MODELING THE IMPACT OF LAND USE/LAND COVER AND CLIMATE CHANGE ON THE HYDROLOGICAL BEHAVIOR OF ANDASA RIVER CATCHMENT BY USING SWAT

M.Sc. THESIS

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APPROVAL SHEET-1

This is to certify that the thesis entitled "**MODELING THE IMPACT OF LAND USE/LAND COVER AND CLIMATE CHANGE ON THE HYDROLOGICAL BEHAVIOR OF ANDASA RIVER CATCHMENT BY USING SWAT**" submitted in partial fulfillment of the requirements for the degree of Master of Science in Water Resources Engineering and Management and it is a record of original research carried out by **Negusu Tarekegn Endalew** under my supervision, and no part of the thesis has been submitted for any- other degree or diploma. The assistance and help received during the course of this investigation have been duly acknowledged. I, therefore, recommend that it is acceptable as fulfilling the thesis requirements.

Brook Abate (PhD)	______________________	________________
Name of the Major advisor	Signature	Date
Alemayehu Muluneh (PhD)	________________________	_________________
Name of Co-advisor	Signature	Date

APPROVAL SHEET-2

We, the under signed, members of the Board of Examiners of the final open defense by **Negusu Tarekegn Endalew** have read and evaluated his thesis "**MODELING THE IMPACT OF LAND USE/LAND COVER AND CLIMATE CHANGE ON THE HYDROLOGICAL BEHAVIOR OF ANDASA RIVER CATCHMENT BY USING SWAT**" and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Water Resource Engineering and Management.

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Name of the Chairperson	Signature	Date
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Name of Major Advisor	Signature	Date
______________________	______________	__________
Name of Internal Examiner	Signature	Date
______________________	______________	__________
Name of External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the Department of Graduate Council (DGC) of the candidate's major department.

Dedication

This Thesis work is dedicated to my Mother Mintamir Belay whom I have lost in the early stage of my childhood and to my father Tarekegn Endalew who shoulder the double role as mother and Father after her departure to grow up his Sons and daughter.

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LIST OF ACRONYMS AND ABBREVAITIONS

ASTER : Advanced Space born Thermal Emissions and Reflectance

BMC : Billion Metric Cube

Can ESM2 : Canadian Earth System Model generation 2

CGCM3 : Canadaian Global Circulation Model

CMIP5 : Coupled Model Inter compression Program Phase 5

CN : Curve Number

DEM : Digital Elevation Model

ENMA : Ethiopian National Meteorological Agency

ET : Evapo- Transpiration

GCM : Global Circulation/Climate Model

GHG : Green House Gases

GIS : Geographic Information System

GLUE: Generalized Likelihood Uncertainty Estimation

GPS : Global Positioning System

HadCM3 : Hadley Center Climate Model generation3

HBV- light: Hydrologiska Byr˚ans Vattenavdelning

HEC- HMS: Hydrologic Engineers Center - Hydrologic Modeling System

IPCC : Intergovernmental Panel on Climate Change

LULC : Land Use/Cover

MOW: Ministry of Water

MOWIE : Ministry of Water, Irrigation and Electricity

PET : Potential Evapotranspiration

PPM : Part Per Million

RCM : Regional Climate Model

RCP: Representative concentration Pathways

SDSM : Statistical Down Scaling Model

SMAR : Soil Moisture Accounting and Routing

SRES : Special Report on Emission Scenario

SUFI2: Sequential Uncertainty Fitting version 2

SURQ : Surface Runoff

SWAT- CUP: Soil and Water Assessment Tool- Calibration and Uncertainty prediction

SWAT: Soil and Water Assessment Tool

UTM : Universal Traverse Mercator

WB : Water Balance

WYLD: Water Yield

ABSTRACT

Andasa River Catchment is one of the tributary of Abay River located in Upper Blue Nile Basin. In the catchment climate change and land use impacts were not well studied and quantified yet. Hydrological modeling of catchments is essential for future water resource development programs to provide information for decision makers and planners. For hydrological model Simulation SWAT model was used after calibrating and validating the sensitive parameters of the catchment. The calibration, validation and uncertainty estimation were done by SWAT-CUP in particular by SUFI2 project. The model has very good performances to use for the catchment and further, the model is capable to simulate climate change impacts and land use scenarios. Following SWAT model setup, future climate change scenarios were developed for the catchment and their subsequent impact on the water balance were estimated. This study used HadCM3 GCM model from fourth assessment report of the IPCC under A2 (high) and B2 (low) emission scenarios and CanESM2 model from fifth assessment report of the IPCC under RCP4.5 and 8.5 representing the maximum and minimum condition of CO_2 *emissions. The coarse GCM resolution was down-scaled by Statistical Downscaling Model (SDSM). The model used to downscale the station level weather variables temperature (minimum and maximum) and rain fall called predictand with the coarse GCM predictors by the principle of multiple regression for the future till 2099 /2100. The future downscaled weather variables were divided into 3 periods; 2013-2042, 2043-2072, and 2073-2099. The change in temperature (˚C) and rain fall (%) is calculated for the three periods in comparison to the base period (1993-2012). The climate projection result indicated increasing monthly temperature and decreasing tendency of rain fall under all scenarios. However, all scenarios agreed in increasing temperature and decreasing rain fall trends in the three periods while averaged. The change in temperature (˚C) and rain fall (%) is introduced to SWAT to simulate the water balances. Based on SWAT model simulation significant reduction of stream flow was observed under almost all scenarios in all future periods. Moreover land use scenarios were developed for the base period (1991-2012) and for future period (2013-2042). Best case scenario (afforestation and conservation) were developed for the two periods. Agricultural land expansions considered as worst case scenario. And their respective hydrological simulation indicated that in best case scenario significant increase in infiltration was observed. Hence, it enhances base flow and maintains stable dry season flow in comparison to worst case scenario.*

Key words: Andasa Catchment, Stream Flow Estimation, Land Use/ Land Cover Scenario SWAT, SUFI2, GCM

1. INTRODUCTION

1.1. BACK GROUND and JUSTIFICATION

Nowadays water resources are a critical component for any type of socio economic development all over the world. Thus its availability and use has to be at the center of any discussion of development.

Water resources systems are a product of multiple interdependent components that produce multiple economic, environmental, ecological and social factors (Loucks *et al*., 2005). And the provisions of water resources are closely linked with the hydrological processes that mainly affected by climate and Land use/cover changes (Praskievicz and Chang, 2009). As a result, concerned bodies like planners and managers are working to figure out how a given water resource system behaves. Most hydrological studies are conducted at watershed level in the principle of water budget (based on input – outputs of water to a defined area). Because it is the basic unit that important part of the hydrologic cycle takes place. Therefore watershed concept provides a coherent, simplifying unit to analyzing and understanding the availability of water (Anisfeld, 2010) and also it enables to have better insight in the relationship land use activities and water quality processes occurring within the watershed (Im *et al*., 2003). According to the hydrological studies of the catchment, involves the computation of water balance of each hydrological response units (HRUs) through the interaction of climate, vegetation and soils to find out local water balance, which is rain fall minus evapo-transpiration resulting soil moisture (Mulligan, 2004).

Ethiopia has twelve river basins with the total mean annual surface flow from all river basins estimated to be 122 Billion Metric Cube (BMC) and the ground water potential is estimated to be 28 BMC (http://www.mowie.gov.et/ground-water-development-gwp-). This considered the country as the water tower of East Africa though it's not uniformly distributed in all part of the country.

Nile basin is one of the major Trans boundary river basins which includes the world's longest river Blue Nile (Abay), Baro- Akobo, Setit-Tekeze (Atbara) and Mereb rivers and covers 33% of the country. The upper part of the basin is mainly known by high demand of water for agriculture, industries, domestic use and hydropower (Ashenafi, 2013). In the sub basin, there is low level of water resource development when it is compared to its potential. It has 155 twh/year of hydropower potential and capable of irrigating 3.8 million hectares of land (Awulachew *et al*., 2007). Moreover, retarded rural development, lack of alternatives and high population growth initiates poor water and land management practices. This makes catchment modeling is very crucial to progress sound water resource development and management activities and has vital role in addressing a variety of water resources, environmental and social problems (Singh and Frevert, 2006). Such models with different levels of complexity are invaluable tools in the planning, design, operation and management of water resources. Hence, application of modeling studies in water management decisions is indeed increasing (Refsgaard *et al*., 2005).

SWAT is a comprehensive modeling tool that requires a diversity of input information to produce model output (Neitsch *et al.*, 2002). It considers water balance as the driving force throughout in the SWAT processes (Arnold *et al*., 2012) and for this motive, the entire land area of a given watershed divided into Hydrological Response Units (HRU) which has unique land use/management/ soil attributes (Neitsch *et al.,* 2002). Numerous peer review papers have been published (Scopus cited in Tue *et al.,* 2016) and people around the world using modeling result generated by SWAT and until 2012, more than 20 peer reviewed papers explained SWAT application for variety of problems particularly in the Upper Blue Nile Basin countries (Van Griensven *et al.*, 2012).

1.2. STATEMENT OF THE PROBLEM

Ethiopian highlands are familiar with soil erosion, sediment transport, deforestation and rapid population growth (Setegn *et al*., 2008). And all the above features are shared by Andasa River since it is one of the main tributaries of Blue Nile River located in north western Highlands of Ethiopia. Additionally, the River has significant contribution for the people residing in the basin as means of domestic and irrigation demand as well as contributes considerable flows to generate hydropower which is installed at Tis Abay Power II few kilometers the point at which Abay and Andasa rivers merg.

While the catchment has such environmental, social and economic significance, yet no research has been conducted in this river particularly in catchment modeling and on the impact of climate change. It is still hard to quantify land use, land management and further more climatic change impacts on the overall behavior of the catchment. Though obviously climate change known to happened and critically affects water resources availability, its effects has not yet predicted and quantified on the stream flow of the catchment. Moreover the extent of climate change and different land use impact remains unknown. In the absence of such studies at the catchment, it is very hard to think about the water resources development infrastructures. Therefore, this study was initiated to model impact of land use/cover and climate change on the hydrology of the river catchment.

1.3. OBJECTIVES

1.3.1. GENERAL OBJECTIVE

The main objective of this research was to model the impact of different land use/land cover and climate change on the hydrological behavior of Andasa river catchment by using SWAT model.

1.3.2. SPECIFIC OBJECTIVES

1. To evaluate performance of SWAT model for the study catchment in the period of 1991-2012.
2. To predict climate change scenario for temperature and rain fall at the catchment for the period 2013-2099.
3. To predict the impact of climate change on the river flow for the period 2013-2099.
4. To evaluate the impact of land use /land cover change on the water balance of the catchment for 1991-2012 and 2013-2043.

1.4. RESEARCH QUESTIONS

The study was guided by the following research questions.

1. How SUFI2 project under SWAT- CUP efficient for calibration and validation technique?

2. At what extent future climate change will alter the stream flow and the overall water balance of the catchment?
3. Which land use/cover highly affects the stream flow of the catchment?
4. How would temperature and rain fall changes under different climate change scenarios?

1.5. SIGNIFICANCE OF THE STUDY

Hydrologic research is indeed necessary as a decision support tool for the betterment of catchment management interventions to tackle existing soil and water conservation problems (Setegn *et al*., 2008).

Though catchment modeling plays fundamental role for every aspect of water related problems and management issues, no considerable modeling is done in this river catchment before. Except Eshetie (2015 unpublished) employed HBV- light, SMAR and HEC- HMS modeling tools to model extreme events of the river catchments and still gaps remains in determining different parameters in their level of sensitivity. It is necessary to use SWAT to look parameters in different ways than other tools used in previous studies. Therefore, this research has significant role to fill the gap in the area of catchment modeling as well as in serving as a sound decision support tool for future development activities in the river catchment.

1.6. SCOPE AND LIMITATION OF THE STUDY

The time period considered in the study was from 1961- 2099 whereas the spatial range of the study is Upper Blue Nile Basin in particular at Andasa River catchment which covers 576 km^2.

Land use/land cover were not Analyzed in different temporal scale rather different land use / land cover change scenarios were developed based on previous studies conducted in Upper Blue Nile Basin. This is considered as the limitation of the study.

2. LITRATURE REVIEW

2.1. CATCHMENT HYDROLOGY

An entire river basin area contributes surface run off flows into a common concentration point or measuring point is considered as hydrological units. Most often equivalently called catchment, drainage basin or watershed (Raghunath, 2006). Watershed is a fundamental concept for all hydrologic planning and design. Therefore, it is the level where all sound water resource management must be undertaken. It has a clear defined boundary with interlinked functional and morphological elements (Karamouz, 2003).

According to Sivapalan (2005) cited in Solomon (2012), the hydrologic response of different watersheds are varied due to the difference in watershed characteristics such as soil properties, geology, watershed size, local climate, topography, anthropogenic activity and vegetation cover. He also recommends that characterization of the hydrologic response of watershed is decisive where the impact of land use in flow regimes is not clearly defined.

2.1.1. DESCRIPTION OF HYDROLOGIC MODELS

Hydrologic phenomena are characterized by extreme complexities that may never be fully understood. Nevertheless, to certain extent of perfection may be represented in a simplified way by means of interconnected subcomponents which form the whole system (Chow *et al.*, 1988). Van Griensven *et al.* (2012) and Sorooshian *et al.*, (2008) cited in Devi *et al.* (2015) stated “Model is a simplified representation of real world system”. In this case the so called system is Hydrological System.

Loucks *et al.* (2005) stated that mathematical models are expressed in terms of algebraic equations include known and unknown variables. The formers are considered as parameters and the latter one as decision variables. Loucks *et al.* (2005) also in particular explained about simulation models that can be statistical or process oriented, or a mixture of both with both spatial and temporal dimensions.

Now a day, due to the advancement of computing technology, computers frequently employed to simulate various issues in many disciplines and the principal techniques of hydrological modeling make use of the two powerful advantages of computer technologies. Such as; its ability

1) To carry out numerous numbers of iterative computation and
2) To answer Yes or No specified queries. With such facilities, mathematical models are built up through logical programming that describes “the land phase hydrological cycle in space and time” (Shaw, 1994).

Stanford watershed model is a famous computer based model first produced by Crowford and Linsley in 1966 and it refined progressively and become very comprehensive model based on water budget principle (Mccuen, 1989; Raghunath, 2006).

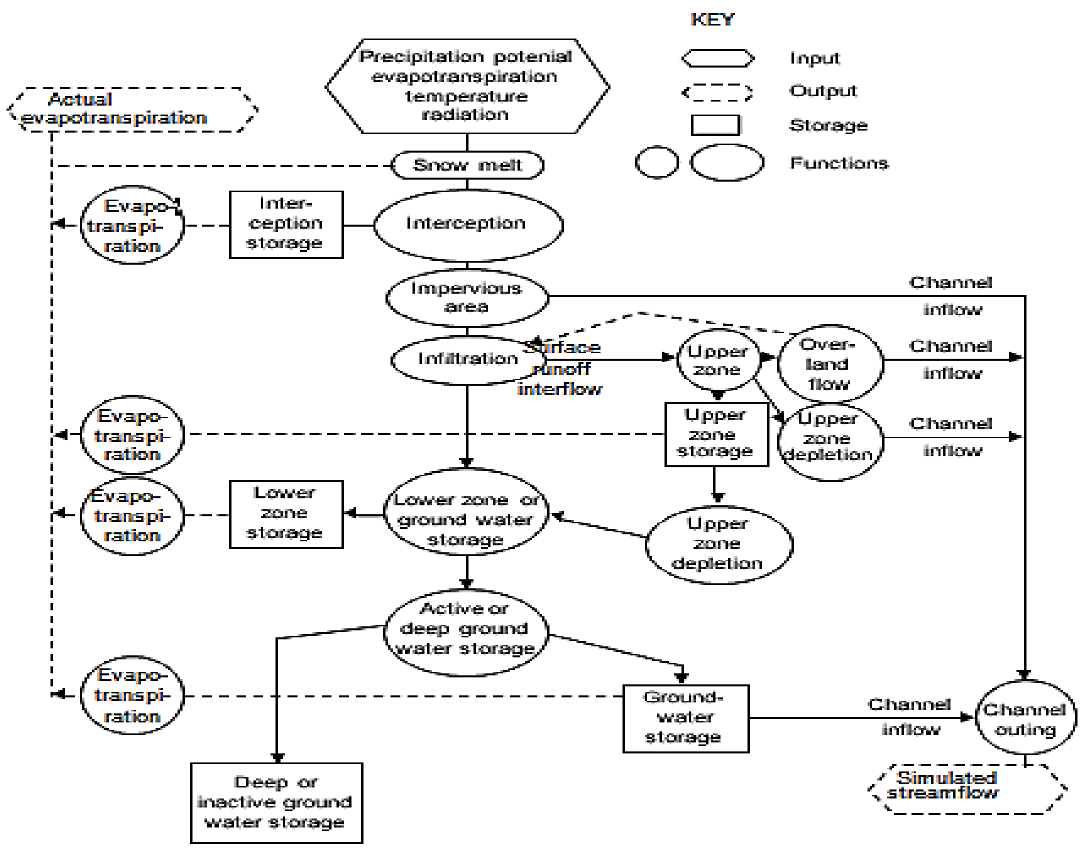


Figure 1: Flow diagram of Stanford watershed Model IV, ESMA **(**Mccuen, 1989; Raghunath, 2006)

According to Van Griensven *et al.* (2012), the ability that a model is representing the physical processes within a catchment cannot be accurately quantified. However there is a means of checking through hydrological mass balance if there should not be a trend of storage.

2.1.1.1. CLASIFICATION OF HYDROLOGICAL MODELS

Hydrological Models are broadly classified as either Theoretical; is based on physical principles or empirical models that simplify the physics and often include empirical component (Loucks *et al.*, 2005). According to Wheather *et* al. (1993) cited in Pechlivanidis *et al.* (2011) models can be classified based on structure, spatial distribution and spatial-temporal applications of model. For example the so called classification metric model has basic features of characterizing observations and responses of the system from the available data.

These models are based on empirical approach and more applicable for ungauged catchments (Pechlivanidis *et al*., 2011). On the other hand, such type of model doesn't take in to account "features and processes of hydrological system" and the relationship between input and output is established statistically based on regression and correlation functions. Devi *et al.* (2015) and Shaw (1994) gives illustrations that Hydrologic models classification based on nature and probability of occurrence of parameters as deterministic; seek to simulate the physical processes in the catchment involved in the transformation rain fall to stream flow, whereas stochastic models describe the hydrological time series of several measured variables such as rain fall, evapotranspiration and stream flow involving distributions in probability. Chow *et al.* (1988) quoted in a very descriptive way as "deterministic models makes for casts while stochastic models makes predictions". In most cases, combinations of deterministic and stochastic approaches are successful in providing better information (Devi *et al.*, 2015).

According to Chow *et al.* (1988) explains the basic questions to be asked to decide the type of model are;

1) Will the model variables be random or not?
2) Will the variables vary or uniform with respect to space? and
3) Will the variables vary or constant with time scale? So that, further illustration is given in the Figure 2 shown below.

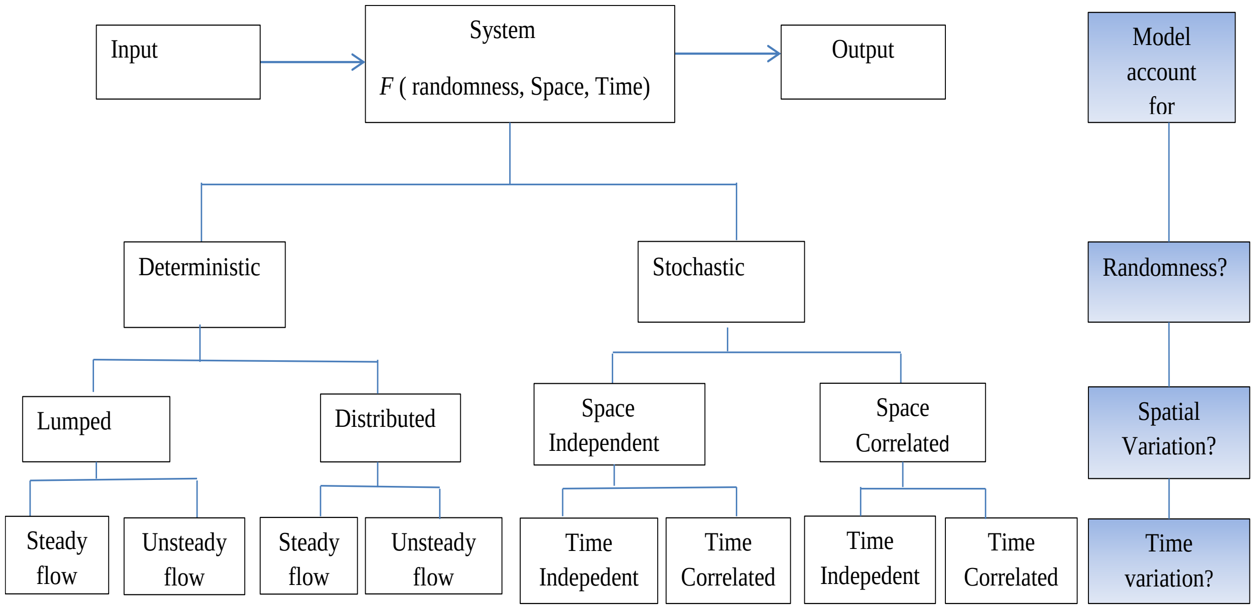


Figure 2: Classification of hydrological models **(** Adopted from Chow *et al*., 1988, p-11**)**

Chow *et al*. (1988) also recommends that professional judgments should be made to practically use models by examining the nature of variables whether random variation is large or not. For example, in areas where the resulting variability in the output may be very small in contrast to the resulting originating from known variables. In such cases deterministic model is more appropriate. In other way, when random variation is dominating, stochastic models are preferred.

Three water balances are considered in most continuous watershed models; namely, one is surface water, the other for unsaturated zone moisture content and for ground water (Loucks *et al.*, 2005).

2.2. EVALUATION OF MODEL PERFORMANCE AND UNCERTAINITIES

Uncertainties may originate from various sources: from Data, model parameters and model structure. Focusing on a single source of uncertainty may produce wrong model output. Therefore, it is recommended to consider all sources of errors in comprehensive, explicit and cohesive way to have reliable prediction by reducing bias and uncertainty (Pechlivanidis *et al*., 2011).

During representation of processes of a system in a model, imperfect representation may occur that leads to model structural uncertainties. In other way, misunderstanding of parametric values of a system constitutes model parameter uncertainties and both this type of uncertainties cumulatively called knowledge uncertainty (UNESCO, 2005).

Based on Liu and Gupta (2007), three aspects should be considered to address uncertainties related to hydrological models properly. Thus: understanding, quantification and reduction of uncertainty and to address such aspects, considerable research effort have been made towards strongly constructed uncertainty frameworks (Pechlivanidis *et al*., 2011) and Generalized Likelihood Uncertainty Estimation (GLUE) is part of this framework.

Sometimes most of hydrologic models is unable to simulate the real hydrological characteristics of agricultural watersheds efficiently due to high management interventions the natural characteristics of the catchment are subjected to modification (Ficklin and Zhang, 2013).

Praskievicz and Chang (2009) noted that in climate impact assessment uncertainties originated from four different aspects. These are, due to choice of General Circulation Models (GCM), due to downscaling large scale climatology in to regional scale climatology, parameters and structures of hydrological model used for impact assessment and finally from the employed model itself.

SWAT input parameters are process based and must be held in the range of realistic uncertainty (Arnold *et al*., 2012). Therefore to achieve this, Arnold *et al*. (2012) also stated that determination of sensitive parameters of a given watershed and sub watershed must be the first step prior to calibration and validation processes.

In general, watershed models are subjected to various uncertainties, due to conceptual/ structural uncertainty, input uncertainty and parameter uncertainty. Conceptual model uncertainties on the other hand may occur due to simplification in the conceptual model, due to process occurring in the catchment but neglected in the model and /or rather due to process included while its occurrences in the system are unknown. In addition to conceptual uncertainties, error input data also rises level of uncertainties coupled with other source of uncertainties (Abbaspour, 2015).

Krause *et al.* (2005) list out why hydrologists seek to evaluate model performance and elaborate in to three reasons as follows:

1) To quantify the modeling capacity of a model to reproduce historic and future watershed behavior.
2) To figure out means of further improvement of the modeling approach by further adjustment of model parameter values, inclusion of additional observational information and representation of important spatial and temporal characteristics of watershed.
3) For comparisons of current modeling efforts with previous study results.

Golmohammadi *et al.* (2014) concluded by describing different model outputs for catchment areas in different geographical location that model performance is site specific and no model is taking all advantages in all aspects.

2.3. REVIEW ABOUT SOIL AND WATER ASSESSMENT TOOL (SWAT)

Soil and Water Assessment Tool (SWAT) is considered as appropriate tool for process-based models at watershed scale studies (Arnold *et al*., 1999). It is a comprehensive, semi-distributed river basin model that requires a large number of input parameters, which complicates model parameterization and calibration. It was developed to evaluate the effects of alternative management decisions on water resources and nonpoint-source pollution in large river basins (Arnold *et al*., 2012).

Based on Devi *et al.* (2015) descriptions, SWAT divides a catchment which has heterogeneous nature in to sub catchment and further to small spatial disaggregation so called Hydrological Response Unit (HRU). HRU is defined as a unit area with uniform land use and soil type regardless of their actual spatial position within the sub catchment (Nasr *et al*., 2004).

Due to minimal input data requirement mostly rain fall and potential evapotranspiration that are available, water balance models are appropriate. However, Easton *et al*. (2008) stated that the modified version of SWAT is better to model correctly.

In order to obtain accurate forecasting of water, nutrient and sediment circulation, it is necessary to simulate hydrologic cycle which integrates overall water circulation in the catchment area and thus, The SWAT modeling tool apply the following water balance equation in the catchment area.

$$SWt = SW0 + Rv - QS - Wseepage - ET - QGW \quad \text{------------------------} \ (1)$$

Where SW_t is the humidity of soil, SW_o is base humidity, R_v is rainfall volume in mm water, Q_s is the surface runoff, $W_{seepage}$ is seepage of water from soil to underlying layers, ET is evapotranspiration, Q_{gw} is ground water runoff and t is time in days). Penman- Monteith, Priestly-Taylor and Hargreaves methods are used for the estimation of evapotranspiration.

As Aston and Dunin (1979); Mullim (1991) and Jemes et al. (1992) cited in Yu (1999), the Green – Ampt infiltration method has been more applicable for small agricultural watersheds and Mullim (1989) also stated that Green –Ampt model predicting runoff volume better than Curve number model for rangeland and cropland areas ranges up to 54 square miles. However, Ficklin and Zhang (2013), in their study conducted at agricultural dominated San Joaquin River watershed, investigated that Curve number method is better than Green – Ampt model for accurate simulation of daily stream flow. For monthly stream flow simulation, both models show similar NSE values. They also noted Green – Ampt model is very good for the prediction of Peak surface flow.

As King *et al.* (1999) cited in Saleh and Du (2004) concluded that no significance advantage is gained by using either Green- Ampt or CN method. So that Surface runoff is estimated by using a modified version of the soil conservation service (SCS) Curve Number (CN) methods and it is a factor of soil permeability, Land Use and antecedent moisture condition. Surface Runoff computed in Curve number (CN) method as follows.

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

$$S = 25.4[\frac{1000}{CN} - 10]) \text{--} (3)$$

Substituting $Ia = 0.2S$ for equation (2) gives,

$$Qsurf = \frac{(Rday - 0.2S)^2}{(Rday + 0.8S)} \text{--} (4)$$

Where, Qsurf is surface runoff or rainfall excess (mm H_2O), Rday is rainfall depth for the day (mm H_2O), Ia is Intial abstraction including surface storage, Interception and Infiltration before runoff begins (mm H_2O) and S is retention parameter of the soil.

For different Antecedent Moisture Content of a soil for slope less than 5% (dry, Average and wet), Curve Number can be calculated as follows.

$$\mathbf{CN1 = CN2} - \frac{20*(100 - CN2)}{(100 - CN2 + \exp[2.533 - 0.0636*(100 - CN2)])} \text{--------------------} (5)$$

$$\mathbf{CN3 = CN2 * \exp[0.00673 * (100 - CN2)]} \text{--------------------------} (6)$$

Where CN1is the moisture condition I Curve Number (dry/wilting Point), CN2 is the Moisture condition II Curve Number (Average Moisture) and CN3 is the moisture Condition III Curve Number (Wet/ Field Capacity). For terrians greater than 5% slope, adjustment will be done by the Equation 7;

$$\mathbf{CN2}s = \frac{(CN3 - CN2)}{3} * [1 - 2 * \exp(-13.86 * slp)] + CN2 \text{----------------} (7)$$

Where CN2s the moisture content II Curve number adjusted for slope, CN2& CN3 moisture content 2& 3 Curve Number for the defualt 5% slope. Slp is the avearge slope in percent of the subbasin.

2.3.1. PREVIOUS SWAT MODELING EXPERIENCE

SWAT needs daily climate input data such as daily rain fall and maximum and minimum air temperature and they are subjected to variability in space and time. Despite of its spatial and temporal variability, rain fall is a major driver of hydrological process. Therefore, physical based hydrological models like SWAT may not generate accurate results in the absence of proper representation of temporal and physical variability of rain fall in the input data and its impacts on accuracy is magnified in areas of large and heterogeneous complex watersheds with sparse and heterogeneous spatial distribution of rain gauges (Tue *et al.*, 2016). So as to consider such spatial effects of rain fall, different methods of processing rain fall data towards accurate results should be taken into account.

Tue *et al.* (2016) investigated that IDW (Inverse Distance Weighted) based interpolated input rain fall data is better in terms of model performance and prediction of uncertainty.

