dr. Keredin Temam Siraj

Co-Advisor: Dr. Abdulkerim Bedewi Serur

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DECLARATION

I hereby declare that this Master Thesis entitled "Evaluation of Climate Change Impacts on Stream Flow of Modjo River Watershed in The Upper Awash River Basin in Ethiopia" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Tesfaye Muse Ekule	________________________	________________
Name of the student	Signature	Date

RECOMMENDATION

we, the advisors of this thesis, hereby certify that we have read the revised version of the thesis entitled "*Evaluation of Climate Change Impacts on Stream Flow of Modjo River Watershed in The Upper Awash River Basin In Ethiopia*" prepared under our guidance by Tesfaye Muse Ekule submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resources Engineering (Specialization in Irrigation Engineering).

Therefore, we recommend the submission of revised version of the thesis to the Department following the applicable procedures.

Dr. Keredin Temam Siraj ________________________ ________________

Major Advisor Signature Date

Dr. Abdulkerim Bedewi Serur________________________ ________________

Co-advisor Signature Date

APPROVAL PAGEOF M.SC THESIS

We, the advisors of the thesis entitled "Evaluation of Climate Change Impacts on Stream Flow of Modjo River Watershed in The Upper Awash River Basin in Ethiopia" and Developed by Tesfaye Muse Ekule, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Keredin Temam Siraj	______________________	______________
Major Advisor	Signature	Date
Dr. Abdulkerim Bedewi Serur	______________________	______________
Co-advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Tesfaye Muse Ekule have read and evaluated the thesis entitled "Evaluation of Climate Change Impacts on Stream Flow of Modjo River Watershed in The Upper Awash River Basin in Ethiopia" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering).

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Final approval and acceptance of the thesis is contingent upon submission of its final copy To the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC)and School Graduate Committee (SGC).

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LIST OF ACRONYMS AND ABBREVATIONS

AGCM	Atmospheric General Circulation Model
AOGCM	Coupled Atmosphere-Ocean General Circulation Model
CanESM2	Canadian Earth System Model
CGIAR	Consultative Group on Agricultural Research
CICS	Canadian Institute for Climate Studies
DDC	Data Distribution Center
FAO	Food and Agriculture Organization
GCM	General Circulation Model
GHG	Greenhouse Gas
ITCZ	Inter tropical Convergence Zone
IPCC	Intergovernmental Panel on Climate Change
NCEP	National Center for Environmental Prediction
NMSA	National Meteorological Services Agency
NSE	Nash-Sutcliffe Efficiency
OGCM	Ocean General Circulation Model
PCP	precipitation
R2	Coefficient of Determination
RCM	Regional Climate Model
RCP	Representative Concentration Pathway
SDSM	Statistical Downscaling Model
SN	Scenarios
SWRRB	Simulator for Water Resources in Rural Basins
SRES	Special Report on Emission Scenario
T-Max	Temperature Maximum
T-Min	Temperature Minimum
WMO	World Meteorological Organization
MoWIE	Ministry of Water, Irrigation and Energy

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ABSTRACT

The concern of Water resources and climate change is escalating to global significance due to high spatiotemporal hydro-climatic variability, which is leading to major challenges of socio-economic development and sustainability. Climate change and its variability are predictable to elicit change in temperature and precipitation series of streamflow of a watershed. The objective of this study is to assess the Impact of Climate Change on streamflow of Modjo river watershed by using SWAT hydrological models. Statistical downscaling Method (SDSM) applied in order to downscale the climate variables at watershed level to downscale the present and future monthly precipitation and temperature from the Canadian center for climate modeling and Analysis (CanESM2). Two future emission scenarios, RCP 4.5 and RCP 8.5 were considered for the three different periods (2020s, 2050s and 2080). Sequential uncertainty Fittings (SUFI_2) calibration process built in SWAT calibration and uncertainty program (SWAT-CUP) calibrated by 1990 to 2008 and validated by 2009 to 2017 flow data. The performance of the model was evaluated through sensitivity analysis, calibration and validation. The output of downscaled data provides input of rainfall and temperature data for the SWAT model to estimate flow. The result revealed that mean T-max is increasing by 1.54°C and 1.44°C under RCP 8.5 RCP4.5 while; mean daily T-min is increasing by 3.27°C and 1.99°C under RCP 8.5 RCP 4.5 respectively. Similarly, annual precipitation also expected to increase up to 2%, 4% and 7% for RCP 4.5 and 2%, 5% and 9% for RCP 8.5 for 2020s, 2050s, and 2080s respectively. The coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE), percent Bias (P_{bias}) and RSR value for the daily streamflow by using SUFI-2 optimization technique was obtained for calibration period 0.87, 0.83,16.4 and 0.41 and for validation period 0.93,0.87,23.1 and 0.29. Simulation of climate change effects on streamflow was increased due to the increment of PCP. The streamflow increased by 4.72m^3/s, 4.84m^3/s, and 5.38m^3/s for Rcp 4.5 while for RCP 8.5 increased to 3.82m^3/s, 3.86m^3/s, 3.32m^3/s for the period of Near (2020), Mid (2050) and Far (2080) respectively. This will exceeds the average flow of the Modjo watershed. Climate change and its variability will trigger the change in temperature and precipitation series, which will affect streamflow patterns, and volume of watershed. Thus, furthermore significantly predictable effect on socio-economic development. Since, T-Max, T-Min and PCP increasing in all scenarios the impact on Koka reservoir, crop production sustainability and others will increase. Thus, application of integrated watershed management strategy for Modjo river watershed to optimize water resources management and option to improve streamflow is vital for the study area.

Key words: *Arc SWAT, Climate Change, GCM, Modjo River Watershed, SDSM, Streamflow, SWAT-CUP,*

1. INTRODUCTION

1.1. Background

Our environment has been influenced by human Activity for centuries. Particularly, since the beginning of the industrial revolution at which the impact extends to a global scale (Bekele*et al*., 2017). Environmental issues become the biggest concern of mankind as a consequence of increasing concentration of greenhouse gases in the atmosphere and the changing climate of the Earth. Globally, temperature is increasing and the amount and distribution of rainfall is being altered, rising sea levels, shifting ecological zones, and alterations in areas that are suitable for farming are some of the changes (Cubasch, 2001; Asfaw, 2013). Furthermore, erratic weather, such as tropical storms and extended heat waves are other likely effects of climate change causing higher incidence of death and injury (Asfaw, 2013). Thus, climate change has become a major topic of interest to the scientific community and similarly this study.

The report of the Intergovernmental Panel on Climate Change (IPCC, 2007; IPCC, 2013) concludes that our climate is changing. One of the most important impacts of climate change is on the world's fresh water supplies, caused by increased temperatures, changed precipitation, and shifts in the historic hydrologic cycle. Climate change has a profound impact on natural resources, of which water is one of the most important. With climate change the amount of rainfall in many parts of Africa is expected to decline while variability may increase dramatically (IPCC, 2007 and Melat, 2020). With climate change and increases in climate variability, the need for managing water resources requires immediate action or attention (Melat, 2020). Due to climate change and variability there is an increase in severity of extreme events which results in fluctuation of storage. This may lead to an increase in floods and droughts (Haileyesus, 2011).

The findings indicate that developing countries, such as Ethiopia, will be more vulnerable to climate change. It may have far reaching implications to Ethiopia for various reasons, mainly as its economy largely depends on agriculture. A large part of the country is arid and semiarid, and is highly prone to desertification and drought. Climate change and its impacts are, therefore, a case for concern to Ethiopia (IPCC, 2007). Hence, assessing vulnerability to climate change and preparing adaptation options as part of the entire program is very crucial for the country (NMA, 2001).

In Ethiopia it is very common to see climate change caused water resource availability hazards in the entire country. This is resulted due to human activities within the river system leading to change in watershed characteristics and river morphology (Ebrahim, 2013). Since the watershed is found in the Great Rift valley and lies between semi- arid to arid, with rainfall varying from 980.8 mm to 913 mm its floor mean temperature is greater than 20°C and evaporation exceeds 2500 mm (Bekele*et al.*, 2017).

According to Gonfa (2015) Modjo watershed is one of the river systems found in the Upper Awash River basin which is sensitive to climate calamities such as precipitation and Temperature. It is for these reasons that climate change has become a major topic of interest. This study will evaluate the impact of climate change on water resource availability. The focus is on the evaluation of how climate change would influence the availability of water resources for the Modjo watershed in Central Ethiopia using downscaled GCM outputs and SWAT hydrological models.

1.2. Statement of the Problem

Globally, Climate change is expected to have adverse impacts on socio-economic development in which the degree of the impact will vary across nations. Particularly, climate change impact is more severe in the developing world. There is strong scientific evidence that indicates the average temperature of the Earth's surface is increasing due to human Activities. The IPCC (Intergovernmental Panel on Climate Change) scenarios project temperature rises of 1.4 ºC - 5.8ºC, and sea level rises of 9-99 cm by 2100 (IPCC, 2014). The IPCC (2007) report indicates that developing countries, such as Ethiopia will be more vulnerable to climate change. As Ethiopia has the following agricultural based industrialization which is strongly tied with climate and being a large part of the country is arid and semi-arid, climate change should be a concern. One of the most important potential concerns of climate change is hydrological components alteration and subsequent changes in river Hydrology (Girma, 2013). By affecting certain components of the hydrological cycle, especially precipitation and runoff, a change in climate can alter the spatial and temporal availability of water resources. Climate change that reduces either the overall quantity of water or the availability of water for use will have important effects on agriculture and industrial and urban development. Most of the research over the Modjo watershed focuses on the sediment accumulation for instance (Gonfa and Kumar, 2016; Gonfa*et al.*, 2015). Climate change and its impacts on river flow hydrology is therefore, a case for concern to Ethiopia particularly on the Modjo Watershed (MoWR and NMA, 2010)

Modjo watersheds contribute water for irrigation, industries, and urban water supply and for the use of society near by the river within Watershed of Modjo. Furthermore evaluating the impact of climate change is a more important task therefore, this study evaluates the pattern of hydrological change and determines the pattern of climate change with its impact on the Modjo watershed. Even though climate has different effects on the watershed characteristics most of them are not identified and investigated in the Modjo watershed. Therefore this study will try to address the impacts of climate change on water resources availability of the Watershed using SDSM and SWAT models.

1.3. General Objective

The general objective of this study is to assess the Climate Change Impacts in time scale on streamflow of Modjo watershed in Upper Awash river basin Ethiopia using SWAT hydrological models.

1.4. Specific objectives

- To develop and evaluate climate scenario data for Precipitation, Tmax and Tmin based on Statistical Downscaling model for modjo watershed.
- To develop temporal variations of climate variables (maximum temperature, minimum temperature and precipitation.
- To evaluate performance of SWAT model in simulating streamflow.
- To evaluate the response of streamflow to the impacts of climate change using the SWAT Hydrological model.

1.5. The Research Questions

- What are the possible outcomes using the Statistical Downscaling Model for the hydrological assessment at the watershed level?
- What are the general trends of Tmax, Tmin and Pcp scenarios in the future compared to the present condition?
- How well does the SWAT hydrologic model perform in simulating streamflow in the study area?
- How future streamflow responses to changes in rainfall and temperatures in the basin.

1.6. Significance of the Study

The Intergovernmental Panel on Climate Change report shows that continued emission of greenhouse gases will cause further warming and long-lasting changes in all components of the climate system, pervasive and irreversible impacts for people and the entire ecosystems (IPCC, 2014). Application of hydrological models in the Watershed at spatial scale would be essential to know water hydrology and to study the impact of climate change on the watershed which helps to set different planning and management scenarios (Cherinet*et al.*, 2019). In addition to that Effective watershed planning requires understanding the types and impacts of climate change. This is an essential indicator for resource base analysis and development of effective and appropriate response strategies for sustainable management of natural resources in the country in general and at the study area in particular. Therefore, it is necessary to study the hydrologic responses to climate change at the watershed level in order to take the effect into account by the policy and decision-makers when planning water resources management. This study may help local and regional community/ policy makers and concerned bodies what types of problems are happening and will happen due to climate impact. Also this study provides knowledge to fill some of the gaps regarding key variables that affect water availability in response to climate change and variability, additionally the results of the study can also be used by researchers and development practitioners as baseline information for further studies that could be conducted in the study area or related settings. Therefore, the study presents a method to quantify climate change and their impact on the Modjo watershed.

1.7. Scope of the Study

Since it was not possible to cover the whole Upper ARB (Awash River Basin) in impact assessment of climate change on water availability the study focuses on the Modjo watershed responding to major stresses of climate change and its impact in terms of the streamflow and the water availability at the watershed level. The study assessed the impact of climate change on surface water from utilized time series of new plausible RCM output climate mode data under two emission scenarios (RCP 4.5 and 8.5) which are used as inputs for hydrological model (SWAT) under assumption of the land use land cover will remain the same, even if in real world always changing and affecting the hydrology of the watershed. Aiming at the objective, this study did not take into account the other development. Moreover, it is beyond the scope of this study to identify the problem of irrigation water allocation, sediment and LULC if it may happen under future scenarios. The study also did not take into account the effect of climate change on the water quality.

1.8. Thesis Organization

This thesis contains five Parts organized as follows. Part one gives a general and concise introduction to the study work on the watershed with its background, statement of the problem that defines the problems addressed on the entire study work and objectives, significance and scope of the study as well as the overall thesis outline. Part two describes reviewed literature about the subject matter and related works that gives a scientific review on facts this study is mainly based on. Part three describes materials and methods adopted for the study including brief description of the study area location and available hydrological, meteorological and spatial data used for this study and as well as how data are analyzed. Part four presents the result of the study and the last Part five ends with research conclusion and recommendations based on the study conducted to indicate direction for future studies. Finally, references and appendices in the form of tables and figures and serving as a supporting document to this thesis are attached to make the work a complete one.

2. LITERATURE REVIEW

2.1. Climate Change

A simple defnition of climate of a region is the average weather condition of the rigion over a longe period of time. Therfore, its safe to say that Climate change is the cange in the weather condition of a place over a long period of time. The IPCC (2007) defines climate change as “a change in the state of the climate that can be identified by changes in the average and/or the variability of its properties, and persist for an extended period of time, normally a decade or longer”. Climate has changed considerably throughout the history of the earth due to the change in its forcing components, whether natural or anthropogenic. Anthropogenic climate change (hereafter “Climate change”) is with high confidence caused by intensification of the greenhouse effect due to increase of GHGs in the atmosphere (IPCC, 2007).

Global atmospheric concentrations of CO_2, CH_4 and N_2O have increased markedly as result of human activity since 1970 and now far exceed pre- industrial value determined from ice cores spanning many thousands of years. The global increase of CO_2 concentration is due primarily to fossil fuel use and land use change. While those of CH_4 and N_2O primarily due to Agriculture. CO_2 is the most anthropogenic GHG. The global atmospheric concentration of CO_2 has increased from pre industrial value of about 280 ppm to 379 ppm in 2005.

At continental, regional and ocean basin scales, numerous long term changes in climate have been observed. These include change in arctic temperature and ice, widespread change in precipitation amounts, ocean salinity, wind patterns and aspects of extreme whether including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (IPCC, 2013).

2.2. General Circulation Model (GCM)

According to PCC (2014) General Circulation Models or GCMs, representing physical processes in the atmosphere, ocean, cryosphere and land surface. And also the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations (Rahman, 2019). While simpler models have also been used to provide globally or regionally- averaged estimates of the climate response, only GCMs, possibly in conjunction within the regional models, have the potential to provide geographically and physically consistent estimates of regional climate change which are required in impact Analysis. For this purpose, models of each component of the climate system have been developed, improved and coupled together. The component to be modeled earliest on a global level was the atmosphere. Atmospheric General Circulation Models (AGCMs) are complex three-dimensional models of the physics and dynamics of the atmosphere. They are very similar to the models used for weather forecasting. A three-dimensional grid is placed over the Earth surface. Within each one of the resulting "boxes", the state of the climate is described (Enyew, 2014).

2.3. Climate Scenarios

Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and other pollutants and with our understanding of the effect of increased atmospheric concentrations of these gases on global climate, These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the behavior of the climate system over long time scale (Worku *et al.,* 2018). A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change and to help policy makers decide on appropriate policy responses.

The goal of working with scenarios is not to predict the future but to better understand uncertainties and alternative futures, in order to consider how robust different decisions or options may be under a wide range of possible futures (Wayne, 2013).The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects (IPCC, 2007). Three basic approaches are used for creating climate change scenarios in climate change impact studies:

- General Circulation Models (GCMs);
- Analogue (historical), and
- Synthetic or incremental changes in climate variables

2.4. Representative Concentration Pathways

The future of anthropogenic greenhouse gas and aerosol emissions (and hence their resultant radiative forcing) is highly uncertain, encompassing substantial unknowns in population and economic growth, technological developments and transfer, and political and social changes (Baldassarre *et al.,* 2011). Recently, the Coupled Model Inter-comparison Project Phase 5 (CMIP5) generated new representative concentration path-ways (RCPs) to explore credible future options; these new generations of RCPs are con-centration pathways used in the IPCC AR5. They are prescribed pathways for greenhouse gas and aerosol concentrations, together with land use change, that are consistent with a set of broad climate outcomes used by the climate modeling community (Worku *et al.*, 2018).

The pathways are characterized by the radiative forcing Produced by the end of the 21st century (Van Vuuren *et al.,* 2011). The development of (RCPs) will help to advances in processing of coordination of new integrated socioeconomic, emissions, and climate sce-narios. There are four different types of (RCPs)developed and named based on their radi-ative forcing power capacity (Table 2.1). Each RCP includes the concentration pathways and corresponding emissions and land use pathways, which are uses as input to climate model for developing global climate projections (GCM) the projections, have near term up to 2035 and long term covers up to 2100 and an extended one up to 2300 (Wayne, 2013).

Table2. 1: Types of Representative of Concentration Pathway (RCPs): source (Wayne, 2013)

Name	**Radiative Forc-ing**	**Co_2 Equ(P.P.M)**	**Pathway Shapes**	**SRES Temp**
RCP 8.5	>8.5 W/m^2 in 2100	>1370 Co_2 eq in 2100	Rising	A1F1
RCP 6.0	6 W/m^2 at Stabi-lization after 2100	850 Co_2 eq (at Stabilization after 2100)	Stabilization Without over-shoot	SREA B2
RCP 4.5	4.5 W/m^2 at Sta-bilization after 2100	650 Co_2 eq (at Stabilization after 2100)	Stabilization Without over-shoot	SREA B1
RCP 2.6	Peak at $3W/m^2$ before 2100 and the decline	Peak at 490 Co_2 eq before 2100 and then decline	Peak & De-cline	None

RCP8.5. pathway arises from little effort to reduce emissions and represents a failure to curb warming by 2100.

RCP6.0. pathway stabilizes total irradiative forcing shortly after 2100 by the application of a range of technologies and strategies for reducing greenhouse gas emissions.

RCP4.5. it is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing.

RCP2.6. is the most ambitious pathway. It sees emission speak early, then fall due to active removal of atmospheric carbon dioxide.

2.5. Comparisons of SRES and RCP Climate Scenarios

Two families of scenarios are commonly used for future climate projections: the 2000 Special Report on Emission Scenarios (SRES, left) and the 2010 Representative Concentration Pathways (RCP, right). The SRES scenarios are named by family (A1, A2, B1, and B2), where each family is designed around a set of consistent assumptions: for example, a world that is more integrated or more divided. In contrast, the RCP scenarios are simply numbered according to the change in radiative forcing (from +2.6 to +8.5 watts per square meter) that result by 2100. This figure compares SRES and RCP annual carbon emissions (top), carbon dioxide equivalent levels in the atmosphere (middle), and temperature change that would result from the central estimate (lines) and the likely range (shaded areas) of climate sensitivity (bottom). At the top end of the range, the older SRES scenarios are slightly higher. Comparing carbon dioxide concentrations and global temperature change between the SRES and RCP scenarios, SRES A1fI is similar to RCP 8.5; SRES A1B to RCP 6.0 and SRES B1 to RCP 4.5. The RCP 2.6 scenario is much lower than any SRES scenario because it includes the option of using policies to achieve net negative carbon dioxide emissions before end of century, while SRES scenarios do not.

2.6. Downscaling Methods

The general circulation method (GCMs) used to simulate the present and future climate with forcing by greenhouse gases and aerosols. Mostly GCMs simulates global and continental scale processes in detail and provide a reasonably accurate representation of the average planetary climate. Over the past decades the sophistication of such model has increased and their ability to simulate the present and past global and continental scale climate has substantially improved. Nevertheless, while GCMs demonstrated significant skill at the continental and hemispherical scale and incorporate a large portion of the complexity of the global system, they are inherently unable to present local sub- grids scale futures and dynamics, such as local topographical futures and convictive cloud process(Wilby *et al.,* 2009).Moreover, GCMs were not designed to for climate change impact studies and do not provide a direct estimation of the hydrological response to climate change. Therefore, there is a need to convert GCMs output into a list daily rainfall series at the scale of the watershed to which the hydrological impact going to be investigated. The method used to convert GCMs output into local meteorological variables requires for reliable hydrological modeling are usually referred to as "downscaling method".

2.6.1. Statistical downscaling

Statistical downscaling involves the establishment of empirical relationships between historical large-scale atmospheric and local climate characteristics. Once a relationship has been determined and validated, future large-scale atmospheric conditions projected by GCMs are used to predict future local climate characteristics (Mearns *et al.,* 2003). In other words, large-scale GCM outputs are used as predictors 5 to obtain local variables or predictands. Statistical downscaling encompasses a heterogeneous group of methods that vary in sophistication and applicability Statistical downscaling methods are computationally inexpensive in comparison to RCMs that require complex modeling of physical processes. Thus, they are a viable and sometimes advantageous alternative for institutions that do not have the computational capacity and technical expertise required for dynamical downscaling. Unlike RCMs, which produce downscaled projections at a spatial scale of 20–50 kilometers, statistical methods can provide station-scale climate information (Mearns *et al.,* 2003).