SWAT simulate runoff by two different assumptions; one is by using Curve Number(CN) the so called SWAT-CN assuming that runoff generated from infiltration excess process where as the other one is SWAT WB generate runoff from saturation excess phenomena (Van Griensven *et al.*, 2012). Tewodros and Birhanu (2012 unpublished) in their study at Mizewa watershed, SWAT-CN approaches takes advantage in prediction over SWAT-WB. They reason out that the soil group of the catchment categorized as soil group C and D characterized by low infiltration potential. On the other hand, the study White *et al.* (2009) conducted in Upper Blue Nile Sub basin in particular at Gumara in Ethiopia and the other one Catskill mountains of New York state, investigated that the Gumara catchment shows significant stream flow prediction that was simulated in the concept of saturation excess (SWAT- WB) than stream flow simulated in terms of infiltration excess (SWAT- CN). The study justifies this result as because of the area is characterized by monsoonal climate.

The result of the above two studies gives different results while the study areas are part of upper Blue Nile Sub Basin, these may be because of the ground water availability of the catchment areas.

2.4. CALIBRATION AND VALIDATION OF HYDROLOGICAL MODELS

Model calibration is a process by which general model is adjusted to enable better representation of site specific hydrologic process and conditions (Daggupati *et al*., 2015). Comparison between simulated model output variables with measured variables is undertaken for the sake of calibration and validation (Arnold *et al*., 2012).

Prior to calibration the first few time periods employed as warm up period to facilitate the important model variables to come in to dynamic equilibrium. However no comprehensive guide line that states the length of warm up period. It is recommended to use two up to three years for hydrological process and five up to ten years for sediment and nutrient related process as warm up period as (personal communication, 2014 cited in Daggupati *et al*., 2015).

Pechlivanidis *et al*. (2011) stated calibration is critical part in modeling process in particular hydrological modeling, because it is practically impossible to measure all hydrological parameters of a system. Furthermore, since hydrological models are subjected to uncertainty at large, calibration is crucial (Abbaspour, 2015)

Beven and Binley (1992) cited in Pechlivanidis *et al.* (2011) GLUE first introduced for over parameterized models to equifinality of parameter sets. It assumes there are no unique sets of parameters which capable to optimizes goodness of fit criteria.

Calibration process should be done either manual or/and automatic but most often practically applied in combined for the better results**.** Van Liew (2005) cited in Daggupati *et al*. (2015) recommends manual adjustments following an automatic calibration may be necessary to keep overall mass balance and adequate representation of the system.

The measured data originated from records of multiple outlets, or single outlet or from other resembled catchments by transforming can be employed for the purpose of calibration and validation (Tewodros and Birhanu, 2012). Daggupati *et al*. (2015) investigated that outlet calibration performed well for very homogenous catchments and for agriculture dominating land use but hardly possible for watersheds characterized by greater variations in topography and land use.

According to Abbaspour *et al*. (2015) a model said to be calibrated when; the 95% Prediction of Uncertainty (PPU) between 2.5% th and 97.5% th percentiles composed of more than x% of the measured data and the difference between 2.5% th and 97.5% th predictions of percentiles is less than the standard deviation of the measured data.

2.5. EFFECTS OF LAND USE/ LAND COVER ON THE HYDROLOGY

Land cover is "the observed physical and biological cover of the earth's land, as vegetation or man-made features." In contrast, land use is "the total of arrangements, activities, and inputs that people undertake in a certain land cover type" (https://en.wikipedia.org/wiki/Land_use).

Due to land use and management aspects, the amount of rain fall that reaches the river channel shows certain variation between almost 100 % to a little 5% reductions. Therefore changes in management practice or land use like urbanization, ploughing, afforestation, deforestation so and so forth can change the hydrological characteristics of a catchment (Holden, 2004).

According to IPCC (2014) human induced land use/cover changes can change evapotranspiration, surface roughness, surface albedo and further affects latent heat flux that cumulatively influence hydrological cycle.

Tekleab *et al.* (2014) noted that a land intensively used for agriculture preclude the infiltration process because of the plough pan effect. Hence it causes the alteration of hydrological systems which is characterized by increased surface run off, reduced base flow and enhanced peak flow.

Generally rapid socio-economic development initiates land use/cover changes. Hence, land use/cover changes causes water scarcity in areas where water availability is limited and further aggravates social problems in their living conditions (Wagner *et al*., 2013)

2.6. CLIMATE CHANGE IMPACTS ON THE HYDROLOGY

Birsan *et al*. (2005) cited in Sirak (2015) noted that human induced climate change coupled with changes in physiographic characteristics of the catchments could alter the stream flow.

The Global Climate Model (GCM) suggests the increasing of greenhouse concentration and it in turns to cause changes at global and regional levels (Wilby and Dawson, 2007). Total anthropogenic Green House Gases (GHG) emissions have risen more rapidly from 2000 to 2010 in comparison to the past three decades and it was considered as the highest emissions in human history that reached 49 gigatones of CO2- equivalents/year (IPCC, 2014). On the other hand, Trenberth *et al.* (2000) stated that due to doubling CO_2 emission, the hydrological cycle is speed up by 10% and it brings increased evaporation and rainfall globally.

GCM developed to simulate present climate and predict future climate change. On the other hand hydrological model establish a frame work to understand and investigate the relationship between climate and water resources (Xu, 1999). The GCM attempts to incorporates the atmospheric circulation, oceanic circulation, land surface process, sea ice and other processes of biogeochemical cycles (Trenberth *et al.*, 2000)

To quantify key factors of human development impact on GHG emissions and their mitigation responses, scenarios are developed that depend on plausible futures (IPCC, 2014).

Solomon (2012) stated that due to climate change 2/3 of world population become more vulnerable to availability and use of water. More particularly, it will cause significant impact on the hydrological system of arid and semiarid Africa where water resource occurrence sensitively affected by climate variability, especially due to rain fall. Solomon (2016) also describes Impact of climate change in Ethiopia Rivers and lakes diminish in size and small streams are dry up in a country considered as water tower of East Africa.

2.6.1. GCM AND DOWNSCALING

General circulation model (GCM) sometimes referred as Global Climate Model used to represent the behavior of atmosphere by integrating multiple physical, chemical and also biological governing laws and it is produced from atmospheric and ocean GCMS (http://weather.unl.edu/RCM/IDB_Mexico/PDF/gcm.pdf). Atmospheric General Circulation Models are the core part of a GCM that frequently used for weather projections at daily bases and it is capable to simulate various processes of the atmosphere by representing in fundamental equations on spherically spatial grids (Lupo and Kininmonth, 2014).

As http://www.pbl.nl/en/publications/2011/special-issue-rcps-climatic-change "Scenarios are designed to allow researchers to explore the long- term consequences of decisions made today, while taking account of the inertia in both the socio- economic and physical System".

Previously climate change scenarios were developed based on considering prescribed levels of emissions to the atmosphere. This is called Special Report on Emissions Scenario in short SRES. SRES characterizes development into four story lines; namely, social, economic, demographic and technological changes and these all symbolized by six families of scenarios that were discussed in the third and fourth IPCC's assessment report. These are A1F1, A1B, A1T, A2, B1 and B2. Their few distinctive features with respect to four story lines are described below.

A1 scenario characterized by;

- Rapid economic growth
- A global population that reaches 9 billion in 2050 and then gradually declines.
- The quick spread of new and efficient technologies.
- A convergent world manifested by income and way of life converge between regions and extensive social and cultural interactions over the globe. A1F1, A1B and A1T are the subset of this scenario.

- A2 scenario elaborated by independently operating, self-reliant nations with continuously increasing population and the other feature of this scenario is regionally oriented economic development.
- A more integrated world with more ecologically friendly systems is the features of B1 scenario. It further manifested by the introduction of clean and efficient technologies as well as more emphasis on global solutions to economic, social and environmental stability.

- B2 scenario characterized by continuously increasing population with a slower rate than in A2. More focus is given on local rather than global solutions to economic, social and environmental stability. And also an intermediate levels of economic development and less rapid and more fragmented technological change than in A1 and B1 are the additional features (https://en.wikipedia.org/wiki/Radiative_forcing).

There are also four RCP Scenarios; RCP8.5, RCP6, RCP4.5, and RCP2.6 (sometimes referred as RCP3 PD to refer Peak and Decline). The numbers stands for radiative forcing (global energy imbalances) measured in watts per square meter, by the year 2100. Forcing, Emission rates and emission concentration are the key metrics of the RCPs (www.theguardian.com). Radiative forcing is defined as "the difference of insolation (sunlight) absorbed by the earth and energy radiated back to space" and caused by due to "changes in insolation and the concentration of radiatively active gases such as greenhouse gases and aerosols" (https://en.wikipedia.org/wiki/Radiative_forcing).

Since SRES run scenarios sequentially, it is less flexible to incorporate newly emerging changes like new observations and advancements (Mosses *et al.*, 2008 cited in Kristvik and Riisness, 2015). This was exposed for more uncertainty due to the future changes of factors contributing for emissions may not go as it was predefined. To minimize uncertainties originating due to factors, the IPCC come up with new thinking of climate change scenario called Representative Concentration Pathways (RCP) during Assessment Report 5 (AR5) (https://militantmoments.wordpress.com/2015/02/10/rcps-vs-sres-scenarios/). SRES followed sequential approach in the process of climate change scenario whereas RCP is done based on parallel approach.

Different RCPs take under considerations the impact of atmospheric concentrations of CO_2 and other greenhouse gases and aerosols for the period of 1850 to 2100 (Australia climate change Science Program).

Table 1: SRES and RCP Scenarios

Scenarios		CO_2 Equivalent (PPM)	When?
SRES	A1F	1550	By 2100, but rising
	A1B	850	Stabilization after 2100
	B2	800	Stabilization after 2100
	B1	600	Stabilization after 2100
RCP	8.5	1370	By 2100, but rising
	6	850	Stabilization after 2100
	4.5	650	Stabilization after 2100
	2.6	490	Peak before 2100 then decline

Source: Australia climate change Science Program, 2017

Downscaling is a term used to describe the process of relating data from the coarse spatial and temporal scale to data at finer spatial and temporal scale. It's mainly to simulated monthly rain fall and temperature at about 200 km resolution to finer spatial entity, may be regional or catchment level (Hamlet *et al*., 2010).

There are two approaches of down scaling the course resolution GCM into finer spatial and temporal resolution: dynamic and statistical downscaling.

Dynamic downscaling method uses Regional Climate Model (RCM) nested with in GCM that modeled the physical dynamics of atmosphere with a resolution of 20 to 50 km. It follows computationally complex and data intensive processes whereas statistical downscaling establish relationship between large and regional scale climate information based on the assumption that the relationship between present large and local-scale processes will remain the same in the future. It takes more advantages over dynamic downscaling where low cost, rapid assessments of localized climate change impacts are required. However it requires sufficient amount of historical climate data for establishing relationships (Wilby and Dawson, 2007). Lijalem (2006) used statistical downscaling method to downscale HADCM3 GCM to study future climate change impact on the water availability of lake Ziway, Ethiopia. Michael (2012) and Netsanet (2013) also used in the study conducted Upper Blue Nile basin to down scale future weather variables in to basin level.

3. MATERIALS AND METHODS

3.1. DESCRIPTION OF THE STUDY AREA

Andasa River catchment is found in Amhara region, West Gojam administrative zone, shared by Mecha, Adet and Bahir Dar zuria woredas. The catchment geographically located in 11^0 09 ' N- 11^0 33 ' N latitude and 37^0 16 ' E- 37^0 28 ' E Longitude with an altitude ranges from 1701 – 3210 meters above sea level (asl). It is one of main tributaries of Abay River in the right bank. The catchment covers an area of 576 km ^{2} at the gauging station. The stream flow gauge station is located at 11.52^0 N latitude and 37.47^0 E longitude. The mean annual rainfall and mean annual flow of the catchment area is 1369.6 mm and 520.3 mm respectively.

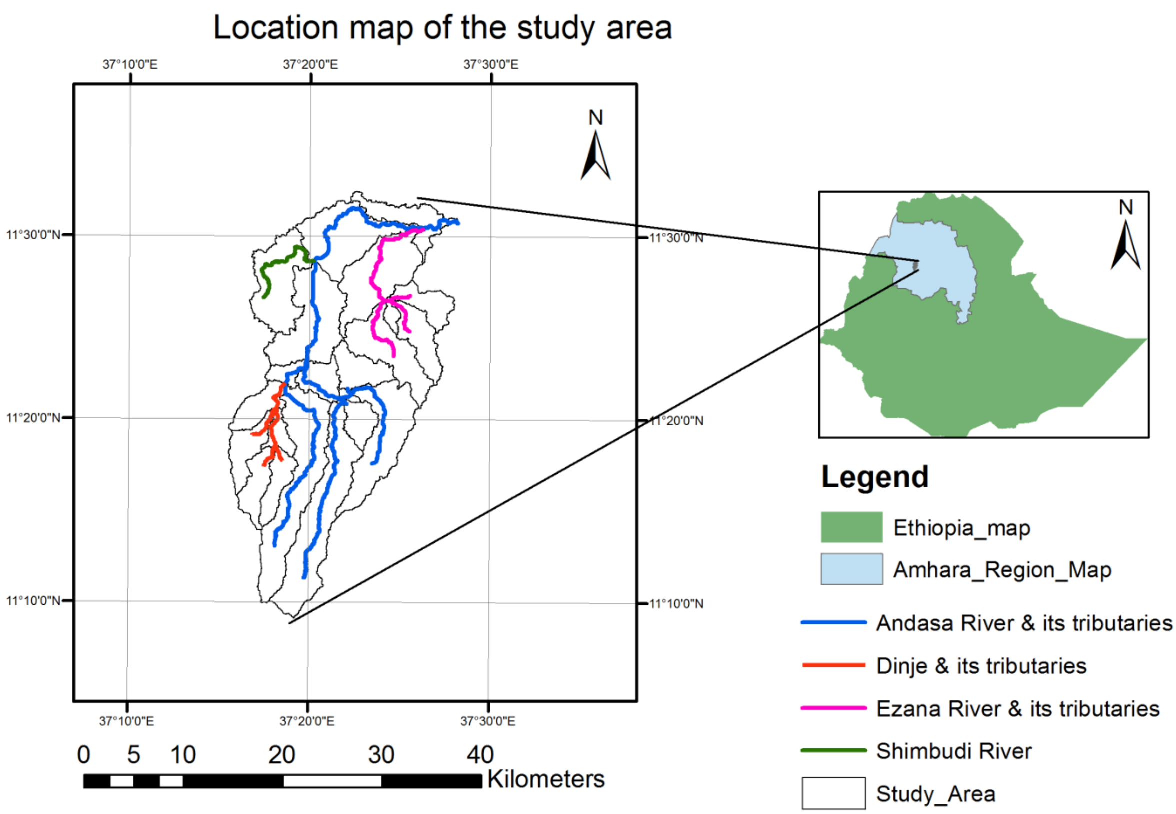


Figure 3: Map of the study area (Author, 2017)

3.1.1. LAND USE/COVER

Based on the map produced by Ministry of Water, Irrigation and Electricity in 1988, the catchment has four types of LULCs. Namely; agriculture, agro-pasture, agro-silvcultural and pastoral land uses. However the land use classification done by this study by using February

2013 satellite image shows that subsistence rain fed agriculture dominating the catchment. Figure 8 shows the land use classification at the end of 2012. Based on personal communication with local elders by Amhara Design and Supervision Works Authority (ADSWA), (2012), few decades ago the catchment predominantly covered with forests. Descriptions are given in Table 2 about the land use shown in the Figure 4.

Table 2: Land use/cover of the catchment and descriptions

LU/LC	**SWAT Code**	**Description**	**Area coverage (km^2)**	**% coverage**
Cultivated land	AGRL	Area temporary covered by crops	258.12	45
Grazing land	PAST	Land covered by grass or herbage and grazed by or suitable for grazing	6.41	1.11
Mixed Forest	FOMI	A forest consisting two or more types of trees including plantation forest	108.86	19
Cropland-Wood land mosaic	CRWO	A composition of cultivated land with woody plants- a continuous stand of a single storey trees with a crown density of between 20–80%.	203.35	34.99

(Source: Ermias *et al.,* 2013; Moges *et al*., 2015; Neitsch *et al.,* 2009)

The supervised LULC was classified based on maximum likelihood whereas the reference data were collected by random sampling.

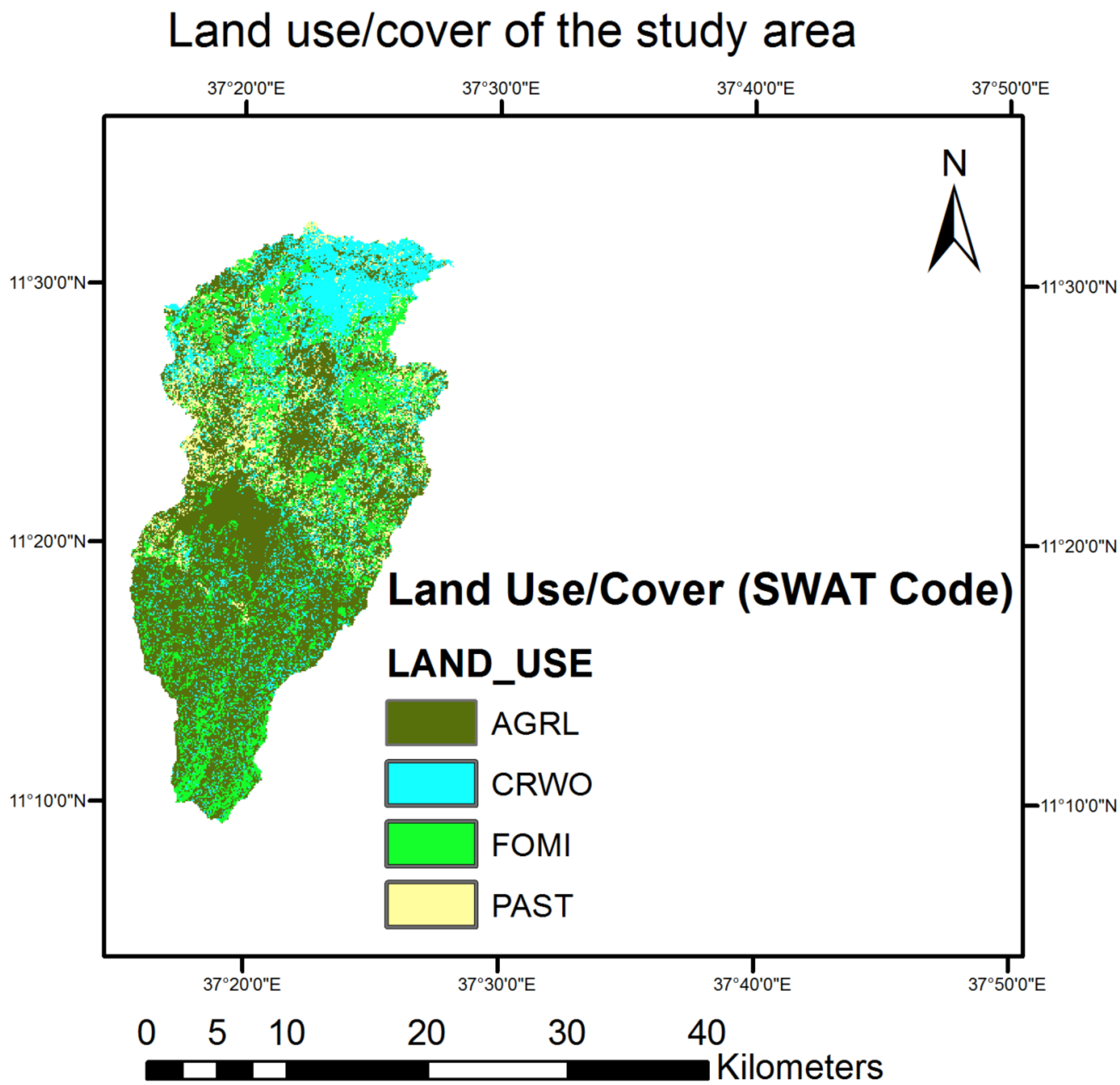


Figure 4: Land use/cover map of the Andasa catchment (Author, 2017)

3.1.2. SOIL

FAO (1997) Soil and terrain classification grouped the study area soil into six mapping unit with 4 dominant soil groups in the top layer.

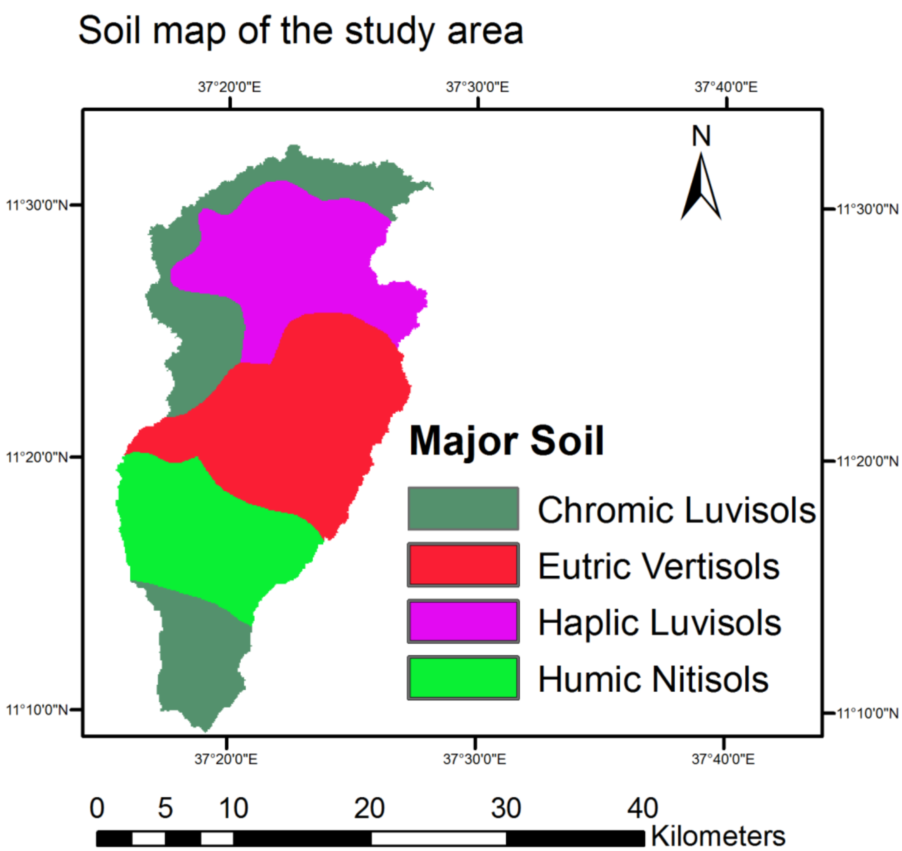


Figure 5: Major soil type of the study area (FAO, 1997)

Table 3: Major soils of study area based on FAO class (FAO, 1997)

S/No.	Soil mapping unit	Major Soil type	Dominant Texture	Coverage (%)
1	LVh.or9-4df	Haplic Luvisols	Clay loam	23.34
2	LVx.or30-4bc	Chromic Luvisols	Clay loam	15.08
3	LVx.or38-5de	Chromic Luvisols	Clay	12.04
3	NTu.mo11-5d	Humic Nitisols	Clay	18.62
5	VRe.rh1-5a	Eutric Vertisols	Clay	16.71
6	VRe.pe13-5ac	Eutric Vertisols	Clay	14.2

3.1.3. GEOLOGY

According to the data obtained from Ministry of Water, Irrigation and Electricity, the study area comprises different underlying Geologic formations. As it shown in Figure 6, the Geologic formations are known as alluvium, Ashangi Basalts, Tarmaber Basalts and volcanic origin basalt rocks are distributed. Moreover in the feasibility study made by Amhara Design and Supervision Works Authority (ADSWA) (2012) the dominant parent material of the catchment is basalt.

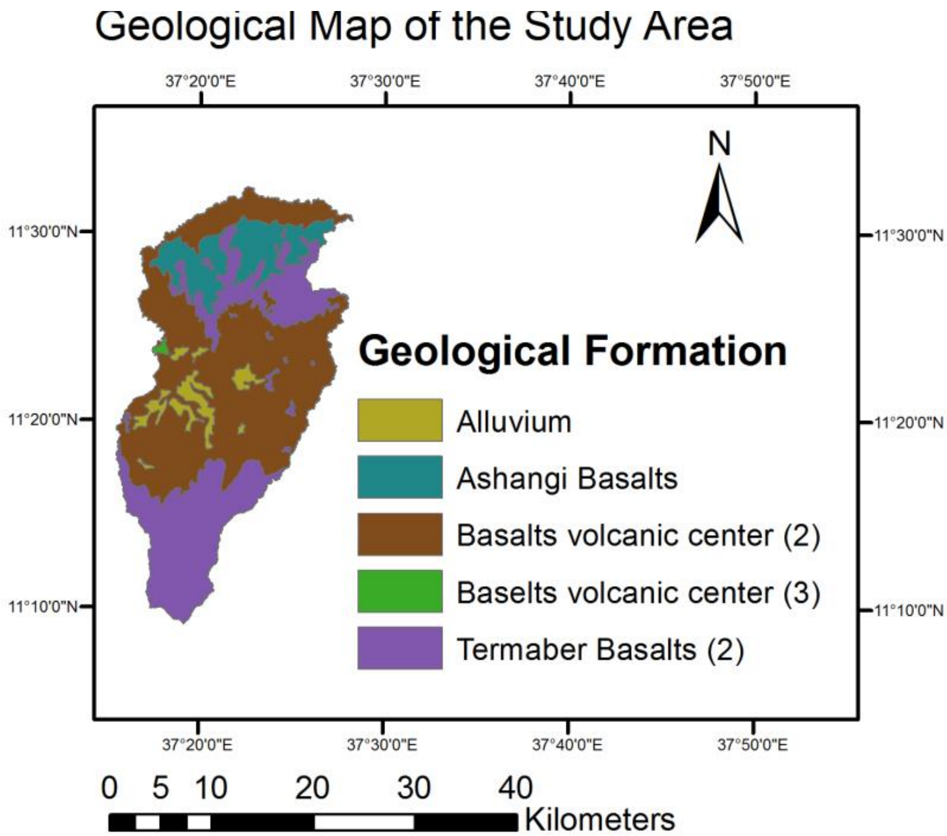


Figure 6: Geological Map of the Study Area (MOWIE, 2000)

3.2. MATERIALS

To achieve the stated objectives, the following materials and application software packages were used.

- GPS was used to collect and locate ground truth sample points.

- Digital camera was used to take descriptive photos in the study area. The application software used throughout this research is illustrated in Table 4.

Table 4: Lists of application software and tools used for the study

Application software	Purpose(application Area)
ARCSWAT 10.1	For hydrological modeling and climate change projection
ARCMAP 10.1	To interface ARCSWAT 10.1, for delineating watershed and to prepare maps.
ERDAS IMAGIN 9.1	Land use/cover classification
SDSM 4.2	To downscale the GCM (HadCM3 & CanESM2) to catchment level
Weather generator Excel macro	To prepare weather generator database
Soil excel macro	To determine physical and chemical parameters of soil in the principle of pedo-transfer function.
Base flow separator	to separate base flow from surface flow from the total stream flow
Dew point calculator	To compute dew point temperature from relative humidity, maximum and minimum temperature
XLSTAT	To test trends of time series data
Other tools used	
Google earth	To facilitate land use classification
Harmonized World Soil Database	For soil type identification and to aid soil input data preparation

3.3. METHODS

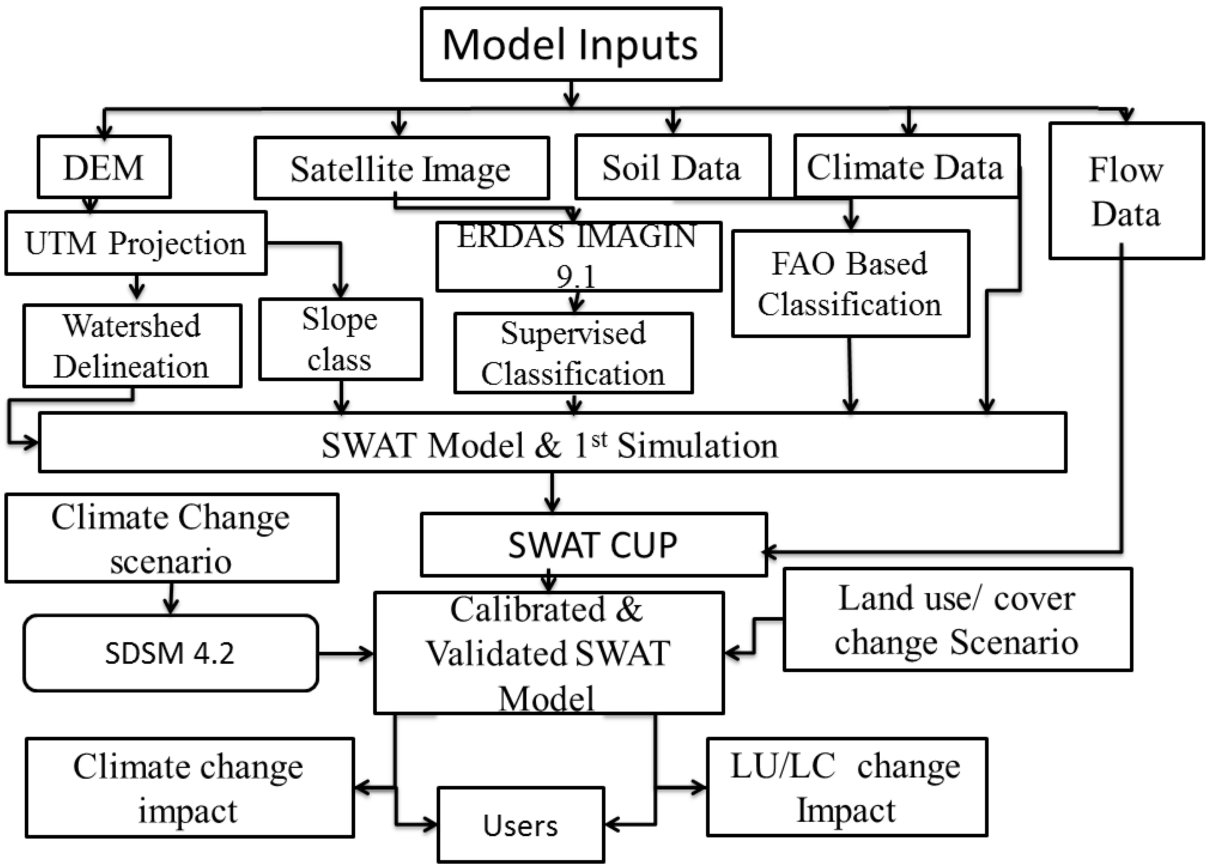


Figure 7: Methodological flow chart of the research (Author, 2017)

3.3.1. DATA COLLECTION AND PREPARATION

For a better modeling effort, all hydrologic system components of the catchment should be critically considered and necessary input data was collected. The following input data were collected from different authorities.

3.3.1.1. METEOROLOGICAL DATA

Daily climatic variables such as rain fall, relative humidity, wind speed, sunshine hours, maximum and minimum temperatures were obtained from the National Meteorological Agency, Addis Ababa. The study used meteorological data of four stations located in and around the study area. (See Table 5).

Table 5: Name of meteorological stations and their respective records

No	Station Name	Location			Meteorological Data						Remarks
		Lat (˚)	Long (˚)	Alt (m)	Rainfall	T Max	T min	RH	Wind Speed	Sun shine hours	
1	Bahir Dar	11.59	37.41	1770	✓	✓	✓	✓	✓	✓	1st class
2	Adet	11.27	37.49	2179	✓	✓	✓	✓	✓	✓	1st class
3	Merawi	11.41	37.16	2000	✓	✓	✓				
4	Meshenti	37.28	11.47	1958	✓						

The spatial distributions of meteorological stations are shown in Figure 8. Stations are located in different districts that shares Andasa catchment in different portions. Bahir Dar station located in Bahir Dar city, Meshenti in Bahir Dar Zuria district and the rest Merawi and Adet stations found in Mecha and Yilmana- Densa districts respectively.

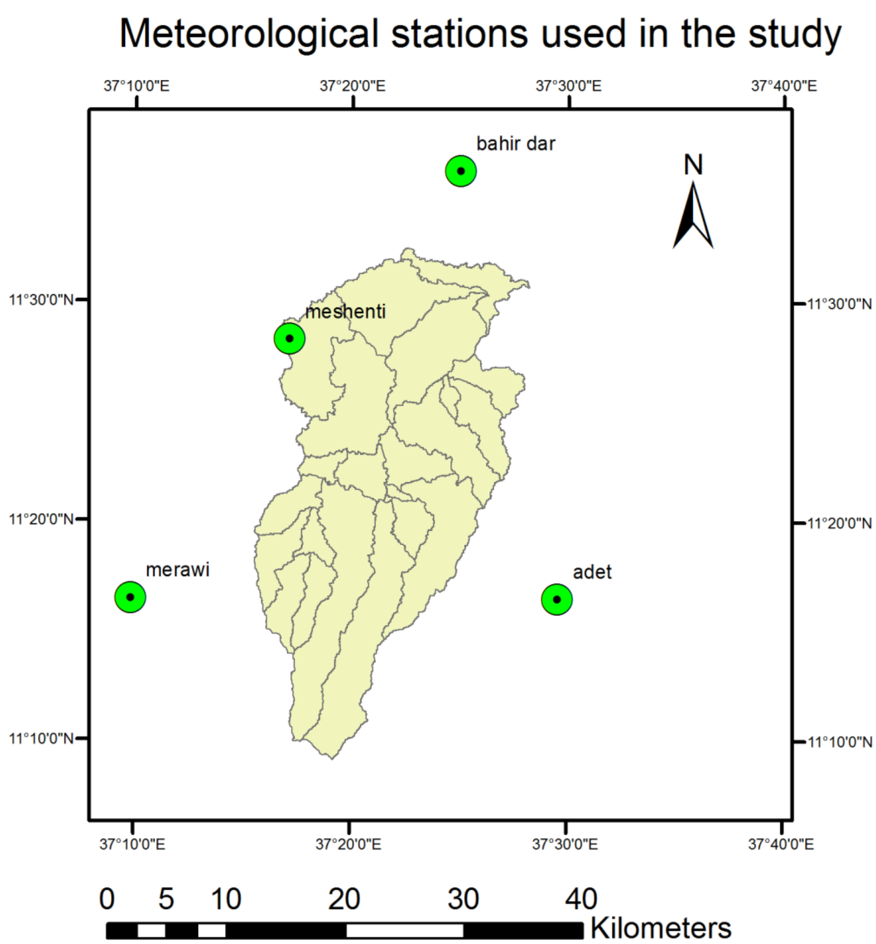


Figure 8: Location of meteorological station (Author, 2017)

Bahir Dar meteorological station was assigned as weather generator stations. Bahir Dar station has all meteorological data except solar radiation that SWAT model requires as input. This station also has minimum missing climate records for other input data. Though most of SWAT input meteorological data are directly measured at the stations, solar radiation was not available and the station also has relative humidity long time missing. SWAT proposes a mechanism to manage missing data by filling -99 (Winchell *et al*, 2013).

Therefore, solar radiation (Rs) is indirectly calculated using the Angosterm equation as follows.

$Rs = a_s + b_s\,(n/N)\,Ra$-- (8)

Where, Rs solar or short wave radiation (MJ $m^{-2}\,day^{-1}$)

a_s = Regression constant expressing the fraction of extraterrestrial radiation reaching the earth on forecast days (n=0). Mostly a_s =0.25 recommended

b_s = extraterrestrial radiation reaching the earth on clear days (n=N), b_s =0.5

n, actual duration of sunshine (hours)

N, Maximum possible duration of sunshine/ daylight hours (hour)

n/N, relative sunshine duration

R_a , Extraterrestrial radiation (MJ $m^{-2}\,day^{-1}$) and ;

$Ra = \frac{24(60)}{\pi}\ \mathbf{Gsc\ dr}\ [\omega s\ \sin(\varphi)\ \sin(\delta) + \cos(\varphi)\ \cos(\delta)\sin(\omega s)] ----$ (9)

Where Ra -Extraterrestrial radiation (MJ $m^{-2}\,day^{-1}$

Gsc solar constant =0.0820 MJ $m^{-2}\,mm^{-1}$

dr   inverse relative distance earth − sun

ωs sunset hour angle (rad)

φ $latitude\ (rad)$

δ $solar\ declination\ (rad)$

Radians can be calculated as $\boldsymbol{radians = \frac{\pi}{180}\ (decimal\ degree)}$ -------------- (10)

To minimize missing records of relative humidity (RH), it is calculated from the equation;

$RH = (e_a / e_s) x100$ -- (11)

$e_s = [e^0\ (Tmax) + e^0\ (Tmin)]/2$ ---(12)

$e^0\ Tmax = 6.11\ exp[(17.27*Tmax)/(237.3+Tmax)]$, --------------------------------- (13)

$e^0\ Tmin = 6.11\ exp[(17.27*Tmin)/(237.3+Tmin)$ ----------------------------------- (14)

$e_a = e^0\ (Tdew) = 6.11exp[(17.27*Tdew)/(237.3+Tdew)]$--------------------------- (15)

FAO (2006) also suggested that substituting Tdew by Tmin when Tdew is not measured is also possible. Threfore, e_a is obtained from Tmin.

Where, e_s for saturated vapor pressure (Pa), e_a for actual vapor pressure (Pa), Tdew for dew point temperatures, Tmax for maximum Temperatures and Tmin for minimum Temperatures.

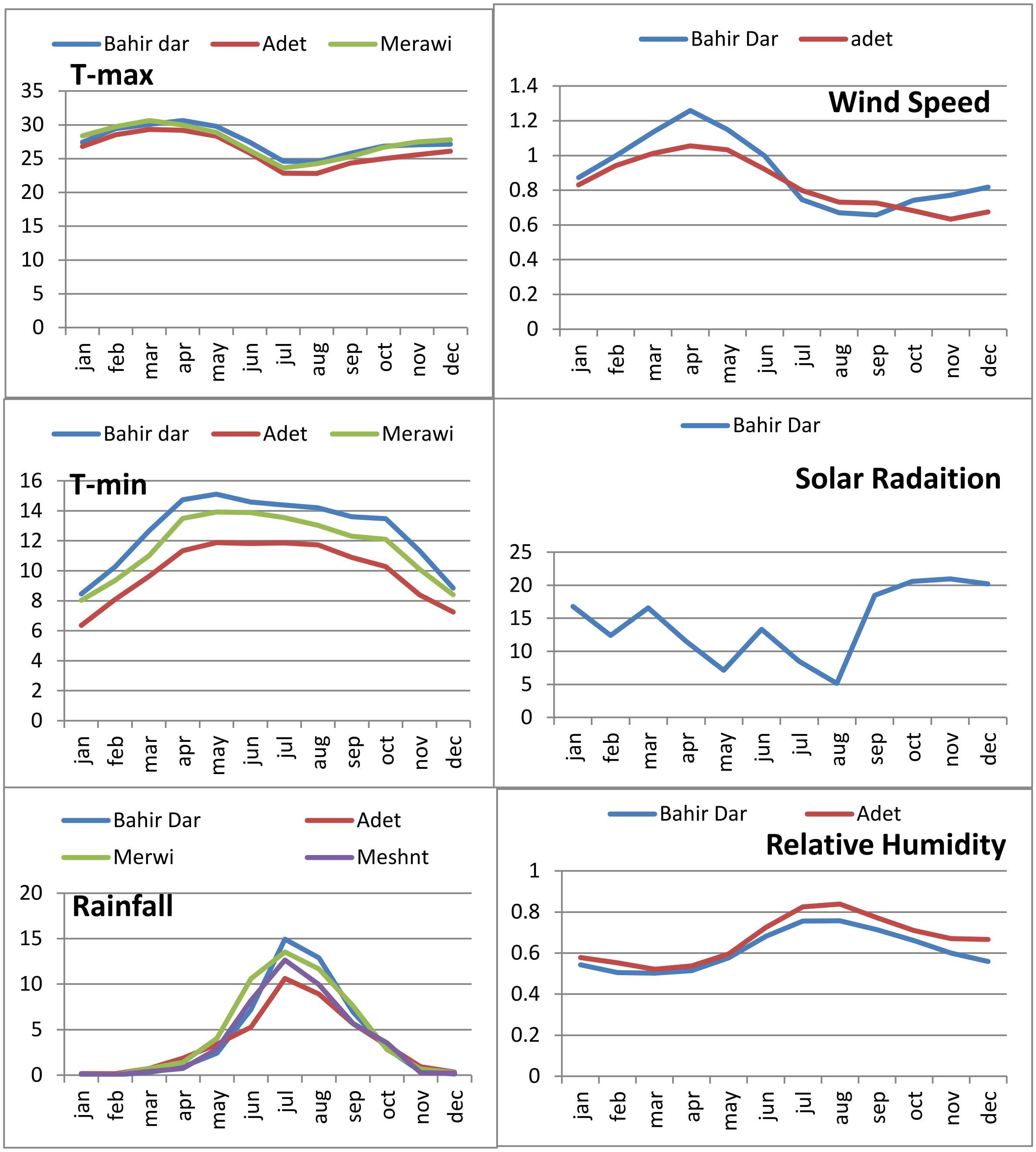


Figure 9: Mean Monthly weather variables used by SWAT (1991-2012).

3.3.1.2. SOIL DATA

Major soil group of the catchment was collected from different sources. i.e Ministry of Agriculture, Ministry of Water, Irrigation and Electricity and also from FAO. The different source soil data were examined, compared and finally classified in to six types of major soil groups. In addition to soil shape file data, data collected during field observation also utilized for the classification.

Tombul et al. (2004) stated that spatial and temporal variability of soil hydraulic properties can have considerable effect on the performance of hydrologic models. As a result, different properties of soil that govern the movement of water were determined by pedo-transfer function, particularly, pedo transfer functions excel macros. More over Harmonized World Soil Database (HWSD) was also used. It generated various properties of soil that are essential for the preparation of user defined Soil data base for SWAT during HRU definition.

Primarily alternative soil data from different sources (From Ministry of Water, Irrigation and Electricity, Ministry of Agriculture and FAO) were examined. Finally, the soil data (shape file) clipped from FAO (1997) was selected because of its detail description. The user soil database was imported from MW SWAT 2012 version (Map window SWAT) since it comprised FAO based user soil databases and the soil look up table was prepared accordingly.

3.3.1.3. DEM AND SATELLITE IMAGE

For the sake of delineation and stream network identification of the catchment, DEM was downloaded particularly from ASTER GLOBAL whereas satellite image that employed for land use classification was downloaded from Landsat 8 in the month of February 2013 from the USGS homepage at 170 - path and 052 - row with a resolution of 30 m x 30m.

Additionally, land use/cover data aged 5 years and above were collected by using GPS (Garmin GPS map 76) as ground truth points for land use/cover classification and further used for the accuracy assessment of land use classification (see Appendix 7.2).

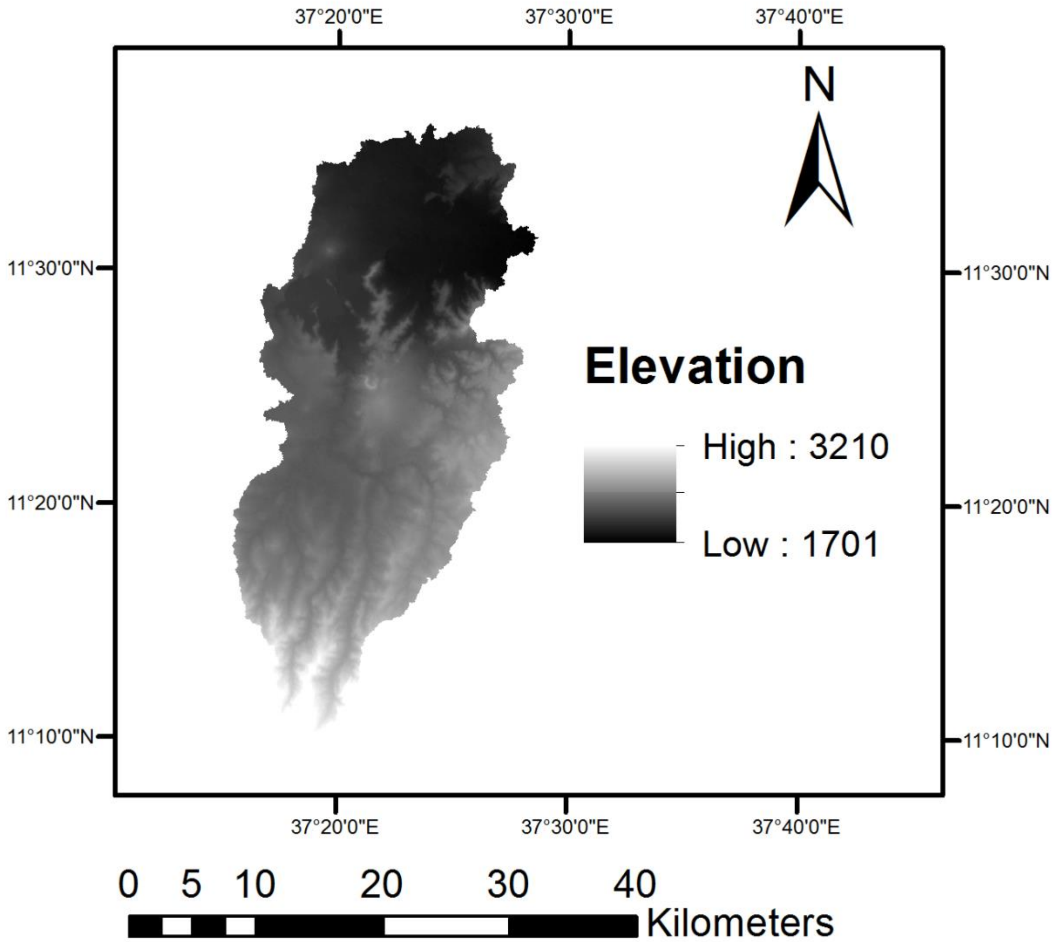


Figure 10: Digital Elevation Model of the study area

Land use/cover of the study area was classified by using ERDAS IMAGINE 9.1 version. Landsat 8 is used which is taken at the month of February 2013 with less than 10% cloud cover. Since the image has insignificant cloud cover no further corrections like (spatial, edge and haze enhancement) were made rather than histogram equalization. Supervised land use /cover classification was done by providing previously identified ground truth points. Ground truth points, previous land use map obtained from Ministry of Water, Irrigation and Electricity and Google Earth 2013 were employed during the classification for better accuracy. The value of overall accuracy assessment and kappa (k^) statistics were 92.6% and 89% respectively. And this indicated that the land use classification was more reliable. (see Table 6.).

Table 6: Land use/cover classification accuracy assessment matrix in the year 2013.

	Grazing land	FOREST (mixed)	Crop land	Cropland/ Woodland	Total	user accuracy
Grazing land	16	0	2	0	18	88.89%
FOREST (mixed)	0	23	0	1	24	95.83%
Crop land	2	1	66	4	73	90.41%
Crop/woodland	0	1	0	34	35	97.14%
Total	18	25	68	39	150	
producer accuracy	88.89%	92.00%	97.06%	87.18%		
	overall accuracy = 92.67%					
	overall kappa(^) statistics =89.2%					

3.3.1.4. DISCHARGE (STREAM FLOW) DATA

Discharge (stream flow) measured at the outlet of the study area was taken from Ministry of Water, Irrigation and Electricity from Hydrology department and from Abay Basin Authority at Bahir Dar office. For the sake of calibration and validation it was arranged in a single column starting from earliest to latest date (January 1st 1991 to the latest, December 31, 2012) in ascii(.txt)format).

Figure 11: Discharge gauge station of Andasa River, near Andasa town

For calibration and validation purpose, the catchment has a long record history of stream flow since 1959. However, the record is obtained from 1973 to 2012 and the study only used from 1991 to 2012 because of inadequacy of meteorological records earlier than 1991 in the four selected meteorological stations.

Two years (1991 and 1992) were assigned as worm up period, 14 years from 1993- 2006 were allocated as calibration period and the rest 6 years for validation of the SWAT model. Based on the Mann-Kendall test, annual discharge of Andasa has slightly decreasing trend at 5% significance level as it shown in Figure 12**.** And the peak discharge recorded in the month of august **(**see Figure 13**)**

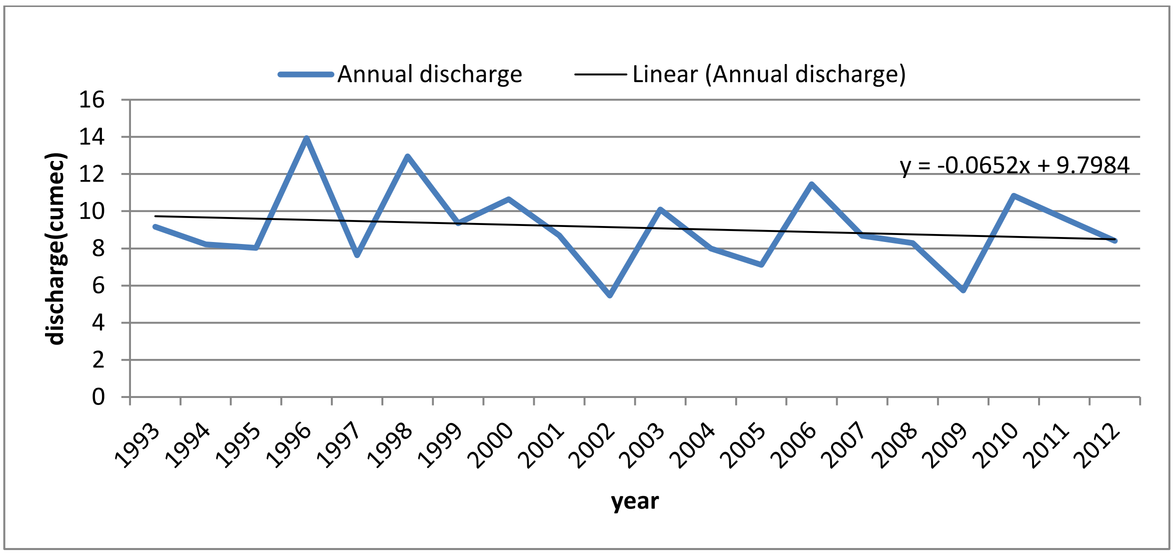


Figure 12: Annual discharge of Andasa River (m^3/s)

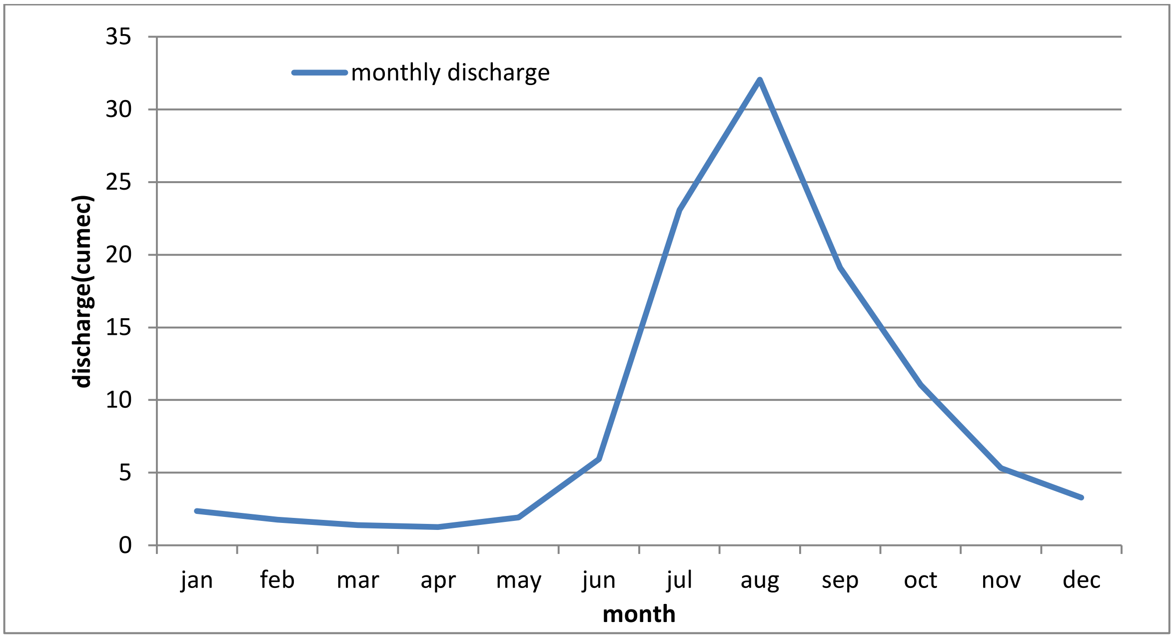


Figure 13: Mean monthly Andasa River discharge (m^3/s)

3.3.1.5. GLOBAL CLIMATE MODELS (GCMs)

For the sake of future climate change projection three GCMs were downloaded from Canadian climate data and scenario home page. These are Hadly center of climate study generation 3 (HadCM3) developed in UK, the second one is Canadian Earth System Model generation two (CanESM2) and the third is also from Canada so called CGCM3. In order to minimize the level of uncertainties, it is more advisable to use more GCMs/scenarios than using a single GCM/scenario for climate change impact studies (IPCC 1999 cited in Setegn et al., 2008). So that three GCMs were downloaded and compared with the observed station level data after down scaling. Finally two GCMs with their two (average and extreme condition) scenarios were selected to evaluate the climate change impact on the hydrology. Both HadCM3 and CanESM2 are produced for contribution of Coupled Model Inter-comparison Program phase 5 (CMPI5) from United Kingdom and Canada respectively. The details are shown in Table 7.

Table 7: Models Used for the climate study

GCM Model	Grid Resolution (long x Lat) °	downscaled Grid Box (X) /Long ˚ x (Y) /Lat ˚	No of future scenarios	Period of projections
HadCm3	2.75x3.75	30 (37.5 ˚) x 11(12.5 ˚)	H3 A2	1961-2099
			H3B2	
CGCM3	2.75x3.75	11(37.5 ˚) x 21(12.99 ˚)	CGCM3A2	2001-2100
			CGCM3A1B	
canESM2	2.8125x 2.8125	15(39.37 ˚) x 37(12.55 ˚)	canESM2 rcp 2.6	2006-2100
			canESM2 rcp 4.5	
			canESM2 rcp 8.5	

The above mentioned three GCM models data were calibrated and validated by records of rain fall, max and min temperature of Bahir Dar station. The Bahir Dar station is appropriate for the calibration and validation purposes because of its long history of records since 1961 for daily rain fall, max and min temperatures and HadCM3 were calibrated and validated for the period of 1961-2000 whereas for canESM2 from 1961-2005 is used with their respective base period of National Center for Environmental Prediction (NCEP) 1961 -2001 and 1961-2005 data sets respectively. Then, the downscaled station level weather variables were interpolated to other stations since they have high correlation with Bahir Dar meteorological station (correlation >0.9 for the three variables).

3.3.2. CALIBRATION AND VALIDATION OF SWAT MODEL

SWAT model was selected because it is best modeling tool for heterogeneous catchments and long term simulations (Devi *et al.,* 2015; Golmohammadi *et al.*, 2014*)* and it is more promising and showed better performance for agriculture dominating watersheds (Golmohammadi *et al.*, 2014). It is also successful for the simulation of management practices and climate scenarios (Bonuma *et al*., 2015). Moreover, it is frequently applied in Nile basin in particular at Upper Blue Nile sub basin and its tributaries and shows good performance (Setegn *et al*., 2008; Awulachew *et al*., 2008; Van Griensven *et al.*, 2012).

The model sensitivity analysis, calibration, validation and uncertainty estimation were done by a project called Sequential Uncertainty Fitting version 2 (SUFI2) under SWAT CUP. However, automatic calibration is mainly used, along with SWAT Cup, manual calibration also employed for the better understanding of parameters of the system. To do better manual calibration, Neitsch *et al*. (2002) were reviewed to follow the principles of calibration. Like GLUE, SUFI2 also accounts for all sources of uncertainties (Abbaspour, 2015). The other advantage of SUFI2 is that less number of simulation (200-500) it required than GLUE (up to 10,000), though it needs manual adjustments of parameter ranges. Nash- Sutcliffe (NS) ≥ 0.5 was the objective function during calibration and validation.

Finally the calibrated and validated model performance was evaluated based on the three statistical parameters shown below.

1. Goodness of fit or coefficient of determination (R^2) between the observed and the final best simulation.

$$R^2 = \frac{\sum_{i=1}^{n} (Qobs,i-\bar{Q}obs)(Qsim,i-\bar{Q}sim)}{\sum_{i=1}^{n}(Qobs,i-\bar{Q}obs)^2(\sum_{i=1}^{n}(Qsim,i-\bar{Q}sim)^2} \quad \textbf{(16)}$$

2. The Nash- Sutcliffe (NS) coefficient

$$\mathbf{NS}=1-\frac{\sum_{i=1}^{n}(Qsim,i-Qobs,i)^2}{\sum_{i=1}^{n}(Qobs,i-\bar{Q}obs)^2} \quad (\mathbf{17})$$

3. Percent of Bias (PBIAS)

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Qsim,i-Qobs,i)*(100)}{\sum_{i=1}^{n}(Qobs,i)}\right] \quad (18)$$

where: $Qobs, i$ is the observed flow at time i (m^3/s), $\bar{Q}obs$ is mean of observed flow (m^3/s), Qsim, i is the simulated flow at time i(m^3/s) and $\bar{Q}$ Sim Mean simulated flow (m^3/s).

3.3.2.1. SWAT MODEL SETUP

1. SWAT project Setup

   It is the first step of SWAT project to specify the directory and the file name of the project.

2. Watershed delineation

The first step in SWAT is watershed delineation. At this stage, the following activities were performed.

I. The Digital Elevation Model (DEM) was selected. Before this step, the DEM was projected in to WGS_ 1984_ UTM_Zone _37N.

II. DEM based flow direction and accumulation is done.

III. Stream network is created

IV. After manually specifying outlet, the watershed of the study area was delineated.

V. The sub basin parameter calculation is done and saved in the predefined directory. The delineated watershed with sub basin is displayed in the Arc Map window. The catchment is classified in to 23 sub basins. The step is shown in Figure 14 below.