2.6.2. Dynamical downscaling

Dynamical downscaling refers to the use of an RCM driven by a GCM to simulate regional climate. An RCM is similar to a GCM but has higher resolution and additional regional information, which enables it to better represent local landscape and possibly local atmospheric processes. The global model simulates the response of the global circulation to changes in atmospheric composition through a large number of processes, but some of them need to be approximated due to the coarse resolution of the models. On the other hand, at the resolution of 25–50 km for portions of the globe, the RCM is able to capture some of those smaller-scale processes more realistically. Atmospheric fields (e.g., surface pressure, wind, temperature, and humidity) simulated by a GCM are fed into the vertical and horizontal boundaries of the RCM. Locally specific data and physics-based equations are then used to process this information and obtain regional climate outputs. The primary advantage of RCMs is their ability to model atmospheric processes and land cover changes explicitly (Wilby *et al.,* 2009).

2.7. Climate Change Impact on Temperature and Precipitation

2.7.1. Climate change impact on temperature and precipitation in global perspective

Warming of the climate system in recent decades is obvious, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global sea level (IPCC, 2014). The global average temperature showed a 100 year linear trend of 0.74°c from 1996-2005 (IPCC, 2014). Trends in precipitation have been observed in many large regions. Globally, the area affected by drought has likely increased since the 1970's(IPCC, 2001). The ocean circulation is also predicted to change and sea level is expected to rise at a rate of about 1.7 mm/year as the ocean expands as heat is gradually diffused downwards in the ocean (Thorpe, 2005). There are also numerous long term changes in other aspects of climate. Some extreme weather events have changed in frequency and/or intensity. Hot days, hot nights, heat waves, and heavy precipitation events have become more frequent over most land areas. There is evidence that most of the warming observed over the last 50 years is attributable to human activities (IPCC, 2001). Human activities such as the usage of fossil fuels, changes in land use (e.g. deforestation), agriculture and industrial activities contribute to the emissions of greenhouse gasses thereby increasing the Concentration of greenhouse gases in the atmosphere (Endalkachew, 2012).

2.7.2. Climate change impact on temperature and precipitation in Africa

Africa has a highly variable and unpredictable climate that is not fully understood by climatologists. However, observational records show that Africa has been warming through the 20th century at the rate of about 0.05°C per decade with slightly larger warming in the June-November seasons than in December-May. The most significant climatic change that has occurred in Africa has been a long-term reduction in rainfall in the semi-arid regions of West Africa. Several reports have noted that Africa is the most vulnerable continent to climate change. The vulnerability to climate change largely depends on its current and future adaptive capacities. This in turn is influenced by such factors as the level of economic development, education, access to credit and adoption of technology. Becausethese factors are not uniform across Africa(Hulme *et al.,* 2005).

2.7.3. Climate change impact on temperature and precipitation in Ethiopia

According to IPCC (2007) the developing countries such as Ethiopia and the other countries in East Africa will be more vulnerable to climate change, mainly Ethiopia because of its low economic, climatic and geographic settings it would be more affected. Arid and semi-arid part of the country is highly prone to drought and desertification and the livelihood depends on available rainfall (Abdo, 2009). The author also reported that the country has a fragile highland ecosystem that is currently under stress due to still increasing population pressure. Therefore, there is a need to quantify and assess the future scenarios of climate change and its impact on water resources of the 20 countries in general and the basin in particular, because the country's future development relies on this resource. Literature shows that some climate change impact studies on hydrology have been conducted in Ethiopia. Among these studies some has shown that the change in rainfall over the Blue Nile basin would be between +2 and +11% for 2030, while rainfall over the White Nile basin would increase between 1 and 10% for the same year (Cherinet, 2019).

The other author run the Nile Forecasting Model with biased corrected precipitation and temperatures from 17 GCMs for 2081-2098 periods to assess effects of climate change on streamflow of the Blue Nile (Elshamy *et al.,* 2009). The conclusion of Elshamy was that the uncertainty in future precipitation change makes the future streamflow of the Blue Nile at Diem very uncertain. Taye *et al* (2013) also investigated the potential impact of climate change on the hydrological extremes of the Lake Tana Watershed, Blue Nile Ethiopia. They stated that an unclear trend is observed for the Watershed for mean volumes and high/low flows for the 2050s using 17 GCMs. From the IPCC Fourth Assessment Report (IPCC, 2007) and the country report of Ethiopia (Tadege, 2007) there is a general consensus on the rise of the temperature.

According to Baldassarre *et al.*(2011) there is generally no significant change detected in the annual rainfall in most of the Nile sub-basins, there appears to be decreasing seasonality in some key watersheds of the upper Nile in Ethiopia such as the southern Blue Nile and Baro-Akobo. Agizew *(* 2015) also showed that climate variability of the Ethiopian Highlands is primarily due to rainfall fluctuations. The conducted research on climate change impacts on hydrology and water resources of the upper Blue Nile river basin, Ethiopia The result suggested that the climate in most of the upper Blue Nile river basin is likely to become wetter and warmer in the 2050s (2040-2069) and droughts are likely to become less frequent throughout the entire basin (Mulugeta *et al.,* 2014). Therefore, there are large uncertainties in predicting climate change impacts on the country's water resources and this leads to unreliable development of water resources plans in the future. By nature, the future is uncertain and this is partly handled via emission scenarios that capture different visions of how the world will develop in the future in terms of population, technology and energy use. Even though much research has been done in continental or global scale studies related to climate change, the magnitude and type of impact at the regional-Watershed scale is not investigated in many parts of the world that also includes Ethiopia (Daba, 2015).

In addition to this, the climate change studies in water resources of Ethiopia has largely focused on existing information over Blue Nile and not much research has been seen from the South western part of the country (BaroAkobo basin). Investigating climate change at local level gives an opportunity to define the degree of vulnerability of local water resources and plan appropriate adaptation measures that must be taken ahead of time. Moreover this will give enough room to consider possible future risks in all phases of water resource development projects at the local scale (Mollaand Abdisa, 2018). Extreme hydrological events have negatively affected Ethiopia's past economic development by affecting crop production through drought and flooding. The future projections also show a likely variability of precipitation, which translates as fluctuating rainfall, reduces the availability of a stable water supply and increases the risk of floods. (Adem *et al*., 2016)Reported that in Ethiopia, climate change is expected to intensify the already high hydrological variability and frequency of extreme events, and drought and flood may have a significant negative effect on the development of the agriculture sector and the economy as a whole. Therefore, projection of climate change impact on water resources of the country should not be neglected in the future development plan.

2.8. Hydrological Models

There are many different reasons why modeling of the rainfall-runoff processes of hydrology is needed. The main reasons behind were limited range of hydrological measurement techniques and a limited range of measurements in space and time (Adem *et al.*, 2016) and (Beven, 2012). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungauged Watersheds and into the future to assess the likely impact of future hydrological change. Hydrological models are characterizations of the real world system. A wide range of hydrological models are used by the researchers, however the applications of those models are highly dependent on the purposes for which the modeling is made.

Beven (2012) Stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models it is vital to understand how the Watershed/watershed responds to rainfall under different conditions.

2.8.1. 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. Beven (2012) suggested four criterions for selecting model structures as below.

- ✓ Consider models which are readily available and whose investment of time and money appeared worthwhile.
- ✓ Decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project.
- ✓ 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 Watershed. 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 Watershed processes.
- ✓ 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.

2.8.2. Soil and water assessment tool (SWAT)

SWAT is a physically based river basin scale model developed by Dr. Jeff Arnold to predict 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 (Arnold *et al.*, 2012). The SWAT model is a continuation of several nonpoint sources modeling but a direct outgrowth of the SWRRB model (Simulator for Water Resources in Rural Basins). SWRRB is a continuous time step model that was developed to simulate nonpoint source loadings from watersheds (Mengistu and Sorteberg, 2012). The number of sub basins in SWRRB was limited to ten and the model routed water and sediment transported out of the sub-basins directly to the watershed outlet which is difficult to use the model for large watersheds. These limitations led to the development of a model called ROTO (Routing Outputs to Outlet), which took output from multiple SWRRB runs and routed the flows through channels and reservoirs (Arnold *et al.*, 2012).

Simulation of the hydrology of a watershed in SWAT is separated into two major divisions. The first division is the land phase of the hydrological cycle which controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. The land phase of the hydrological cycle is simulated by SWAT based on the water balance equation:

$$sw_t = sw_0 + \sum_i^t \quad = 1\ (R_{day} - Q_{suf} \text{ --} E_a - W_{seep} - Q_{gw}\ )$$

Where: sw_t : Is the final soil water content (mmH_2o), sw_0 : Is the initial soil water content on day i (mmH_2o), t: is the time in days

R_{day} : is the amount of precipitation on day i (mmH_2o)

Q_{suf}: Is the amount of runoff on day i (mmH_2o)

E_a : Is the amount of evapotranspiration on day i (mmH_2o)

W_{seep} :Is the amount of water entering the vadose zone from the soil profile on day i - (mmH_2o)

Q_{gw} :Is the amount of return % low on day i (mmH_2o)

2.9. Climate Change Impact on Streamflow

2.9.1. Previous studies conducted on climate change impact on streamflow: Global perspective

Climate change is considered as one of the biggest challenges of 21st century to the whole world will face. It is now widely accepted that climate change is already happening and further change is inevitable over the last century (between 1906 and 2005), the average global temperature rose by about 0.74 °C. This has occurred in two phases, from 1910s to 1940s and more strongly from the 1970s to the present (IPCC, 2007). According to the International Panel on Climate Change Scientific Assessment Report, global average temperature would rise between 1.4 and 5.8°C by 2100 with the doubling of the CO2 concentration in the atmosphere. Sea level rise, change in precipitation pattern (up to ±20%), and change in other local climate conditions are expected to occur as a consequence of rising global temperature (Cubasch*et al.*,2001). This is expected to have a potential impact on different socio-economic sectors (IPCC, 2001).

It is estimated that, for the 20th Century, the total global mean sea level has risen 12-22c m, this rise has been caused by the melting of snow cover and mountain glaciers (both of which have decline on average in both hemispheres) (IPCC, 2007). The IPCC also notes that observations over the past century shows, changes are occurring in the amount, intensity, frequency and types of precipitation globally (IPCC, 2007). IPPC also states the projected global surface warming lies within the range 0.6 to 4.0 °C at the end of next century (IPCC, 2007).

3. MATERIALS AND METHODS

3.1. Study Area Description

3.1.1. Location

The Modjo watershed is located in the central part of Ethiopia between latitude of 8°35′00″N to 9°05′11″N and longitude of 38°54′35″E to 39°15′30″E and has Located in an altitude ranging between 1780m to 2700m above mean `sea level (m.a.s.l) (Fig 3.1). The watershed is Located in the Upper Awash River Basin. The watershed and their Major towns in the area include Bishoftu, Modjo, Ejere, and ChefeDonsa towns. The total area of the watershed is 2017.21 km^2 and it is characterized by a rugged and undulating topography with higher elevation at upstream of the watershed.

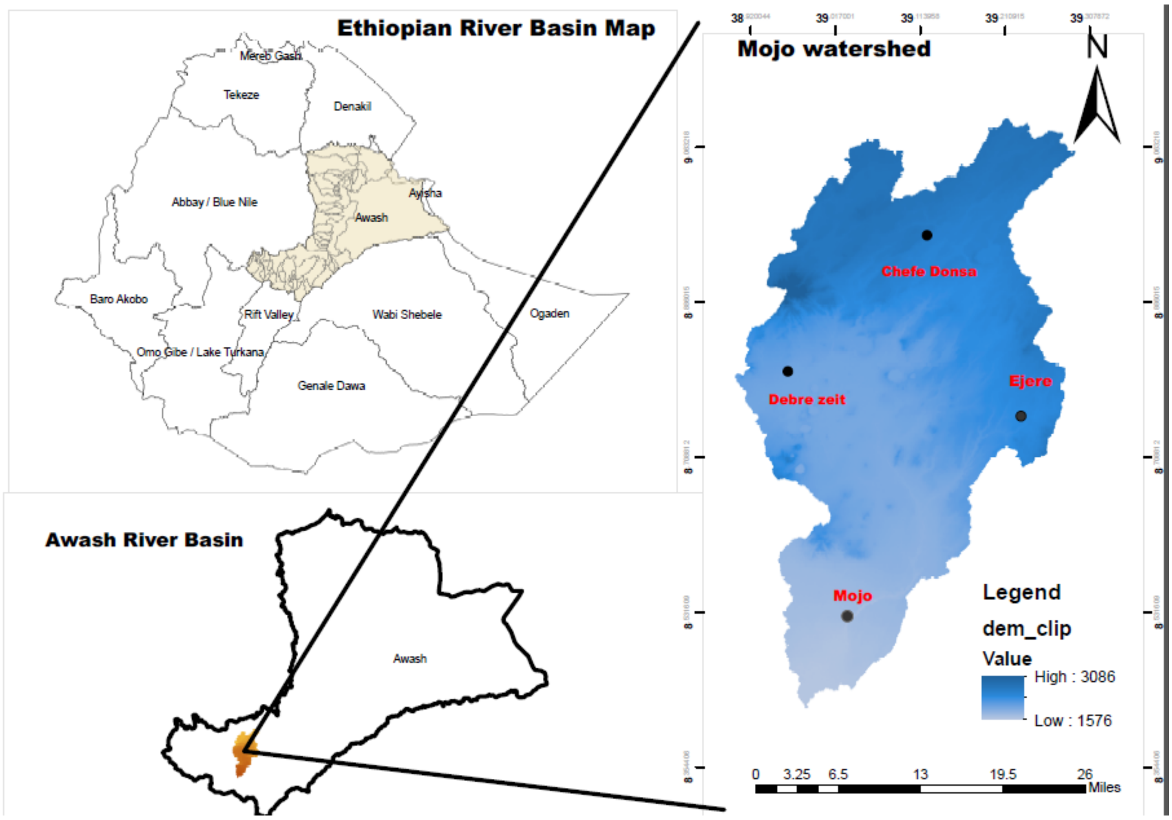


Figure:-3.1 Location map of Modjo watershed

3.1.2. Geology

Ethiopia can be divided into four major physiographic regions, widely known as the western plateau, southern plateau, main Rift and Afar depression. The Upper Awash River Basin is enclosed within the north-central plateau and adjoining escarpment and rift valley. The regional geology of the Upper Awash River Basin is underlined by a wide range of high grade metamorphic rocks and situated in different rock categories that have different ages of formation. For these Mesozoic sedimentary successions, Tertiary and Quaternary age groups of the acidic, basic volcanic rock, Quaternary Lacustrine and Alluvial deposits compromise the regional geology of the study area. Modjo Watershed includes the uppermost part of the Awash Basin, which is composed from the same geological formation of Upper Awash Sub-Basin. According to a geological survey of Ethiopia studied by (OWWDSE, 2017) the major Geological formation found in this study area includes Addis Ababa Ignimbrite.

3.1.3. Soil type

According to the Ministry of Water and Energy's dominant soil types identified in the Modjo watershed.

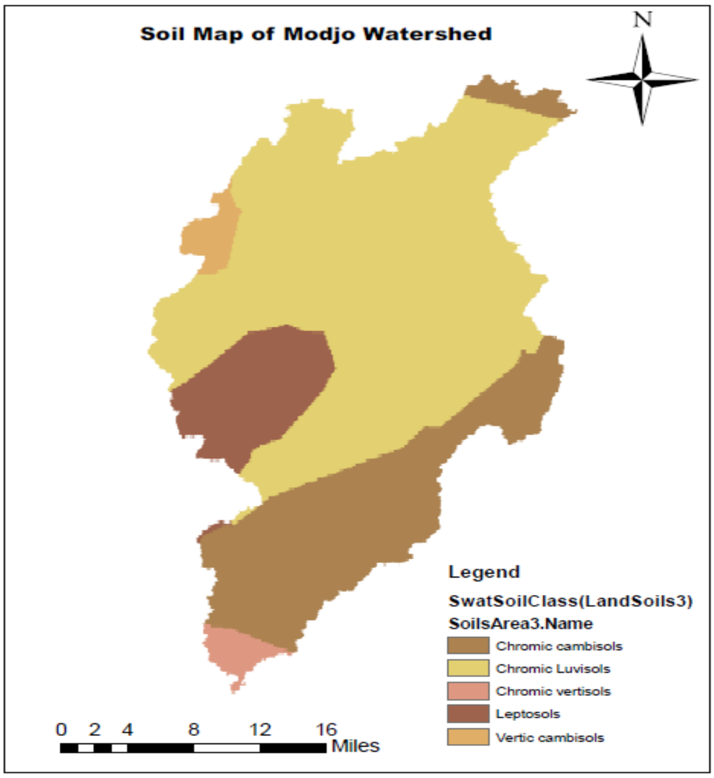


Figure 3. 2. Soil map of Modjo Watershed

The Watershed includes Chromic cambisols, Vertic cambisols, Leptosols, Chromic luvisols and Pellic vertisols covers, Figure (3.2) shows soil types and the area coverage of Modjo Watershed respectively which is extracted from Awash basin soil map and FAO soil Map.

3.1.4. Landuse

The dominant landuse type in Modjo Watershed is rainfed agricultural land. According to the Oromiya water and design office Land cover classification, the major land use found in the Watershed areas are Agriculture, settlement, waterbody, and others are available in the Watershed (Figure3.3).

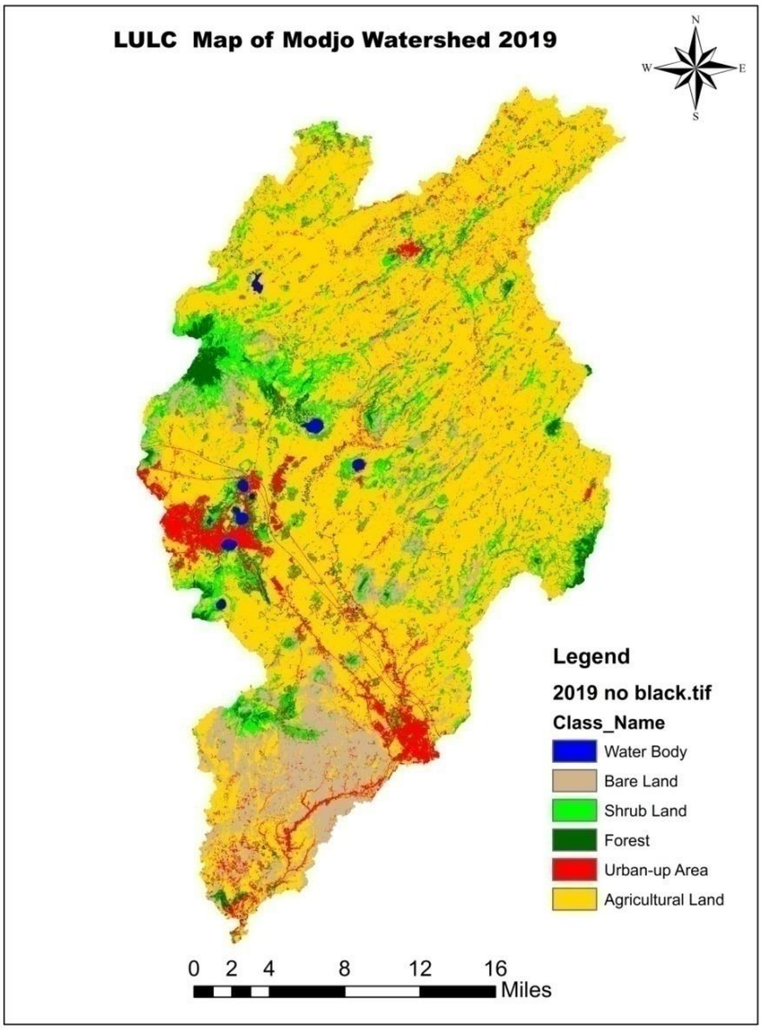


Figure 3. 2LULC map of Modjo Watershed

3.1.5. Climate

The study area was reported to exhibit most rainfall occurs between June and October thirty years from (1988-2018) rainfall records for 4 stations within and adjacent to the study area show an average annual rainfall between 980.8 mm/day and 913 mm/day with a mean annual value of 947.3 mm air temperature that averaged 20.40 ˚C varying between a minimum of 11.6 ˚C in August and a maximum of 29.20 ˚C in May, with average annual temperature decreasing with an increase in altitude.

The climate data for 4 stations found within and nearby the Modjo River from 1988 to 2018 is collected from the Ethiopian National Meteorological Service Agency. However, they are missing for both precipitation and temperature. The inverse distance weighting comparison with the nearest station within the same zone and simple arithmetic mean method were taken to detect and fill in the missing gaps in the data series.

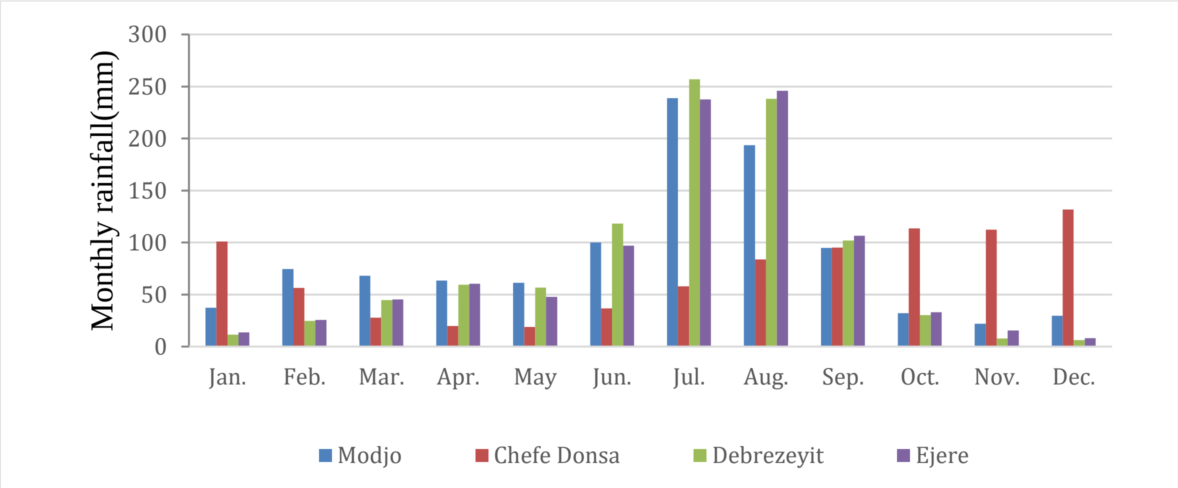


Figure 3. 3Average monthly rainfall of Modjo Watershed (1988–2018)

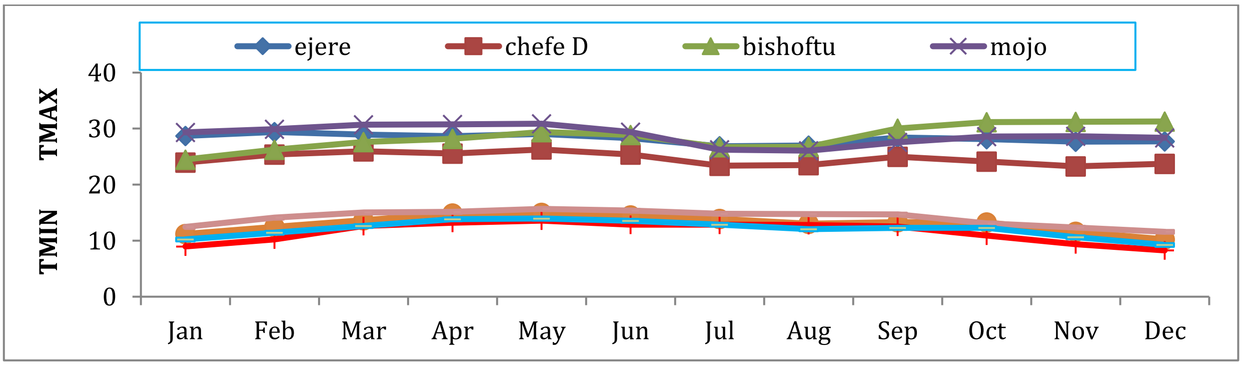


Figure 3. 4 Mean monthly maximum and minimum temperature of Modjo Watershed (1988–2018)

3.1.6. Rainfall pattern

Rainfall is one of the most widely measured meteorological data in the Upper Awash Basin as well in Modjo Watershed. There are around 156 rainfall gauging stations in the whole Awash Basin. Among these total gauging stations, around 50 meteorological stations were available in the Upper Awash River Basin to present the rainfall distribution (sonder, 2015) From these 50 meteorological stations of the Upper awash sub basin, 4 meteorological stations were available in/around the Modjo Watershed (Table 3.2).

On the basis of the (1988–2018) recorded data, the watershed receives mean annual rainfall between 950 mm and 1100 mm. The mean annual rainfall of the area was calculated using arithmetic mean method from the monthly long term rainfall record of four stations, namely DebreZeit, Modjo, ChefeDonsa and Ejere obtained from the National Meteorological Agency of Ethiopia (NMSA, 2019).

3.1.7. Hydrology

The Modjo Watershed and its tributaries are a perennial source of water in the study area. The total annual mean flow of Watershed 214.55 m3/s (Gonfa *et al.*, 2015). Modjo River which joins Lake Koka from the north, the storage is mainly fed during the wet season from June to September. After being released through the dam the Awash descends into the Rift Valley northwest towards Awash Station from where the river follows the valley northwards into Gedebassa Swamp near Hertale. However, this river is highly polluted due to the discharge of chemicals from the various industrial plants located along the Watershed(Bekele *et al.*, 2017). The Modjo River drains the area flowing southward and finally entering into the Koka reservoir. Other major surface water in the Watershed includes Koka reservoir, Bishoftu, Hora, Kuriftu lakes. The Watershed drains to Modjo river and to Koka hydroelectric power dam and finally into Awash River. The majority of the Watershed particularly the central and lower part of the Watershed has a mono modal rainfall pattern (Gonfa and Kumar, 2016).

3.2. Materials and Software programs Used

Hydrologic modeling was done using Soil and Water Assessment Tool (SWAT) models. It is a semi-distributed model which can be applied to model the impact of climate change on streamflow etc. at watershed scale. It requires a certain input data which includes; weather, hydrological and spatial data. The Geographical Information System was used to process the spatial data and as an interface to the SWAT model. For this study GIS version 10.4 and SWAT 2012 was used. The Sequential Uncertainty Fitting, ver. 2 (SUFI-2) is one of the uncertainty analysis programs that is integrated in an independent program called SWAT Calibration and Uncertainty Program (SWAT-CUP) in order to carry out parameter and model uncertainties. For the data Quality and Homogeneity tests the RAINBOW Software was also used.

Table 3. 1 Material and their purpose used in this study

Id	Name	Purpose
1	Arc GIS 10.4	Uses for map preparation and uses SWAT models extension
2	ArcSWAT 2012	Arc GIS interface for SWAT modeling
3	SDSM	for assessing local climate change impact using a robust statistical downscaling technique
4	SWAT-Cup	For the SWAT model SWAT calibration, validation and sensitivity analysis
5	RAINBOW	For data Quality analysis

3.3. Data Collection and Their Sources

3.3.1. GCMs and RCPs emission scenario

Use of all available GCMs and emission scenario will result in a better understanding of climate change. However, due to the limited amount time available to complete the study, this research deals with the output from CanESM2 model for RCP 4.5 and RCP 8.5 scenarios. CanESM2 is a coupled atmospheric-ocean GCM developed at Canadian Center for Climate Analysis. CanESM2 is applied in this study because the model is widely applied in many climate change studies and it provides large scale daily predictor variables which can be used for Statistical Downscaling Model (SDSM) (Gedefaw *et al.*, 2018).

SWAT has different components. Hydrologic components of the model work on the weather balanced equation, which is based on the surface runoff, precipitation, percolation, Evapotranspiration, and return flow data. Weather is one of the model components that need data on precipitation, air temperature, solar radiation, wind speed and relative Humidity data. The data required for the SWAT model setup were DEM, Land use data, soil data, precipitation and other weather data used for preparation of the weather generation file. For calibration and validation purposes, river discharge data were required at the outlet of the watershed. The Federal Ministry of Water Irrgation and Energy of Ethiopia (MoWIE), the National Meteorology Service Agency (NMSA) and USGS are the major sources of data required for this research. The table below showed the data and data source of geographical data used in SWAT model simulation.

Table 3.2: Data's and their source used for this study

St. No	Data type	Year of production	Scale	source	Purpose of Data acquisition
1	SRTMDEM30*30	2010	30M	USGS	Used for Delineation of the watershed and produce sub basin parameters such as slope and stream network
2	Weatherdata	1988-2018	30M	NMSA	For WGEN preparation
3	SOIL	2010	1:250000	MoWE	For generation of HRU of study area
4	LULC	2019	30M	MoWE	ForHRUanalysisinS WATmodeling
5	Streamflow	1980-2017		MoWE	Forperformancechecking with simulated data

3.3.2. Meteorological data

The meteorological data elements such as daily precipitation, maximum and minimum temperature, daily wind speed, daily solar radiation and daily relative humidity are climatic elements to set up the SWAT model. The data for weather elements should be provided on a daily basis. Four meteorological data stations (DebreZeit, Modjo, ChefeDonsa and

Ejere are available within and nearby the study area. The stations record daily precipitation data for 30 years between 1988 and 2018.

3.3.3. Hydrological data

SWAT simulated streamflow at Watershed scale on continued daily time step (Neitsch, 2011)SWAT_CUP uses these data values for comparing the observed value and simulated flow data. The observed flow data was prepared based on the requirement of the SWAT model used for calibration and validation. Daily streamflow data was obtained from Ethiopian Ministry of water, Irrigation and Energy Department of Hydrology for the year 1990 up to 2018.

3.3.4. DEM

Digital elevation model (DEM), 30*30 resolution is downloaded from (http://urs.earth data.nasa.gov)and describes the elevation of any point in a given area at a specific spatial resolution as a digital file. DEM of the essential inputs required by SWAT is to delineate a Watershed into a number of sub-Watersheds or sub-basins and to analyze the drainage pattern of the Watershed, slope, stream length, and width of a channel within the Watershed.

3.3.5. Soil and Land Use Data

Soil and land use/land cover data are used as input into the SWAT hydrological model to delineate sub-Watersheds further into hydrologic response units (HRUs). The soil data used includes the information to describe the physical and chemical properties of the soil like soil texture, hydraulic conductivity, bulk density, etc. Land use/land cover influences the hydrological properties of the Watershed and is used as an input for the SWAT model. Modjo Watershed land use/land cover changes from time to time due to several factors mainly changing agricultural practice, urbanization, new hydropower, and irrigation development. Soil and land use/land cover 2019 data of Modjo Watershed is obtained from the Ethiopian Ministry of Water, Irrigation and Energy as shape file format.

3.4. Data Quality Analysis

3.4.1. Meteorological data analysis

Meteorological data is the main input for hydrological modeling. The station which represents the Watershed is selected based on the data availability including the existence of enough length of record and distance from the area of interest and also the location of the station available in the Watershed area. Accordingly, four-station is available in the study area. See on the Appendix.

3.4.2. Filling of missing data

In the modeling of climate, the complete record of hydrological data is very important in the case that climate data like temperature, rainfall, humidity, solar radiation and wind speed of our stations should be filled. Data for the period of those missing data could be filled using different estimation techniques (Flato *et al.,* 2014). The arithmetic mean Normal ratio, Regression, and distance power method are the most commonly used methods for estimation of missing climate datasets. For this study the inverse distance (reciprocal-distance) weighting method (IDWM) was used for estimating missing data (Gassman *et al.*, 2013). This weighting distance method for estimating the missing value of an observation, which uses the observed values at other stations, is determined by equation below.

$$V_0 = \frac{\sum_{i=1}^{n} {Vi}/{Di}}{\sum_{i=1}^{n} {1}/{Di}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; 3.1$$

Where, V_0 is the estimated value of the missing data, V_i is the value of the same parameter at i^{th} nearest weather station; D_i is the distance between the station with missing data and the i^{th} nearest weather station.

3.4.3. Data quality assessment

In most of Engineering, water resource development and management studies hydrological as well as meteorological data are more dependent so assessing the quality of those data should be properly managed. According to this thesis, the quality of the data passed through two methods.

3.4.3.1. Consistency test

A consistency record is one where the characteristics of the record have not changed with time. Inconsistency of rainfall data happens in different ways for stance due to replacement of old instruments by a new one or shifting of the rain gauge station and also change of ecosystem or observational error. Therefore, adjustment of the inconsistency of rainfall data is necessary. Double mass curve (DMC) was used to check the consistency of rainfall for adjustment of inconsistent data. This technique was based on the principle that when each recorded data comes from the same parent sample, they are consistent. A group of 4 base stations in the neighborhood of the station were selected. A consistent record is one where the characteristics of the record have not changed with time.

A double-mass curve is a graph of the cumulative annual precipitation of group stations versus the cumulative mean annual precipitation of selected stations of one or more gauges in the region that has been subjected to similar hydro meteorological occurrences and is known to be consistent. If a rainfall record is a consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope. A change in the slope of the double mass curve would suggest that an external factor has caused changes in the character of the measured values. If a change in slope is evident, then either the record needs to be adjusted with the early or the later period of record adjusted. A group of base stations in the neighborhood of the station were selected and checked by using the following equation (Gedefaw *et al.*, 2018).

$$Px = \frac{1}{n} * \left(\left(\frac{Nx}{N1}\right) * P1 + \left(\frac{Nx}{N2}\right) * P2 + \cdots + \left(\frac{Nx}{Nn}\right) * Pn \right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.2$$

Where, P_x is the missing data at station x, Nx is the missing data stations normal annual rainfall, Ni is normal annual rainfall at station i, and n is number of nearby gauges The station-average method for estimating missing data uses n gauges from a region to estimate the missing point rainfall, PX, at another gauge. The result is plotted on the figure below.

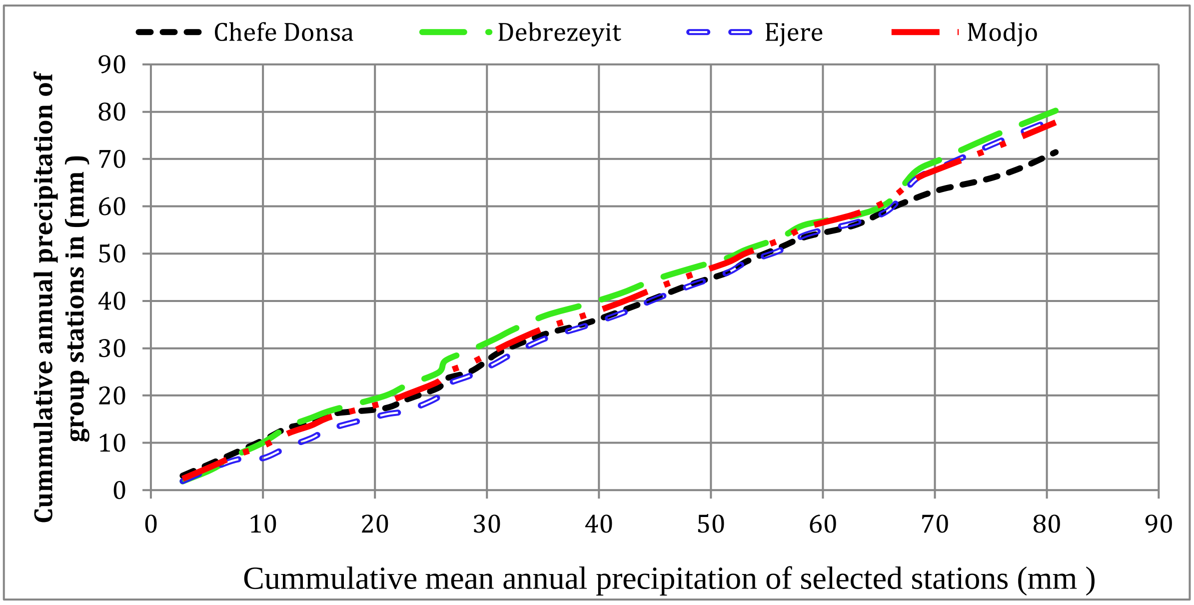


Figure 3.6. Double mass curves for selected stations

3.4.3.2. Homogeneity test

Homogeneity is an important issue to detect the variability of the data. In general, when the data is homogeneous, it means that all collection of data belongs to the same statically population having the time-invariant mean, therefore test of homogeneity of data series are based on evaluating the significance of change of mean value, However, it is a hard task when dealing with rainfall data because it is always caused by changes in measurement techniques and observational procedures, environment characteristics and structures, and location of stations. There are a lot of methods used for analyzing the homogeneity for instance, (Ismail *et al.*, 2014) in this study; the homogeneity analysis was used by the RAINBOW software. To test the homogeneity of the watershed data, RAINBOW rescales the cumulative deviations by dividing the S_k's by the sample standard deviation value. By evaluating the maximum (Q) and range (R) of rescaled cumulative deviations from the mean homogeneity of a time series data can be tested. High values of Q or R indicates the data time series is not from the same population and fluctuations are not purely random. The RAINBOW indicates the data was homogenous and the result is plotted as follows (Figure 3.6)

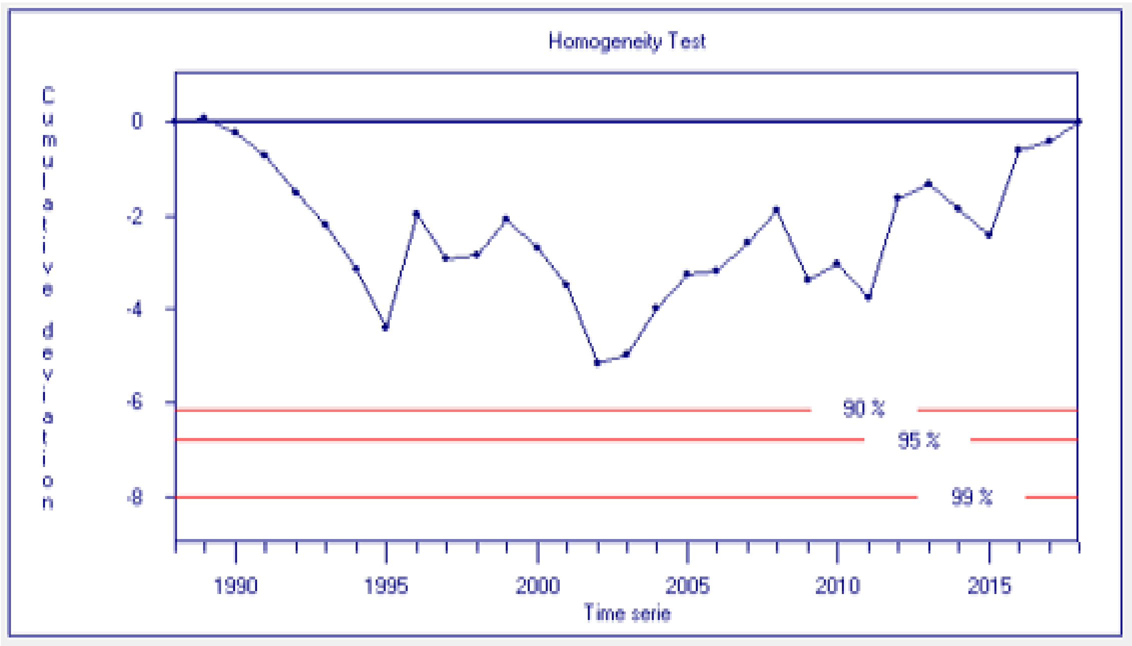


Figure 3.7. Homogeneity test of four rainfall station (1988-2018)

3.5. Methodologies

3.5.1. Statistical downscaling method

Statistical Downscaling Model (SDSM) is a hybrid of multiple linear regression and stochastic downscaling model developed by Rob Wilby and Christian Dawson (Worku *et al.,* 2018). It is a freely available decision support tool for assessing local climate change impact using a robust statistical downscaling technique. In SDSM downscaling, a multiple linear regression model is developed between a selected large-scale predictor variables and local scale predictands such as temperature and precipitation. And the parameters of the regression equation are estimated using an ordinary Least Squares algorithm. Precipitation is modeled as a conditional process in which the local precipitation amount is correlated with the occurrence of wet days. As the distribution of precipitation is skewed, a forth root transformation is applied to the original series to convert it to the normal distribution, and then used in the regression analysis. Minimum and maximum temperatures are modeled as unconditional process, where a direct link is assumed between the large scale predictors and local scale predictands.

SDSM which is designed to downscale climate information from coarse-resolution of GCMs to local or site level is applied here to downscale the precipitation, maximum and minimum temperatures for the study area. SDSM uses linear regression techniques between predictor and predictands to produce multiple realizations (ensembles) of synthetic daily weather sequences. The predictor variables provide daily information about large scale atmosphere condition, while the predictands described the condition at the site level. SDSM software is published in different version at various times, among them the 4.2.2 version is adopted for this particular study.

3.5.2. Statistical downscaling model (SDSM)

Statistical Downscaling Model (SDSM) is a decision support tool for assessing local climate change impacts using a robust statistical downscaling technique. SDSM facilitates the rapid development of multiple, low cost, single site scenarios of daily surface weather variables under present and future climate forcing. SDSM calculates statistical relationships, based on multiple linear regression techniques, between large-scale (the predictors) and local (the predictands) climate. These relationships were developed using observed weather data and, it was assumed that these relationships remain valid in the future.for this study SDSM version 4.2.9 were used. The Model used to obtain downscaled local information for future time period by driving the relationships with GCM derived predictors (Getahun, 2018).

3.5.3. SDSM performance evaluation

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability. The performance of the model in simulating precipitation and temperature is evaluated using the SDSM model. Three methods were used to evaluate the model efficiency during the validation and calibration periods, these are coefficient of regression (R^2), Nash Sutcliffe simulation coefficient (NSE) and percent Bias (PBIAS). The values of R2 ranges from 0.0 to 1.0 with higher values indicating better agreement and the values of NSE ranges from minimum infinity to 1.0 with higher values indicating better agreement (Moriasi, 2015). Percent Bias measures the average tendency of the simulated data to large or smaller than the observed. Positive values indicate model underestimation and negative values indicate model overestimation.

3.5.4. Precipitation and temperature scenario statistics

Predictors from CanESM2 experiment for the period 1988-2099 were used to downscale the Present and future climate forcing and the calibrated model was then used for the scenario generation from 2018 to 2099. The generated scenario was divided into three 30 years of data ranges based on the recommendation of the WMO as the 2020s, as near future; 2050s, as mid Future and 2080s as Far future. For the case of simplicity the generated scenarios were dealt individually for each predictand and the result of the model was reported graphically for precipitation and Temperature. All the comparisons in the result analysis were done with respect to the baseline period (1988-2018) data.

In this study changes in precipitation and temperature were adjusted to see the effect of climate change in the streamflow. The changes were applied by setting adjustment factors into the interface. The model calculates the change in precipitation, maximum and minimum temperature using equations 3.3, 3.4 and 3.5 respectively. The adjustment terms were applied from month to month so as to simulate seasonal changes in climatic conditions.

$R_{day,adj} = R_{day} * (1 + \frac{adj_{pcp}}{100})$ ………………………………………………………….. 3.3

Where: $R_{day,adj}$ is the adjusted precipitation falling in the sub basinOn a given day (mmH_2O), $R_{day,}$is the precipitation falling in the sub-basin on a given day (mmH_2O)

$adj_{pcp}$is the percent change in rainfall

$T_{max,adj} = T_{mx} + adj_{tmp}$ …………………………………………..…………………3.4

Where: $T_{max,adj}$ is the adjusted daily maximum temperature, T_{mx} is the daily maximum temperature, adj_{tmp} is the change in temperature

$T_{min,adj} = T_{mn} + adj_{tmp}$……………………..…………………………….……………..3.5

Where: $T_{min,adj}$ is the adjusted daily minimum temperature

$T_{mx}$is the daily minimum temperature, adj_{tmp} is the change in temperature

3.5.5. SWAT model setup

3.5.5.1. SWAT modeling

SWAT is widely used to simulate hydrological processes under the scenario of changes in landuse,landcover as well as climate change. The SWAT model is a physically-based, continuous time Watershed model that simulates hydrological processes in the Watershed. This model is coupled with ArcSWAT in ArcGIS Geographical Information System interface to process the data sets and construct the required input for the initial modeling setup (Mengistu *et al.*, 2012).