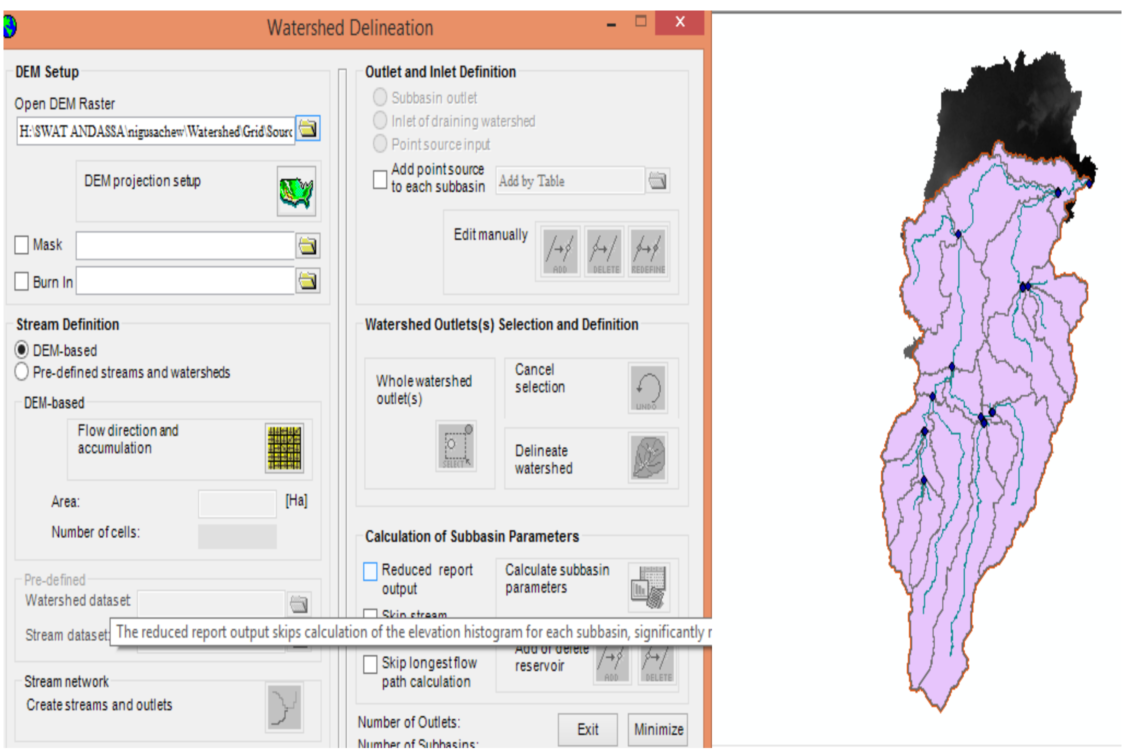


Figure 14: Watershed delineation

3. Hydrologic Response Unit (HRU) analysis

   At this step data like land use and Soil either in polygon shape file or grid form along with their look up table and slope (from DEM) feed to SWAT to creat HRU.

   Input data imported to the SWAT one by one.

   I. Land use of the study area classified into four groups and correlated with SWAT Crop database.
   II. Soil type of the study area first defined based on FAO classification and grouped into six type of dominant soil group. The FAO soil classification, further classified in to four based on their dominant texture in order to correlate with SWAT user soil Database. For this sake user soil database is prepared and imported to SWAT database prior to model setup.
   III. The study area classified in to 3 slope classes: From 0-5%, 5-10% and 10-90%.

The HRU of the basin defined in different threshold values as it shown in Table 8. For this study, 5% (land), 10% (soil) and 15 % (slope) threshold values were selected. The maximum numbers of HRU were selected by thinking the basin with more HRU, the more it tends to lumped system and the more homogeneity it represent.

Table 8: Different HRU definitions of the catchment

parameters		Threshold values (%)			Remark
	Land	20	5	10	
	Soil	10	10	10	
	Slope	20	15	10	
Numbers of HRU		111	127	124	127 HRU is selected

To complete the HRU definition overlay the input parameters was done and prior to that create HRU feature class and create overlay report was checked.

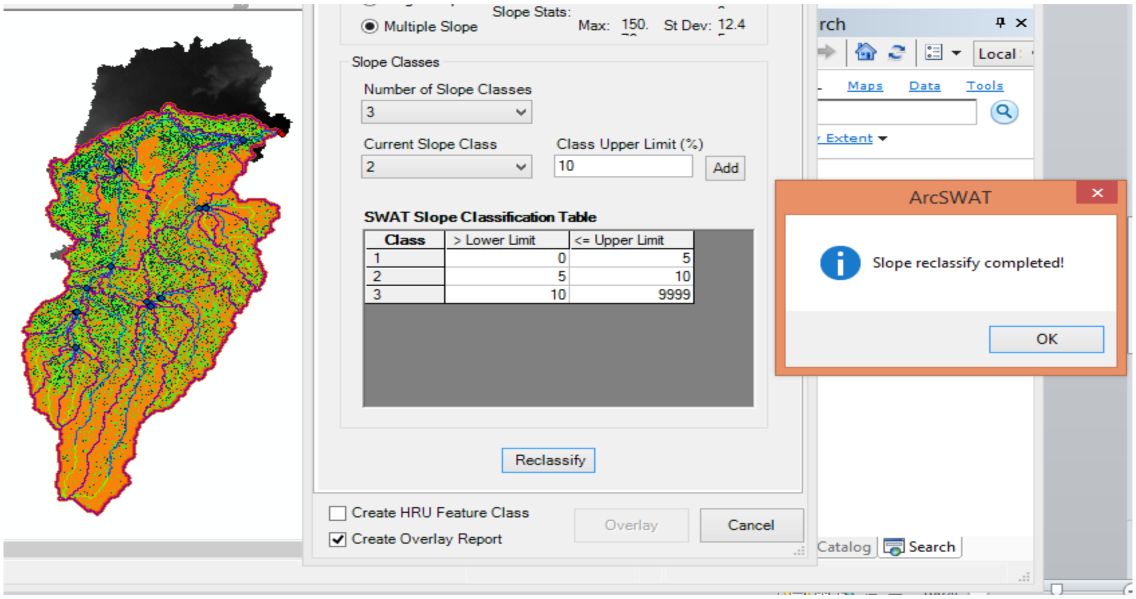


Figure 15: Final step of the HRU definition

4. Write input tables menu

   Here all weather data and station location including the weather generator written to SWAT database. After weather station writing, other SWAT input tables were written.

5. Edit Input SWAT menu

   At this stage, SWAT model database is edited. For instance, CN adjustment for slope >5% and channel routing method was changed into Muskingum and its corresponding values were edited. Additionally, Potential Evapo- Transpiration (PET) was adjusted to be simulated in Penman-Monteith.

6. SWAT simulation menu

This is the final step of SWAT model to produce the specified output. Under this, there are menu enabled to display and access an output (in this case only flow and water balance is the interest of the study and extracted from SWAT files output.rch, output.bsn and output .hru).

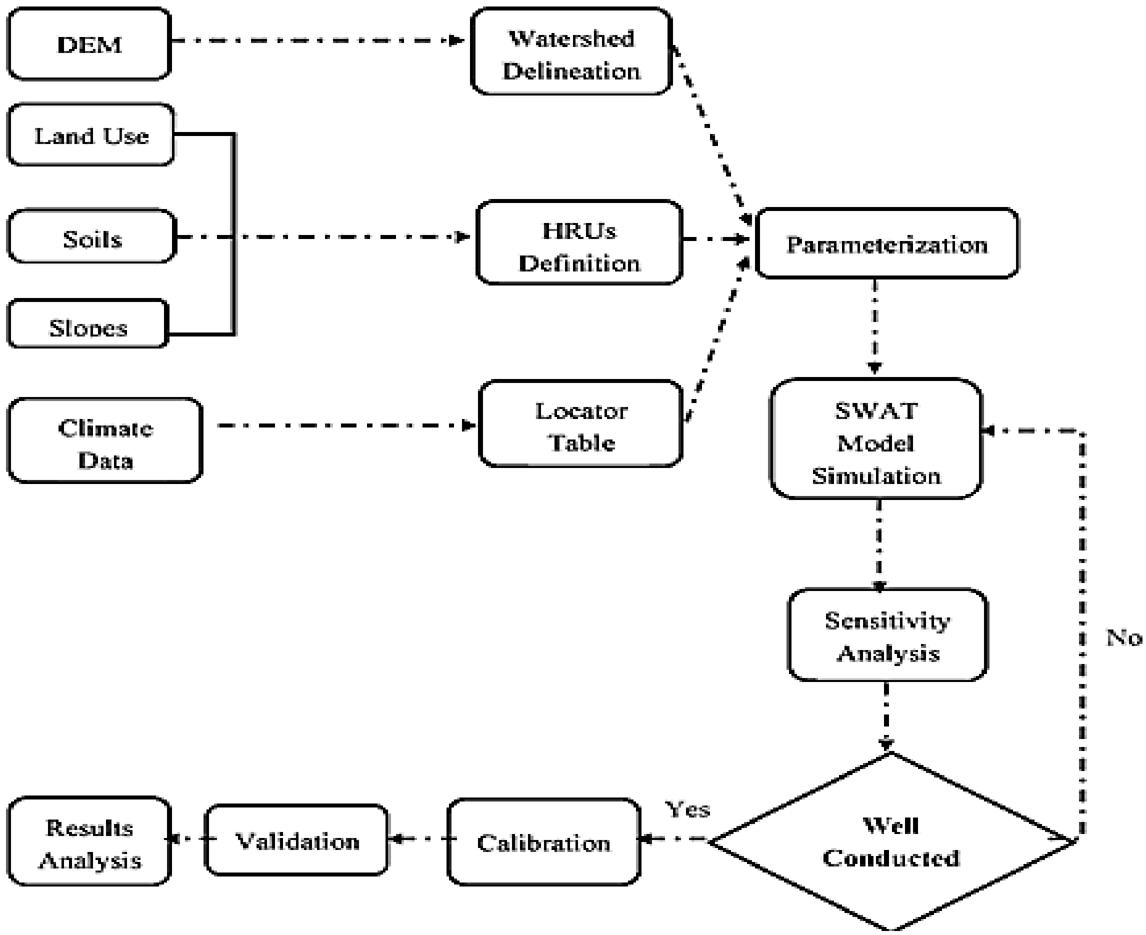


Figure 16: Flow chart of summarized logical SWAT model steps (Akpoti *et al*., 2016).

3.3.3. PREDICTION OF CLIMATE CHANGE

Statistical Downscaling Model (SDSM) is selected because it is efficient where low cost, rapid assessments of localized climate change impacts are required. However it requires sufficient amount of historical climate data for establishing relationships (Wilby and Dawson, 2007).

It is very challenging to downscale rain fall because of its low predictand – predictor relationships. McMahon (2015) stated that a given GCM is not expected to replicate the observed data, instead similar values of long period means with the observed is expected.

Therefore it is more advised to apply various GCMs with multiple scenarios to minimize uncertainties in this regards (Wilby and Dowson, 2007).

Three GCMs were used to draw future climate scenarios. Two of which were based on the SRES Scenario. Namely; HadCM3 and CGCM3 and the other one was CanESM2 which is developed based on the newly climate change scenario system called Representative Concentration Pathways (RCP). Though three types of GCMs were used, only two were selected based on their better correlation with the historical records. Their respective coefficient of determination has illustrated in Table 9. And two scenarios were used from each GCMs. Namely; A2 and B2 from Had CM3 and RCP 4.5 and RCP 8.5 from CanESM2 in order to represent the extremes of CO_2 emissions as indicated in Table 1in the review section.

Table 9: R^2 value of the downscaled GCMs

no	GCM	Climatic variables	Type of scenario	Performance evaluation (R^2)	Remarks
1	HadCM3	T-Max	SRES	0.72	
		T-Min	SRES	0.80	
		Rain fall	SRES	0.79	
2	CGCM3	T-Max	SRES	0.69	Its projection is extremely overestimated. Specially for rain fall
		T-Min	SRES	0.75	
		Rain fall	SRES	0.80	
3	canESM2	T-Max	RCP	0.84	Selected for climate impact study as RCP
		T-Min	RCP	0.82	
		Rain fall	RCP	0.86	

3.3.3.1. SDSM MODEL SETUP

The SDSM software characterizes the daily weather series in to seven discrete steps.

1) **Quality control and data transformation;**

At this stage the observed data was checked for missing data and weather the missing is filled with -999 or not. And transformation was done for daily observed rain fall data.

2) **Screening of predictor variables;**

This stage was the critical and challenging stage of statistical downscaling model because of the type and numbers of predictors selected can have considerable effect on the overall model output. Based on the strength of relationship between predictor (among NCEP 26 parameters) and predictand (catchment level weather variables), predictors were screened. These screened predictors for each GCM are shown in Table 10.

3) **Model calibrations;**

   Weather station level variables called predictand along with selected predictors are computed by the principle of multiple regressions.

4) **Weather generator (by using observed predictors);**

   Generates ensembles of synthetic daily weather series for a given observed atmospheric predictor variables.

5) **Statistical analysis**

   Statistical Analysis provides the statistical summaries for the generated and observed data for baseline period.

6) **Graphing model output;**

   Compare the result (graphically) for baseline period from generated and observed data series.

7) **Scenario generation (by using climate model predictors).**

   The final step in SDSM the scenario generator operation produces ensembles of synthetic daily weather series (maximum 100 ensembles) for the potential existing predictor variables supplied by a climate model. By default it has 20 ensembles.

   Along all the steps of SDSM, it is critical to specify the type of process as either conditional or unconditional with respect to the nature of the weather variable. In unconditional process it is assumed that there is a direct link between the pridictors and pridictand; e.g. temperature whereas for processes like rain fall are considered as conditional process due to the intermediate process between regional forcing and local weather.

CORRELATION MATRIX

Analysis Period: 1961-01-01 - 2000-12-31 (January)

Missing values: 2
Missing rows: 2
Values less than or equal to threshold: 1216

		1	2	3	4	5	6	7	8	9	10	11	12	13
1	bd-PCP_61-00.dat	1	-0.278	-0.057	0.006	0.386	0.117	-0.451	-0.129	-0.187	0.393	0.316	0.423	0.417
2	ncepp__faf.dat	-0.278	1	0.542	-0.249	-0.884	0.025	0.830	0.236	-0.086	-0.862	-0.311	-0.449	-0.578
3	ncepp__uaf.dat	-0.057	0.542	1	-0.491	-0.229	0.415	0.178	-0.094	-0.524	-0.254	0.154	-0.233	-0.114
4	ncepp_thaf.dat	0.006	-0.249	-0.491	1	0.311	-0.239	-0.305	-0.026	-0.063	0.340	-0.007	0.207	0.099
5	ncepp_zhaf.dat	0.386	-0.884	-0.229	0.311	1	0.190	-0.943	-0.323	-0.325	0.953	0.539	0.502	0.666
6	ncepp5_uaf.dat	0.117	0.025	0.415	-0.239	0.190	1	-0.183	-0.398	-0.412	0.130	0.524	0.238	0.229
7	ncepp8_vaf.dat	-0.451	0.830	0.178	-0.305	-0.943	-0.183	1	0.344	0.351	-0.991	-0.546	-0.446	-0.611
8	ncepp8_zaf.dat	-0.129	0.236	-0.094	-0.026	-0.323	-0.398	0.344	1	0.362	-0.317	-0.189	-0.338	-0.355
9	ncepp8thaf.dat	-0.187	-0.086	-0.524	-0.063	-0.325	-0.412	0.351	0.362	1	-0.340	-0.405	-0.049	-0.213
10	ncepp8zhaf.dat	0.393	-0.862	-0.254	0.340	0.953	0.130	-0.991	-0.317	-0.340	1	0.499	0.426	0.599
11	ncepr500af.dat	0.316	-0.311	0.154	-0.007	0.539	0.524	-0.546	-0.189	-0.405	0.499	1	0.270	0.332
12	nceprhumaf.dat	0.423	-0.449	-0.233	0.207	0.502	0.238	-0.446	-0.338	-0.049	0.426	0.270	1	0.898
13	ncepshumaf.dat	0.417	-0.578	-0.114	0.099	0.666	0.229	-0.611	-0.355	-0.213	0.599	0.332	0.898	1

PARTIAL CORRELATIONS WITH bd-PCP_61-00.dat

	Partial r	P value
ncepp__faf.dat	0.413	0.0784
ncepp__uaf.dat	-0.779	0.0000
ncepp_thaf.dat	-0.679	0.0008
ncepp_zhaf.dat	0.529	0.0173
ncepp5_uaf.dat	-0.127	0.4757
ncepp8_vaf.dat	-0.814	0.0000
ncepp8_zaf.dat	0.327	0.1719
ncepp8thaf.dat	-0.347	0.1470
ncepp8zhaf.dat	-0.770	0.0000
ncepr500af.dat	-0.577	0.0076
nceprhumaf.dat	-0.154	0.4393
ncepshumaf.dat	0.135	0.4657

Figure 17: correlation between Predictand (rain fall) and HadCM3 Model predictors

The pridictors shown In Table 10 were screened based on the value of correlation results between predictand (station level weather vriable) and the model's pridictors as shown in Figure 17.

Table 10: Global sensible predictors for the local weather variables (Canadian climate data and scenario webpage)

Predictors	**code**	**Sensible predictors for the variables (predictands) of the GCMs**								
		HadCM3			CGCM3			canESM2		
		T-min	T-max	Pcp	T-min	T-max	pcp	T-min	T-max	Pcp
Mean sea level pressure	mslp	x	X		x	x		x	x	
Surface airflow strength	**_f	x		x						
Surface zonal velocity	**_u		X	x						
Surface meridional velocity	**_v		X				x		x	
Surface vorticity	**_z	x	X							X
Surface wind direction	**_th			x		x				
Surface divergence	**_zh			x			x		x	X
500 hPa airflow strength	**_f						x			X
500 hPa zonal velocity	**_u			x						X
500 hPa meridional velocity	**_v						x			
500 hPa vorticity	**_z						x			
500 hPa geopotential height	p500	x	X		x	x		x	x	X
500 hPa wind direction	P5th							x		
500 hPa divergence	P5zh									X
850 hPa geopotential height	p850	x	X					x		
850 hPa airflow strength	**_f		X							
850 hPa zonal velocity	**_u									
850 hPa meridional velocity	**_v			x						X
850 hPa vorticity	**_z			x	x				x	
850 hPa wind direction	P8th			x						X
850 hPa divergence	P8zh			x			x		x	X
Relative humidity at 500 hPa	r500			x						
specific humidity at 500 hPa	s500				x	x		x		
Relative humidity at 850 hPa	r850									
specific humidity at 850 hPa	s850				x					
Near surface relative humidity	rhum			x						
Surface specific humidity	shum		X	x						
Mean temperature at 2m	temp		X	x	x	x		x	x	X
Unknown	precp						x	x		

Predictors shown in Table 10 were selected based on their significant (sensible) relationship with the local weather variables. The relationship to be said significant or not was based on the statistical partial r and P-value as indicated in Figure 17. A correlation results which had partial r values ≥ ±5 with a P- value ≤ 0.05 were considered as significant (sensible) predictor. The relationship further proved by looking scatterplot graph to cross check whether the significance of the predictor is due to the presence of outliers or not.

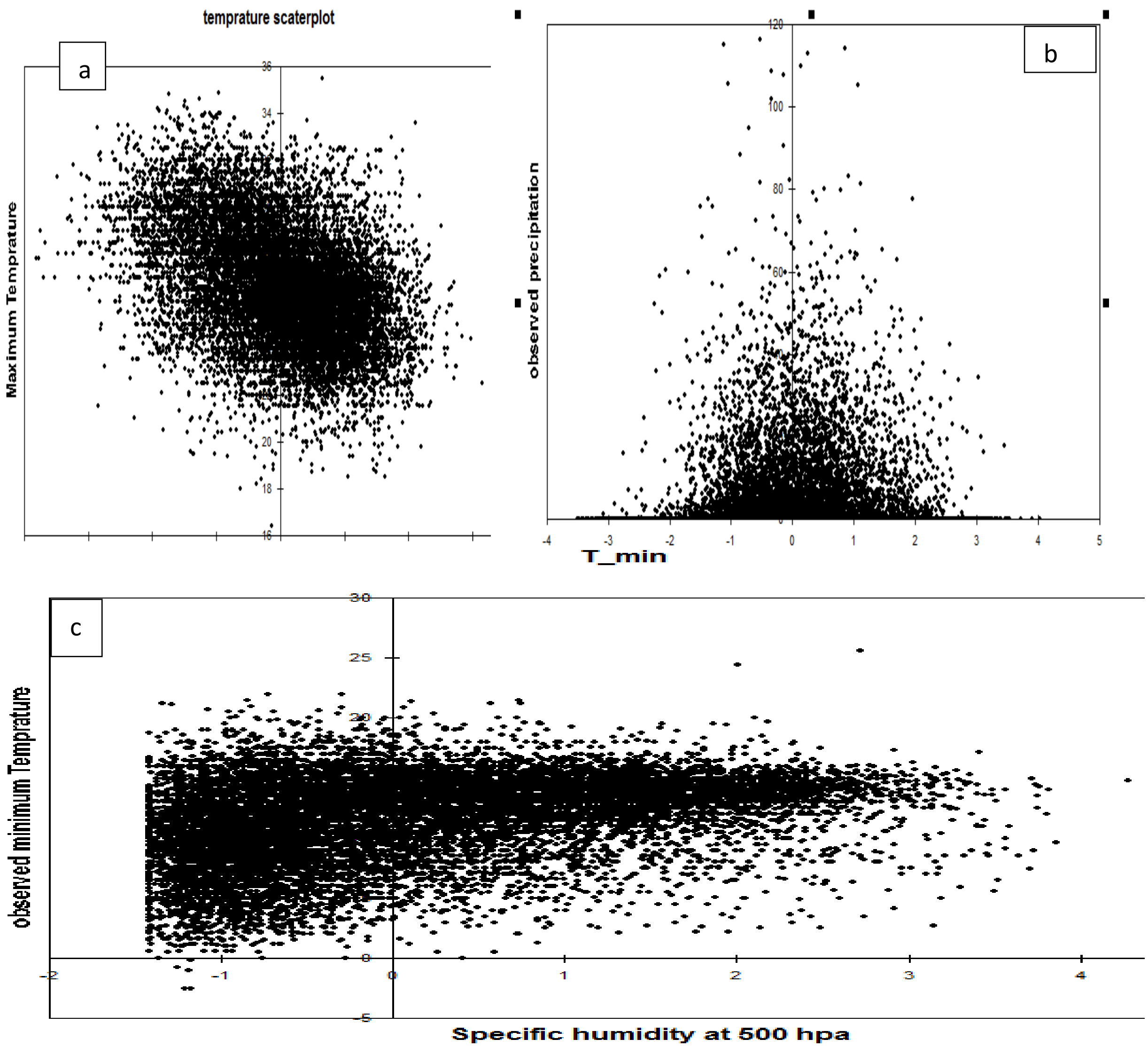


Figure 18: Scatterplots of positive (b&c) and Negative correlation (a**)**

3.3.4. PREDICTION OF CLIMATE CHANGE IMPACT

SWAT allows introducing changes in weather variables to simulate impact of climate change (Neitsch *et al*., 2009). Since each meteorological station has high correlation with Bahir Dar station, the down scaled future weather variable of Bahir Dar was interpolated to the rest stations. Lijalem (2006) also followed the same procedure in climate change impact study at Ziway catchment. The correlation between stations for rain fall, T-min and T-max are illustrated in Table 11, 12 and 13 respectively.

Table 11: Correlation matrix for rain fall among stations

	Bahir Dar	**Merawi**	**Meshenti**	**Adet**
Bahir Dar	1			
Merawi	0.971722	1		
Meshenti	0.985015	0.989519	1	
Adet	0.988634	0.969199	0.981128	1

Table 12: Correlation matrix for T-min among stations

	Bahir Dar	**Adet**	**Merawi**
Bahir Dar	1		
Adet	0.984066	1	
Merawi	0.989356	0.99017	1

Table 13: Correlation matrix for T-max among stations

	Bahir Dar	***Adet***	***Merawi***
Bahir Dar	1		
Adet	0.986765	1	
Merawi	0.948568	0.976791	1

To evaluate the Impact of climate change on the hydrology of the catchment, the monthly change in rain fall (%) and temperature (˚C) for each future time were calculated in relation to the base period. Before computing change in temperature for both time periods (base period and Future periods), average (mean) temperature were calculated from minimum and maximum temperatures. After doing so, change in rain fall (%) and temperature (˚C) calculated by using equations shown below.

$$\Delta P2020s = \frac{(V2020s - Vbase)}{Vbase} \times 100 ------------------ (19)$$

$$\Delta P2050s = \frac{(V2050s - Vbase)}{Vbase} \times 100 -------------- (20)$$

$$\Delta P2080s = \frac{(V2080s - Vbase)}{Vbase} ------------------ (21)$$

And for temperature, it is calculated as;

$$\Delta T2020s = V2020s - Vbase ------------- (22)$$

$$\Delta T2050s = V2080s - Vbase ------------ (23)$$

$$\Delta T2080s = V2080s - Vbase ------------- (24)$$

Where; V base is the mean of all ensembles or a single ensemble for each statistic for the base period (Wilby and Dawson, 2007).

$\Delta T and\ \Delta P$ Is added under Sub basin at Arc SWAT to the existing calibrated and validated SWAT model which is referred as base period to simulate the water balances for the three future time periods.

3.3.5. IMPACT OF LAND USE/COVER CHANGE ON WATER BALANCE

The following land use/ cover change scenarios were developed.

1. One single base period scenario (1991-2012) was developed based on the output of previous land use studies. It is reported that plantation forestry is increasing in the basin (Ermias *et al.*, 2013; Moges *et al.*, 2015). Also deforestation is decreasing (Rientjes et al., 2011). Hence, Crop land-wood land mosaic (CRWO) which lies in 10% slope and above, changed in to Mixed Forest (FOMI) by afforestation through afforestation campaign. The developed scenario was compared with real situation to evaluate the change.

2. Worst case scenario and best case scenario were developed for the future period (2013-2042). The projected averages of the four scenarios for the period 2013- 2042 were used for temperature and rainfall.
    I. Worst case scenario: if all land use/cover changed in to agriculture;
    II. Best case scenario: if all land use/covers above 10% changed in to mixed forest.

3.4. CONCEPTUAL FRAMEWORK

The basic working principle of this research is based on water balance principles for a defined spatial and temporal scale. When a river channel process analyzed, surface runoff can be referred as the input, the channel itself as storage whereas a runoff out the channel (outlet) considered as output (Mccuen, 1989). The conceptual representation of hydrologic systems stated in mathematical terms as follows.

$$\boldsymbol{I - O = \frac{\Delta S}{\Delta t}} \quad \text{--} \ (25)$$

Where, I, O, S and t denote the input, output, storage and time respectively.

4. RESULT AND DISCUSSION

4.1. SWAT MODEL PERFORMANCE ON ANDASA CATCHMENT

4.1.1. SENSITIVE PARAMETERS

Sensitivity parameters of the model were identified in SWAT CUP and the most ten sensitive parameters were selected and used for model calibration and validation. Similar studies in the area particularly in Tana sub basin Setegn *et al*. (2008) and Abay basin, Betrie *et al*. (2011) were reviewed to select parameters to be analyzed. Fifteen sensitive parameters for stream flow were selected and analyzed. Then after, top ten sensitive parameters shown in Table 14 were selected based on their P- value and used for further calibration process. The higher absolute value of t- stat and the smaller P-value ($x \leq 0.05$) is considered as sensitive parameters (Abbaspour , 2015).

Table 14: Sensitive parameters

Sensitive parameters	t-stat	P-value	Sensitivity rank
R__SOL_K(..).sol	-14.33	0.00	1
R__CN2.mgt	-10.61	0.00	2
R__RCHRG_DP.gw	-8.60	0.00	3
R__CH_N2.rte	6.54	0.00	4
R__REVAPMN.gw	-5.38	0.01	5
R__ESCO.bsn	4.01	0.02	6
V__GWQMN.gw	-3.52	0.02	7
R__CH_K2.rte	3.48	0.03	8
V__ALPHA_BF.gw	3.35	0.03	9
R__GW_REVAP.gw	-2.47	0.04	10

4.1.2. CALIBRATION AND VALIDATION

Neitsch *et al*. (2002) recommends understanding about the real condition of the catchment before going to calibrate the water balance and stream flow. Therefore it is required to have observation data recorded at the outlet of the catchment.

During SWAT CUP calibration, the measured data from 1993-2006 and 2007-2012 were used to calibrate and validate the model respectively. It was recommended to allocate more measured data (about 2/3 to 3/4) for calibration. Based on the calibrated result shown in Table 17, the model is very good since the values of calibration and validation were in 0.75 < NSE < 1.00, PBIAS < ±10 (Moriasi, 2007). However, in validation phase, the value of PBIAS a little bit out of the range of very good model performance class. To decide the possible numbers of iterations to achieve best simulation, the value of P- factor and R – factors also additional determinants beside of maximum R^2 and NSE values. (Value approaches to unity is the area of interest in calibration (Abbaspour, 2015).

Abbaspour (2015) recommends that for discharge calibration R -factor and P- factor values should be > 70% and approaches to 1 respectively. Because, a value of P-factor tell us how much percent of the observed (measured) data can the model bracketed particularly by 95 % of Prediction of Uncertainty (95PPU) whereas R-factor justifies the thickness of 95PPU enveloped. In this case 98% and 76% percent of the observed data were enveloped for calibration and validation respectively. The value of r- factor for calibration was 1.04 and 0.79 for validation also shows the good performances of the model (Abbaspour, 2015).

Table 15: Calibrated parameters and their fitted values

parameters	Description	Value ranges	Fitted values
R__SOL_K(..).sol	Soil Hydraulic conductivity	0-1	0.25
R__CN2.mgt	Curve Numbers	± 25	-13
R__RCHRG_DP.gw	Deep Aquifer percolation fraction	0-1	0.4
R__CH_N2.rte	Manning's roughness coefficient for main channel	0.025-0.065	0.05
R__REVAPMN.gw	Threshold Depth Of water in the shallow Aquifer for " revap" to occur	0-500	300
ESCO.bsn	Soil Evaporation Compensation Factor	0-1	0.5
V__GWQMN.gw (mm H_2O)	Threshold depth of water required to return flow to occur	0-1500	110
R__CH_K2.rte	Channel Hydraulic conductivity	0-500	1.5
V__ALPHA_BF.gw	Base flow alpha factor	0-1	0.1
R__GW_REVAP.gw (mm)	Ground water recharge coefficient	0.02-0.2	0.02

Calibrated water balance

After calibrating stream flow via SUFI2 in SWAT CUP, further calibration of water balance of the catchment was required to check whether the processes are reasonably represented in time and space. Van Griensvan *et al.* (2012) noted that parameters like GW Revap and CH_K causes losses of water out of the system that is not accounted in the water balance. Therefore it is advisable to minimize such values to keep loses in reasonable ranges.