In SWAT Watersheds are divided in to sub Watersheds which are further delineated into hydrological response units (HRUs) that consist of homogeneous soil, landuse and climate. HRUs are defined separately for each sub-Watershed based on landcover, soil and slope in a specific sub- Watershed. Thresholds for HRU definition are sequentially applied to land covers, soils in each landcover ,and slopes in a combination of land cover and slope. According to (Winchell *etal.*,2010) if a land cover percentage in the sub-Watershedis below the land cover threshold no HRU for that specific landcover will be defined regardless of the distribution of soils and the land cover areas will be re apportioned in to the other qualified landcovers mean tha the threshold value which added in the HRU definition will depend on the value of landuse ,soil and slope of the each subbasin Watershed if the value percent of landuse is smaller than the threshold value of land cover no HRU is created in the subbasin and addition of landuse and soil is smaller than the threshold still no HRU is created for aparticular sub basin and also fors lope, In this case the threshold value which is given in the modelling Modjo Watershedis 20% for land use and 10% for soil and slope. The model predicts the hydrology ultimately stream low at each HRU using a water balance equation,contains precipitation, surface runoff, evapotranspiration, infiltration, and subsurface inflow.

3.5.5.2. HRU definition

Land use Land cover map of 2019 was used for simulation of streamflow. The LULC map was chosen based up on the meteorological and hydrological data present on the study area. The land use and the soil data in a projected Raster format were loaded into the SWAT interface to determine the area and hydrologic parameter of each land soil category simulated within each sub watershed. The LULC classes were defined using a lookup table. A look up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover land use classes. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification was done.

As for the land use, the soil layer in the map was linked to the user soil database information by loading the soil look up table and re-classification applied. The DEM data used during the watershed delineation was also used for slope classification. After the reclassification of the land use, soil overlay operation was performed.

The second step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub watershed. In multiple HRU definitions, a threshold level was used to eliminate minor land use, soil or slop classes in each sub basin. Land use or a soil which covers less than the threshold level is eliminated. After the elimination processes the area of the remaining land use or soil was reapportioned so that 100% of the land area of the sub basin was modeled.

The third step in HRU definition is a selection of slope classification options (Single or multiple) and if multiple options are selected that defines the range of the slope. For this study multiple slope options (an option for considering different slope classes for HRU definition) was selected and the slope classes were classified into five and the range was 0-5 %, 5-15%,15-25%,25-35 and above 35%.

Finally after defining HRUs within a sub basin is completed the HRU will be set. For this study the multiple HRU option was selected and 20%, 10% and 10% were the threshold area of land use, soil and slope in each HRU from the sub basin values respectively. The reason for taking these threshold values was in order to keep the HRU to a reasonable and manageable number and also considering computer processing time required. Even though the application of these thresholds elements the land use and soils that covered relatively small areas in the sub basin.

3.5.5.3. Weather data definitions

The WXGEN (SWAT software specification file coding scheme for weathering Generator file) weather Generator model included in SWAT was used to fill in gaps in measured records. The meteorological stations used for daily precipitation data were ChefeDonsa, DebreZeit, Ejere and Modjo stations were included and the Modjo stations were selected to be principal stations for the weather generator. The WGEN weather generator was provided with all the necessary statistical information from the meteorological records of the watershed. These statistical values were calculated from the meteorological data available in the study area watershed. The number of years for calculating the statistical values depending on the availability of the data in the stations. Other meteorological data(daily precipitation, daily maximum and minimum air temperature, daily relative humidity, daily solar radiation, and daily wind speed) including the corresponding location table were prepared accordingly to the SWAT format and integrated into the model using the weather data input wizard.

3.5.5.4. Model simulation

After the model was set up the next step was to run the model and the result from the simulation cannot be directly used for further analysis. Instead the ability of the model to sufficiently predicts the streamflow. The simulation results will be evaluated through sensitivity analysis, model calibration and model validation (Cunderlik, 2003).

3.5.6. Sensitivity analysis

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameter for a given watershed (Abbaspour, 2013). Therefore, methods to reduce the number of parameters via sensitivity analysis were important for the efficient use of these models (Gizaw *et al.,* 2017). Sensitivity analysis is a process of testing and identifying model parameters that affect mostly the output from the model when parameters are changed. In other words sensitivity analysis is the process of determining the rate of change in model output with respect to the change in model input parameter (Abbaspour, 2013). Therefore, a parameter is considered sensitive when the change in that parameter causes a large change in model output.

The current version of a SWAT model SWAT 2012 provides the algorithmic technique for sensitivity analysis. Two types of sensitivity analysis are allowed when using SUFI2

(Sequential Uncertainty Fitting version 2) Global Sensitivity and One-at a time sensitivity analysis however, Global Sensitivity were used for this study. Sensitivity of one parameter often depends on the values of other related parameters; hence, the problem at one time analysis is that the correct values of other parameters that are fixed are never known. The disadvantage of the global sensitivity is that it needs a large number of simulations. Both procedures, however, provide insight into the sensitivity of the parameters and are necessary steps in model calibration (Mengistu *et al.*, 2012).For the present study Global sensitivity analysis was used to conduct the sensitivity analysis.

Table 3.3 SWAT parameters sensitivity classes

Class	MRS	Sensitivity Category
I	0.00≤MRS<0.05	Small to Negligible
II	0.02≤MRS<0.2	Medium
III	0.2≤MRS<1	High
IV	MRS>1	Very High

3.5.7. Calibration and Validation

Theoretically calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by fully selecting values for mode input parameters (within their respective uncertainty ranges) by comparing model prediction (output) for a given set of assumed conditions with observed data for the same conditions. The final step is validation of the component of interest (streamflow). Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on the project goals. Validation involves running a model using parameters that were determined during the calibration processes and comparing the prediction to observed data not used in the calibration.

During the calibration processes to maximize the model efficiency hydrological parameters selected during sensitivity analysis using SUFI 2 algorithms were considered. The calibration was performed using monthly performed flow data from the year 1990- 2008. The calibrated model was validated using data from 2009-2017 on a monthly time step.

3.5.8. Model performance Evaluation

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability. The performance of the model in simulating streamflow is evaluated using the SWAT model. Three methods were used to evaluate the model efficiency during the validation and calibration periods, these are coefficient of regression (R^2), Nash Sutcliffe simulation coefficient (NSE) and percent Bias (PBIAS). The values of R^2 ranges from 0.0to 1.0 with higher values indicating better agreement and the values of NSE ranges from mini um infinity to 1.0 with higher values indicating better agreement (Moriasi, 2015). A value of 0.0 for R^2 indicates that none of the variance in the measured data is simulated by the model prediction. In other ways the value of 1.0 indicates that all of the variance in the measured data is replicated by the model predictions. Percent Bias measures the average tendency of the simulated data to large or smaller than the observed. Positive values indicate model underestimation and negative values indicate model overestimation.

Coefficient of Determination (R^2): is the index of the correlation of measured and simulated values. The values of R^2 Ranges from 0 to 1. The more the values of R^2 approaches 1, the better is the performance of the model and the values of R^2 less than 0.5 indicate poor performance of the model.$R^2$is calculated by the following equation:

$$R^2 = \frac{[\sum(Qmj-Qm(Qsj-Qs)]2}{\sum[(Qmj-Qm)2\ (Qsj-Qs)]2} \ldots\ldots 3.6$$

Coefficient of determination R^2 where Q is variable (e.g., discharge),and m and s stands for measured and simulated, I is thei^{th} measure or simulated data and Qs mean of the simulated value, Qm is the mean of the observed value.

Nash Sutcliffe simulation coefficient (NSE); is the normalized statistics which measures the relative magnitude of the residual variance as compared to measured data variance. Similar to R^2, the more the NSE approaches 1, the better will be the model performance and vice versa.

$$\text{NSE} = 1- \frac{\sum((Qm-Qs))^2)2_i}{\sum(Qmj-Qm)^2} \ldots\ldots 3.7$$

Nash Sutcliffe, where Q is variable (e.g. discharge), m and s stands for measured and simulated respectively and the bar stands for average.

Root Mean square error observation standard deviation ratio (RSR); it is an error index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating higher accuracy of the model performance. Values approaching to 1 indicate a poor model performance,

$$RSR=\frac{RMSE}{STDEVobs}=\frac{\left\lfloor\sqrt{\sum_{i=1}^{n}(Oi-Si)2}\right\rfloor}{\left\lfloor\sqrt{\sum_{i=1}^{n}(Oi-S)2}\right\rfloor}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.8$$

Percent Bias (PBIAS):

Percent bias measures the average tendency of the simulated data to large or smaller than the observation. The optimum value is zero, where lower magnitude values indicate better simulations. Positive value indicates model underestimation and negative values indicate model over estimation (Gupta *et al.*, 1999). Percent bias (P_{bias}) is calculated by the following equation.

$$P_{bias} = 100*\frac{\sum_{i=1}^{n}(Qm-Qs)i}{\sum_{i=1}^{n}(Qmj)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

Where Q is a variable (e.g., discharge) m and s stands for measured and simulated respectively.

Table: - 3. 4 Performance evaluation criteria (PEC), Statistical threshold value and corresponding assigned weight (Moriasi *et al.*, 2015)

PEC	NSE	R^2
Very Good	1 ≥NSE≥ 0.75	$0.75 \le R^2 \le 0.85$
Good	0.75 ≥ NSE≥ 0.65	$0.60 \le R^2 \le 0.75$
Satisfactory	0.65 ≥ NSE ≥0.5	$R^2 \le 0.60$
Unsatisfactory	NSE ≥ 0.5	$0 \le R^2 \le 0.5$

3.5.9. Climate change impact analysis on streamflow

SWAT model helps to simulate climate change impact by manipulating the climatic input that is read into the model (precipitation, temperature, solar radiation, relative humidity, wind speed, carbon dioxide level and potential evapotranspiration). In this study changes in precipitation and temperature were took the lion share to see the effect of climate change in the stream flow. The changes were applied by setting adjustment factors into the interface. The model calculates the change in precipitation, maximum and minimum temperature using the data that has three future time series from: 2020-2049, 2050-2079 and 2080-2099 for all statically downscaled and two RCP scenarios (RCP 4.5 and RCP 8.5) were considered.

3.6. Conceptual Frameworks of the Study

For the present study SWAT model was selected to model streamflow and sediment yield of Modjo watershed. The SWAT model was chosen for physically based, uses readily available input, is computationally efficient, enable users to study long term impacts capability for application to large scale Watersheds (> $100km^2$), and capability for interface with the Geographic information system (GIS). After the suitable model was selected, the necessary data required to run the model were collected and prepared as to the requirement of SWAT model format. The Geographic data such as the digital elevation map, land use/ land cover map, soil map and the hydro Meteorological data such as the streamflow data, daily rainfall data, and other whether data used for generating the weather generator file such as minimum and maximum daily air temperature, wind speed, relative humidity and solar radiation data were collected and processed as per the input requirement format of SWAT model. After the necessary data preparation, the watershed was delineated based on the outlet of the watershed and the hydrological response unit of the area was generated by the overlaying the slop, land use/land cover and soil data.

Based on the prepared weather file, the SWAT model was run using 2010 LULC map and the model sensitivity analysis was collected using SWAT model software to identify the most sensitive parameter to model streamflow. Model calibration and validation was performed by using the selected parameter in sensitivity parameter analysis. Finally the performance of the model in predicting streamflow was evaluated by using standard model critical such as R^2 , NSE and P_{bias}. The impact of climate change on streamflow was assessed by using the LULC map of 2010.

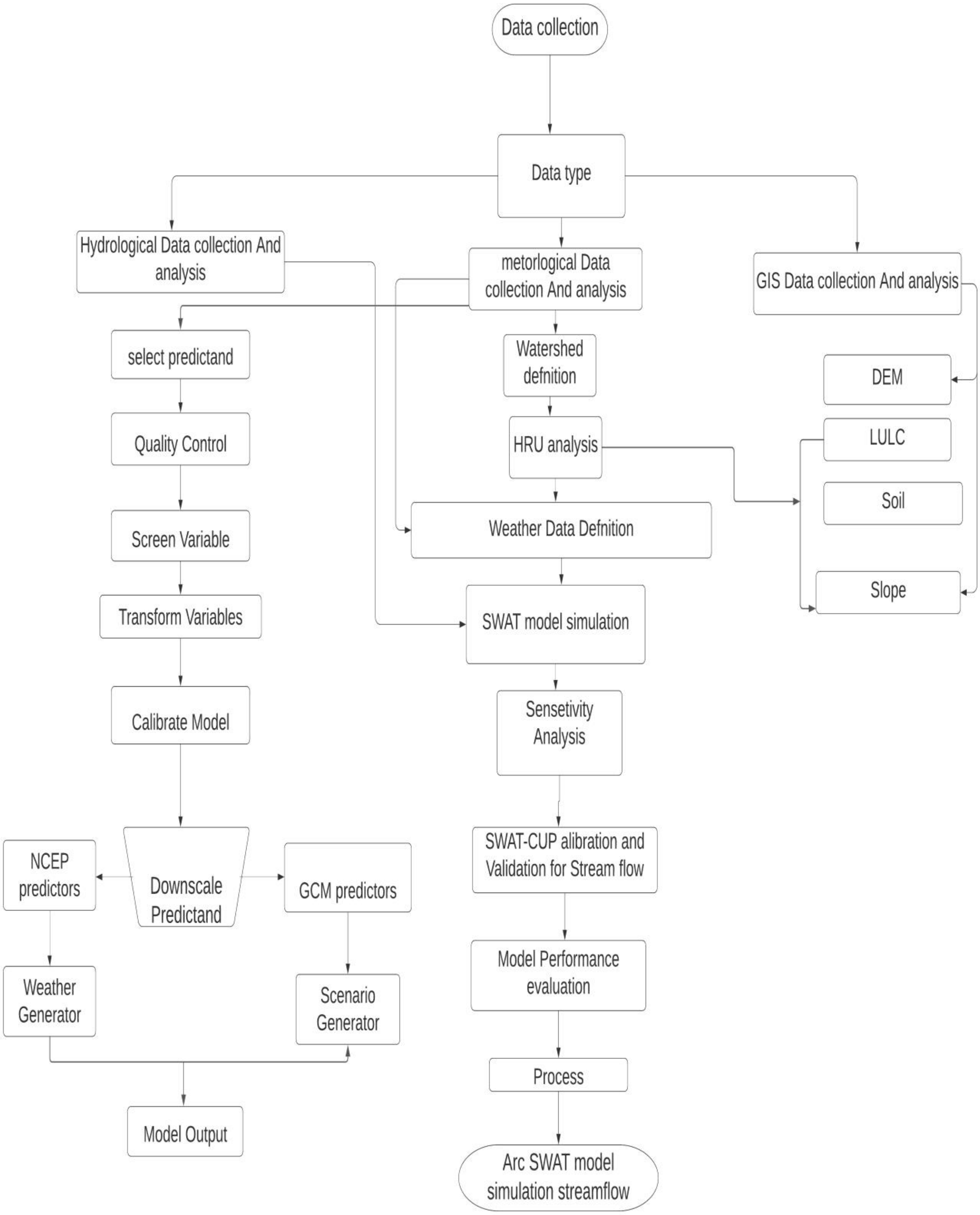


Figure 3. 5: Flow chart of method of data analysis for streamflow simulation

4. RESULTS AND DISCUSSION

4.1. Downscaling GCM Outputs

4.1.1. Predictor variables selection

The choice of predictor variables is one of the most influential steps in the development of statistical downscaling procedure. Identifying empirical relationship between gridded predictors and single site predictands is central to all statistical downscaling. The screen variable option in SDSM assists the choice of appropriate downscaling predictor variables through seasonal correlation analysis, partial correlation analysis and scatter plots. One of the approach is to choose all predictors and run the explain variance on a group of eight at a time. Out of the groups, those predictors which have high explained variance are selected. The best correlated predictor variables selected for precipitation, maximum temperature and Minimum temperatures are listed in Table blow.

Table 4. 1: Selected predictor variables for the predict ands (precipitation, maximum and Minimum temperature) at Modjo watershed

Predictor	Predictands		
	PRCP	TMAX	TMIN
Ncepp-fgl	✓		
Ncepp-zgl	✓	✓	✓
Ncepps500gl	✓		✓
Ncepp850gl		✓	✓
nceptempgl		✓	

The strongest correlation was obtained between the predictands and each predictor for each month. The precipitation showed a better correlation with ps500 in the months May, June, October and November. The correlation of maximum temperature with the predictor variables was exceptionally strong for all the selected predictors. Most of the predictors gave better correlation from May to August. P8_gl also showed a good correlation from October to December. The correlation between minimum temperature and p500 was strongly correlated for all months except March and October. P1_zgl also showed good correlation with the minimum temperature from September to December. see the correlation matrix , scatter plots on the appendix.

4.1.2. Calibration and validation

The calibration was carried out from 1988-2008 for twenty years and the withheld data from 2009-2018 were used for model verification. The model develops better multiple regression equation parameters for the maximum and minimum temperature than the precipitation. This is mainly due to the conditional nature of precipitation. In conditional models, there is an intermediate process between regional forcing and local weather (e.g. local precipitation amounts depend on wet–/dry–day occurrence, which in turn depend on regional–scale predictors such as humidity and atmospheric pressure) (VanVuren *et al.*, 2014). This can clearly be seen in the R^2 values presented in Table 4.2.

The SDSM software reduces the task of statistically downscaling daily weather series into seven discrete steps:

- quality control and data transformation;
- screening of predictor variables;
- model calibration;
- weather generation (using observed predictors);
- statistical analyses;
- graphing model output;
- Scenario generation (using climate model predictors).

Table: - 4. 2: Calibration and Validation result of the Statistical downscaling Model for Modjo watershed

Parameter	Observed	Calibration	Validation
		Rcp 4.5	Rcp 8.5
NES	0.71	0.69	0.61
R^2	0.73	0.65	0.62
p_{bias}	2.1	9.8	5.4

Twenty ensembles of synthetic daily weather series generated using NCEP-reanalysis data for the verification of the calibrated model. The mean of the 20 ensembles of maximum temperature and minimum temperature values gave better R^2 values, inferring that future projections would also be well replicated. The precipitation verification showed that the calibrated model wasn't able to replicate the independent data set. This is due to the complicated nature of precipitation processes and its distribution in space and time. Climate model simulation of precipitation has improved over time but is still problematic (Bader *et al.*, 2008). Also added that rainfall predictions have a larger degree of uncertainty than those for temperature (Thorpe, 2005). This is because rainfall is highly variable in space and so the relatively coarse spatial resolution of the current generation of climate models is not adequate to fully capture that variability. The summarized monthly values of the observed precipitation, maximum temperature and minimum temperature vs. the corresponding modeled values are shown in Figure 4.1, Figure 4.2, and Figure 4.3 respectively.

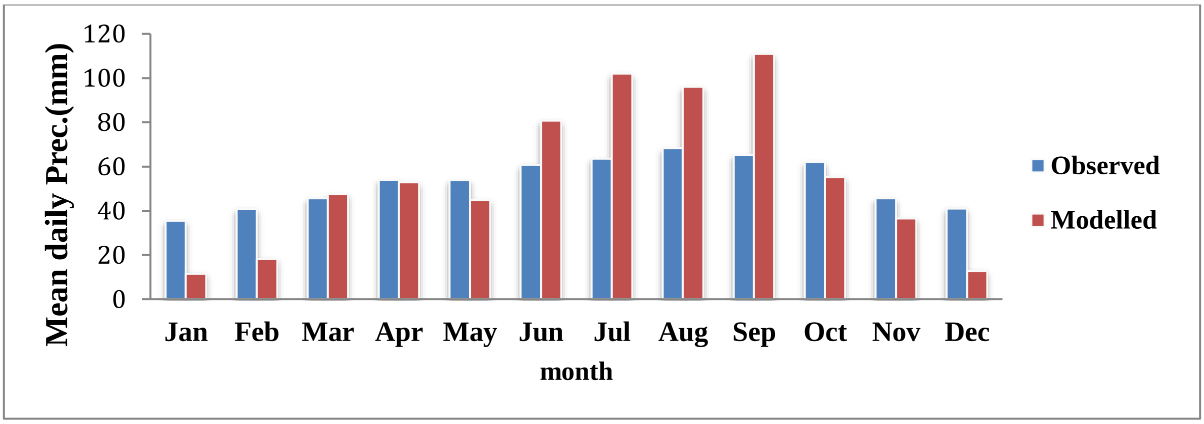


Figure: - 4. 1: Observed and modeled mean daily precipitation for Modjo watershed

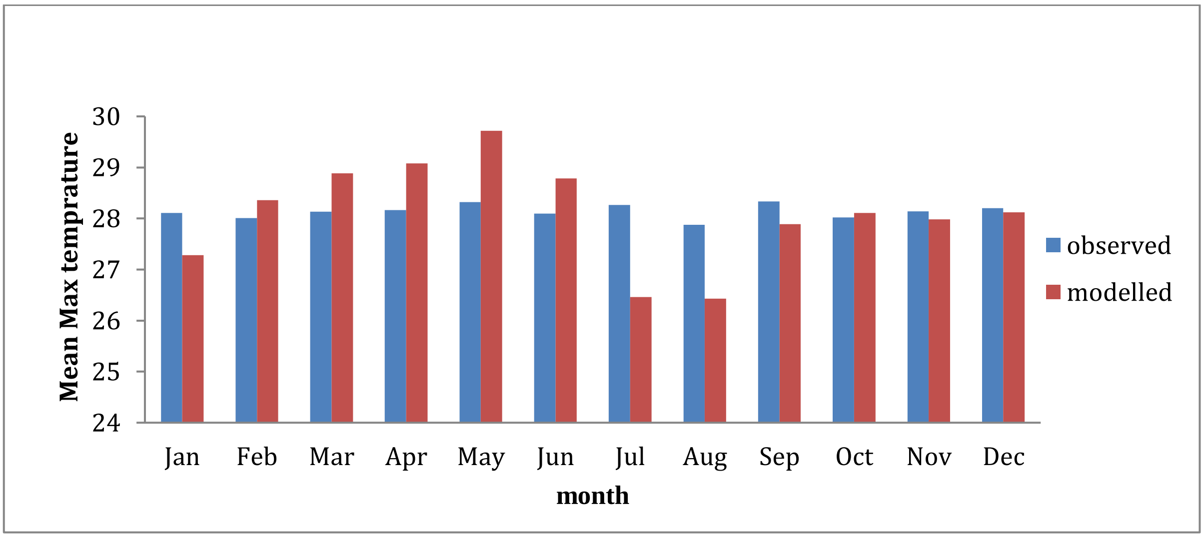


Figure: - 4. 2: Observed and modeled mean daily maximum temperature for Modjo watershed

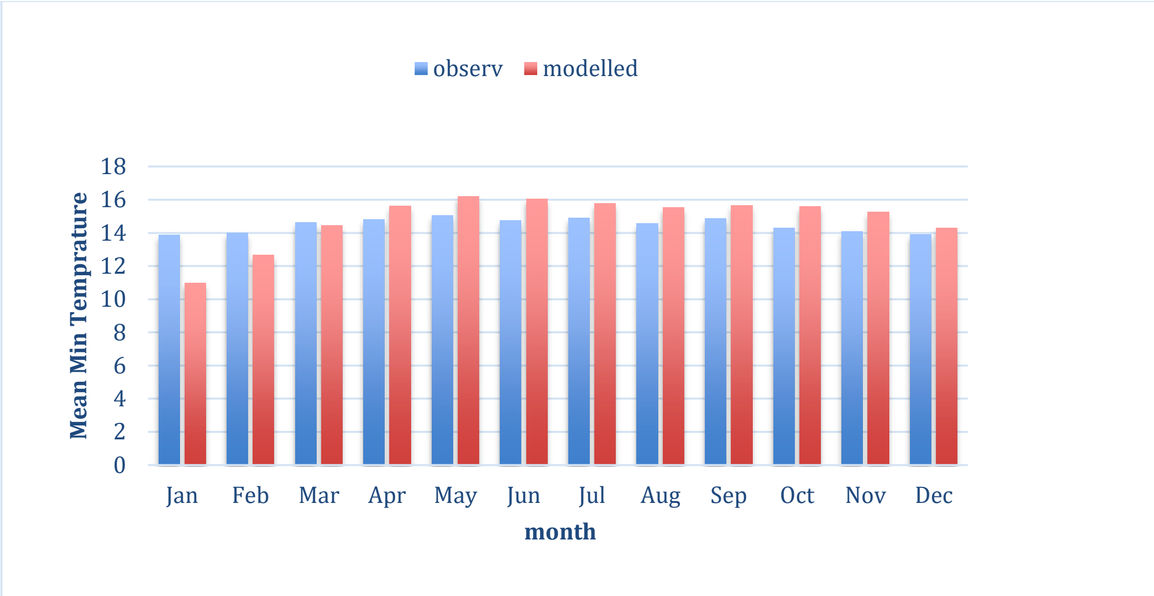


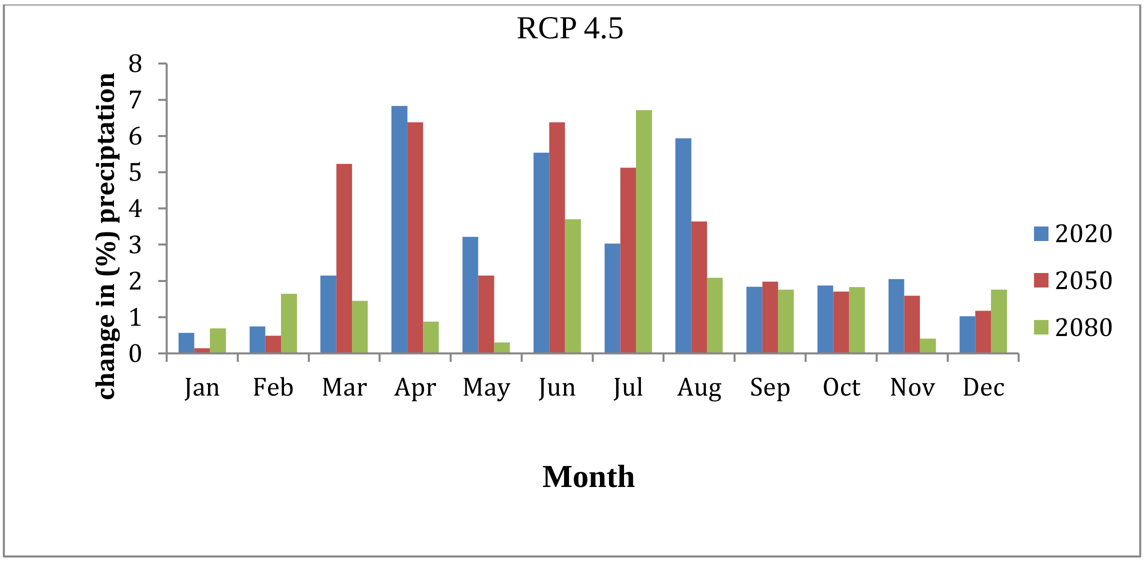
Figure:- 4. 3: Observed and modeled mean daily minimum temperature for Modjo watershed

4.1.3. Scenario Generation

The Predictors from Canadian Earth System Model experiment for the period 1988-2099 were used to downscale the Present and future climate forcing. The scenario generator produces 20 ensembles of synthetic weather series and the mean of the ensembles was used here in the analysis. The generated scenario was divided into three 30 years of data ranges based on the recommendation of the WMO as the 2020s, (2010-1039) as near future; 2050s, (2040-2069) as mid Future and 2080s (2070-2100) as Far future. For the ease of simplicity the generated scenarios were dealt individually for each predictand as below. All the comparisons in the following analysis were done with respect to the baseline period (1988-2018) data. The summarized SDSM result is presented below.

4.1.3.1. Precipitation Scenario

The results of downscaling the future precipitation for 2020s (2010-2039) 2050s (2040-2069) and 2080s (2070-2100) using CanESM2 are presented in figure 4.4. The precipitation projection exhibited a decrease in annual mean precipitation in the 2020s and 2050s near and mid future time periods (Sep up to Feb). However, for months from March up to August the rainfall experience increases in total amount in future periods. In general future projection of precipitation for selected station will shows increasing trend in rainfall amount especially on far future periods it shows increasing trend for the main rainy season as can be seen in Figure 4.4 below.



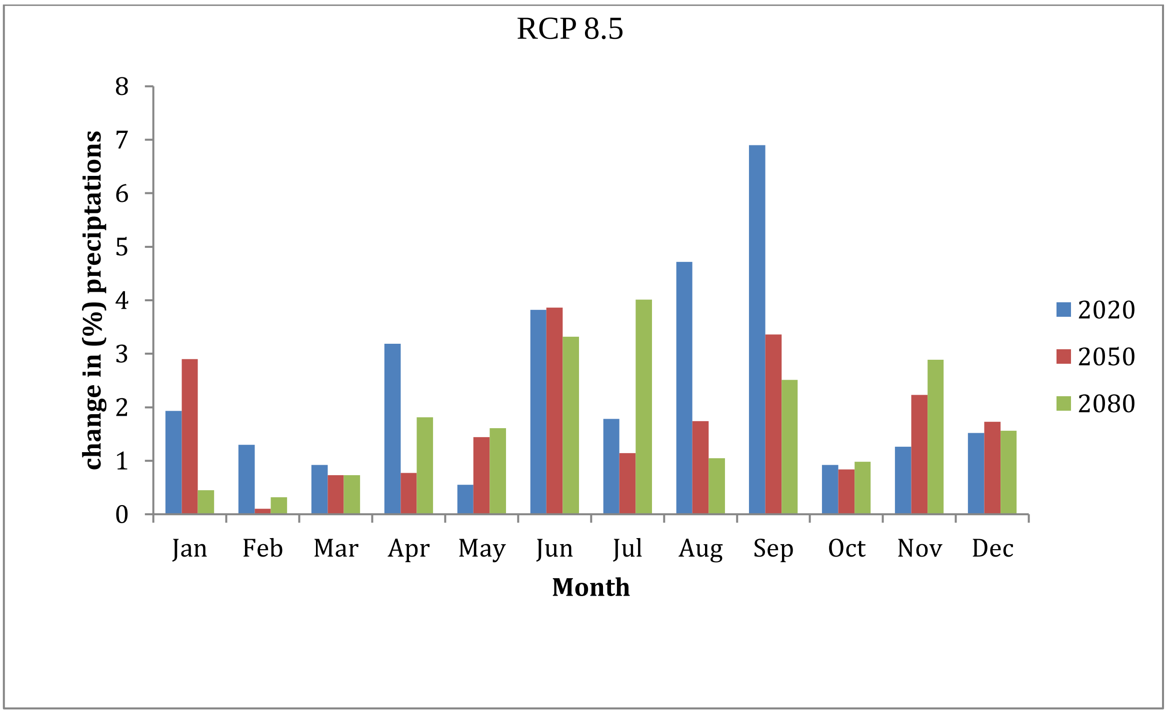


Figure: - 4. 4: change in monthly precipitation in the future from the baseline period average precipitation.

These predicted values generally show an increasing trend with respect to the baseline period. The results above show that an increase of rainfall with change of 2% (2020s) 4% (2050s) and 7% (2080s) for RCP 4.5 scenario with respect to the baseline period and 2% (2020s) 5% (2050s) and 9% (2080s). The above results thus indicate that the increasing annual rainfall in the future is somewhat higher for RCP 4.5 and also that the increases are higher in March, August and September.

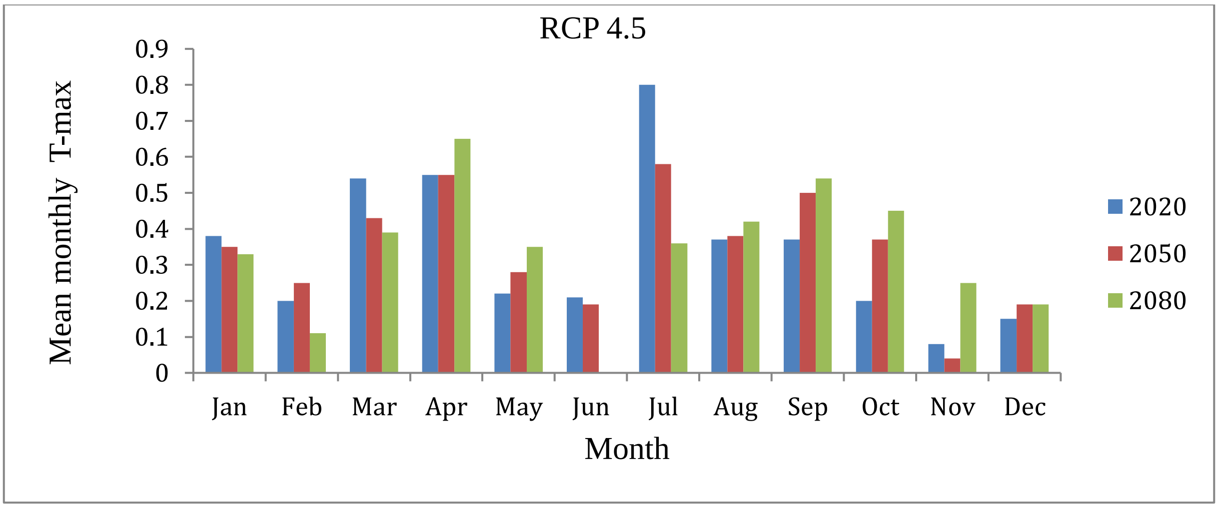
Table: - 4. 3 changes of precipitation for the future RCP 4.5 and RCP 8.5 scenario.

scenarios	Base period	2020s	Change	2050s	Change	2080s	Change
	(1988-2018)	(2010-2039)	%	(2040-2069)	%	(2070-2100)	%
RCP 4.5	980	996	2	1012	4	1043	7
RCP 8.5	980	998	2	1025	5	1067	9

4.1.3.2. Temperature Scenario

A. Maximum Temperature Scenarios

Modjo watershed exhibits an increase in projected maximum temperature under both GCM models and RCP climate scenarios (Figure 4.5). The mean annual maximum temperature showed an increasing trend and varies from 1 to 1.54°C under RCP 8.5 and from 0.99 to 1.44°C under RCP4.5 scenarios at the future three-time periods and . The maximum temperature scenario generation showed that there may be an increase in mean Maximum temperature in all the months except Jun, Nov and Dec in the 2020s and 2050s. However, there may be an increase in temperature for the rest of all the months.



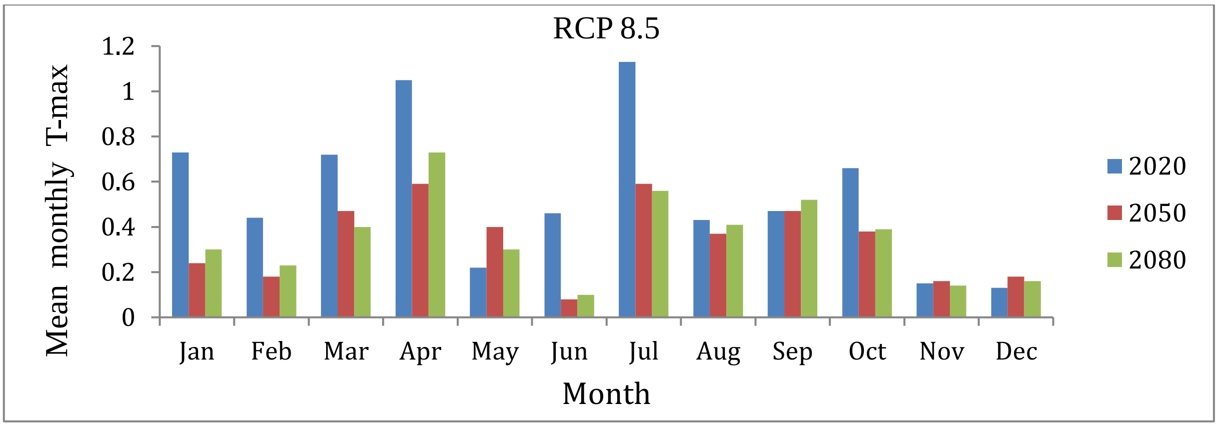
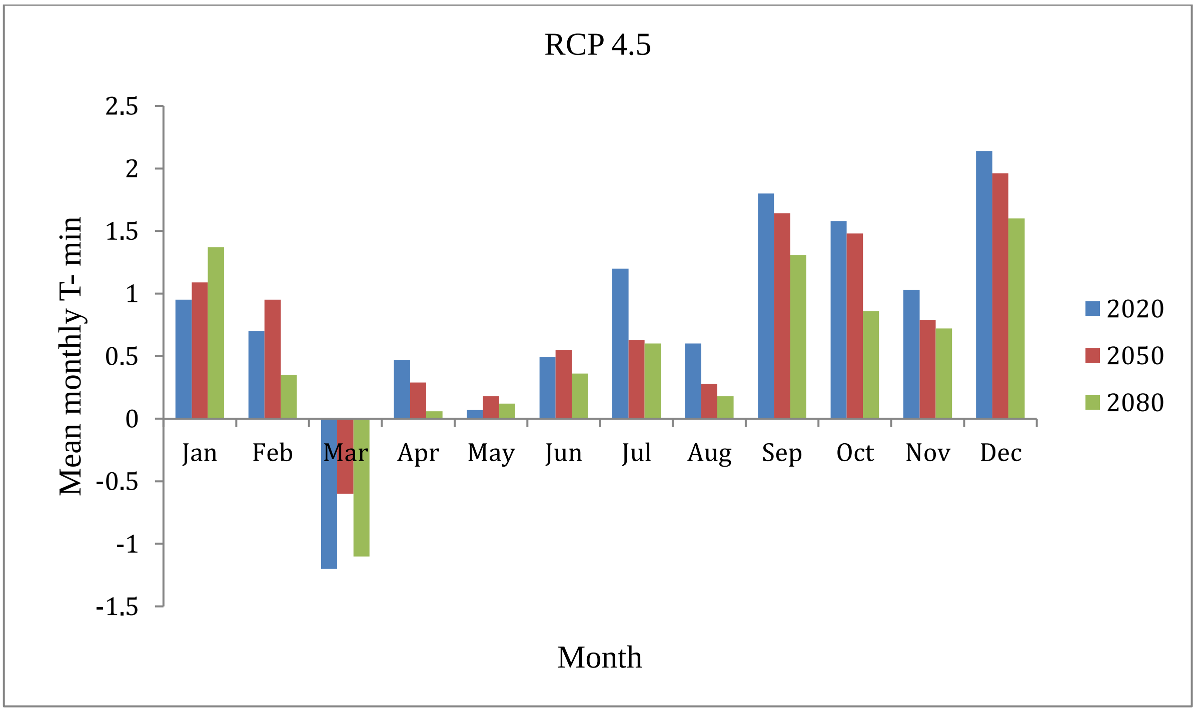


Figure: - 4. 5: change in mean maximum temperature for the period 2020-2099 from the baseline period mean maximum temperature.

B. Minimum Temperature Scenarios

The annual mean minimum temperature trend in the long run may be increasing as compared to the baseline period. mean annual minimum temperature varies 1.09 to 3.27°C under RCP8.5 and from 1 to 1.99°C under RCP 4.5 climate scenarios for the three-time periods analysis. Therefore, there may be an increase in temperature for the rest of all the months.



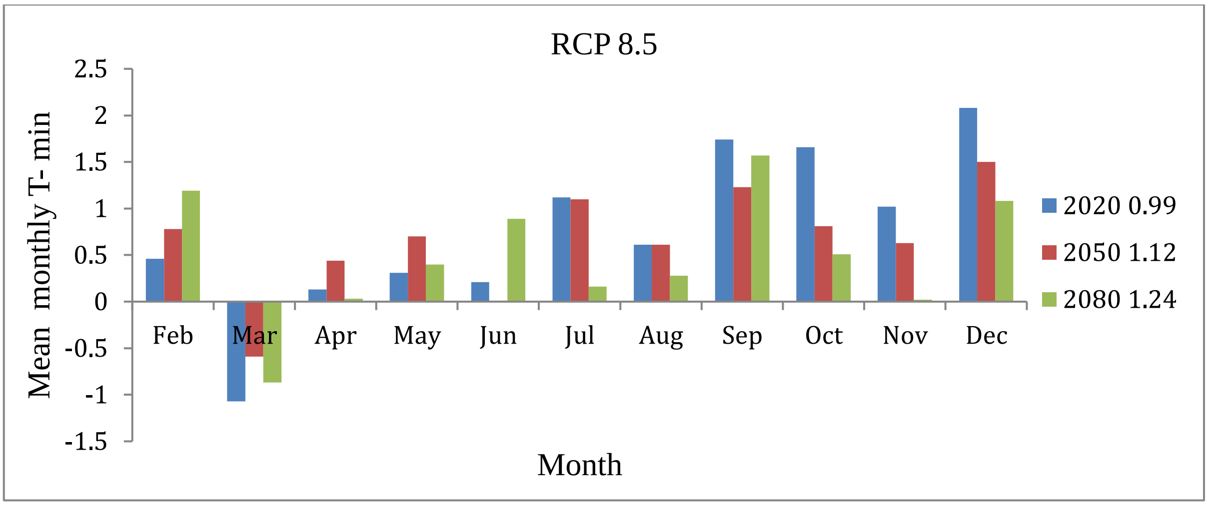


Figure: - 4. 6: Change in mean minimum temperature (2020-2099) from the baseline Period mean minimum temperature at Modjo watershed.

4.2. SWAT Model Evaluation

4.2.1. Watershed delineation

Watershed delineation based on the digital elevation model (DEM) is the prerequisite to set up the SWAT model. After delineation of Modjo Watershed topographic report statics show that the elevation minimum, maximum and mean of the Watershed is 1576, 3037 and 2080 respectively and also 29 sub-basins are formed and the land use, soil and slope distribution of the Watershed are shown in the (table 4.4).

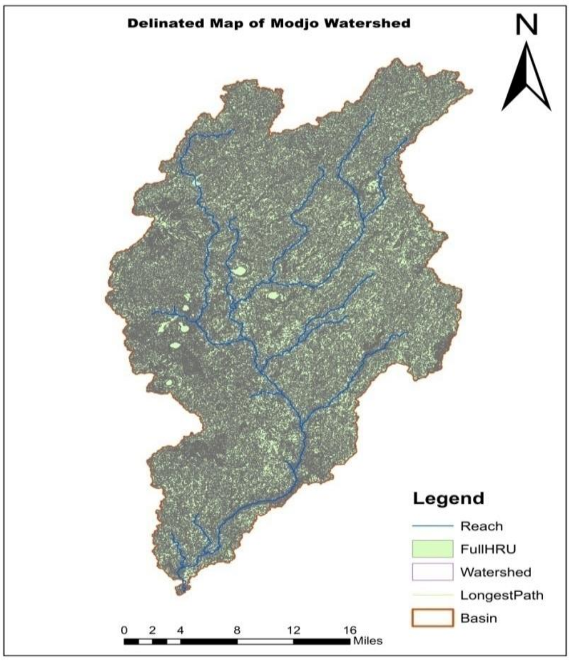


Figure 4.7 delineated map of the Area

Table: - 4. 4 Detailed Land use/Soil/Slope distribution SWAT model class

Land use		Area(Ha)	Area(acres)	%Wat.Area
Bear land	BARR	904.7802	2235.7572	25.53
shrub land	SHRB	1383.6067	3418.75	3.81
Forest	FRST	4885.0959	12071.3163	1.87
Agricultural Land	AGRL	159469.6143	394057.3905	64.66
Urban area	URBN	185.05	457.2794	2.11
Water Body	WATR	99.1877	245.0977	3.06

soil	Area(Ha)	Area(acres)	%Wat.Area
Chromic cambisols	43051.9635	106383.5545	25.29
Vertic cambisols	3400.9695	8403.9656	2
leptosols	17031.3861	42085.4067	10
Pellic vertisols	107393.5598	256479.0734	60
Chromic luvisols	2988.5413	7384.8350	1.76

Slope	Area(Ha)	Area(acres)	%Wat.Area
0-5	126202.43	31852.51	39.39
5-15	23174.99	57266.57	46.62
15-25	5655.71	13975.54	8.2
25-35	2369.38	5854.86	4.5
>35			1.28

4.2.2. SWAT model HRU analysis

The result of HRU threshold analysis is classified based on the Land Use, Soil and slope of the Modjo Watershed result which is based on (Winchell *et al.*, 2010) classification over the analysis of SWAT. In the study area, 29 sub basins were created and the HRU threshold is for Land use 20%, for soil 10%, and for slope 10% and finally 83 HRU was created.