The calibrated water balance is presented in Table16.

Table 16: Yearly water balance

Year	Rain fall (mm)	ET(mm)	SURQ(mm)	LAT(mm)	GW(mm)	WYLD (mm)	SW(mm)	PERC(mm)
1993	1306.43	637.09	84.12	405.27	122.22	686.09	167.53	191.64
1994	1242.52	619.04	60.07	390.81	114.94	637.5	169.58	170.55
1995	1208.9	612.04	58.64	376.75	98.35	596.21	184.55	146.4
1996	1568.05	706.48	126.13	502.83	125.39	816.93	179.32	237.94
1997	1302.42	705.37	54.12	399.16	111.97	640.84	172.11	150.98
1998	1446.78	665.73	108.77	463.11	120.92	758.6	158.46	222.83
1999	1450.78	635.17	107.95	463.65	143.48	797.07	162.67	239.8
2000	1412.37	673.22	90.7	435.35	133.69	744.61	168.15	207.63
2001	1433.08	640.1	112.65	455.84	141.14	791.74	171.1	221.34
2002	1219.35	656.54	54.99	365.05	113.5	611.24	163.66	150.38
2003	1306.95	584.24	78.7	421.06	122.3	688.61	160.28	226.35
2004	1191.36	609.56	56.83	370.52	115.05	618.15	156.28	158.46
2005	1255.42	579.95	77.67	395.3	107.9	643.98	173.89	184.89
2006	1939.74	701.54	241.85	624.95	174.53	1124.2	195.56	349.7
2007	1421.79	703.84	85.52	443.09	165.92	808.59	179.17	205.76
2008	1384.43	712.18	72.28	429.74	120.44	701.12	177.99	171.41
2009	1084.95	610.63	53.55	323.62	84	521.17	170.83	104.31
2010	1311.32	624.3	92.64	412.39	96.84	651.72	161.42	191.42
2011	1448.8	628.16	134.23	461.66	134.74	803.39	150.73	235.44
2012	1455.65	573.51	178.99	451.29	157.19	878.39	142.26	260.32
average	1369.555	643.94	96.52	429.572	125.23	726.01	168.277	201.38

Based on the calibrated and validated results presented in Table 16 and Figure 19, 48 % of the rain fall contributed to stream flow where as 47% was lost as evapotranspiration and the rest was lost as deep aquifer recharge. Moreover, 66% of the stream flow was contributed from base flow.

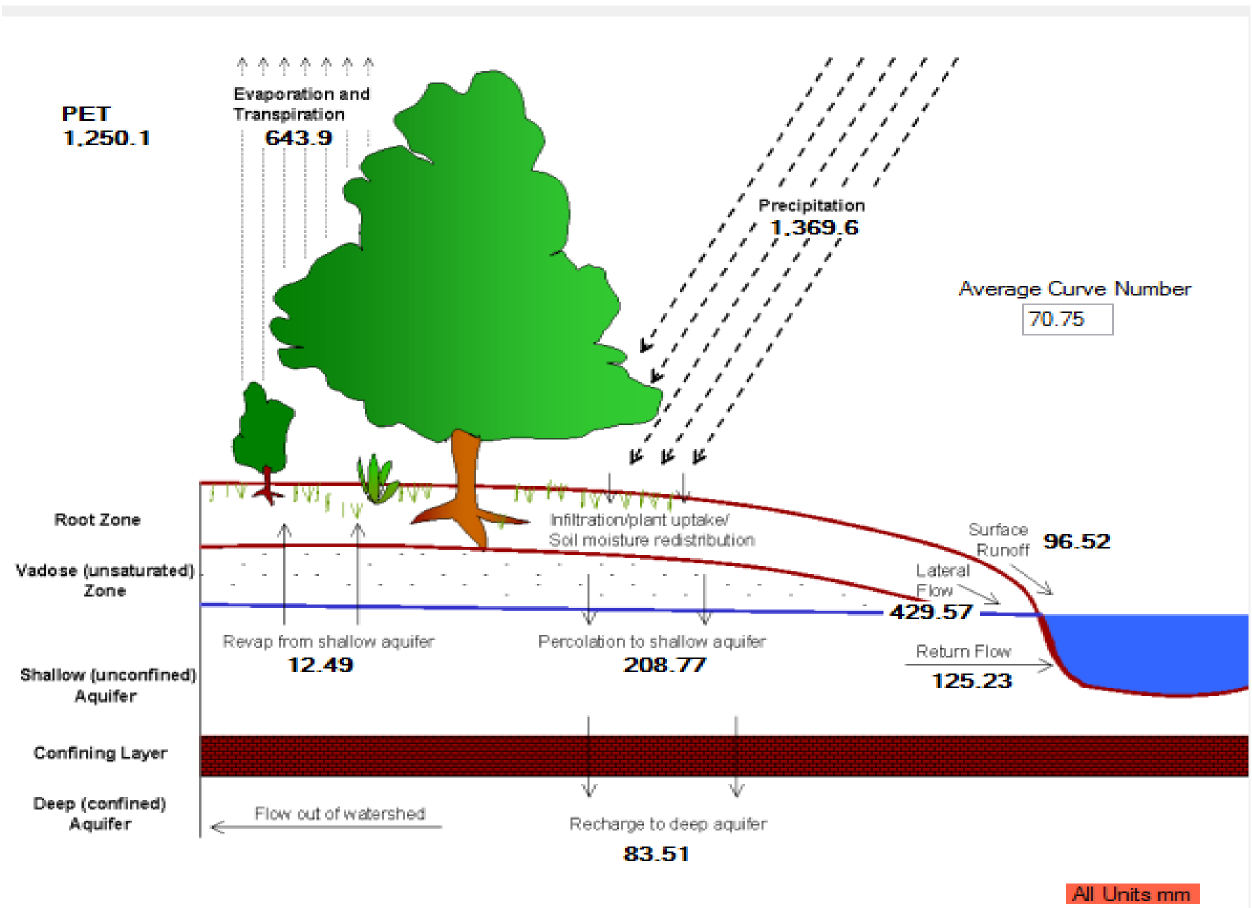
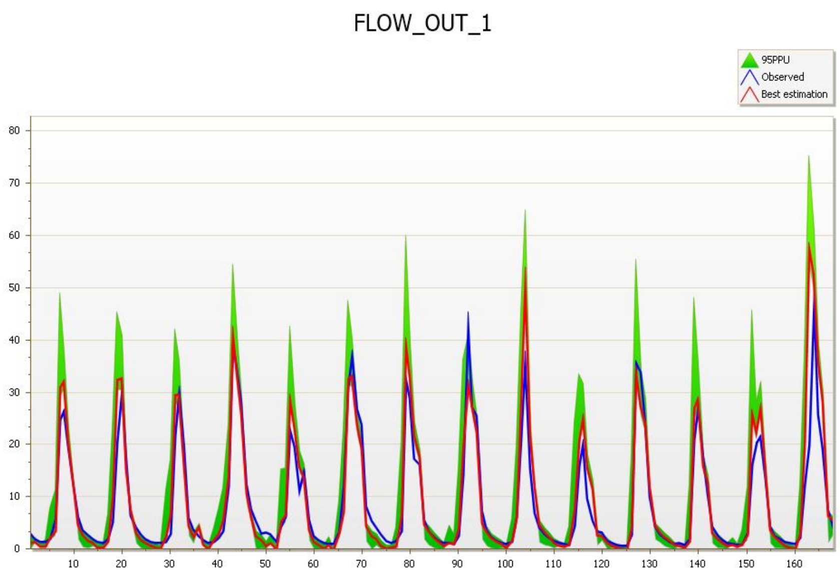


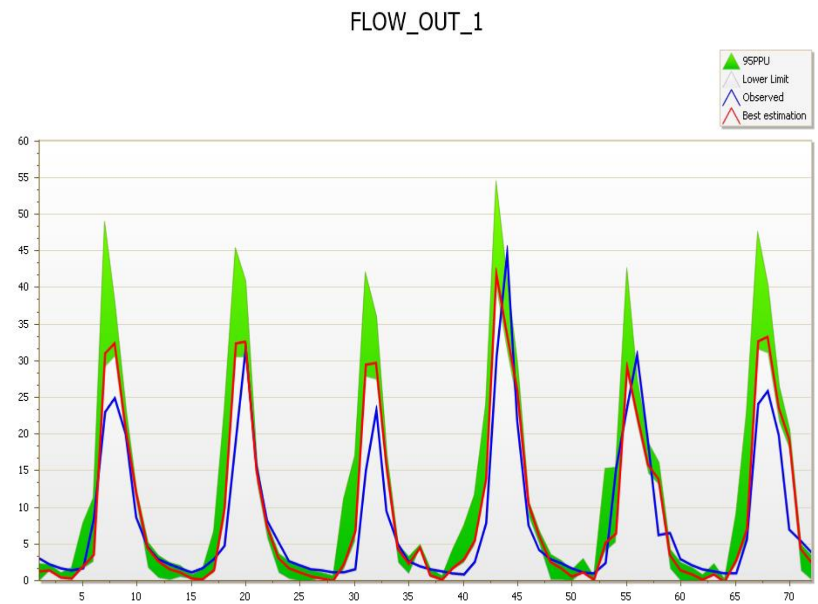
Figure 19: Schematic representation of water balance

Table 17: Statistical Values of calibration and validation process

Goal_type= R2	No_sims= 300		Best_sim_no= 257		Best_goal = 8.42e-001				
Variable	p-factor	r-factor	R2	NS	bR2	MSE	PBIAS	Mean_sim(Mean_obs)	StdDev_sim(StdDev_obs)
calibration	0.98	1.04	0.86	0.84	0.8007	1.9e+001	-10.4	10.41(9.43)	11.11(10.98)
validation	0.76	0.79	0.82	0.80	0.68	1.9e+001	-13.4	9.67(8.53)	9.14(9.88)



a) Calibration (1993-2006)



b) Validation (2007-2012)

Figure 20: Calibration (a) and Validation (b)

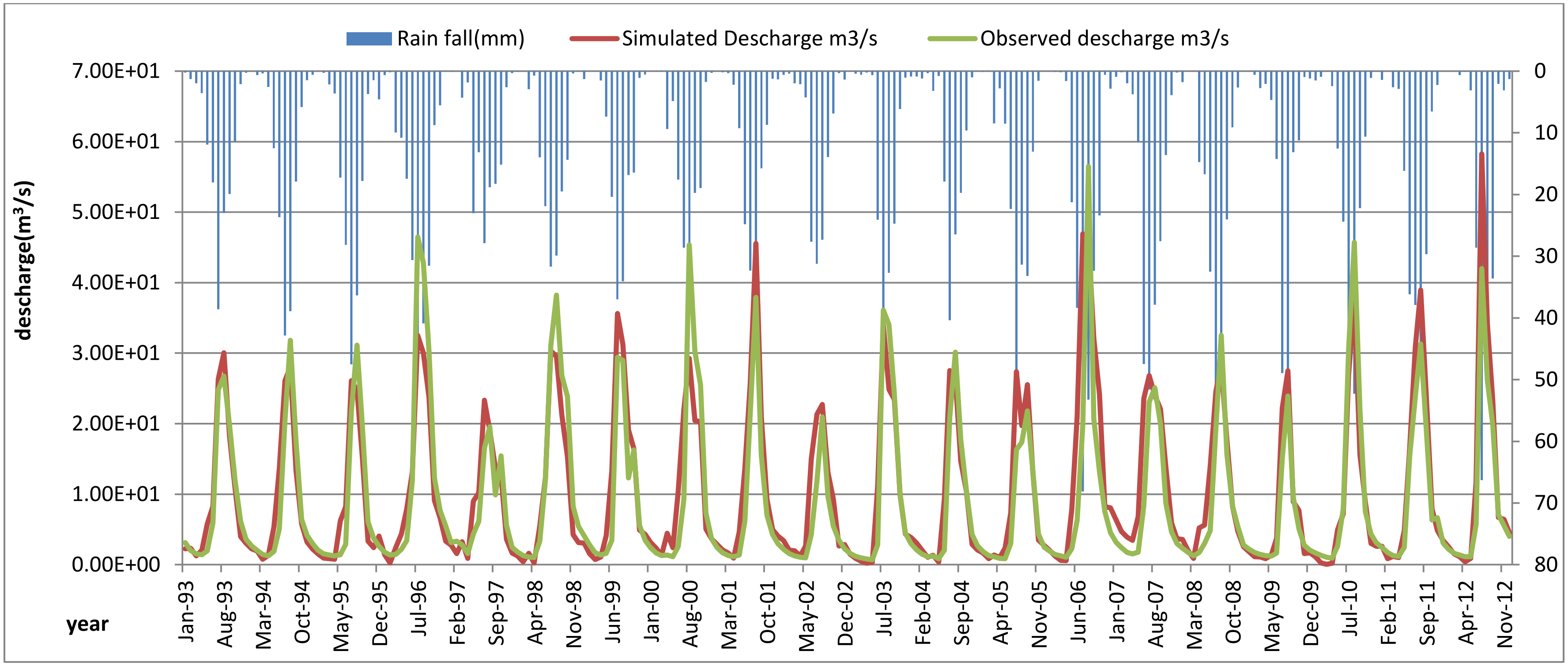


Figure 21: Rain fall versus simulated and observed flow

The SWAT model performed very well and it was approved that the model can be applicable for any further studies in the area of hydrology, LULC and climate change impacts. In comparison to previous study conducted by Eshetie (2015 unpublished), SWAT showed better performance than HBV-Light, SMAR and HEC_HMS as they were used to model extreme events and climate change impact studies in the catchment. In the previous study the NSE value for both periods (calibration and Validation) were for HBV- Light (0.56 and 0.57), HEC- HMS (0.441 and 0.453) and for RRL- SMAR (0.43 and 0.441). SWAT model takes the advantages over HEC- HMS, HBV- Light and RRL- SMAR is mainly because of its multiple data intensive feature.

4.2. CLIMATE CHANGE SCENARIO (TEMPERATURE AND RAIN FALL) OF THE CATCHMENT

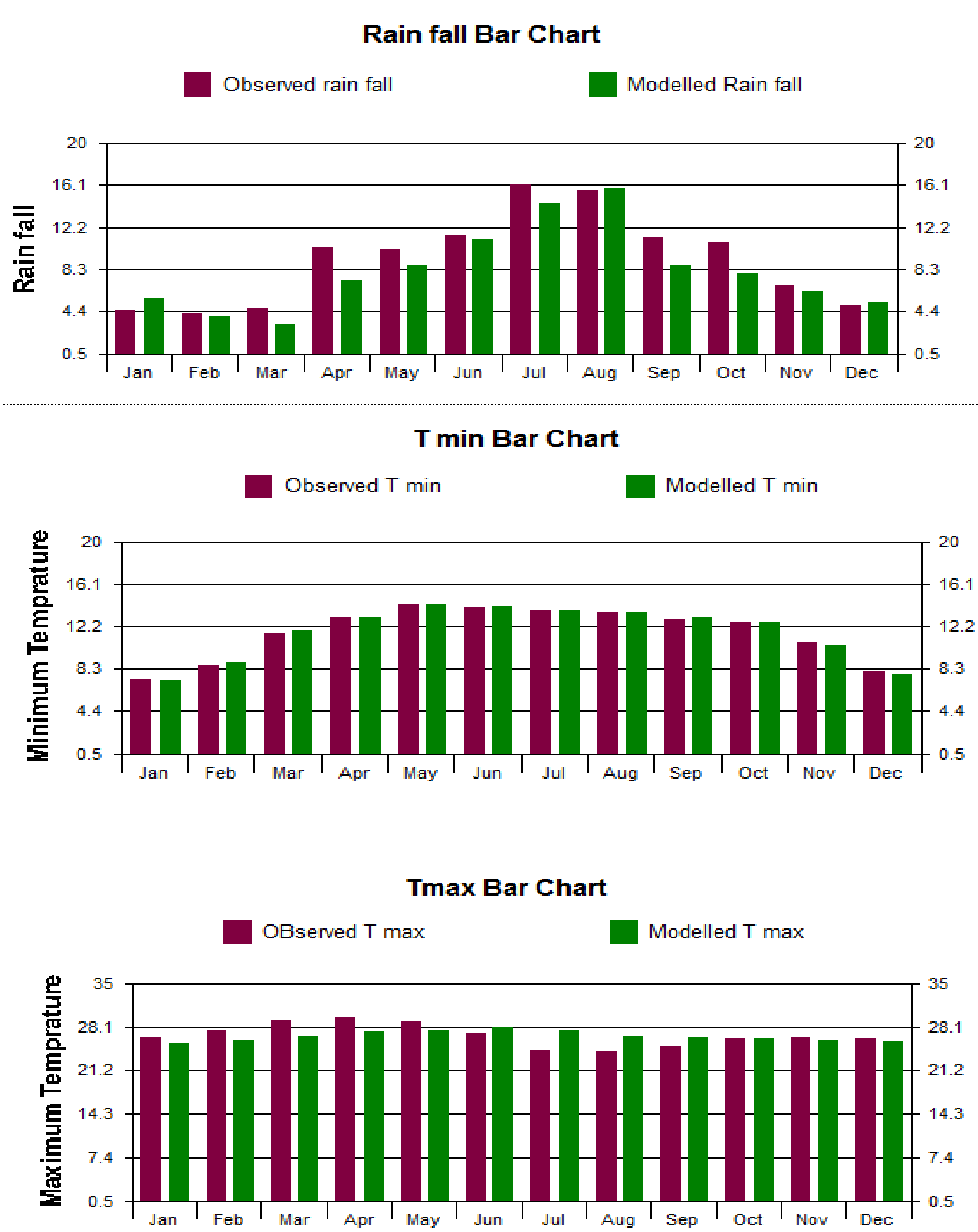


Figure 22: Bar chart of observed and modeled variables of Can ESM2 Model

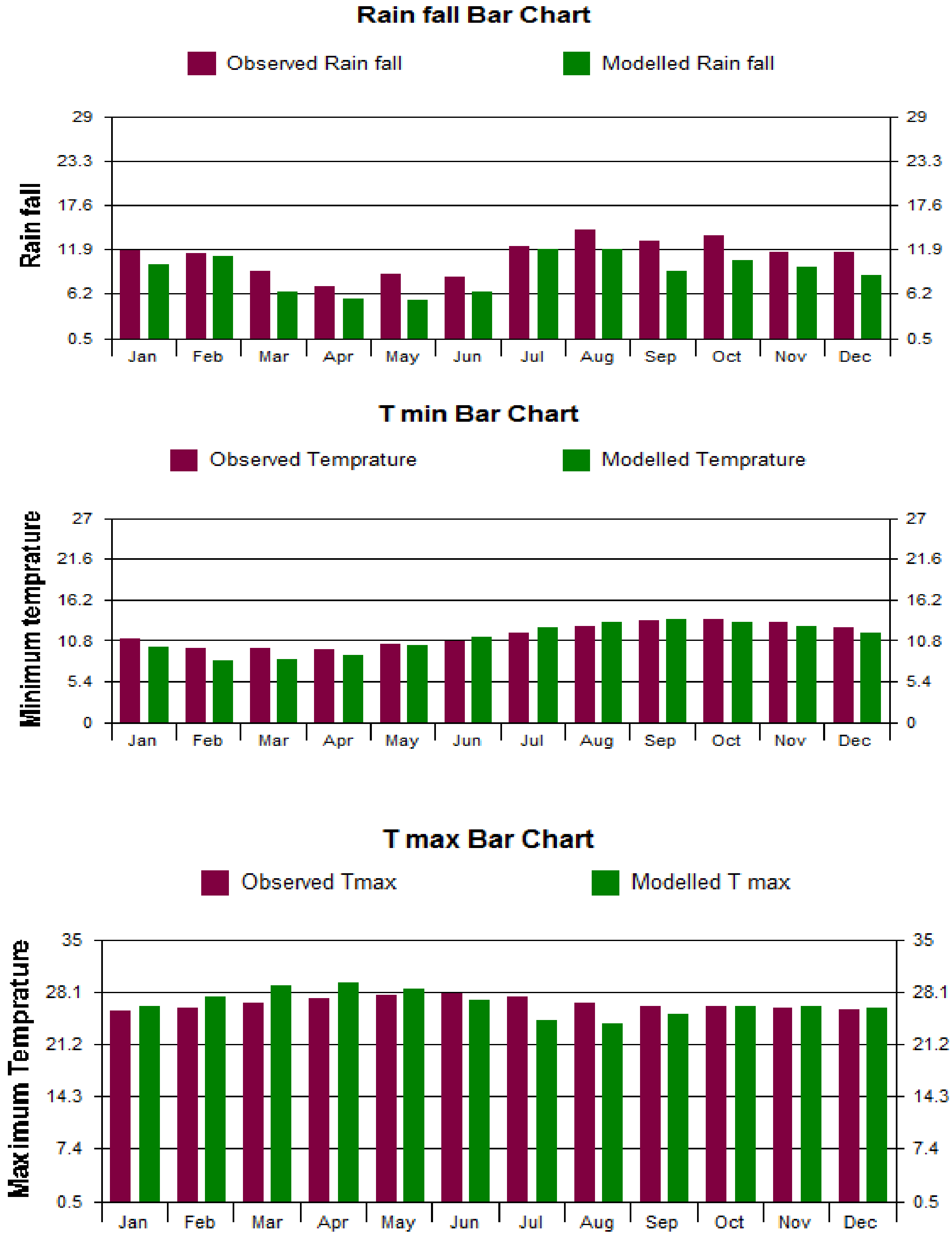


Figure 23: Bar chart of observed and modeled variables of HadCM3 Model

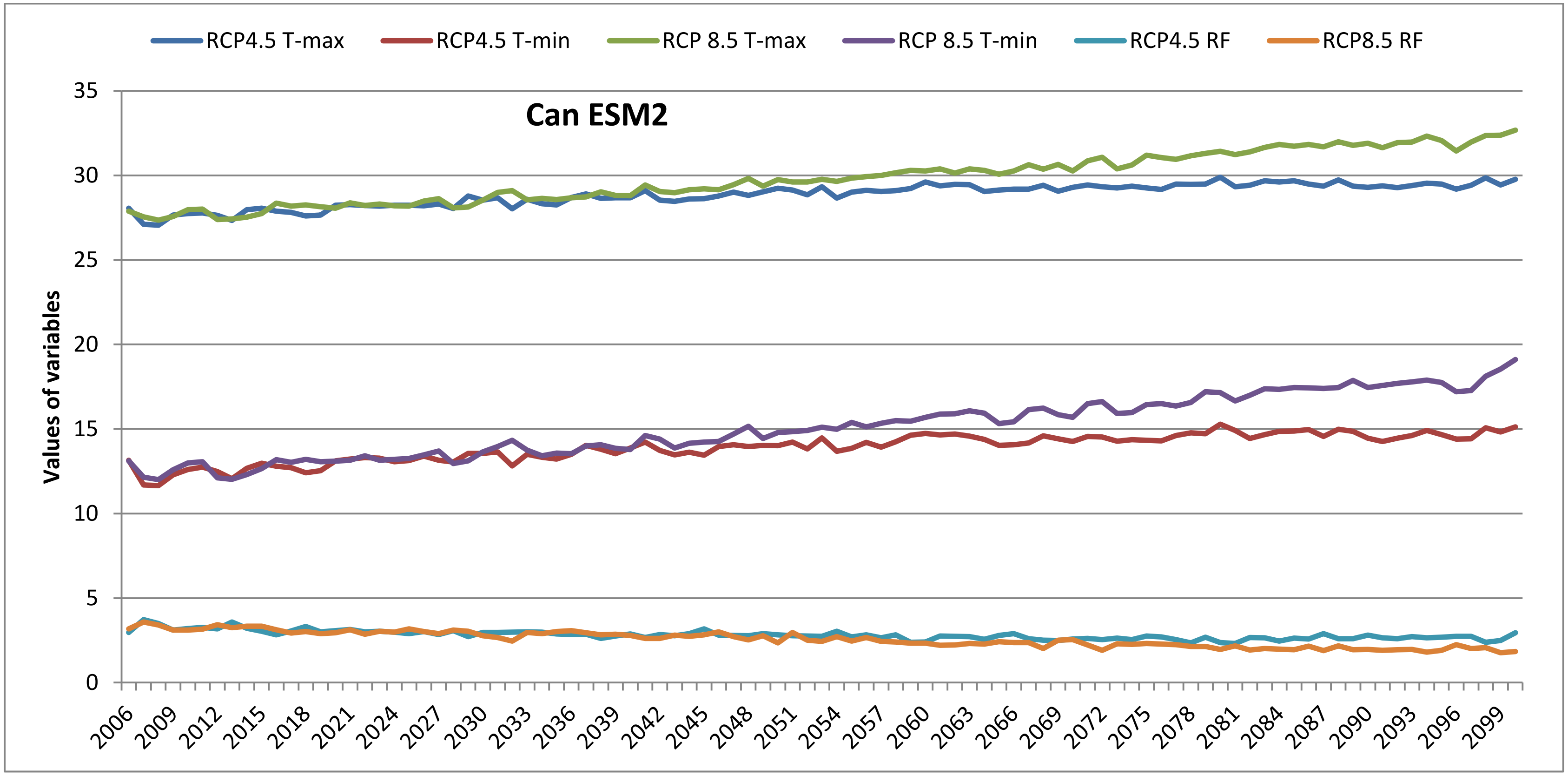


Figure 24: CanESM2 weather variables projections (2006-2100)

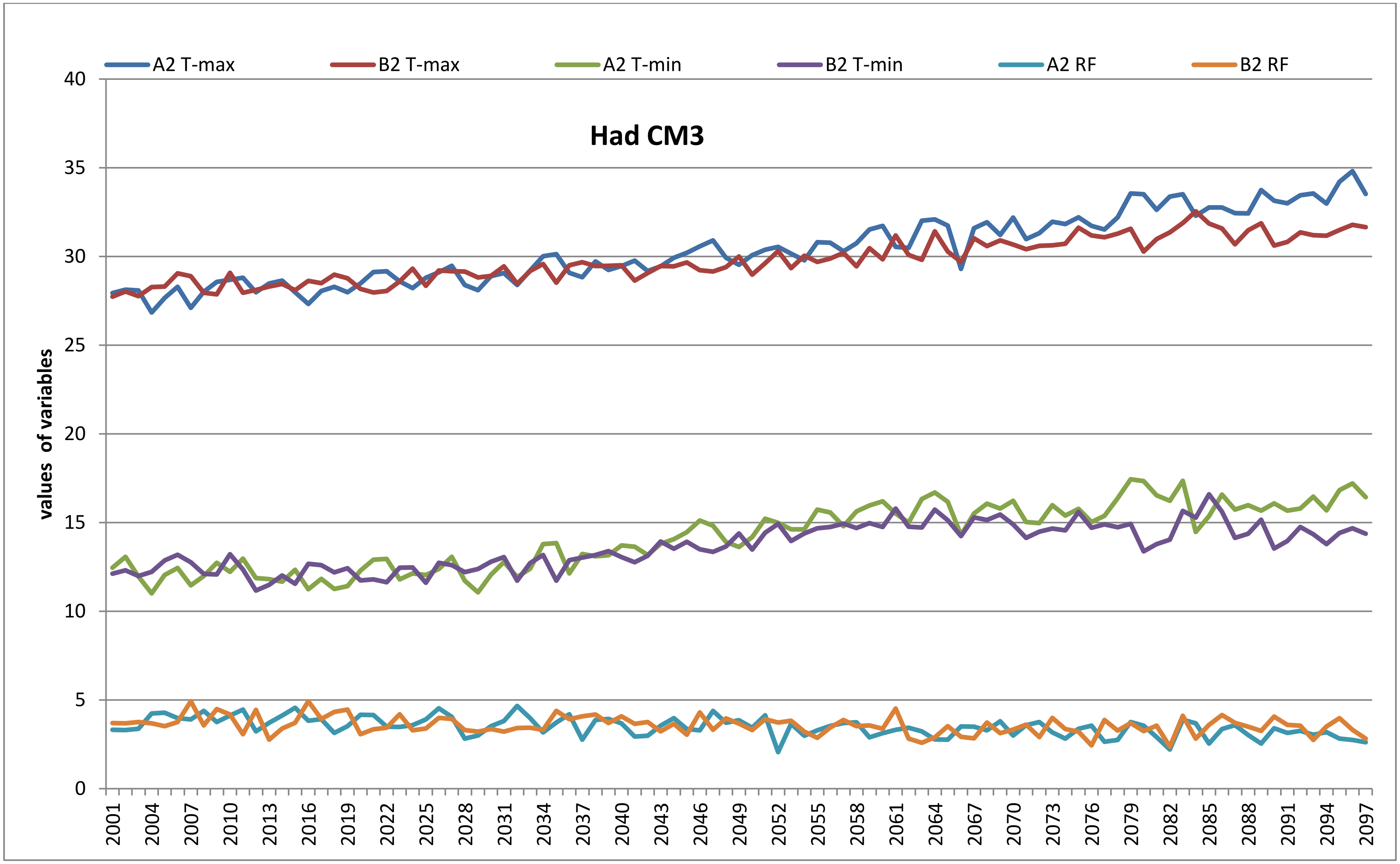


Figure 25: HadCM3 weather variables projections (2006-2099)

The downscaled weather variables (T-min, T- Max and Rain fall) in the two GCMs were equally divided in to three time periods: 2020s (2013-2042), 2050s (2043-2072) and 2080s (2073-2099). This enables to evaluate the trend and extent of changes in temperature and rain fall in compression to the base period 1961-2000/2005. Slicing the future time period is a common ways of climate change study and also used by (Elshamy *et al*. (2009), Gebre and Ludwig (2015) and Setegn *et al.* (2011*)* follows the same procedure in their climate change studies.