4.3. Modeling Streamflow

4.3.1. Sensitivity analysis for streamflow simulation

Global sensitivity analysis was done for 11 parameters shown in the appendix. According to the result of global sensitivity analysis, the curve number (CN2) was found to be the most sensitive parameter followed by the surface run off lag time (SURLAG), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) the Available water capacity of the soil layer (SOL-K), Manning's "n" value for the main channel (CH_N2) and Available water capacity of the soil (SOL_AWC). The sensitivity for each parameter was assigned depending on p-value and t-stat. Here, t-stat provides a measure of sensitivity and hence large absolute values are more sensitive. On the other hand, p-value indicates the significance of sensitivity and hence a value closed to zero has more significance. Therefore, ranking in both cases (t-stat or p-value) gives the same result i.e. a parameter will have the same rank where it's ranked based on the t-stat or p-value.

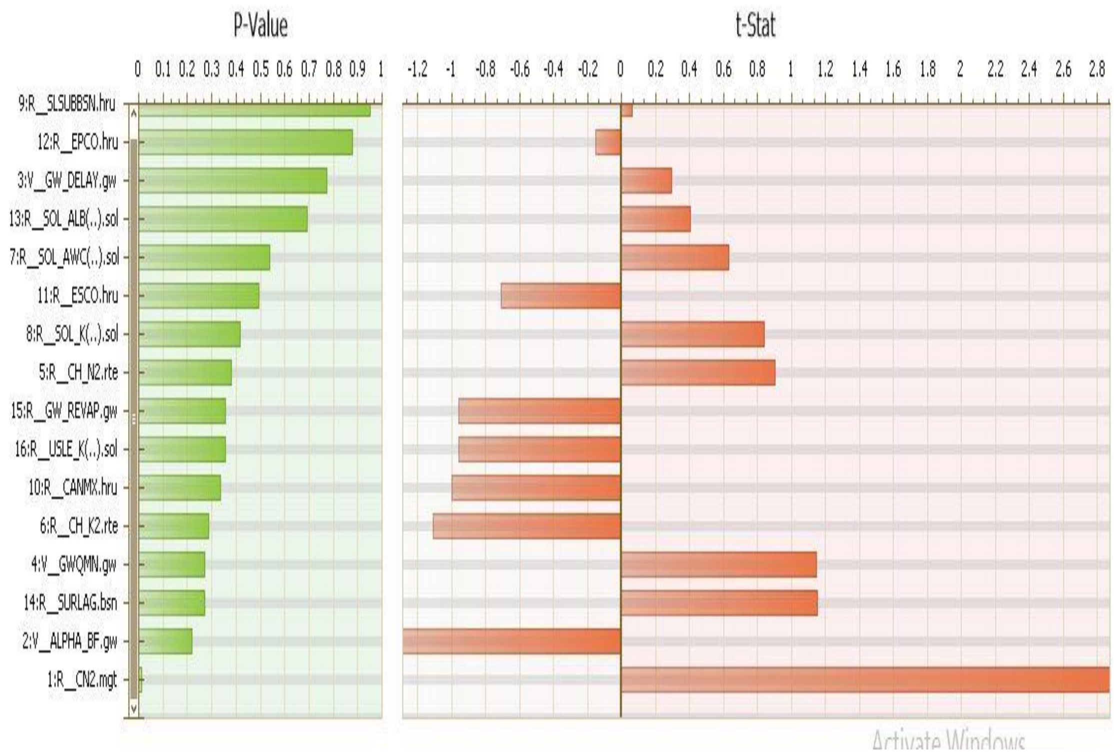


Figure 4.8 the results of sensitivity analysis for flow calibration

Table: - 4. 5 Result of sensitivity Analysis for flow calibration

Parameter name	t-stat	p-value	Rank
CN2.mgt	2.87	0.01	1
ALPHA_BF.gw	-1.28	0.2	2
SURLAG.bsn	1.153	0.26	3
GWQMN.gw	1.14	0.269	4
CH_K2.rte	-1.10	0.288	5
CANMX.hru	-0.997	0.33	6
USLE_K(..).sol	-0.956	0.356	7
GW_REVAP.gw	-0.956	0.3563	8
CH_N2.rte	0.90	0.38	9
SOL_K(..).sol	0.83	0.41	10
ESCO.hru	-0.705	0.492	11
SOL_AWC(..).sol	0.633	0.537	12
SOL_ALB(..).sol	0.404	0.692	13
GW_DELAY.gw	0.29331	0.773	14
EPCO.hru	-0.153	0.88	15
SLSUBBSN.hru	0.061	0.9518747	16

4.3.2. Streamflow calibration and validation

As the SWAT model considers many parameters, it's mandatory to identify which of the basin parameters are most important to govern the streamflow. For calibration of streamflow, governing parameters should be prioritized according to their order of influence. Prioritization of the parameter has been done using the Latin Hypercube Global sensitivity analysis method. The entire study area has been divided into 29 sub basins and 83 HRUs. For each sub basin, the parameter has been ranked according to their order of influence. The computed result of the sensitivity analysis of streamflow is indicated in table 4.6

4.3.2.1. Model calibration

The calibration of the swat model for the streamflow was done by using the monthly observed streamflow data at the Modjo gauging station for the year 1990 and 2017. During the calibration period from 1990-2008, the simulated monthly flow matched well with the measured monthly flow with the values of 0.87 for R2, 0.83 for ENS and 16.4, 0.41 for P_{bias} and RSR respectively. Fig 4.7 shows the comparison of the simulated versus the observed monthly flow. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volume. It is clearly seen on the scatter plot of the simulated versus the observed monthly flow that was agreed by the model.

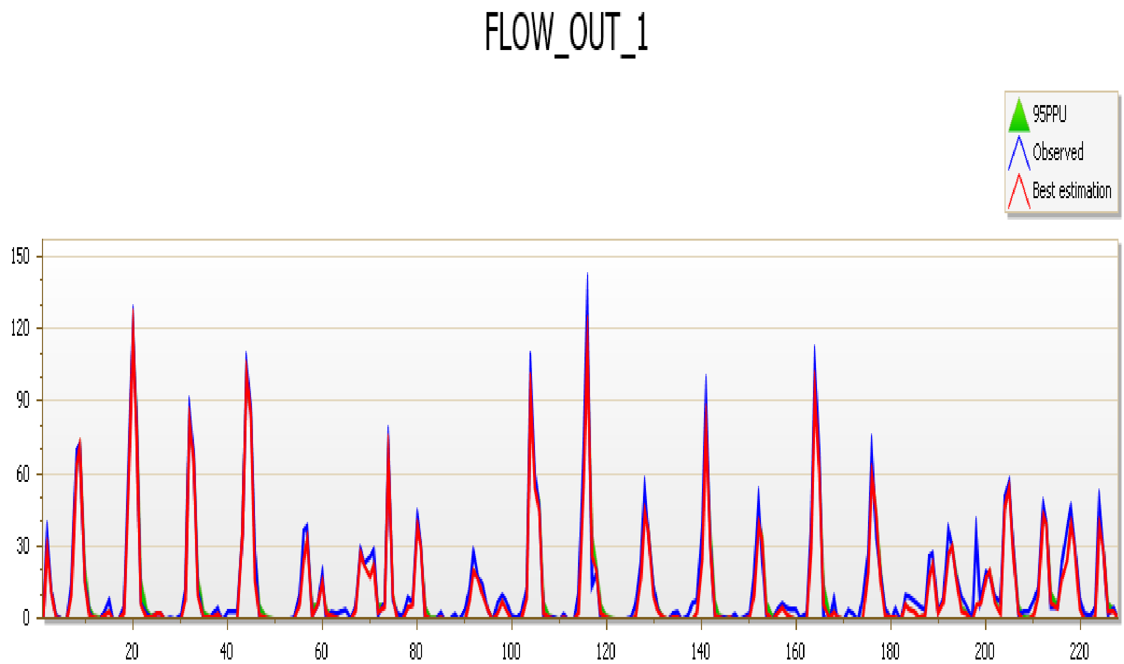


Figure: - 4. 9 simulated and observed monthly flows generated from SWAT CUP during calibration

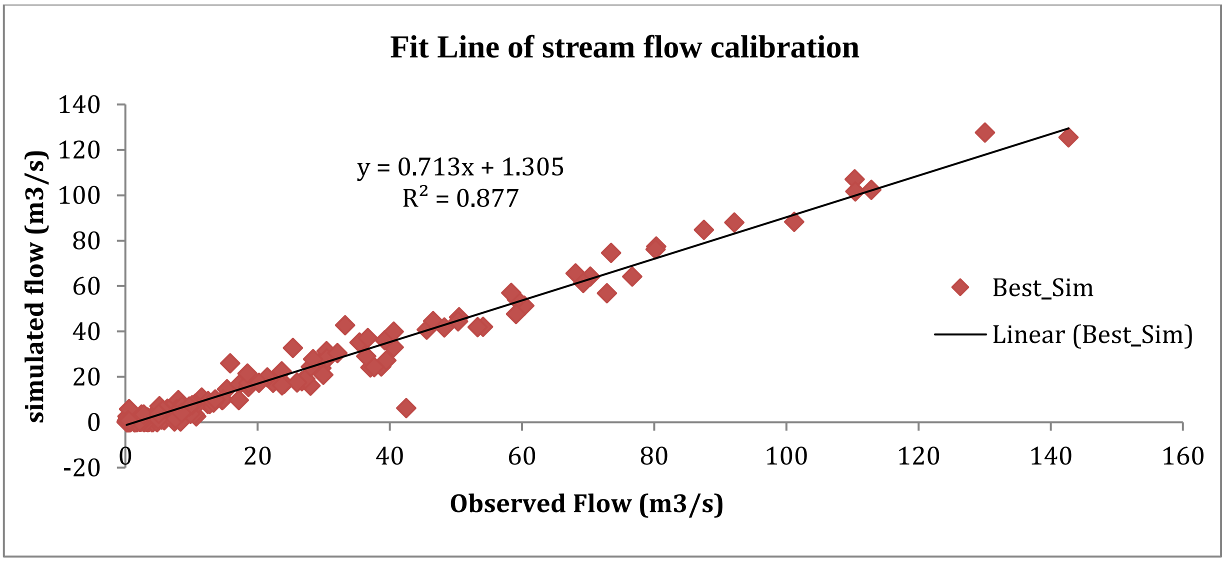


Figure: - 4. 10 simulated and observed monthly scatter plot for flow calibration

4.3.2.2. Model validation

The model with calibrated parameters was validated by using an independent set of measured flow data which were not used during model calibration. The model performance in validation was carried out from 2009- 2017, without further adjustment of the parameter selected for model calibration. Accordingly a good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient with the values of 0.79 for R^2, 0.73 for Nash-Sutcliffe simulation efficiency (ENS) and 13.1, 0.29 for percentage of bias (Pbias) and RSR respectively. The output results were clearly shown on the scatter plot of the simulated versus the observed monthly flow that was agreed by the model.

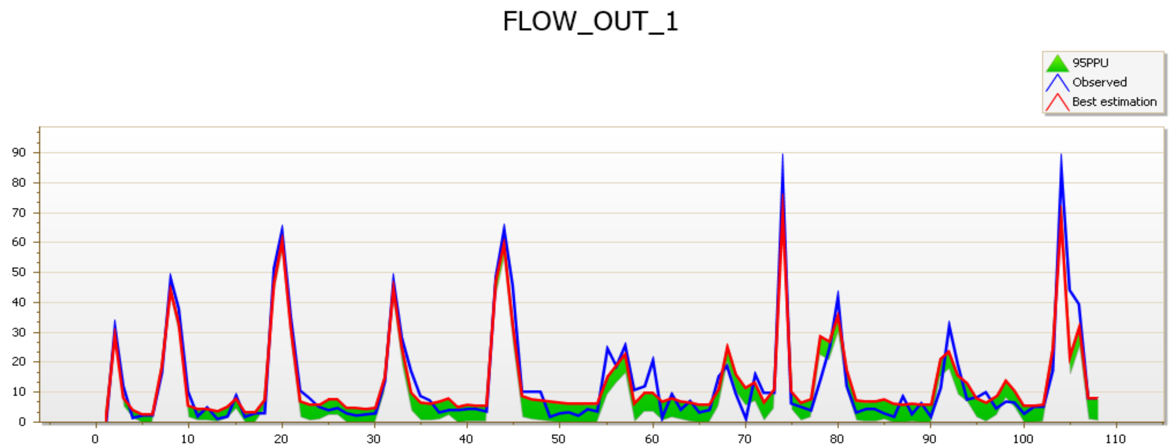


Figure: - 4. 11. Simulated and observed monthly flows generated from SWAT CUP during

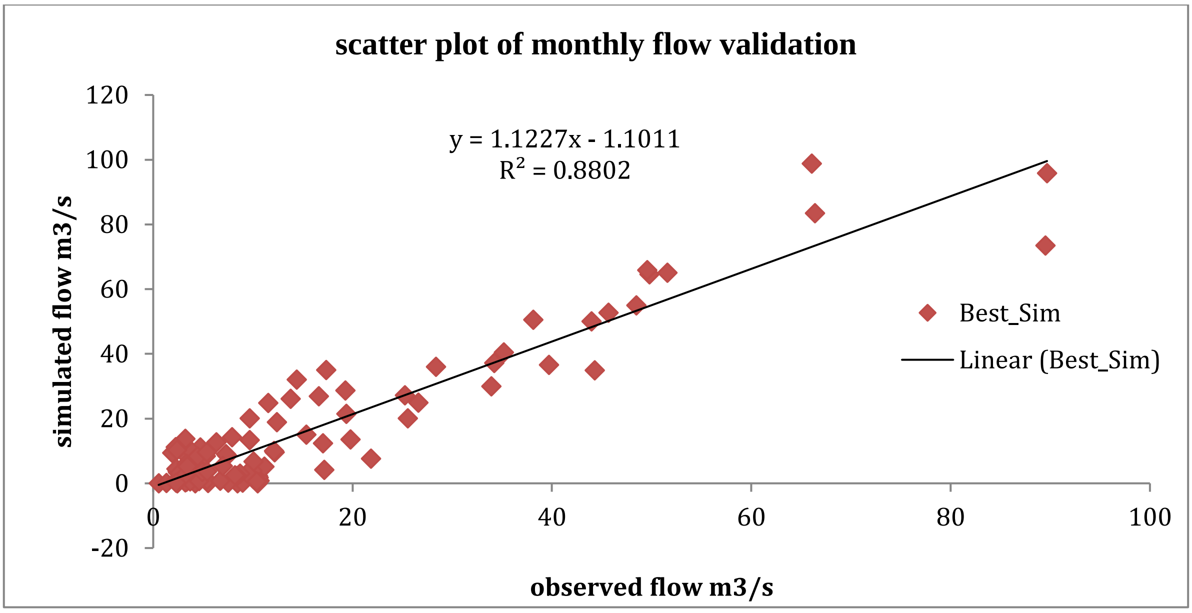


Figure: - 4. 12 simulated and observed monthly scatter plot for flow Validation

4.3.3. Model performance Evaluation for streamflow Calibration and Validation

The performance of the model to simulate the streamflow during the Calibration and Validation period has been evaluated based on the computed results of the indicator and the suggested model performance rating standard. The computed statistical indicators from 0.87 for R^2, 0.83 for NSE,16.4% for pbias and 0.41 for RSR. The values of all statistical indicators fall in the range of good and very good model performance in accordance with (moriasi and Wale, 2015). Likewise, the model was evaluated for the performance of the validation period. The computed statistical indicators range from 0.79 forR^2, 0.73 for NSE, 13.1 for pbias and 0.29 for RSR. Similar to the calibration period, the model performance rating was evaluated in terms of (moriasi and Wale, 2015)and model performance evaluation criteria and was found to be good and very good.

Result of	**R^2**	**NSE**	**P^{bias}**	**RSR**
calibration	0.87	0.83	16.4	0.41
validation	0.79	0.73	13.1	0.29

4.3.4. Climate change impact analysis on streamflow

After calibrating the hydrological models with the historical record, the next step is the simulation of river flows in the Watershed by using precipitation and Temperature as input to hydrological models. Subsequently the hydrological model was used to identify possible trends in the simulated river flow. Based on this, hydrological impact of the Modjo watershed is analyzed using Arc SWAT 10.4 hydrological model using the data that has three future time series from: 2020-2049, 2050-2079 and 2080-2099 for all statically downscaled. The impact of climate change was analyzed taking the 1988-2018 river flow as the baseline flow against which the future flows for the 2020s (2020-2049), 2050s (2050-2079) and 2080s (2080-2100) compared. Precipitation, minimum and maximum temperature were the climate change drivers considered for the impact assessment. The monthly percentage change in mean flow for RCP 4.5 scenario the period 2020s (2020-2049), 2050s (2050-2079) and 2080s (2080-2100) are presented in Figure below. In the 2020s and 2050s the monthly mean flow may show increase for all the months except March, May and October. Under RCP4.5 the stream increases by 4.72m^3/s, 4.84m^3/s, and 5.38m^3/s by the year Near (2020), Mid (2050) and Far (2080) respectively.Similar study conducted in Awash River Basin has also indicated a very high variability of discharge for both annual and seasonal basis and correlated the variability of discharge with the variability of rainfall (Melat, 2020).

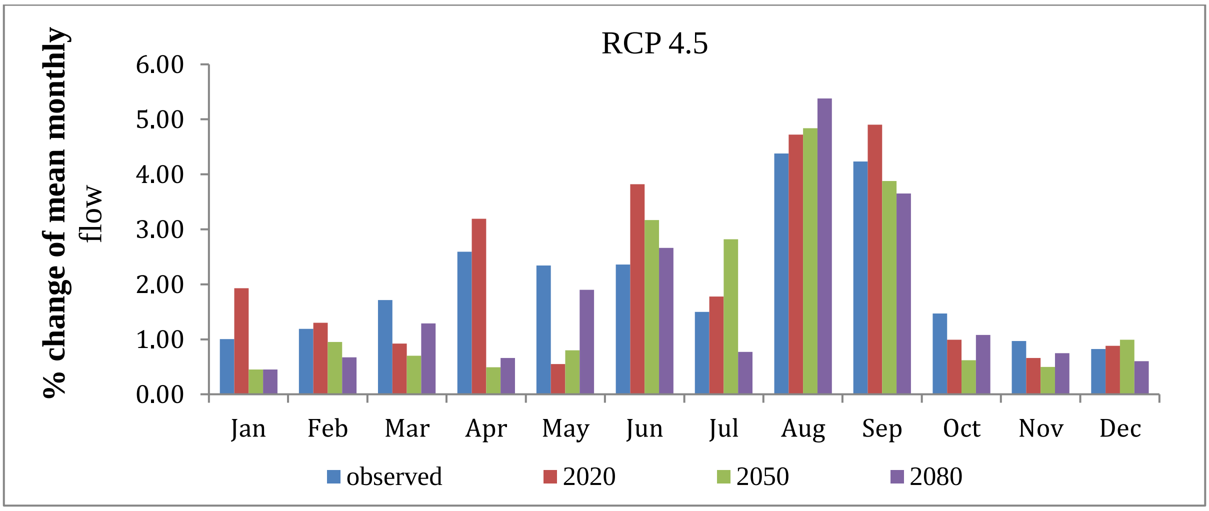


Figure: -4.14: Monthly percentage change Vs Observed in flow volume for the RCP 4.5 scenario.

The monthly percentage change in mean flow for RCP 8.5 scenarios for the period of 2020s, 2050s and 2080s also presented in Figure below. In the near (2020s) and mid (2050s) periods the monthly mean flow may show increase for all the months except Oct, Nov and Dec. For scenario 8.5 the increase becomes 3.82m^3/s, 3.86m^3/s, 3.32m^3/s by the year Near (2020), Mid (2050) and Far (2080) respectively.

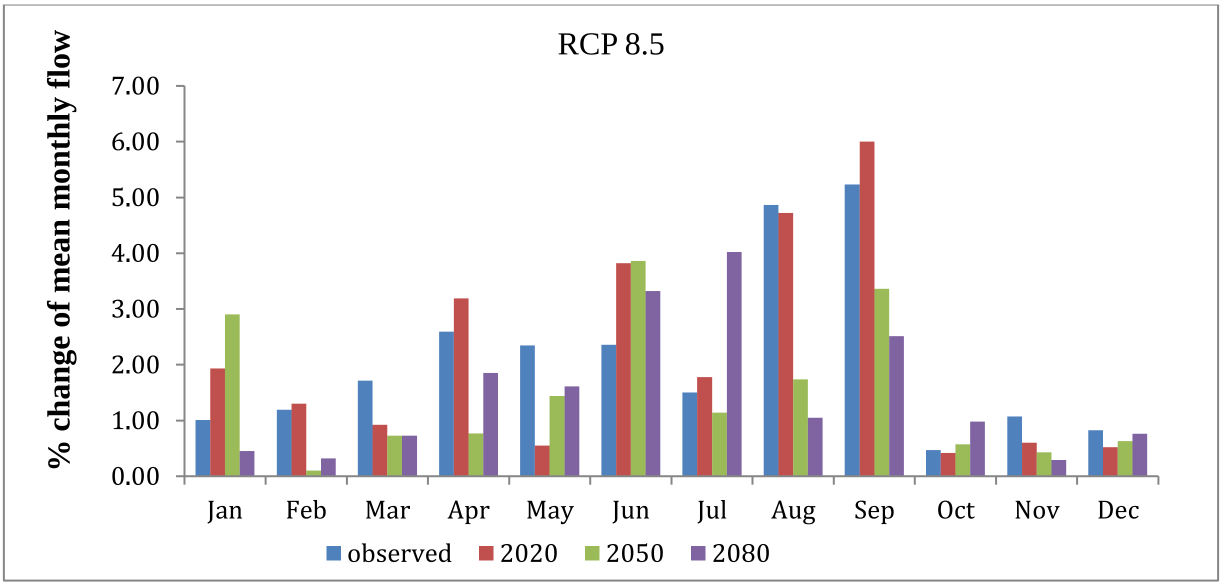


Figure: - 4.15: Monthly percentage change Vs Observed in flow volume for the RCP 8.5 scenario.