The two GCMs used in the future climate scenario studies shows an agreement in temperature increase for the three sliced future periods and in monthly bases as well. However, consensus reached in decreasing mean rain fall changes for all time periods, for all types of scenarios, but no agreement was shown when analyzed in monthly bases. Mostly multiple GCMs used in future climate change studies shows agreement for the direction of mean temperature change. However, it is unlikely to show consensus whether the future change in rain fall is increasing or decreasing. Few of the GCMs show increasing, other decreasing and few show no change. For instance; Elshamy *et al*. (2009) in the study conducted in Blue Nile used 17 GCMs from IPCC AR 4 and 10 GCMs shows increasing while 7 are decreasing. On the other hand, Gebre and Ludwig (2015) used 5 recent RCP based GCM for the study conducted in Tana sub basin. Four of the GCMs showed an increasing rain fall change while one GCM showed decreasing trend for 2030s and 2070s except for RCP 8.5. However in this study, despite of using the latest RCP based scenario which was founded during the IPCC Assessment Report 5 (AR5), the result of rain fall didn't show the same direction with above mentioned studies. Because the result obtained during this study, dominantly shows decreasing trend for monthly bases while the study conducted by Gebre and Ludwig (2015) absolutely indicating increasing rain fall across all time periods except one GCMs showing reduction in rain fall.

As it is clearly shown in Figure 26 (b), the monthly change in rain fall in most of the months along all future periods simulates reduction. However in the period 2013-2042 in the months of March and April increasing was observed. In the period of 2043-2099, all models showed increasing at March and RCP 4.5 and 8.5 also increasing again at April. During 1972- 2099, January, February, March, April and May months' showed positive change in rain fall. But a remarkable increase was projected at the month of April which was above 100%.

Temperature changes presented in Figure 26 (a) showed increasing for all months of the three time periods for both Scenarios originating from SRES (HadCM3) and recent RCPs (Can ESM2). Temperature also keeps the same increasing trends for all time periods for the averaged future time periods as illustrated in Figure 27 whereas rain fall decreased for all scenarios and time periods.

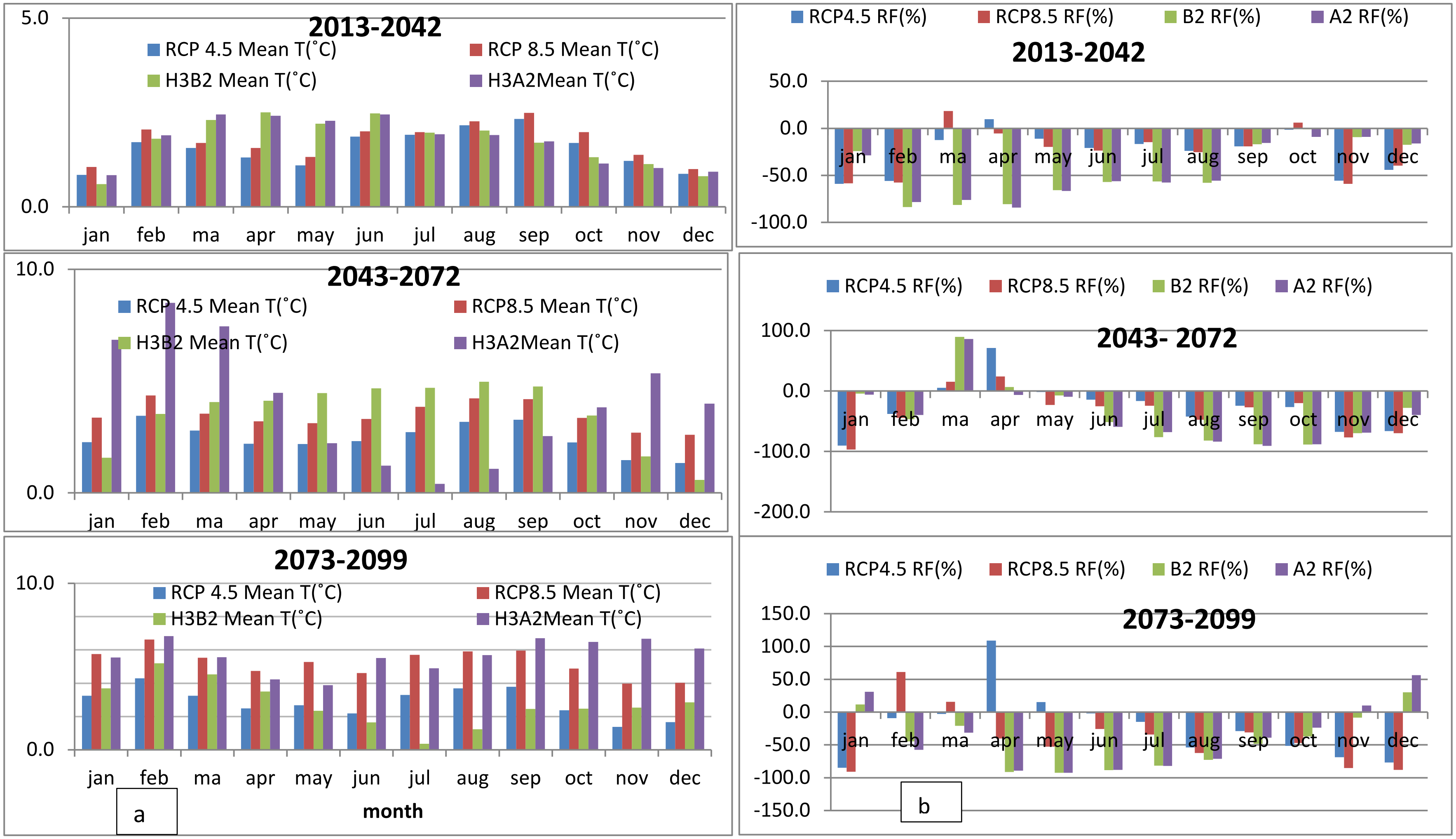


Figure 26 : Mean Monthly Change in Temperature (a) and Rain fall (b) for three time periods

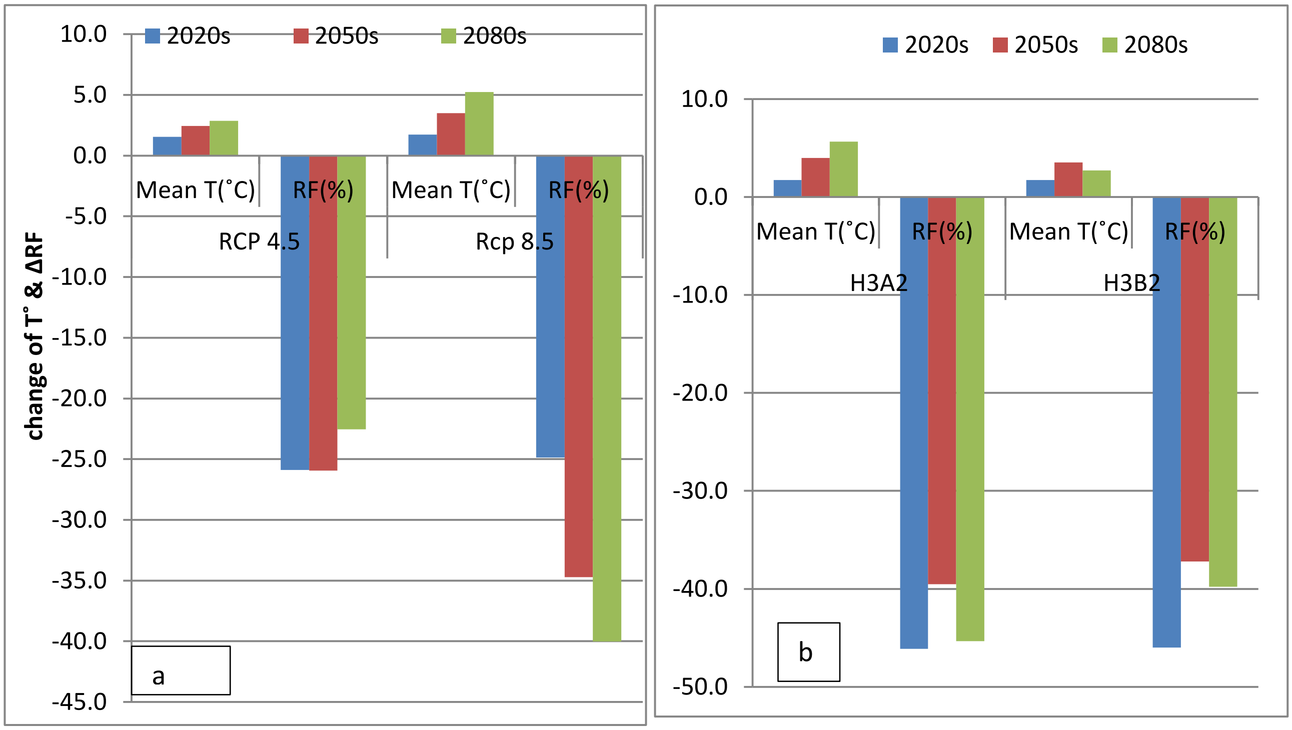


Figure 27: Change in temperature (˚C) and rain fall (%) for CanESM2 (a) and HadCM3 (b).

The generalized change in temperature and rain fall follows increasing and decreasing trends respectively as it shown in Figure 27. Both scenarios from the two GCMs were chosen, in order to represent the average and extreme level CO_2 Emissions. RCP 8.5 and A2 scenarios were based on the assumption of extreme CO2 emissions while RCP4.5 and B2 for average conditions.

Beyene *et al.* (2009) discussed that SRES A2 scenarios projected warmer temperature than SRES B2 and the same thing is also observed here. Among RCP scenarios, 8.5 is more wormer than 4.5 and these all might be linked with the CO_2 emissions they represent because in B2 scenario the world population assumed to be stagnant with high economic growth and technological advancement. Hence less CO_2 emissions are assumed in B2 scenario whereas the reverse is true for A2 Scenario. Their respective CO_2 emissions equivalent is figured out in Table 1 in literature review section.

IPCC (2014) projected global mean surface temperature will rise by 1.4˚C and 1.8˚C in the period 2046-2065 and 2081-2100 respectively under RCP 4.5 scenario. And by RCP 8.5 scenario, it is suggested to increase by 2˚C and 3.7˚C with respect to the above mentioned periods. However, as it clearly indicated in Table 18, the model used in this study, a little bit over estimated than the global mean temperature. The reason behind is that the global mean temperature projection was made by using multiple GCMs average.

Abdo (2008) also projected the mean temperature of Gilgel Abay catchment for the end of the century will be 3.7 ˚C and 2.7 ˚C for HadCM3 A2 and B2 scenarios respectively. More over IPCC-DCC cited in Abdo (2008), the future increase in temperature for Africa ranges from 2 ˚C to 5 ˚C at the end of 2100. The result obtained in this study, more or less agrees for B2 scenario where as A2 scenario showed great variation. (See Table 18).

4.3. IMPACT OF CLIMATE CHANGE ON THE HYDROLOGY OF THE CATCHMENT

Table 18: Summery of temperature and rain fall changes

GCM/ Scenario		HaDCM3		CanESM2	
		A2	**B2**	**RCP4.5**	**RCP8.5**
ΔRF(%)	2020s	-46.1	-46	-25.9	-24.9
	2050s	-39.5	-37.2	-25.9	-34.7
	2080s	-45.3	-39.8	-22.5	-40
ΔT (˚C)	2020s	1.7	1.7	1.5	1.7
	2050s	4	3.5	2.5	3.5
	2080s	5.7	2.7	2.9	5.2
ΔPET (%)	2020s	5	5	4.4	5
	2050s	12.7	10.5	7.1	10.2
	2080s	17.3	8.4	8.4	15.8
ΔWYLD (%)	2020s	-71.3	-71.1	-31	-32
	2050s	-86.6	-86.7	-38	-50.7
	2080s	-90	-87.7	-40.3	-66.8
ΔSW (%)	2020s	-24.8	-24.5	-12.7	-13
	2050s	-71.4	-76.8	-18.4	-23.1
	2080s	-34	-50	22.3	-34.3

Based on the study, the hydrology of Andasa catchment will be highly affected due to the future climate change. It is known that climate change critically alter water resource system components. A decreasing trend in rain fall coupled with an increasing temperature alters surface runoff, ground water flow, deep percolation and most importantly evapotranspiration and water yield of the catchment. It is clearly shown both in Table 14 and Figure 28.

Netsanet (2011) in the study conducted at Upper Blue Nile basin investigated that due to future climate change, the simulated stream flow has reduced in the range of -10% to -61% where as in this study, the minimum reduction ranges 22.5% by RCP4.5 scenario in the period of 2073-2099 to a maximum of 46% is projected by Had CM3 model B2 scenario in the time of 2013-2042.

Netsanet (2011) also investigated an increasing of PET and decreasing of actual evapotranspiration and elaborates the reason that PET increases due to the increasing of temperature alone. Whereas actual evapotranspiration is decreasing since it depends on temperature and other factors directly or indirectly affected by rain fall such as Soil moisture, interception by canopy and plant transpiration. In other way, when the soil layer is not in the position to fulfill the evaporative demand, causes a reduction of Actual evapotranspiration for the HRU (Neitsch *et al.*, 2009)

The declining trend in rain fall that ranges -22.5% to -46.1% coupled with the raising of temperature for all sliced periods results a diminished water yields in the catchment. As indicated in Table 18, the water yield for the three periods under four scenarios ranges minimum -31% and a maximum of -90% from the base period.

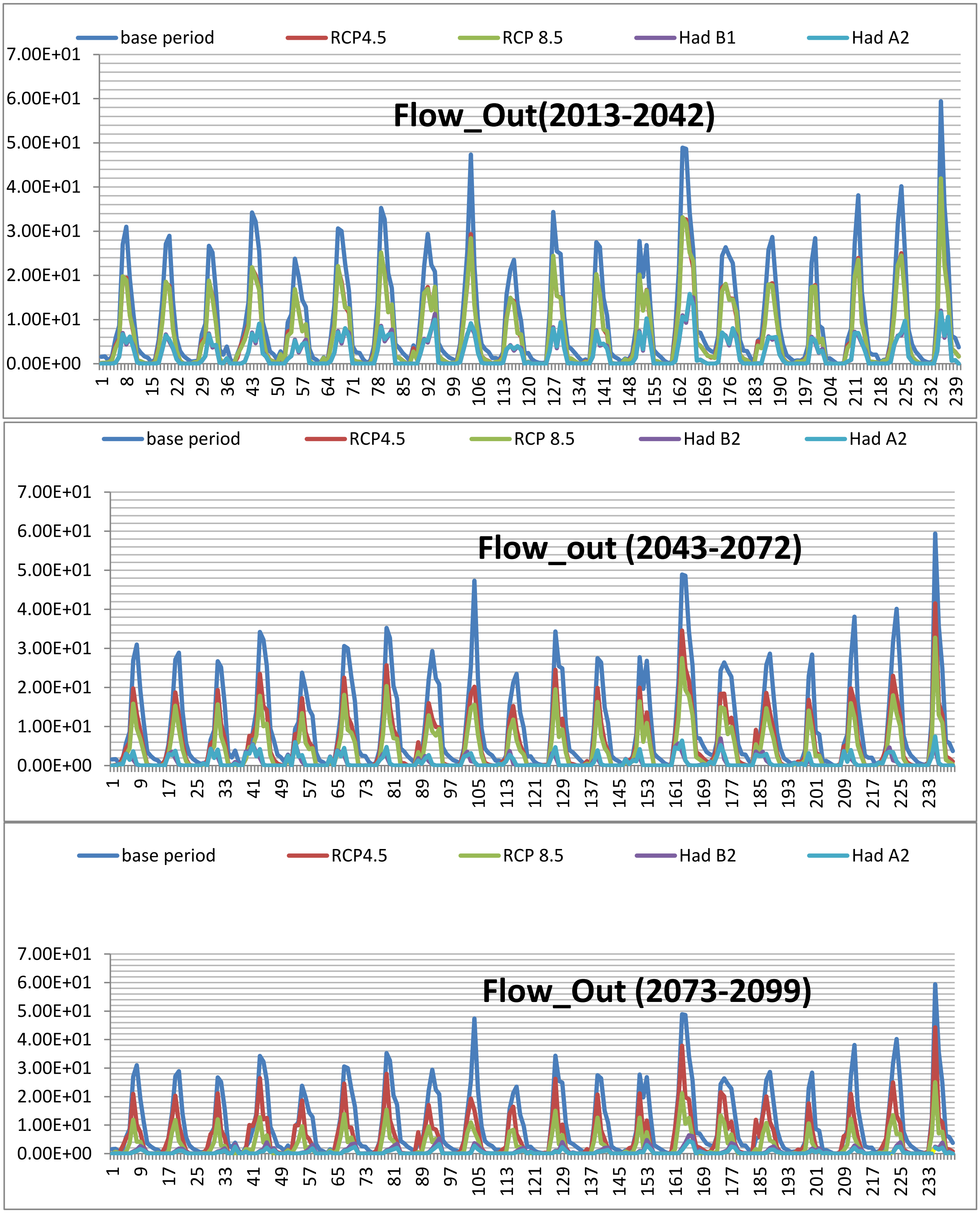


Figure 28: Stream flow for the base period and future scenarios

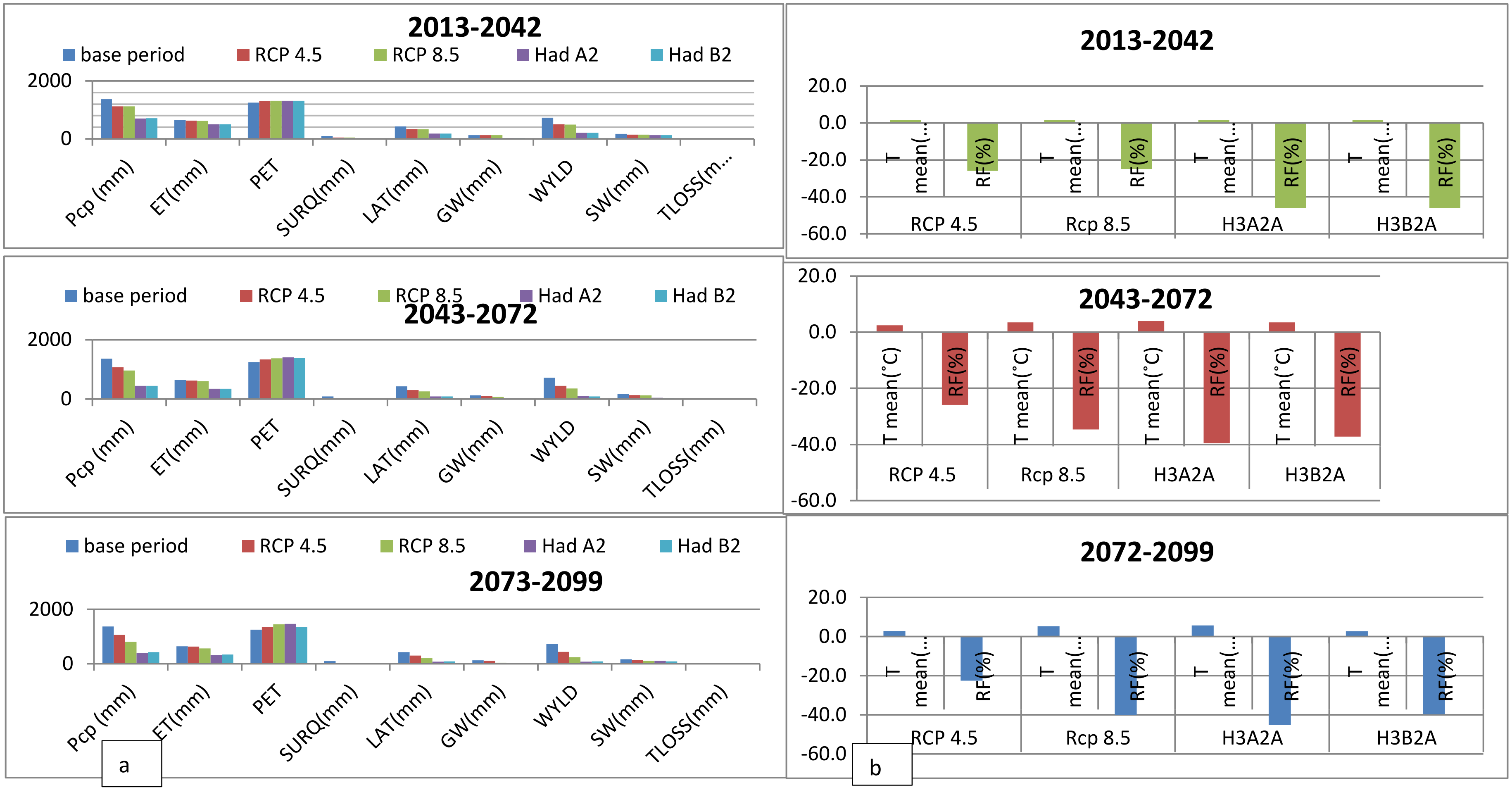


Figure 29: Change of water balance (a) due to change of temperature and rain fall (b) of the Catchment**.**

NB: Pcp : Rain fall, ET : Actual Evapotranspiration, PET : Potential Evapo- Transpiration, SURQ: surface flow, LAT: Lateral flow GW : Ground Water recharge, WYLD: Water Yeild, SW : Soil Water, Tloss: Transmission Loss

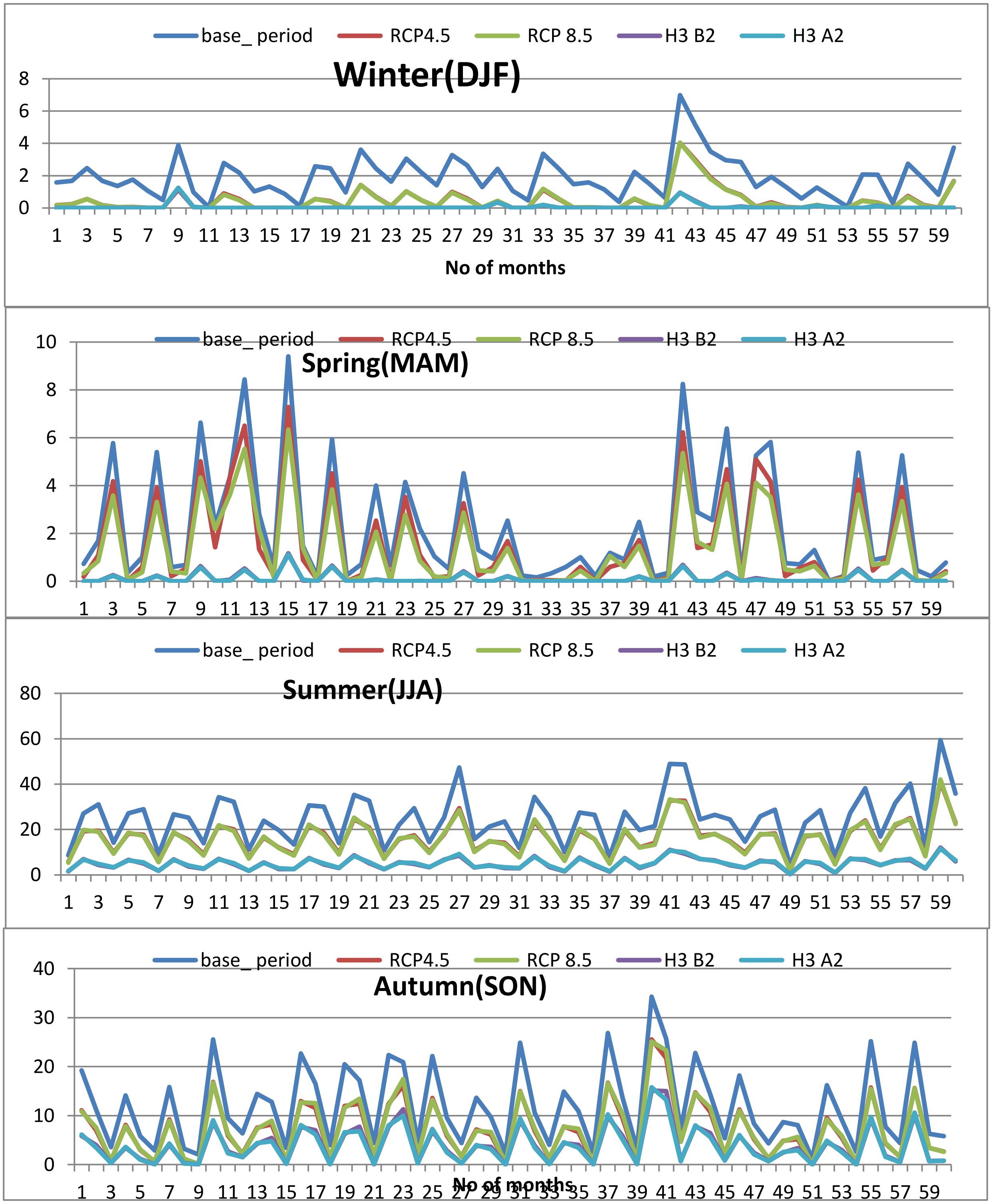


Figure 30: Seasonal Flow in the period of (2013-2042)

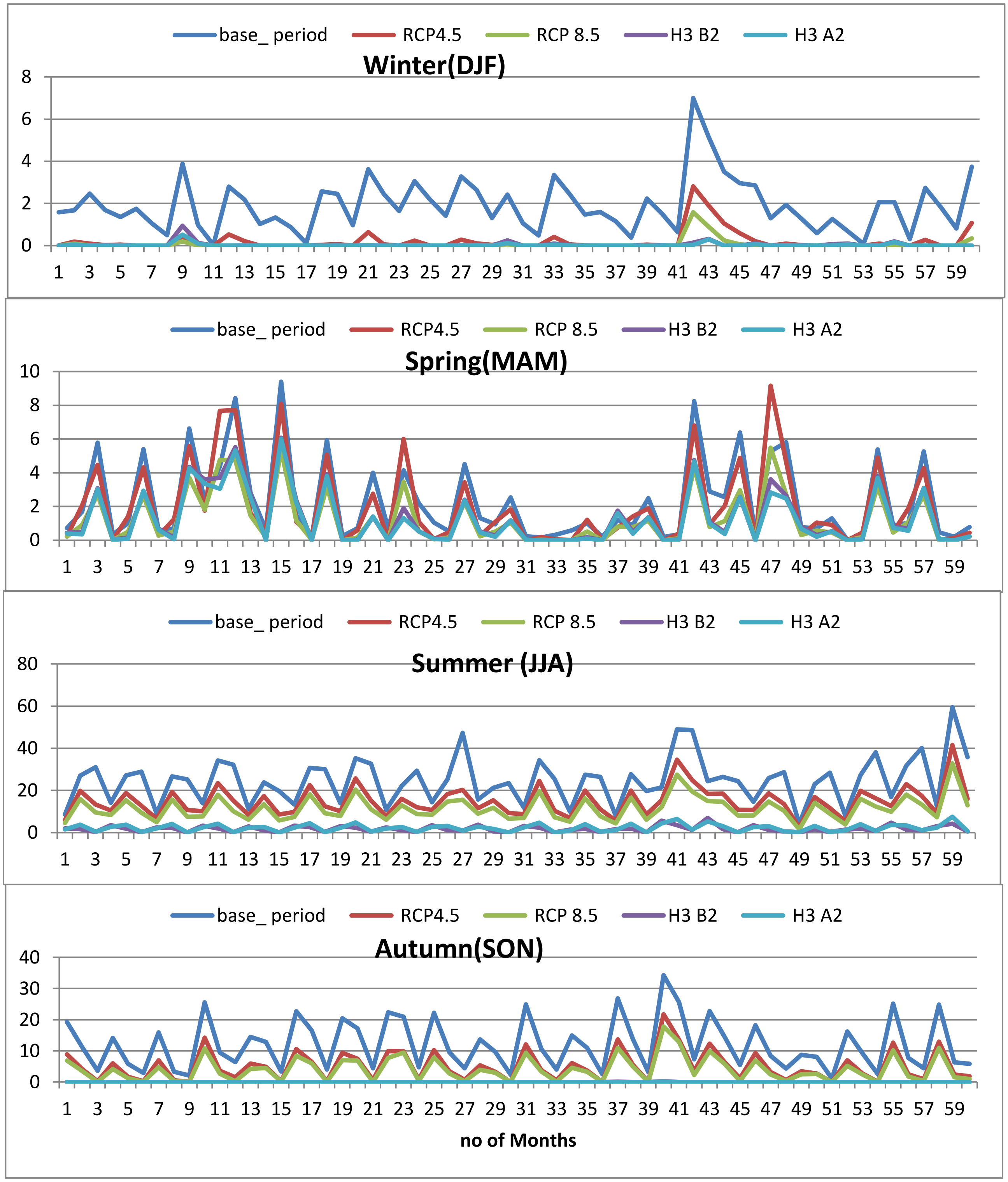


Figure 31: Seasonal flow in the Period of 2043-2072

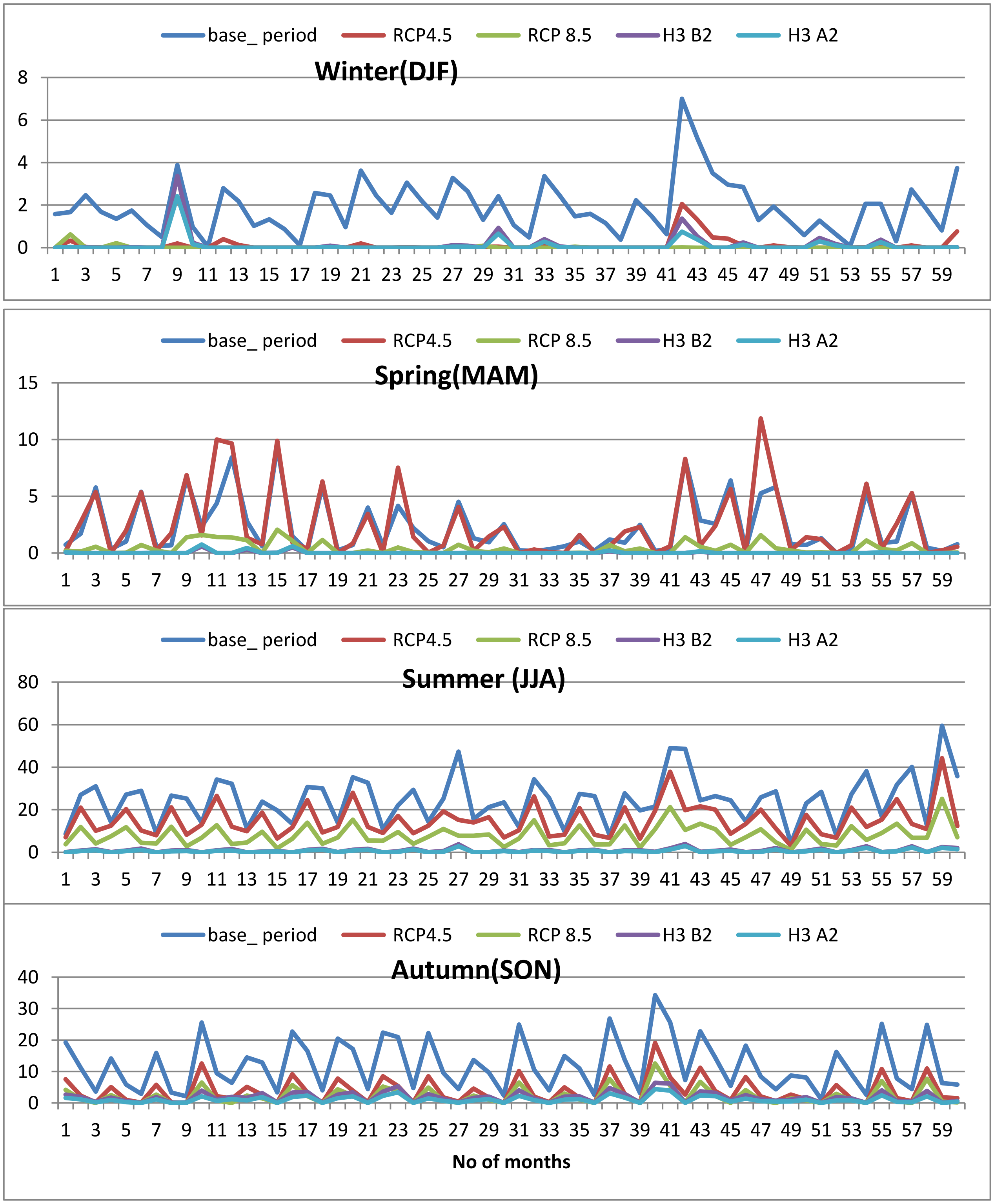


Figure 32: Seasonal flow in the Period of (2073-2099)

Despite the increase in stream flow projected RCP 4.5 in the season of spring for 2020s (Figure 30) and 2080s (Figure 32), the rest seasons in all sliced time period indicated a reduction in stream flow and the raising of stream flow observed in springs of 2020s and 2080s is because of the increase in rain fall in March, April and May for RCP 4.5 scenario. In particular at April in 2080s more than double increases in rain fall results maximum stream flow than the base period.