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4.4. DISCUSSION

4.4.1. Sensitivity parameters for Streamflow simulations

Model sensitivity calibration and validation was carried out to identify the most sensitive parameters for simulation of streamflow at Modjo watershed. The sensitivity parameters selected for the study area showed similarity with watersheds which have similar topography and watershed conditions. A study conducted by (Bezabih, 2019) at Melka Kunture watershed demonstrated the most sensitive parameters for flow calibration were CN2, ESCO, ALPHA-BF, and SOL-AWC most of the selected parameters are similar with selected parameters at Modjo watershed. The result of previous studies conducted on Areas which have similar watershed conditions with Modjo watershed revealed that, parameters sensitivity was dependent on hydrological and topographic conditions presented on the area. Therefore, most of the simulated parameters on such watersheds were found to be similar.

4.4.2. Modjo sub watershed Streamflow status

Previous study findings and outputs of the present study revealed that the Arc SWAT model fits well to simulate various hydrological components to tropical watersheds; also it was initially developed for the temperate zone of the USA (Neitsh, 2011). For Example R2 values of 0.84 and NSE of 0.78 for monthly time step, respectively, were achieved when simulating streamflow for Keleta watershed in central Ethiopia, (Bekele, 2017). On the other hand a case study was provided by Tadelech (2015) in the Kulufo Watershed, south West Ethiopia, which assessed the steam flow status using an Arc SWAT Hydrological model. An R^2 value of 0.86 and NSE of 0.88 for both monthly and daily time step flow simulation model performance were achieved. Similar study conducted in Awash River Basin has also indicated a very high variability of discharge for both annual and seasonal basis and correlated the variability of discharge with the variability of rainfall (Melat, 2020). The result of variability analysis in maximum, minimum and average stream flow at Modjo gauging station indicates that there is a high variability for both annual and seasonal basis. Therefore, studies carried out to test the applicability of the SWAT model in tropical regions including the present findings reported reasonable accuracy.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The first step in effective watershed management planning is an attempt to obtain a scientific understanding of the hydrological characteristics of the watershed as well as defining the adequate tools for long term predictions of the watershed characteristics. Therefore, the following conclusion was drawn from the study:-

- The watershed exhibits an increase trends on projected climate variables (T- max, T-min and PCP) for the future periods. Generally future projections of precipitation and Temperature for selected station were shows increasing trend in rainfall amount and Temperature variability especially on far future periods.
- The current study confirmed that the SDSM model has a good predictive capacity from the historically data for PCP, T-max and T-min. Therefore the model can be used for simulating PCP and Temperature from gauging stations of the watersheds that are having similar climatic Variables and conditions with Modjo watershed.
- The response of streamflow under changing Climate scenario indicated that the average monthly streamflow were increased from the period 2020s to 2080s Under RCP4.5 and RCP8.5 respectively due to the increments of Tempreature and Preciptation of the watershed.
- The current study confirmed that the SWAT model has a strong predictive capacity from the watershed for streamflow. Therefore the model can be used for simulating streamflow from ungauged watersheds that are having similar physiographic and climatic conditions with Modjo watershed.

5.2. Recommendations

- The study results provide valuable information on climate change impacts on streamflow with respect to T-Max and T-Min and PCP as climatic variability. Thus the finding result can be used to design appropriate mitigation measures of which sustainable watershed management strategies which further contribute to reduce extreme weather event particularly drought and flood in the watershed.
- The SWAT model prediction output depends on the quality of input data. One of the constraints in conducting this research work was lack of the continuous measured suspended meteorological and hydrological data. The streamflow data used for this study were 20 years monthly flows for both calibration and validation. Therefore, there is possible discrepancy while predicting the Long-term streamflow over the study area. Hence, the responsible authority should give the time and frequency of sampling method and recording reliable will improve the calibration result.
- It's recommended that the calibrated model can be used for further analysis of the effect of climate on water resources as well as to investigate the effect of the different management scenarios on streamflow in the watershed.
- Results of any impact studies are highly dependent on the quality of input data. Therefore, increasing the number of meteorological and hydrological stations is very important so responsible bodies should have exposure to the measurements in addition to installation and measurements accuracy. In addition the data handling system and quality check should be improved.
- Even though the current study confirmed that the SWAT model has a strong predictive capacity from the watershed for streamflow, comparison of other different model is vital for further accuracy of prediction of streamflow of future scenario with respect to climatic variability's and as well as land use and land cover dynamics in relation with impact on streamflow.
- Future detailed research for the study area is need and has to include impact of land use and land cover dynamics in relation with impact on streamflow and adaptation option to climate change.

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APPENDIX

Appendix 1: selected meteorological stations names, locations, and variables in the study area (source: (NMSA, 2019))

Station	Lat	Long	Elev	RF	TEMP	RH	WND	SUN
DebreZeit	8.733333	38.95	1900	✓	✓			
ChefeDonsa	8.97	39.1232	2392	✓	✓			
Ejere	8.7733	39.25683	2254	✓	✓			
Modjo	8.60533	39.10816	1763	✓	✓	✓	✓	✓

Appendix 2: Numbers of stations and their description

Id	Name	Latitude	Longitude	Elevation
1	Chefe Donsa	8.97	39.12	2392
2	Debrezeit	8.73	38.95	1900
3	Modjo	8.61	39.11	1763
4	Ejere	8.77	3926	2254

Appendix 3:- simulated Average monthly streamflow (m3/s)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	0.2663	32.94	10.81	0.6627	0.0056	3.2	9.779	64.11	74.61	14.51	2.031	0.7277
1991	0.2312	1.606	3.296	2.89	1.2	2.655	51.37	127.6	77.43	6.259	1.101	0.9553
1992	2.807	2.616	0.0002	0.0008	0.0001	0.0155	8.067	87.93	65.52	9.347	1.029	0.6586
1993	1.231	2.507	0	0.2007	0.03	0.0977	35.17	107	84.7	16.13	1.721	0.8841
1994	0.3855	0.1241	0.0004	0.0753	0.98	0.0556	6.01	24.15	36.14	2.418	5.87	17.36
1995	2.583	2.149	0.9471	0.162	2.1	0.98	3.83	28.67	22.46	18.1	23.89	3.435
1996	5.13	76.07	9.738	0.3711	0.2231	4.996	5.722	40.81	29.58	1.786	0.2366	0.2641
1997	1.146	0.0004	0	0.1673	0.89	1.2	8.115	20.83	16.68	10.09	3.989	0.3785
1998	2.539	8.229	4.665	0.12	0.54	0.2326	8.622	101.7	54.03	44.57	2.682	0.8271
1999	0.4049	0.0665	0.6424	0.32	1.4	2.571	56.83	125.5	25.9	19.78	2.687	0.7916
2000	0.2567	0.0724	0.0001	0.023	0.56	0.8449	16.86	47.66	37.04	9.837	3.261	0.456
2001	0.1404	1.067	1.166	0.62	0.43	0.353	3.062	24.48	88.27	28.93	2.088	0.7512
2002	0.2617	0.6109	0.3119	1.15	0.1345	0.92	9.726	41.97	32.72	2.405	0.4164	2.218
2003	5.518	3.038	0.7825	0.43	0.54	0.0014	28.99	102.3	61.32	5.782	0.8149	3.592

2004	0.5726	0.0387	0.3097	0.1471	0.9	0.2686	19.01	64.1	42.76	15.45	2.061	0.5584
2005	1.187	0.2529	7.048	4.294	3.698	1.213	1.64	17.47	24.4	3.366	6.992	27.17
2006	31.25	17.24	3.742	2.95	0.0513	6.251	7.421	17.32	21.46	6.975	3.477	46.23
2007	56.9	28.04	2.943	0.4068	0.2266	1.6	9.986	44.36	39.84	7.006	5.162	16.29
2008	24.25	41.77	30.46	4.095	0.365	0.1114	1.153	41.85	27.8	3.377	3.712	0.5645
Avarage	7.2137	11.49673	4.045384	1.004516	0.751274	1.450879	15.33489	59.46368	45.40316	11.90095	3.853732	6.532216

Appendix 4: measured Average streamflow for Calibration and Validation

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Nov	Oct	Dec
1990	0.2595	40.6029	18.519	6.5339	0.2256	0.3866	18.6302	86.3267	79.4916	19.362	0.2306	0.2964
1991	0.2833	3.3696	8.613	0.3389	0.2044	8.4346	65.3599	150.05	80.3226	12.3544	0.3989	0.6851
1992	7.6226	7.6817	0.3706	0.6529	0.2515	1.3477	12.4664	110.145	75.078	15.5244	0.2837	0.3143
1993	2.2916	5.3148	0.2217	6.1505	9.414	3.5337	42.4131	130.316	89.5383	27.9829	4.3837	0.2983
1994	0.2216	0.1863	0.3159	0.2549	0.3501	0.7898	9.6382	37.0638	39.2326	2.4647	6.3545	22.344
1995	0.3056	3.3514	2.4777	3.6044	4.8164	1.3116	5.0781	39.6899	23.6247	26.7001	29.6394	2.4375
1996	6.9445	97.221	15.9999	2.935	7.0498	9.9901	7.7347	55.5738	35.5356	0.531	0.3882	0.3328

1997	3.4563	0.2897	0.3845	2.3465	0.3261	8.9814	12.7594	29.9416	13.2582	14.7626	4.5046	0.3997
1998	7.4045	10.5685	7.6324	1.7731	0.5185	2.7913	13.3206	126.45	59.2371	49.5401	5.5245	0.4785
1999	0.4846	0.4146	2.539	0.3959	0.4324	10.7033	72.8508	142.705	28.8297	21.4475	0.357	0.3175
2000	0.357	0.3134	0.279	0.2785	0.443	5.8524	24.0153	59.0699	39.6552	13.6315	4.4084	0.3609
2001	0.3778	2.3434	3.5181	0.4333	1.4155	7.401	8.1808	38.6955	108.181	31.5247	0.449	0.449
2002	0.4625	0.397	2.5055	0.4234	0.4695	2.8815	17.1596	54.083	25.3433	0.4502	0.3859	4.4835
2003	6.5844	5.4772	4.7563	4.1895	0.6288	2.8246	36.4446	128.866	69.2785	9.5632	0.403	10.4598
2004	0.4218	0.2339	4.6501	2.9035	0.3031	8.346	26.247	26.6976	49.2561	18.5894	5.4095	0.4144
2005	5.4817	0.1916	13.5616	9.7045	9.4879	5.7354	4.6188	25.9519	28.0667	4.5893	8.5661	39.4772
2006	30.4372	18.6263	9.8203	6.5021	1.5835	10.4729	10.0781	29.1919	28.464	9.6477	7.5166	60.486
2007	58.374	30.4849	2.4503	5.1016	3.1865	7.5828	15.5835	65.3315	41.6038	8.146	5.6479	23.6798
2008	27.6453	48.2267	36.0926	11.5062	2.7226	2.1585	4.9689	53.2889	28.4011	2.7724	4.0402	0.54
2009	0.54403	0.21771	0.17119	0.9053	0.46471	0.45107	6.6139	17.7814	8.1338	1.49806	0.39893	0.48184
2010	0.33845	0.31582	0.67006	2.2887	3.23342	3.21983	14.5779	15.058	13.1711	0.67697	0.45453	0.36803
2011	0.23023	0.00592	1.34029	0.61078	0.83897	3.3748	13.7886	14.5683	18.3583	7.14715	0.96357	0.53606
2012	0.47555	0.25803	0.20842	0.72147	0.52671	1.8868	8.45252	26.3758	5.65903	0.58097	0.47807	0.403

2013	0.32139	0.20221	0.64271	0.6265	0.68048	4.04123	25.5414	9.3831	6.60767	1.15261	1.1054	0.83006
2014	0.67748	0.95771	0.56268	0.43077	1.51142	1.3371	30.3634	19.2609	9.6566	2.24297	1.037	1.0467
2015	1.05819	0.52518	0.33574	0.2806	3.44368	4.40557	5.25474	13.9594	2.41397	0.71097	0.6826	0.599
2016	0.19377	0.28457	19.4092	0.35117	11.7155	26.3902	70.5375	33.9128	19.783	7.89642	8.71491	10.391
2017	4.91901	7.30252	1.96833	0.4103	55.4056	59.3693	47.3376	53.6759	44.2855	9.68758	8.41833	8.19438
Avarage	**6.006211**	**10.19159**	**5.714861**	**2.594792**	**4.34463**	**7.35718**	**22.50056**	**56.90764**	**38.23096**	**11.47064**	**3.969466**	**6.82518**

Appendix 5:- Average Annual precipitation

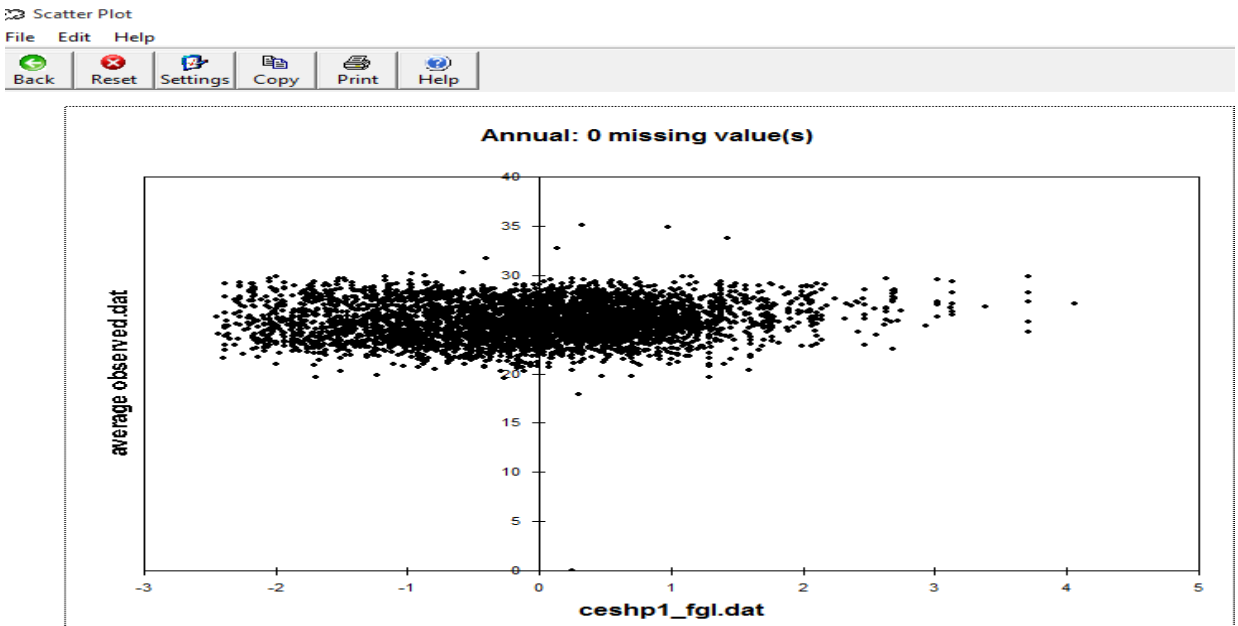
Year	ChefeDonsa	Debrezeyit	Ejere	Modjo
1989	3.04779006	1.849589	1.90082	2.83178
1990	2.63049451	2.4815934	2.63507	2.57123
1991	2.51972603	3.2564384	1.99836	2.40712
1992	2.3182377	2.426776	0.20191	2.18033
1993	2.67465753	3.3868493	2.4126	2.27288
1994	0.91763699	1.8763736	1.85014	2.0589
1995	2.00054795	1.6176309	2.08137	1.84137
1996	1.14610656	2.9437158	2.82377	4.61011
1997	1.90511003	2.3408219	0.8937	2.08301
1998	2.49109589	2.6978082	2.90767	2.8326
1999	1.88090659	2.5227397	2.52247	0.62685
2000	1.6613388	2.2841096	2.11175	2.32814
2001	3.51794521	2.3684932	2.52356	2.15918
2002	1.70191781	1.8819178	2.03014	1.54603
2003	2.62520548	2.9843836	3.20301	2.90438
2004	2.17868852	2.329235	2.60055	3.53033
2005	2.76534247	2.5076712	2.76	3.34219
2006	2.55150685	2.7375342	2.85644	2.83562
2007	2.97561644	2.3808219	2.93205	3.2589
2008	2.4863388	2.2431694	2.78251	3.30656
2009	2.33191781	1.7534247	2.14055	1.65014

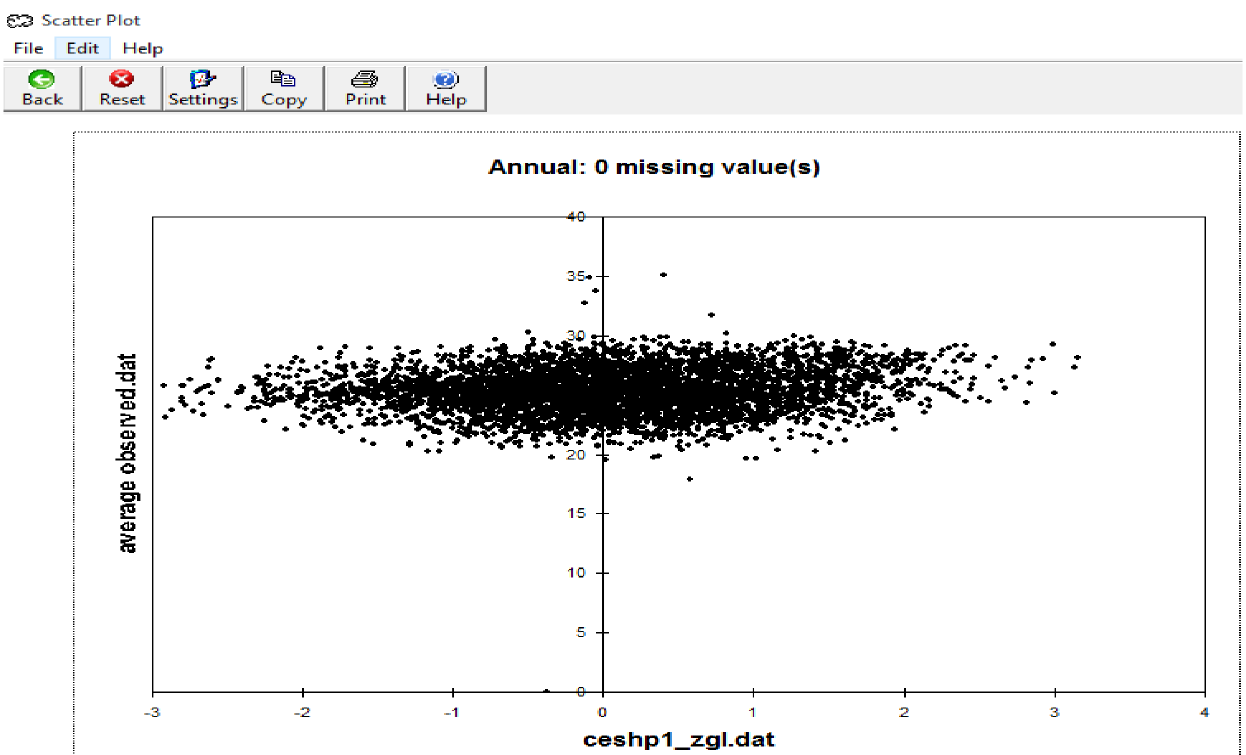
2010	3.01534247	2.5180822	2.55808	3.04219
2011	2.19260274	2.750411	3.25425	2.24082
2012	2.47595628	1.8769231	2.54098	4.39754
2013	3.35013699	2.8334247	2.6537	3.00384
2014	2.35726027	6.4569863	6.45699	2.39753
2015	1.88054795	2.7	2.7	2.35452
2016	2.19726776	4.4136612	4.36448	4.15956
2017	2.32972603	2.8720548	2.92137	2.93342
2018	3.31572802	2.9270548	2.92336	3.09185

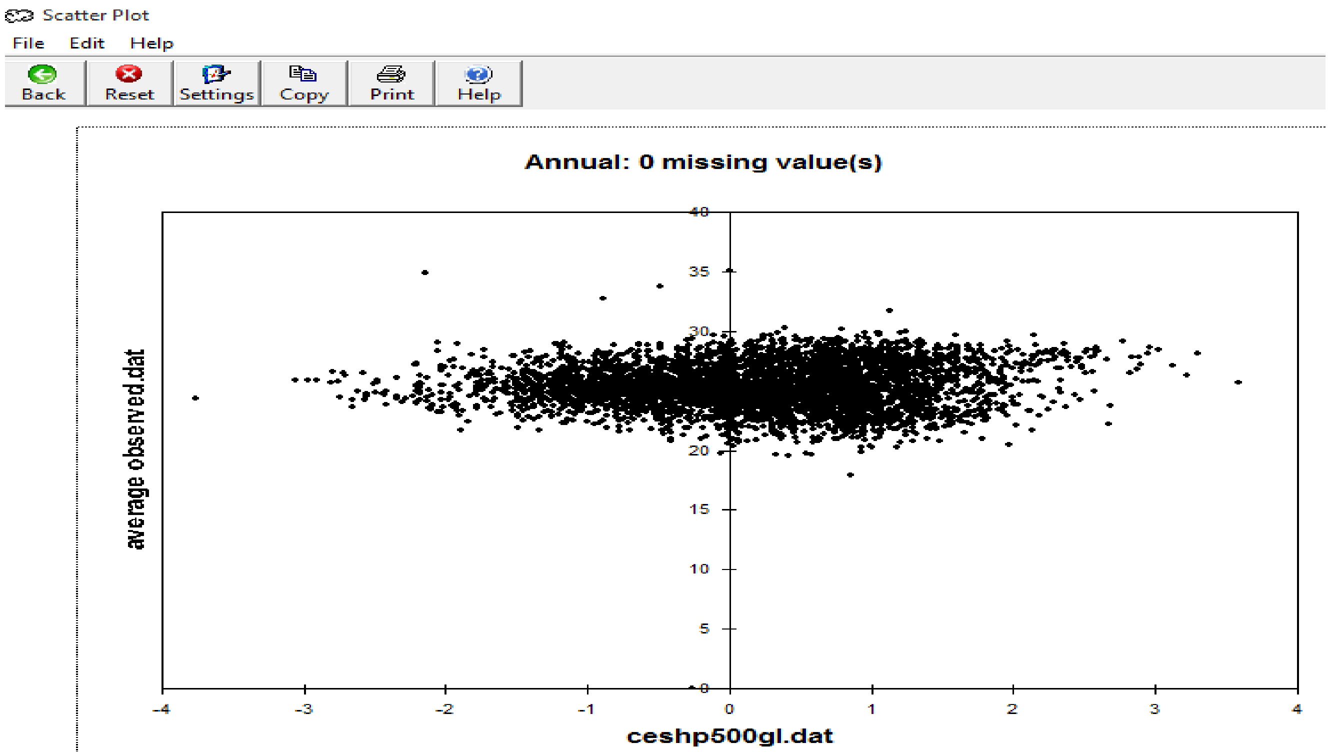
Appendix 6: selected parameter for both streamflow calibration and validation