The other thing to be noted in the Figure 30, 31 and 32 is that the Hadley center model scenarios A2 and B2 always lies below due to their extreme reduction in rain fall projection whereas temperature projection was all most near the same with CanESM2 scenarios(RCP4.5 and RCP8.5).

Though variations in simulated stream flow among Scenarios, even among one GCM scenarios (especially between A2 and B2) were observed, but all scenarios capable to simulate the seasonal patterns. For example; during summer (the rainy season for the study area) all scenarios of the two GCMs simulate relatively high stream flow than other seasons. This indicated that both models were efficient to simulate the seasonal variability let alone inter variations in magnitude of simulation.

Beyene *et al.* (2009) reported that the multi model averages of 11 GCMs show increases in rain fall early in the century and decline the end of 21st century.

4.4. COMPARISON OF LAND USE/COVER BASED ON WATER BALANCE

4.4.1. LAND USE/COVER SCENARIO FOR THE PERIOD (1993-2012)

Based on previous literature values, the following land use change scenario is developed. " if Land Uses currently classified as a combined land use so called " cropland-wood land mosaic (CRWO) which lies in 10% slope and above afforested by either soil and conservation program or by the land owners for their economic values". As it shown in figure 33 and 34, changes were observed due to 58.45 km^2 CRWO land use changed in to mixed forest (FOMI) and raised its initial coverage from 108.85 km^2 to 167.18 km^2.

As the result of the following suggested scenario, lateral flow and return flow shows increments while surface flow and actual evapotranspiration is decreasing. These elaborates that the afforestation more favors for infiltration and less demand for actual evapotranspiration than the base period land use (CRWO). The same result for subsurface flow increments was stated by Rientjes et al. (2011), though they stated differently about actual evapo-transpiration. Rientjes *et al.* (2011) noted that forest areas increases actual evapotranspiration losses than agriculture. But in this study it was observed that 0.6% reduction in actual evapo-transpiration. It is probably because of the change in land use is not from agriculture to forest rather it is from mixed land use of cropland and wood land in to forest area.

The simulation result for the two cases is illustrated in Figure 33 and summarized in Table 15.

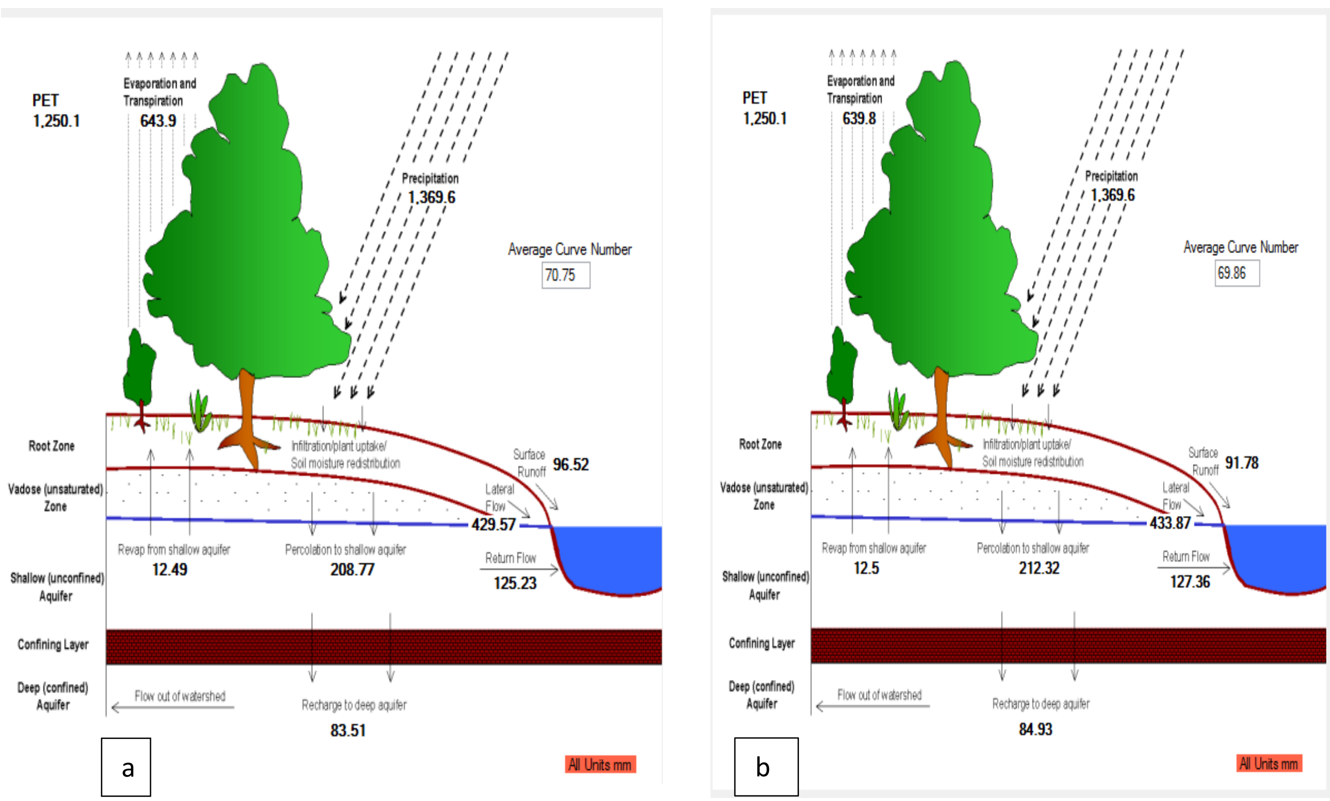


Figure 33: Water balance for (a) base LULC and (b) land use change scenario (right)

It is clearly indicated in Figure 33; the afforestation scenario produced an improved dry season flow than the previous flow due to the enhanced recharge.

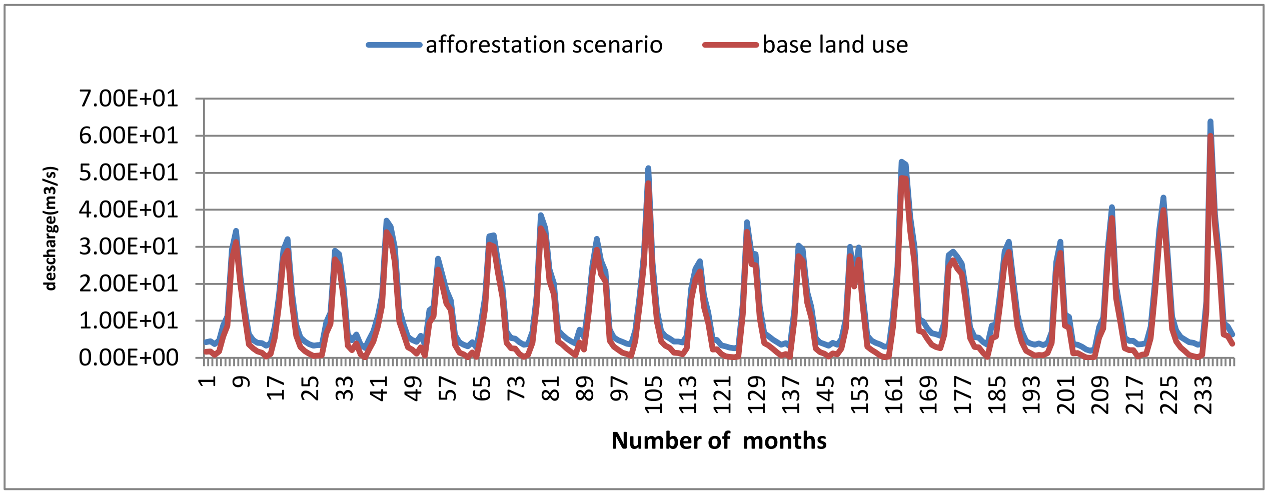


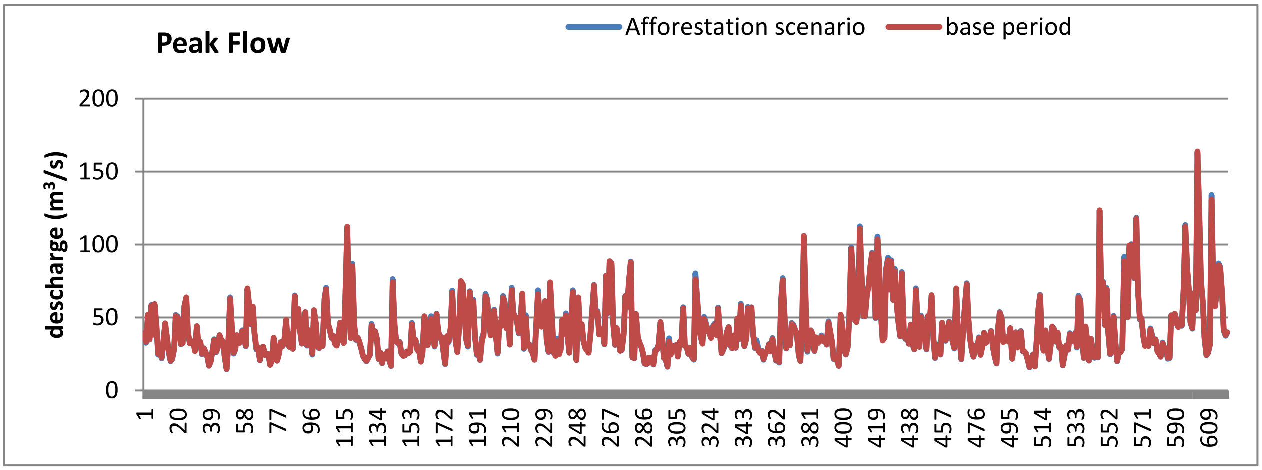
Figure 34: Stream flow for the two Cases

According to the Result obtained in land use change scenario, afforestation in sloppy areas (10% and above) can maintain stable dry season flows. For instance; surface flow reduced by 4.9 percent whereas lateral flow, return flow and ground water (shallow and deep aquifer) recharge raised by 1 and 1.7 percent respectively. It is presented in Table 19.

Table 19: Summery of Hydrological Components**.**

Hydrological components	Base land use	Land use change (Afforestation Scenario)	Change (%)
PET	1250.1	1250.1	0
ET	643.9	639.8	-0.6
Revap	12.49	12.5	0.08
SURQ	96.52	91.78	-4.9
LAT Q	429.57	433.87	1
Return Flow	125.23	127.36	1.7
Shallow aquifer recharge	208.77	212.32	1.7
Deep Aquifer Recharge	83.51	84.93	1.7

Based on 30 days filtered minimum and maximum flows, the difference is more apparently observed as indicated in Figure 35. The afforestation scenario produced greater minimum flow than base period. However, in the case of peak flow, the difference is not that much visible.



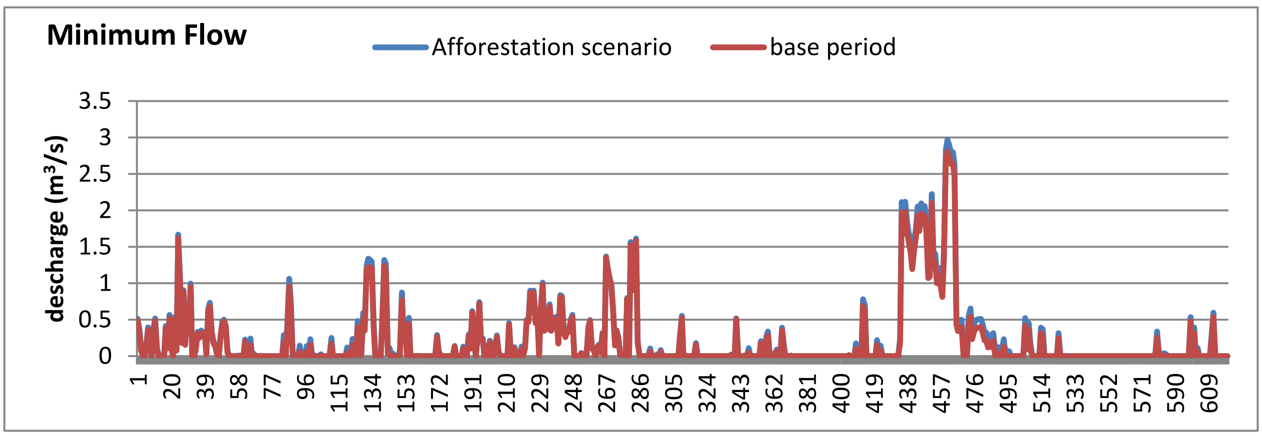


Figure 35: peak and minimum flow

In contrast to this study, the study conducted by Tekleab *et al.* (2014) at Jedeb catchment, Upper Blue Nile basin agricultural land use practices causes extreme peaks due to the reduction of retention capacity of the soil. However, the afforestation scenario in this study enhances infiltration which is manifested by the increased base flow, return flow, aquifer recharge and by the reduction of surface flow. Hui *et al.* (2014) simulate for the " conversion of farm land to forest land, terrace and no till farming'' scenarios and agreed with result obtained in this study.

4.4.2. LAND USE/COVER SCENARIO FOR THE PERIOD (2013-2042)

The worst case scenario (if all LULC of the catchment has changed in to agricultural land) due to agricultural land pressure and the best case scenario (conservation activity implemented (enclosure and Afforestation) were developed for the future period (2013-2042).

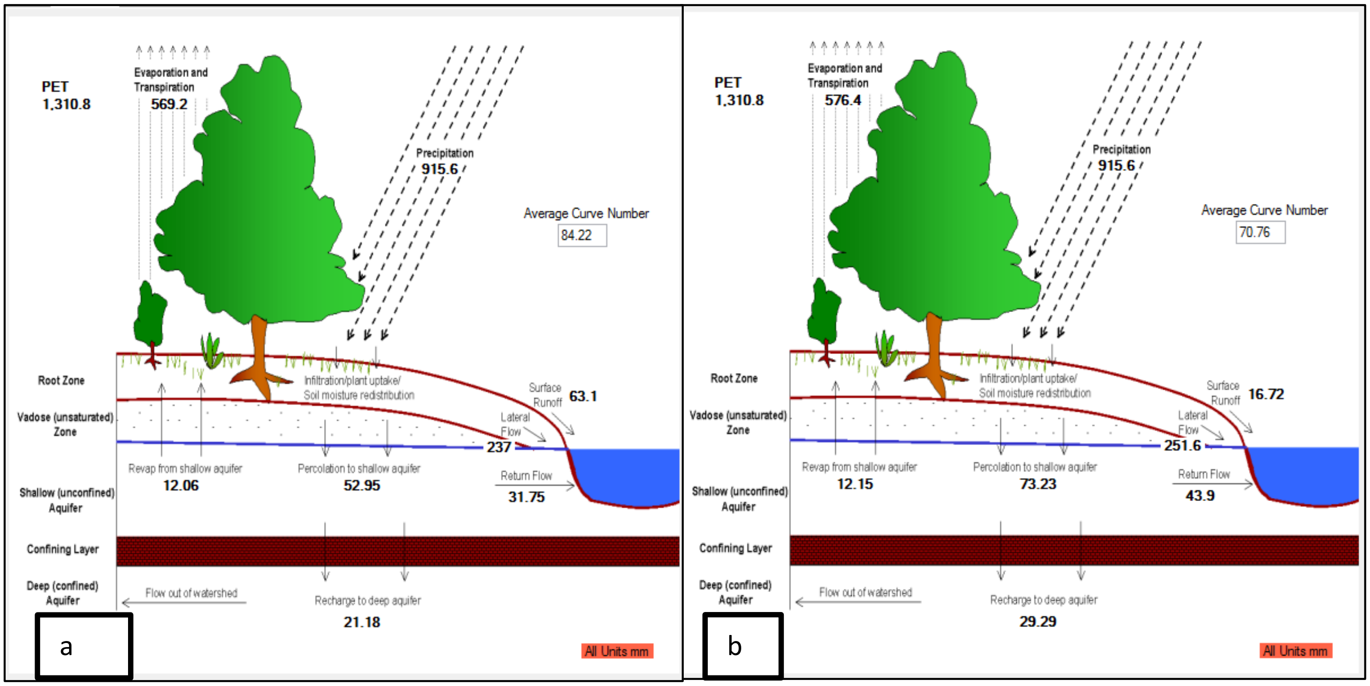


Figure 36: conservation Scenario (a) and agricultural Expansion scenario (b)

Based on the result shown Figure 36, high stream flow with low base flow and ground recharge were observed in Figure 36 (a) in comparison to Figure 36 (b), which represent the conservation scenario. The reason behind is that agriculture aggravates surface run off by reducing the possibility of infiltration and further aquifer recharges. Whereas conservation activity initiates infiltration by improving cover to intercept surface flow and pore space of the soil. This was approved by Tekleab *et al*. (2014) in the study conducted in Jedeb mesoscale catchment. The PET here in Figure 36 has changed from the base period presented in Figure 33 is because of the change in weather input data particularly temperature in the future period (2013-2042). However, the change in evapotranspiration in Figure 36 (a) and (b) is due to the change in land use/cover. These are noticeable from Curve number variability between Figure 36 (a) and (b).

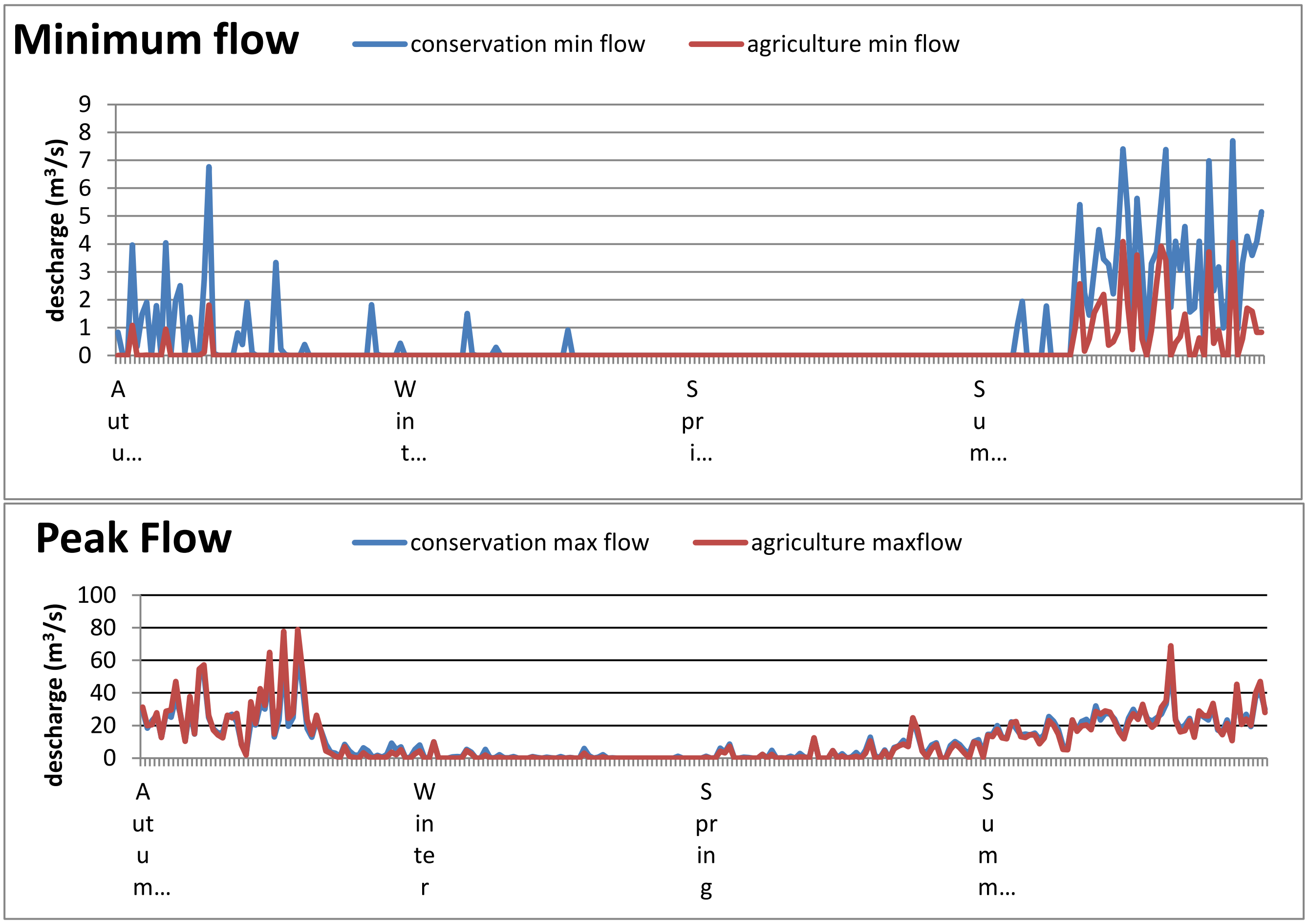


Figure 37: Minimum and peak flow of the future scenarios

The illustration presented in Figure 36 and 37, the land use change scenarios results changes in water balance components. For instance, conservation scenario in particular afforestation scenario maximizes evapotranspiration losses than agricultural land use expansions. This is mainly due to plant transpiration. The same finding is obtained by (Rientjes *et al*., 2011).

The seasonal stream flow response of the catchment for the two future period (2013-2042) scenarios are graphically shown by separating 30 day minimum and peak flow. The same result is presented in figure 35. The conservation scenario improves dry season flow.

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSION

The SWAT model was calibrated and validated to Andasa River catchment by using measured stream flow for the period of 1991-2012. The R^2 and Nash-Sutcliffe Efficiency (NSE) have a value of 0.86 and 0.84 respectively for calibration and 0.82 and 0.8 for validation respectively. The statistical values of R^2 and Nash-Sutcliffe Efficiency (NSE) obtained implied that SWAT model perform very well for the catchment.

Based on the results of sensitivity analysis conducted via SWAT CUP particularly by SUFI2 project, identified soil hydraulic conductivity (Sol_K), curve number (CN_2), deep aquifer percolation fraction (Recharge_DP), manning roughness coefficient for main channel (CH_N_2) and soil evaporation compensation factor (ESCO) were the top five sensitive parameters.

Future climate scenario was developed for the catchment level by downscaling GCMs by using SDSM 4.2. Three GCMs were used to downscale temperature (maximum and minimum) and rain fall for the period of 1961-2099/100. Among the three GCMs, two were selected based on R^2 value during calibration process; namely; HadCM3 the IPCC AR4 scenario and CanESM2 the IPCC AR5 (RCP based Scenario). And two scenarios were used from each selected GCMs in the way to represent the two extremes (low and maximum) of CO_2 emissions. Namely; A2 and B2 from Had CM3 and RCP 4.5 and RCP 8.5 from Can ESM2. An increase in monthly temperature and decreasing tendency of rain fall under all scenarios were observed. All scenarios agreed in increasing temperature in monthly as well as in the three sliced time periods. For Rain fall no consensus among scenarios in monthly bases were shown. However, decreasing rain fall trends were seen in the three periods while averaged.

Based on the result of climate change impact study, the hydrology of the catchment was highly affected. Except potential evapo-transpiration (PET), other hydrological components decline from the base period 1993-2012. The increasing trend in PET directly linked with the rise in temperature whereas actual evapotranspiration is reduced due to the increasing trend of projected temperature as well as decreasing tendency of rainfall. Actual evapotranspiration is partly depending on rain fall through soil moisture and canopy interceptions. Except RCP4.5 during spring season in the period of 2043-2072 others show reduction in rain fall subsequently in stream flow. The result obtained implied that, the catchment is more sensitive for climate change since it shows a drastic decline in stream flow due to the increasing temperature and decreasing rain fall.

Different land use scenarios in two temporal scale were developed by taking in to account literatures about the trends in land use change around the study area and by possible assumptions about the future. Reports show that afforestation has been encouraged in the recent time and also based on personal observation; afforestation/rehabilitation campaign has been promoted as part of Soil and water conservation measure in the study area. The one scenario is that if mixed land use so called previously cropland- wood land (CRWO) with slope 10% and above afforested so called in SWAT FOMI (mixed forest). This scenario has changed 58.2 km^2 land changed from CRWO to FOMI and results reduction of surface flow by 4.9% and increases base flow by 1%, return flow by 1.7% and shallow and deep aquifer recharge by 1.7%. The land use change scenario also produces stable base flow during dry season of the year. On the other hand for agricultural scenario which is developed for the future showed that high surface flow with low infiltration and ground water recharge when compared with the conservation scenario. Evapotranspiration was higher in conservation scenario than agriculture due to plant transpiration.

5.2. RECOMMENDATIONS

Based on the finding of the study, the following points are recommended.

- Due to decreasing rain fall and increasing in temperature, Andasa catchment and the people resides in side the catchments might very vulnerable because of water scarcity in the future. Therefore it is very imperative that every development project implemented in and around the catchment should encourage efficient water utilization
- More concern should have given for integrated water resource management.
- The livelihoods and the land use system of the people reside in the catchment have to be modified in way to adapt climate change impacts.
- Soil and water conservation activities and soil moisture enhancement techniques including afforestation should get high concern to compensate the projected climate change impact.
- Climate change induced land use change and change in land use by itself is not considered. Therefore future research intervention is expected to evaluate long term land use change impact on the catchment hydrology.
- Based on the investigation, RCP scenario based Projection earns better performances over SRES based Scenarios. Therefore it is more recommended to use RCP based scenarios.
- Soil and water conservation interventions should be effectively implemented and more emphasis has to give for afforestation interventions.

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7. APPENDIX

Appendix Table 7. 1: Andasa River flow data (m^3/s)

Year	Jan	Feb	mar	Apr	may	Jun	Jul	aug	sep	oct	Nov	dec
1993	3.1	2.0	1.5	1.4	2.0	5.9	24.8	26.7	19.7	12.1	6.2	3.6
1994	2.7	2.0	1.5	1.2	1.9	5.1	20.4	31.8	17.7	6.4	4.2	3.0
1995	2.0	1.5	1.4	1.2	1.4	2.9	21.7	31.2	19.7	6.1	3.8	2.6
1996	1.8	1.4	1.5	2.2	3.4	12.0	45.6	42.8	30.2	12.4	7.7	5.5
1997	3.1	3.3	2.8	1.6	4.4	6.2	16.5	19.6	9.9	15.4	5.6	2.5
1998	1.8	1.3	1.1	1.0	3.3	12.1	31.1	38.2	26.8	23.8	8.3	5.4
1999	4.1	2.8	1.7	1.4	1.6	3.5	29.4	29.0	12.3	16.3	5.6	3.5
2000	2.4	1.7	1.3	1.4	1.1	2.6	9.3	40.6	30.3	25.5	7.4	3.7
2001	2.4	1.7	1.3	1.1	1.4	6.2	21.6	37.9	15.5	7.0	4.2	3.0
2002	2.2	1.6	1.3	1.0	1.0	4.3	11.9	21.0	9.7	5.5	3.5	2.2
2003	1.6	1.2	1.0	0.8	0.7	2.8	36.1	34.0	24.2	10.1	4.5	3.0
2004	2.1	1.5	1.1	1.2	0.8	2.0	20.9	30.1	17.8	10.5	4.3	2.7
2005	1.9	1.3	1.1	0.9	0.9	3.0	16.3	17.4	21.8	13.4	4.3	2.5
2006	1.9	1.4	1.3	1.1	2.2	6.3	19.8	56.1	20.7	13.2	7.5	4.5
2007	3.2	2.4	1.7	1.5	1.8	8.4	23.1	25.1	20.0	8.7	4.7	3.0
2008	2.3	1.7	1.2	1.7	3.0	4.8	19.3	32.5	15.7	8.3	5.4	2.8
2009	2.2	1.7	1.5	1.3	1.2	1.7	15.1	23.9	9.6	5.1	2.7	2.1
2010	1.7	1.3	1.1	1.0	2.7	7.9	30.7	45.7	21.9	7.6	4.3	3.1
2011	2.4	1.8	1.3	1.2	2.5	15.3	23.9	31.3	19.1	6.3	6.6	3.1
2012	2.2	1.6	1.4	1.1	1.1	5.7	24.2	26.1	19.9	7.1	5.6	4.0

Appendix Table 7. 2: Weather data

	Rain fall (mm)				Solar Rad(MJ/m^2/day	Minimum Temprature(˚C)			Maximum Temprature (˚C)			Relative Humidity (%)		Wind speed (m/s)	
Month	Bahir Dar	Adet	Merwi	Meshnt	Bahir Dar	Bahir Dar	Adet	Merwi	Bahir Da	Adet	Merwi	Bahir Dar	Adet	Bahir Dar	Adet
jan	0.1	0.2	0.1	0.1	16.8	8.5	6.4	8.0	27.4	26.8	28.4	54.3	57.8	0.9	0.8
feb	0.0	0.2	0.0	0.0	12.4	10.3	8.1	9.4	29.5	28.6	29.8	50.5	55.2	1.0	0.9
mar	0.3	0.7	0.7	0.4	16.6	12.7	9.6	11.0	30.1	29.3	30.6	50.2	52.1	1.1	1.0
apr	0.9	1.9	1.4	0.7	11.5	14.7	11.3	13.5	30.6	29.2	30.0	51.5	53.7	1.3	1.1
may	2.4	3.4	4.0	2.9	7.1	15.1	11.9	13.9	29.8	28.3	28.9	57.6	59.5	1.1	1.0
jun	7.2	5.3	10.6	8.2	13.3	14.6	11.8	13.9	27.4	25.8	26.2	68.1	72.4	1.0	0.9
jul	15.0	10.6	13.5	12.7	8.5	14.4	11.9	13.5	24.6	22.8	23.6	75.6	82.6	0.7	0.8
aug	12.9	8.9	11.7	10.0	5.2	14.2	11.7	13.0	24.6	22.8	24.3	75.7	83.9	0.7	0.7
sep	7.0	5.7	7.6	5.7	18.5	13.6	10.9	12.3	25.8	24.3	25.3	71.4	77.2	0.7	0.7
oct	2.9	3.3	2.8	3.5	20.6	13.5	10.3	12.1	26.8	25.0	26.7	66.1	70.9	0.7	0.7
nov	0.4	0.9	0.7	0.3	21.0	11.3	8.4	10.1	27.1	25.6	27.5	60.0	67.0	0.8	0.6
dec	0.1	0.3	0.3	0.2	20.2	8.9	7.3	8.4	27.1	26.1	27.8	55.9	66.6	0.8	0.7

Appendix Table 7. 3:Mann_kendall Trend test

XLSTAT 2017.02.44125 - Mann-Kendall trend tests - Start time: 2017-05-10 at 3:31:24 AM / End time: 2017-05-10 at 3:31:28 AM
Time series: Workbook = Book3 / Sheet = Sheet1 / Range = Sheet1!$A$2:$A$7306 / 7304 rows and 1 column
Significance level (%): 5
Confidence interval (%)(Sen's slope): 95
Run again:

Summary statistics:

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
4.021	7304	0	7304	0.382	195.000	9.113	15.077

Mann-Kendall trend test / Two-tailed test (4.021):

Kendall's tau	-0.020
S	-542040.000
Var(S)	43299986481.333
p-value (Two-tailed)	0.009
Alpha	0.05

An approximation has been used to compute the p-value.
Test interpretation:
H0: There is no trend in the series
Ha: There is a trend in the series
As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0, and accept the alternative hypothesis Ha.
The risk to reject the null hypothesis H0 while it is true is lower than 0.92%.
Ties have been detected in the data and the appropriate corrections have been applied.
Sen's slope: 1.447E-4
Confidence interval: [-0.000 , 0.000 [

7.1. GCM outputs

Appendix Table 7. 4: Projected climate change in the period 2013-2042

month		january	february	march	april	may	june	july	august	september	october	novembe	december	Annual
	PCP	-59.0	-56.0	-12.4	9.8	-11.1	-20.8	-16.7	-23.9	-19.3	-1.4	-55.7	-44.2	-25.9
	T_min	0.5	1.7	1.7	1.4	0.6	2.1	2.4	2.0	2.4	1.7	1.2	0.9	1.5
	T_max	1.2	1.7	1.4	1.2	1.6	1.6	1.4	2.3	2.3	1.6	1.2	0.8	1.5
RCP 4.5	T-mean	0.8	1.7	1.6	1.3	1.1	1.9	1.9	2.2	2.3	1.7	1.2	0.9	1.5
	PCP	-58.4	-57.6	18.3	-5.3	-19.7	-23.7	-14.7	-25.5	-19.2	6.0	-59.0	-39.5	-24.9
	T_min	0.6	2.0	1.9	1.7	0.7	2.2	2.5	2.3	2.6	2.1	1.3	1.1	1.7
	T_max	1.5	2.1	1.5	1.4	1.9	1.8	1.5	2.3	2.4	1.9	1.5	0.9	1.7
RCP 8.5	T-mean	1.1	2.0	1.7	1.6	1.3	2.0	2.0	2.3	2.5	2.0	1.4	1.0	1.7
	PCP	-28.8	-78.4	-76.1	-84.2	-66.6	-56.2	-57.6	-55.6	-15.6	-9.2	-9.2	-16.0	-46.1
	T_min	0.6	2.3	3.1	2.7	1.8	1.9	0.4	0.3	0.3	0.3	0.7	0.8	1.3
	T_max	1.0	1.5	1.8	2.1	2.7	3.0	3.4	3.5	3.2	2.0	1.3	1.1	2.2
H3A2	T-mean	0.8	1.9	2.4	2.4	2.3	2.5	1.9	1.9	1.7	1.1	1.0	0.9	1.7
	PCP	-24.2	-83.7	-81.4	-80.6	-65.7	-57.0	-56.5	-58.0	-17.1	-1.0	-9.5	-17.6	-46.0
	T_min	-0.1	2.0	3.1	3.0	1.9	1.9	0.6	0.4	0.4	0.4	0.8	0.7	1.2
	T_max	1.3	1.6	1.5	2.0	2.5	3.0	3.4	3.7	3.0	2.3	1.5	0.9	2.2
H3B1	T-mean	0.6	1.8	2.3	2.5	2.2	2.5	2.0	2.0	1.7	1.3	1.1	0.8	1.7

Appendix Table 7. 5: Projected climate change in the period 2043-2072

month		january	february	march	april	may	june	july	august	september	october	november	december	Annual
	PCP	-90.4	-37.8	5.3	71.1	-1.5	-14.3	-16.3	-42.2	-24.2	-26.7	-67.8	-66.3	-25.9
	T_min	2.0	3.8	3.3	2.4	1.8	3.1	3.2	3.1	3.3	1.9	1.1	1.2	2.5
	T_max	2.5	3.1	2.2	2.0	2.5	1.5	2.2	3.3	3.3	2.6	1.9	1.4	2.4
RCP 4.5	T-mean	2.3	3.5	2.8	2.2	2.2	2.3	2.7	3.2	3.3	2.3	1.5	1.3	2.5
	PCP	-97.1	-44.5	15.4	24.1	-23.1	-25.4	-24.5	-47.6	-26.8	-20.2	-76.7	-69.9	-34.7
	T_min	3.3	5.1	4.3	3.5	2.7	4.2	4.5	4.2	4.3	3.0	2.5	2.7	3.7
	T_max	3.5	3.6	2.8	3.0	3.5	2.4	3.2	4.2	4.1	3.7	2.9	2.5	3.3
RCP 8.5	T-mean	3.4	4.4	3.5	3.2	3.1	3.3	3.9	4.2	4.2	3.3	2.7	2.6	3.5
	PCP	-6.1	-39.8	86.2	-6.5	-9.3	-59.4	-68.0	-83.8	-90.9	-88.3	-69.0	-25.2	-38.3
	T_min	6.5	10.3	9.4	5.2	2.1	1.5	-0.3	0.0	1.6	2.9	4.6	5.0	4.1
	T_max	7.2	6.7	5.5	3.8	2.3	0.9	1.1	2.2	3.5	4.7	6.1	7.1	4.2
H3A2	T-mean	6.8	8.5	7.4	4.5	2.2	1.2	0.4	1.1	2.5	3.8	5.4	6.0	4.2
	PCP	-4.4	-46.8	89.8	6.8	-7.5	-51.3	-76.5	-81.9	-88.2	-88.4	-70.0	-28.0	-37.2
	T_min	-0.6	4.2	5.9	5.8	5.6	5.2	3.6	2.7	2.0	0.1	-2.4	-3.7	2.4
	T_max	3.8	2.9	2.2	2.4	3.4	4.1	5.8	7.2	7.5	6.8	5.7	4.9	4.7
H3B1	T-mean	1.6	3.5	4.1	4.1	4.5	4.7	4.7	5.0	4.8	3.5	1.6	0.6	3.5

Appendix Table 7. 6: Projected climate change in the period 2073-2099

month		january	february	march	april	may	june	july	august	september	october	november	december	Annual
	PCP	-85.0	-9.1	-2.8	108.9	15.2	-2.1	-15.0	-54.1	-29.0	-51.7	-68.8	-76.7	-22.5
	T_min	3.2	5.1	3.9	2.5	2.7	3.6	3.7	3.5	3.7	1.8	0.9	1.3	3.0
	T_max	3.3	3.5	2.5	2.4	2.6	0.8	2.9	3.9	3.9	3.0	1.9	2.0	2.7
RCP 4.5	T-mean	3.2	4.3	3.2	2.5	2.7	2.2	3.3	3.7	3.8	2.4	1.4	1.7	2.9
	PCP	-90.8	61.3	15.5	-40.1	-52.5	-25.7	-34.1	-62.3	-31.0	-47.2	-85.5	-87.9	-40.0
	T_min	6.0	8.2	6.9	4.7	5.0	6.2	6.4	6.1	6.0	3.9	3.7	4.0	5.6
	T_max	5.5	5.1	4.1	4.8	5.5	3.0	5.0	5.7	5.9	5.9	4.2	4.1	4.9
RCP 8.5	T-mean	5.7	6.6	5.5	4.7	5.3	4.6	5.7	5.9	6.0	4.9	4.0	4.0	5.2
	PCP	11.6	-44.7	-20.8	-91.2	-92.3	-88.4	-81.8	-72.7	-48.3	-36.9	-8.6	30.2	-45.3
	T_min	5.5	9.1	7.5	4.9	2.9	5.1	2.4	2.6	4.2	4.3	5.4	5.7	5.0
	T_max	5.6	4.5	3.6	3.5	4.8	6.0	7.4	8.8	9.2	8.7	8.0	6.4	6.4
H3A2	T-mean	5.5	6.8	5.6	4.2	3.9	5.5	4.9	5.7	6.7	6.5	6.7	6.1	5.7
	PCP	30.9	-57.6	-31.6	-89.4	-92.5	-87.9	-82.1	-71.3	-39.0	-23.6	10.1	56.3	-39.8
	T_min	4.0	6.0	5.1	3.4	2.1	3.7	1.7	2.2	3.1	2.8	3.6	3.9	3.5
	T_max	3.4	4.4	4.0	3.5	2.6	-0.4	-1.0	0.3	1.9	2.1	1.5	1.8	2.0
H3B1	T-mean	3.7	5.2	4.5	3.5	2.3	1.7	0.4	1.2	2.5	2.5	2.5	2.8	2.7

7.2. Land Use classification accuracy assessment report

ACCURACY TOTALS

Class Name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy	Users Accuracy
grazing land	18	18	16	88.89%	88.89%
FOREST	25	24	23	92.00%	95.83%
Crop land	68	73	66	97.06%	90.41%
crop-wood/land	39	35	34	87.18%	97.14%
Totals	150	150	139		

Overall Classification Accuracy = 92.67%

----- End of Accuracy Totals -----

KAPPA (K^) STATISTICS

Overall Kappa Statistics = 0.8918

Conditional Kappa for each Category.

Class Name	Kappa
grazing land	0.8737
FOREST	0.9500
Crop land	0.8246
crop-wood/land	0.9614

----- End of Kappa Statistics -----

Appendix Table 7. 7: Ground Truth Coordinates collected by GPS on field (1)

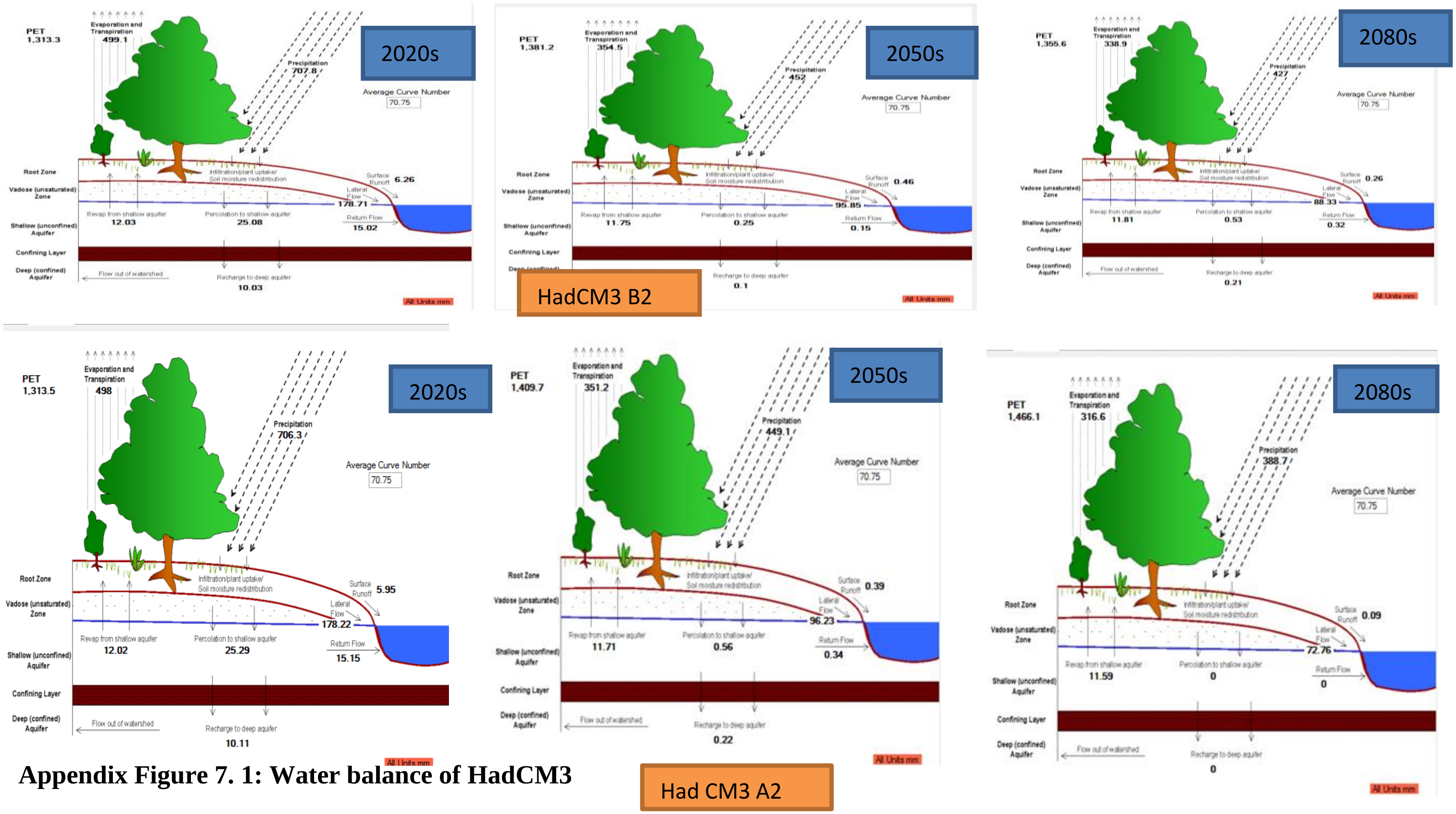
No-	latitude(◦	longtitude(◦)	altitude (m)	land use	N0-	latitude(◦)	longtitude(◦)	altitude (m)	land use	No-	latitude(◦)	longtitude(◦)	titude (m)	land use
1	11.41321	37.15207871	2000.1	AGRL	29	11.18009971	37.28678319	2884.1	AGRL	57	11.50218372	37.48603838	1730.7	CRWO
2	11.41064	37.16370877	2002.3	AGRL	30	11.18009971	37.28678319	2884.1	AGRL	58	11.50221432	37.47958524	1725.0	CRWO
3	11.30435	37.29288077	2168.8	AGRL	31	11.24062568	37.28752197	2547.6	AGRL	59	11.50157243	37.47942615	1725.0	CRWO
4	11.29559	37.29265128	2146.5	FOMI	32	11.18009971	37.28678319	2884.1	AGRL	60	11.50322258	37.48993454	1729.8	CRWO
5	11.29266	37.2928832	2140.5	PAST	33	11.18009971	37.28678319	2884.1	CRWO	61	11.54087509	37.39173292	1780.0	CRWO
6	11.29415	37.29259009	2137.8	PAST	34	11.21668856	37.28778734	2707.2	CRWO	62	11.18009971	37.28678319	1780.0	CRWO
7	11.29248	37.29298789	2140.7	PAST	35	11.18009971	37.28678319	2884.1	CRWO	63	11.32026013	37.29505621	2080.9	CRWO
8	11.29163	37.2924082	2145.1	FOMI	36	11.23211419	37.29001458	2618.7	CRWO	64	11.82796215	36.08866498	736.3	CRWO
9	11.2901	37.29162106	2147.2	FOMI	37	11.24614424	37.28898453	2535.6	CRWO	65	11.29265651	37.2928832	2140.5	PAST
10	11.28817	37.29044524	2155.6	AGRL	38	11.28199523	37.28706407	2170.3	CRWO	66	11.29414925	37.29259009	2137.8	PAST
11	11.28454	37.28859368	2167.2	AGRL	39	11.30611844	37.29235003	2164.5	CRWO	67	11.29248225	37.29298789	2140.7	PAST
12	11.27628	37.28539389	2191.9	AGRL	40	11.30824425	37.2913981	2151.8	FOMI	68	11.291633	37.2924082	2145.1	FOMI
13	11.27444	37.28624356	2191.0	AGRL	41	11.31152736	37.29369751	2116.5	AGRL	69	11.50111	37.44034	1961.5	CRWO
14	11.27244	37.2874726	2214.5	FOMI	42	11.32177591	37.29496016	2078.2	CRWO	70	11.53421	37.427666	1961.5	CRWO
15	11.27072	37.28711386	2226.8	AGRL	43	11.32433047	37.29499947	2074.4	CRWO	71	11.55971	37.572222	1961.5	CRWO
16	11.26472	37.28614876	2286.8	AGRL	44	11.32781893	37.29713585	2073.2	CRWO	72	11.29010456	37.29162106	2147.2	FOMI
17	11.26209	37.28551559	2321.0	FOMI	45	11.31925011	37.26240258	2199.8	PAST	73	11.28817379	37.29044524	2185.7	AGRL
18	11.26081	37.28480489	2327.0	AGRL	46	11.32250774	37.26175013	2221.2	FOMI	74	11.2899	37.35551	2191.6	CRWO
19	11.25546	37.28745626	2434.2	CRWO	47	11.32407851	37.26019755	1742.0	AGRL	75	11.26209031	37.28551559	2321.0	FOMI
20	11.25331	37.28767033	2473.8	AGRL	48	11.519087	37.49819834	#VALUE!	FOMI	76	11.26081199	37.28480489	2327.0	AGRL
21	11.24408	37.28825312	2540.6	FOMI	49	11.51947475	37.49837595	1693.5	FOMI	77	11.25546031	37.28745626	2434.2	CRWO
22	11.23671	37.28878227	2558.4	PAST	50	11.51417295	37.4912572	1712.2	FOMI	78	11.25331177	37.28767033	2473.8	AGRL
23	11.22864	37.2891297	2598.6	PAST	51	11.51413213	37.49133423	1706.7	FOMI	79	11.37	37.31	2260.3	CRWO
24	11.21353	37.28774753	2671.1	AGRL	52	11.5141742	37.49126567	1705.5	FOMI	80	11.5148	37.406971	1782.8	CRWO
25	11.18511	37.28735894	2835.5	AGRL	53	11.51255138	37.49056176	1705.0	FOMI	81	11.50605	37.4001	1786.7	CRWO
26	11.1822	37.28611909	2874.0	FOMI	54	11.5120369	37.49171796	1708.1	CRWO	82	11.498369	37.387421	1780.0	CRWO
27	11.1801	37.28678319	2884.1	FOMI	55	11.51099436	37.49614427	1712.0	CRWO	83	11.498369	37.387142	1785.2	CRWO
28	11.1801	37.28678319	2884.1	FOMI	56	11.53645489	37.41402962	1771.3	CRWO	84	11.511818	37.378413	1782.8	CRWO

Appendix Table 7. 8: Ground Truth Coordinates collected by GPS on field(2)

No	latitude UTM	longtitude UTM	altitude (m)	land use	No	latitude UTM	longtitude UTM	altitude (m)	land use
85	386553	994805	2415.53	CRWO	118	323170	1274367	1812	PAST
86	386553	994805	2415.54	CRWO	119	323888	1273681	1812	PAST
87	317512	1252522	2075	CRWO	120	317006	1267930	1817	PAST
88	316813	1252743	2069	AGRL	121	316373	1267432	1969	FOMI
89	319605	1252467	2120	AGRL	122	315525	1267385	1969	FOMI
90	319701	1252576	2120	AGRL	123	315076	1244726	2382	FOMI
91	319110	1252970	2060	AGRL	124	321076	1274016	1823	PAST
92	318815	1252345	2065	AGRL	125	320448	1274368	1823	PAST
93	318730	1253581	2057	AGRL	126	386552	994805	2415.56	PAST
94	317917	1252063	2098	FOMI	127	311260	1252737	2112	AGRL
95	312986	1247176	2184	FOMI	128	310964	1254235	2131	AGRL
96	316813	1252643	2071	AGRL	129	313523	1255888	2080	AGRL
97	317512	1252521	2070	CRWO	130	324381	1276666	2415.57	PAST
98	313896	1238781	2653	AGRL	131	312743	1251877	2081	PAST
99	313926	1237821	2653	AGRL	132	312653	1253196	2098	PAST
100	314835.76	123767	2575	FOMI	133	315694	1258244	2045	PAST
101	314410	1237843	2575	FOMI	134	312315	1269366	1973	PAST
102	314811	1238634	2548	FOMI	135	319398	1268129	2415.58	AGRL
103	314861	1236497	2914	FOMI	136	321348	1267810	2415.59	AGRL
104	318458	1246484	2271	FOMI	137	314742	1253858	2415.60	AGRL
105	317637	1259243	2029	PAST	138	318485	1249241	2415.61	AGRL
106	316051	1258263	2030	PAST	139	318513	1249339	2415.62	AGRL
107	315274	1237183	2931	PAST	140	318513	1249338	2415.63	AGRL
108	315618	1239847	2667	PAST	141	314562	1253708	2415.64	AGRL
109	319140	1250577	2118	PAST	142	314742	1253858	2415.65	AGRL
110	319581	1250331	2056	PAST	143	315155.04	1241726	2418.8	AGRL
111	316665	1256847	2051	PAST	144	315961	1267770	1969	AGRL
112	318011	1256443	2001	PAST	145	313401	1263740	2045	AGRL
113	317979	1256565	2089	PAST	146	315440	124458	2322	AGRL
114	386553	994805	2415.55	PAST	147	315332	1243794	2365	AGRL
115	314161	1270129	1957	FOMI	148	313344	1250053	2201	AGRL
116	314968	1269564	1924	FOMI	149	311610	1250317	2131	AGRL
117	321946	1274462	1811	PAST	150	311260	1252737	2112	AGRL

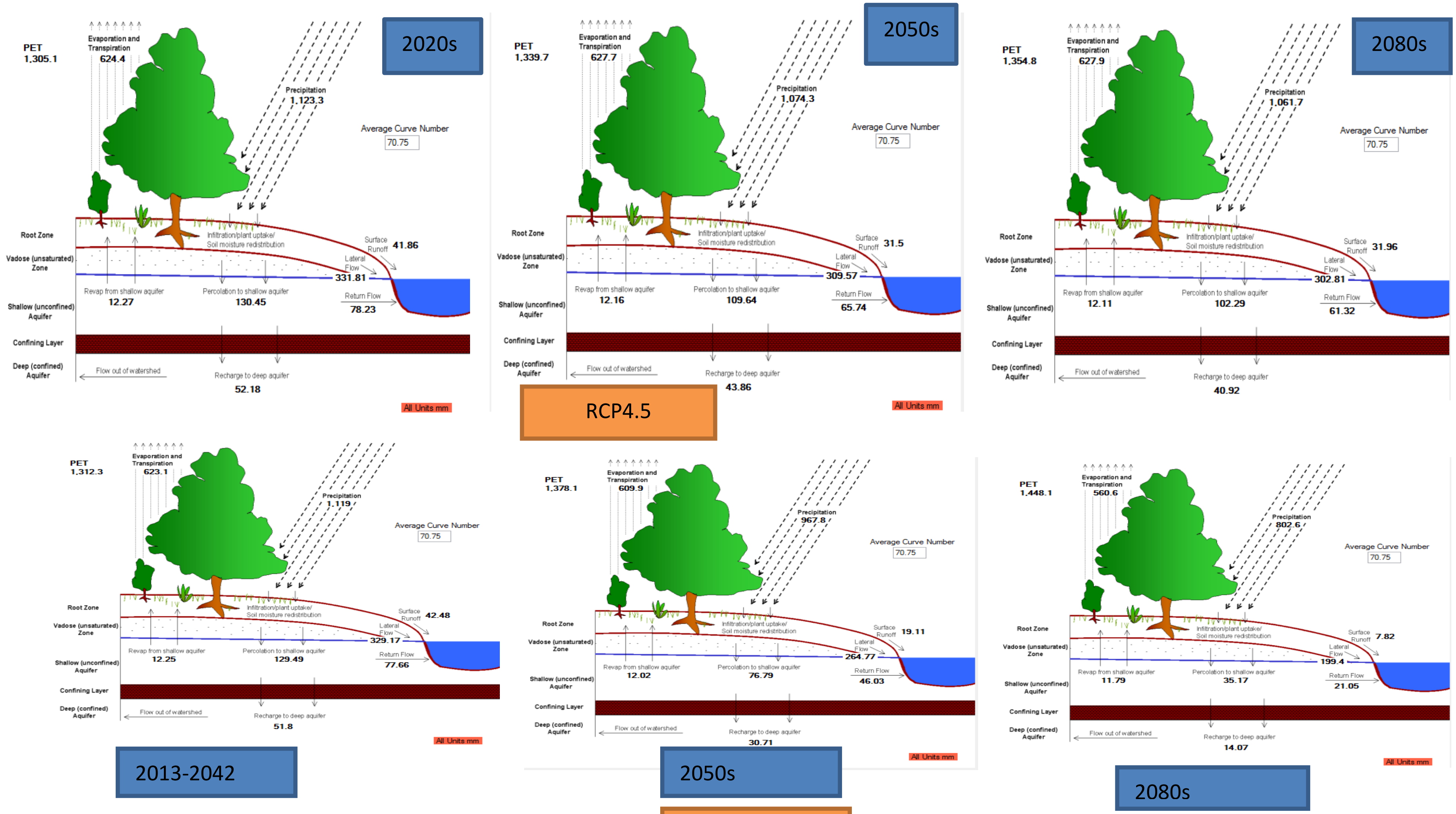
7.3. Water Balanace of GCMS (figurative representation)

7.3.1. HADCM3 Model



Appendix Figure 7. 1: Water balance of HadCM3

7.3.3. CanESM2 model



Appendix Figure 7. 2: water balance of CanESM2