S/N	Parameter	Description	Range Variable
1	CN2.mgt	SCS runoff curve number	35-98
2	SURLAG.bsn	Surface runoff lag time	0.05-24
3	GWQMN.gw	Threshold depth of water in the shallow aquifer	0-5000
4	CH_N2.rte	Manning “n” Value for the main Channel	-0.01-0.3
5	SOL_K(..).sol	Saturated Hydraulic conductivity	0-2000
6	SOL_AWC(..).sol	Available water content of soil	0-1
7	SOL_ALB(..).sol	Moist soil Albedo.	0-0.25
8	GW_DELAY.gw	Ground water Delay	0-500
9	SLSUBBSN.hru	Average slope length	10-150
10	EPCO.hru	Plant uptake compensation Factor	0-1
11	ALPHA_BF.gw	Base flow Alfa factor	0-1

Appendix 7: The correlation matrix (scatter plots) results for Modjo watershed



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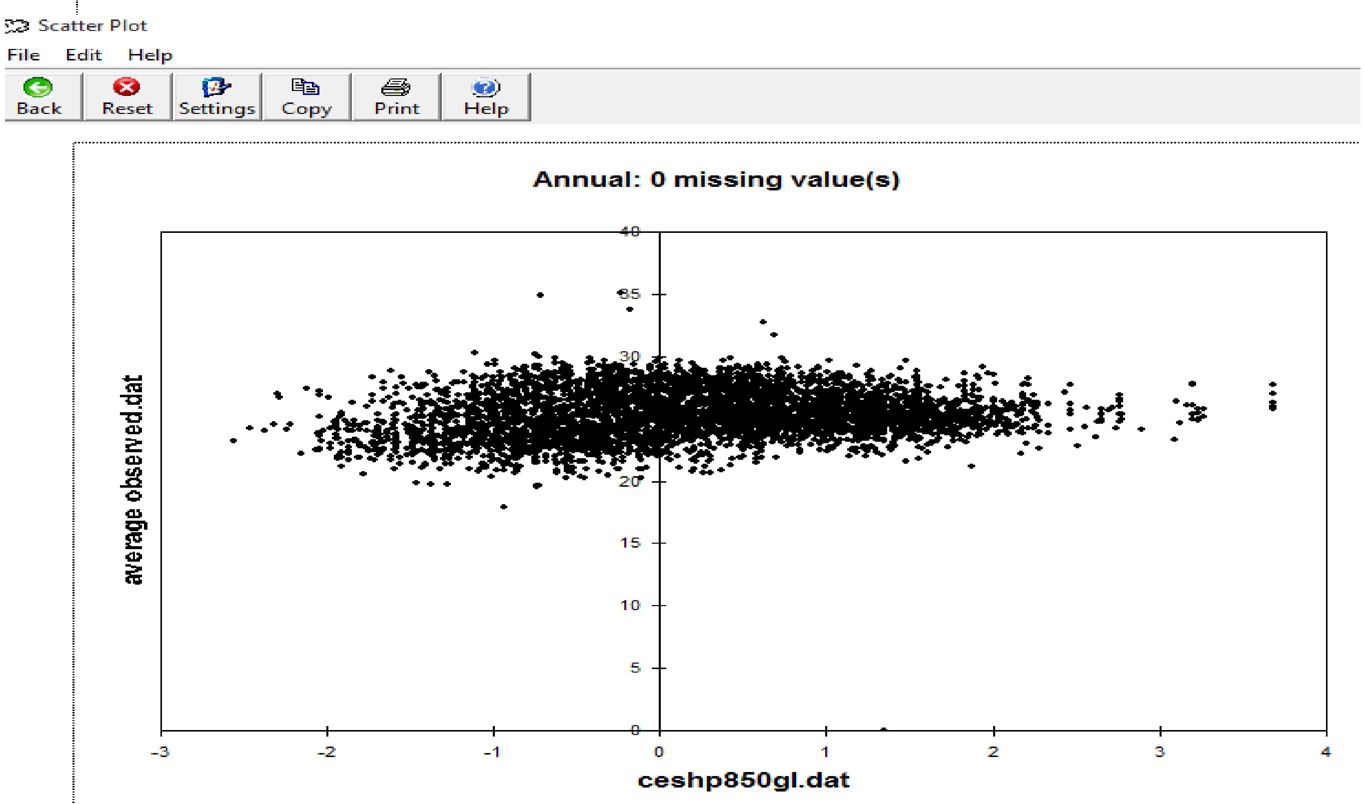
3
4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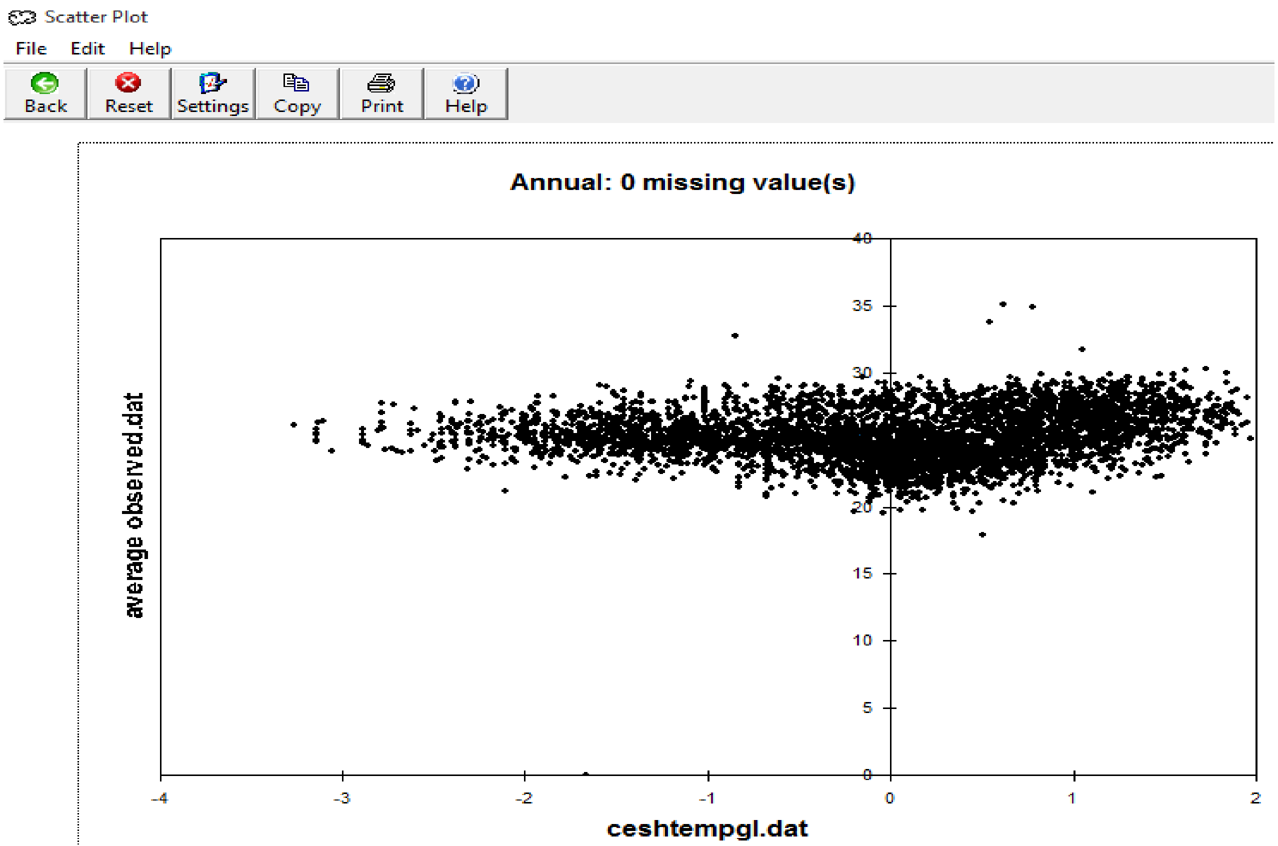
3
4



Appendix 8: selected parameter for both streamflow calibration and validation

	Area [ha]	Area[acres]	
Watershed	170266.4192	420736.8352	
Number of Subbasins: 29			
	Area [ha]	Area[acres]	%Wat.Area
LANDUSE:			
Barren --> BARR	27162.4722	67119.8269	15.95
Agricultural Land-Generic --> AGRL	320.2998	791.4769	0.19
Forest-Mixed --> FRST	1991.8839	4922.0447	1.17
Range-Grasses --> RNGE	123435.2207	305014.6021	72.50
Bermudagrass --> BERM	8746.7679	21613.7008	5.14
Pasture --> PAST	2218.8398	5482.8641	1.30
Wetlands-Non-Forested --> WETN	1346.4684	3327.1908	0.79

Water --> WATR 5044.4664 12465.1288 2.96
SOILS:
Be9-3c-26 43031.9669 106334.1417 25.27
Ne10-3b-154 3397.5760 8395.5802 2.00
Ne13-3b-158 17039.4191 42105.2565 10.01
Vp14-3a-286 103805.3279 256508.1556 60.97
Xh16-a-309 2992.1293 7393.7011 1.76
SLOPE:
0-5 68388.0135 168990.2007 40.17
15-25 11162.8493 27583.9587 6.56
25-35 3613.4659 8929.0549 2.12
35-9999 4088.9974 10104.1171 2.40
5-15 83013.0931 205129.5036 48.75
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 1 11606.7328 28680.8171 6.82
LANDUSE:
Barren --> BARR 1419.4222 3507.4632 0.83 12.23
Agricultural Land-Generic -->AGRL 41.0877 101.5298 0.02 0.35
Forest-Mixed --> FRST 106.0494 262.0533 0.06 0.91
Range-Grasses --> RNGE 9377.1213 23171.3356 5.51 80.79
Bermudagrass --> BERM 636.2962 1572.3198 0.37 5.48
Pasture --> PAST 17.4187 43.0426 0.01 0.15
SOILS:
Be9-3c-26 1527.7258 3775.0867 0.90 13.16
Vp14-3a-286 10069.6698 24882.6576 5.91 86.76
SLOPE:

0-5 4992.5176 12336.7607 2.93 43.01
15-25 447.7640 1106.4473 0.26 3.86
25-35 97.5449 241.0384 0.06 0.84
35-9999 36.2720 89.6298 0.02 0.31
5-15 6023.2970 14883.8681 3.54 51.89
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 2 7658.2912 18924.0205 4.50
LANDUSE:
Barren --> BARR 1104.6554 2729.6586 0.65 14.42
Agricultural Land-Generic --> AGRL 21.6197 53.4234 0.01 0.28
Forest-Mixed --> FRST 86.7863 214.4533 0.05 1.13
Range-Grasses --> RNGE 6072.7867 15006.1597 3.57 79.30
Bermudagrass --> BERM 354.6250 876.2961 0.21 4.63
Pasture --> PAST 7.7872 19.2426 0.00 0.10
SOILS:
Be9-3c-26 944.5054 2333.9202 0.55 12.33
Vp14-3a-286 6703.7549 16565.3135 3.94 87.54
SLOPE:
0-5 3079.1205 7608.6607 1.81 40.21
15-25 298.1678 736.7876 0.18 3.89
25-35 64.7567 160.0171 0.04 0.85
35-9999 32.2759 79.7554 0.02 0.42
5-15 4173.9394 10314.0130 2.45 54.50
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 3 13212.7744 32649.4262 7.76

LANDUSE:
Barren --> BARR 2310.9542 5710.4833 1.36 17.49
Agricultural Land-Generic --> AGRL 6.5576 16.2043 0.00 0.05
Forest-Mixed --> FRST 96.5203 238.5065 0.06 0.73
Range-Grasses --> RNGE 10300.2119 25452.3387 6.05 77.96
Bermudagrass --> BERM 484.0360 1196.0771 0.28 3.66
Pasture --> PAST 18.7508 46.3341 0.01 0.14
SOILS:
Vp14-3a-286 13217.0308 32659.9439 7.76 100.03
SLOPE:
0-5 4151.9098 10259.5768 2.44 31.42
15-25 1116.0288 2757.7629 0.66 8.45
25-35 262.5106 648.6769 0.15 1.99
35-9999 168.9618 417.5129 0.10 1.28
5-15 7517.6198 18576.4144 4.42 56.90
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 4 9367.1424 23146.6772 5.50
LANDUSE:
Barren --> BARR 1807.1428 4465.5402 1.06 19.29
Range-Grasses --> RNGE 7140.9652 17645.6821 4.19 76.23
Bermudagrass --> BERM 284.5402 703.1131 0.17 3.04
Pasture --> PAST 27.1527 67.0958 0.02 0.29
Wetlands-Non-Forested --> WETN 105.3321 260.2810 0.06 1.12
SOILS:
Vp14-3a-286 9365.1331 23141.7121 5.50 99.98
SLOPE:

0-5 3177.6901 7852.2311 1.87 33.92
15-25 782.6136 1933.8774 0.46 8.35
25-35 205.1313 506.8896 0.12 2.19
35-9999 152.6701 377.2555 0.09 1.63
5-15 5047.0280 12471.4586 2.96 53.88
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 5 9223.7824 22792.4275 5.42
LANDUSE:
Barren --> BARR 1115.7214 2757.0033 0.66 12.10
Range-Grasses --> RNGE 7548.7686 18653.3847 4.43 81.84
Bermudagrass --> BERM 367.8428 908.9578 0.22 3.99
Pasture --> PAST 6.7626 16.7106 0.00 0.07
Wetlands-Non-Forested --> WETN 160.0475 395.4853 0.09 1.74
Water --> WATR 30.3291 74.9447 0.02 0.33
SOILS:
Ne13-3b-158 610.2706 1508.0092 0.36 6.62
Vp14-3a-286 8619.2013 21298.4773 5.06 93.45
SLOPE:
0-5 2764.6611 6831.6157 1.62 29.97
15-25 957.3133 2365.5691 0.56 10.38
25-35 279.5195 690.7067 0.16 3.03
35-9999 223.6771 552.7173 0.13 2.43
5-15 5004.3009 12365.8777 2.94 54.25
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 6 1942.9376 4801.0960 1.14
LANDUSE:

Barren --> BARR		216.4022	534.7407	0.13	11.14
Range-Grasses --> RNGE		1699.6589	4199.9422	1.00	87.48
Bermudagrass --> BERM		21.8247	53.9298	0.01	1.12
Pasture --> PAST		6.2503	15.4447	0.00	0.32
SOILS:					
Ne13-3b-158		871.2443	2152.8882	0.51	44.84
Vp14-3a-286		1072.8918	2651.1692	0.63	55.22
SLOPE:					
0-5		879.5438	2173.3967	0.52	45.27
15-25		117.4228	290.1576	0.07	6.04
25-35		21.1074	52.1575	0.01	1.09
35-9999		22.8493	56.4617	0.01	1.18
5-15		903.2128	2231.8839	0.53	46.49
		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	7	5565.1328	13751.7214	3.27	
LANDUSE:					
Barren --> BARR		1490.3267	3682.6718	0.88	26.78
Agricultural Land-Generic --> AGRL		0.5123	1.2660	0.00	0.01
Forest-Mixed --> FRST		1.6394	4.0511	0.00	0.03
Range-Grasses --> RNGE		3449.8322	8524.7079	2.03	61.99
Bermudagrass --> BERM		153.7972	380.0406	0.09	2.76
Pasture --> PAST		3.0739	7.5957	0.00	0.06
Wetlands-Non-Forested --> WETN		8.9143	22.0277	0.01	0.16
Water --> WATR		456.7808	1128.7281	0.27	8.21
SOILS:					
Ne10-3b-154		96.6228	238.7597	0.06	1.74

Ne13-3b-158 400.5285 989.7260 0.24 7.20
Vp14-3a-286 5067.7256 12522.6033 2.98 91.06
SLOPE:
0-5 1915.3439 4732.9106 1.12 34.42
15-25 532.0912 1314.8240 0.31 9.56
25-35 226.8534 560.5662 0.13 4.08
35-9999 372.5561 920.6047 0.22 6.69
5-15 2518.0322 6222.1835 1.48 45.25
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 8 3647.8976 9014.1374 2.14
LANDUSE:
Barren --> BARR 1264.8053 3125.3971 0.74 34.67
Agricultural Land-Generic --> AGRL 1.4345 3.5447 0.00 0.04
Forest-Mixed --> FRST 134.0218 331.1746 0.08 3.67
Range-Grasses --> RNGE 1982.9696 4900.0170 1.16 54.36
Bermudagrass --> BERM 127.1568 314.2108 0.07 3.49
Wetlands-Non-Forested --> WETN 104.0001 256.9895 0.06 2.85
Water --> WATR 35.7596 88.3639 0.02 0.98
SOILS:
Ne10-3b-154 223.6771 552.7173 0.13 6.13
Ne13-3b-158 436.9029 1079.6090 0.26 11.98
Vp14-3a-286 2989.5677 7387.3713 1.76 81.95
SLOPE:
0-5 1059.5716 2618.2543 0.62 29.05
15-25 298.1678 736.7876 0.18 8.17
25-35 176.6465 436.5023 0.10 4.84

	35-9999 523.2794 1293.0495 0.31 14.34
	5-15 1592.4825 3935.1038 0.94 43.65
	Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN #	9 3533.9264 8732.5088 2.08
LANDUSE:	
Barren --> BARR 727.6934 1798.1667 0.43 20.59	
Agricultural Land-Generic --> AGRL 5.2256 12.9128 0.00 0.15	
Forest-Mixed --> FRST 55.2276 136.4703 0.03 1.56	
Range-Grasses --> RNGE 864.4817 2136.1775 0.51 24.46	
Bermudagrass --> BERM 92.3193 228.1256 0.05 2.61	
Pasture --> PAST 35.9646 88.8703 0.02 1.02	
Wetlands-Non-Forested --> WETN 268.8633 664.3748 0.16 7.61	
Water --> WATR 1483.0518 3664.6952 0.87 41.97	
SOILS:	
Ne13-3b-158 3531.1880 8725.7421 2.07 99.92	
Vp14-3a-286 1.6394 4.0511 0.00 0.05	
SLOPE:	
	0-5 1270.5432 3139.5758 0.75 35.95
	15-25 281.7737 696.2769 0.17 7.97
	25-35 122.2386 302.0576 0.07 3.46
	35-9999 227.3658 561.8322 0.13 6.43
	5-15 1630.9062 4030.0507 0.96 46.15
	Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN #	10 20303.7696 50171.6299 11.92
LANDUSE:	
Barren --> BARR 2287.7975 5653.2620 1.34 11.27	

Agricultural Land-Generic --> AGRL 18.5458 45.8277 0.01 0.09
Forest-Mixed --> FRST 341.8171 844.6472 0.20 1.68
Range-Grasses --> RNGE 14623.4402 36135.2518 8.59 72.02
Bermudagrass --> BERM 2266.4852 5600.5982 1.33 11.16
Pasture --> PAST 44.6739 110.3915 0.03 0.22
Wetlands-Non-Forested --> WETN 415.3857 1026.4387 0.24 2.05
Water --> WATR 298.4752 737.5471 0.18 1.47
SOILS:
Ne10-3b-154 3077.2762 7604.1033 1.81 15.16
Ne13-3b-158 1810.0118 4472.6296 1.06 8.91
Vp14-3a-286 15409.3326 38077.2314 9.05 75.89
SLOPE:
0-5 7126.5179 17609.9821 4.19 35.10
15-25 1703.8599 4210.3231 1.00 8.39
25-35 757.4077 1871.5923 0.44 3.73
35-9999 1174.6377 2902.5885 0.69 5.79
5-15 9534.1973 23559.4783 5.60 46.96
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 11 1642.5984 4058.9428 0.96
LANDUSE:
Barren --> BARR 168.4494 416.2470 0.10 10.26
Range-Grasses --> RNGE 1407.5365 3478.0930 0.83 85.69
Bermudagrass --> BERM 22.0296 54.4362 0.01 1.34
Pasture --> PAST 10.8611 26.8383 0.01 0.66
Water --> WATR 34.7350 85.8320 0.02 2.11
SOILS:

Ne13-3b-158 1478.8508 3654.3143 0.87 90.03
Vp14-3a-286 164.7608 407.1321 0.10 10.03
SLOPE:
0-5 933.1320 2305.8159 0.55 56.81
15-25 41.0877 101.5298 0.02 2.50
25-35 10.0414 24.8128 0.01 0.61
35-9999 4.3035 10.6340 0.00 0.26
5-15 655.0470 1618.6539 0.38 39.88
Area [ha] Area[acres] %Wat.Area %Sub.Area
SUBBASIN # 12 5776.6912 14274.4928 3.39
LANDUSE:
Barren --> BARR 996.4543 2462.2883 0.59 17.25
Range-Grasses --> RNGE 4590.4522 11343.2368 2.70 79.47
Bermudagrass --> BERM 179.9253 444.6044 0.11 3.11
Pasture --> PAST 11.8857 29.3702 0.01 0.21
SOILS:
Vp14-3a-286 5778.7175 14279.4998 3.39 100.04
SLOPE:
0-5 2214.1265 5471.2173 1.30 38.33
15-25 410.9797 1015.5515 0.24 7.11
25-35 76.9498 190.1469 0.05 1.33
35-9999 30.3291 74.9447 0.02 0.53
5-15 3046.3323 7527.6394 1.79 52.73
Area [ha] Area[acres] %Wat.Area %Sub.Area