JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULITYOF CIVIL AND ENVIRONMENTAL ENGINEERING

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

Rainfall-Runoff Modeling Using SWAT Hydrologic Model: Case Study of DabusRiver Watershed, Ethiopia

BY: Melkamu Weregna

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulic Engineering.

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Jimma, Ethiopia

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Main Advisor: Dr-ing Tamene Adugna
Co-advisor: Mr Tolera Abdissa (MSc.)

APPROVAL PAGE SHEET

The undersigned certify that they have read the thesis entitled: **Rainfall-Runoff Modeling Using SWAT Hydrologic Model Case Study of Dabus River Watershed, Ethiopia** and here by recommend for acceptance by the Jimma University in partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering.

Dr.Ing: Tamene Adugna (Main Advisor)	Mr. Tolera Abdissa (M.Sc.) (Co-Advisor)
Date	Date
(External Examiner)	(Internal Examiner)
Date	Date

DECLARATION

Here with I Melkamu Weregna, affirm that I have done this thesis work on my own. I did not enlist unlawful assistance of someone else. Cited sources of literature are perceptibly marked and listed at the end of this thesis. The work was not submitted previously in same or similar form to another examination committee and was not yet published, and also it will not be presented for the same purpose of award.

Signature

ABSTRACT

Rainfall-Runoff modelling is essential for effective and sustainable water resources planning and management of the watershed. The derivation of relationships between the rainfall over a catchments area and the resulting flow in a river is fundamental problem for the hydrologist. In most developing countries, like Ethiopia there are usually no plenty of rainfall records. Therefore objective of this study was to achieve the runoff simulation and investigate rainfall runoff relationship in the study area. This study was carried out on Dabus watershed which is located in the western Ethiopia. Weather data of six stations for a period of 1994 to 2016 were collected and combined with other maps of the study area, such as 30m x 30m Digital Elevation Model (DEM), land use, soil and slope as input data for Soil and Water Assessment Tools (SWAT) model which works in conjunction with Arc GIS. In this study the watershed area was delineated using the SWAT model and then divided into 75 sub-basins. Land use land cover, soil and slope were overlaid to the delineated watershed, and then these sub basins are further divided into 323 HRUs which stands for Hydrological Response Unit. Then by using 23 years of daily weather data SWAT simulation was done for monthly basis to find out Runoff volume and runoff for corresponding Rainfall. After running the model, the Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT calibration and uncertainty program (SWAT-CUP) were used to evaluate the data uncertainty and for model calibration and validation by using (1996-2016) years observed stream flow at Dabusnear@Asossa gauging station. The first two years (1994-1996) for warm-up and the next (1996-2008) for the calibration and finally (2009-2016) were used for the validation period. The simulated average annual surface runoff was 228.74 mm. The model performance evaluation statistics showed that during calibration, monthly results were 0.88 and 0.80 for coefficient of determination (R^2) and Nash–Sutcliffe model efficiency (NSE) respectively. During validation monthly results were 0.88 and 0.76 for coefficient of determination (R^2), and Nash–Sutcliffe model efficiency (NSE) respectively. The coefficient of correlation (r) for rainfall in a period and the corresponding runoff is found to be 0.9 Hence, it can be concluded that SWAT is able to fairly explain the hydrological characteristics of the Dabus catchment.

Keywords:Dabus river watershed, Rainfall-Runoff modelling,SWAT and SWAT-CUP

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ACRONOMYS

DEM	Digital Elevation Model
DMS	Degrees Minutes Seconds
EMA	Ethiopian Mapping Agency
ET	Evapo-transpiration
GIS	Geographic information system
HBV	Means Hydrological Bureau Water balance-section
HRU	Hydrologic Response Units
LM	Linear model
LPM	Linear perturbation model
ISRIC	International Soil Reference and Information Center
MoWIE	Ministry of Water, Irrigation and Electricity
NMSA	National Meteorological Service Agency
PBIAS	Percent bias
PET	Potential Evapotranspiration
SMAR	Soil Moisture Accounting and Routing
SRTM	Shuttle Radar Topography Mission
SUF-2	Sequential uncertainty fitting
SWAT	Soil and Water Assessment Tools
SWAT-CUP	SWAT-calibration and uncertainty programs
UTM	Universal Transverse Mercator
WISE	World Inventory of Soil Emission

1. INTRODUCTION

1.1 Background

Water is a sustainable resource, and the need for integrated water resources management is on the agenda of every state. Proper planning and management of water resources is vital for wise utilization and sustainable development of the resource. The total renewable surface water resources of Ethiopia is estimated at 122 BCM (billion cubic meters) per year from 12 major river basins, and 22 lakes. Renewable ground water resources are estimated to be about 2.6 BCM (The World Bank, 2006). To plan, utilize and manage the available scarce resources of water, hydrological modelling and identification of temporal variability of water resources is very much essential (Bekele, 2015).

Land and rainwater management interventions were practiced continuously in different ways; it has not been done systematically. It is essential to understand the hydrological response of the catchment in order to suggest better land and water management practices (Tafesse, 2012). Rapid land use change due to intensive agricultural practice results in increasing rates of soil erosion. This manifested in significant impacts downstream by reducing the storage capacity of reservoirs and high de-silting costs of irrigation canals.

A river’s flow rate and water quality is dependent on the land-use practices within their entire watershed. Therefore, watershed management is an essential part of maintaining healthy productive rivers. Particularly a better understanding of the hydrological characteristics of different watersheds in the headwaters of the Blue Nile River is of considerable importance given the government special interest towards developing water resources of this river at a larger scale.

The use of hydrological modeling systems for water resources planning and management is becoming increasingly popular. Since theses hydrological models deal with land phase of hydrological cycle, data related to topography and physical parameters of watershed are a necessary pre-requisite for this model. Computer based geographic information system furnish this requirement efficiently. Theses system links land cover data to geographic data and to other information related to geographic location (Ayenew, 2008). Understanding on hydrologic process to develop suitable model for a watershed are the most important aspect in water resources development and management programs.

Water resources development is the basic and crucial infrastructure for a nation's sustainable development and to utilize water in a sustainable manner, it is necessary to understand the quantity and quality of in space and time through studies and researches.

Establishing a rainfall-runoff relationship is the central focus of hydrologic modeling from its simple form of unit hydrograph to rather complex models based on fully dynamic flux equations. As the computing capabilities are increasing, the use of these models to simulate a catchment response has become a standard. Models are generally used as utility in various areas of water resources development, in assessing the available resources, in studying the impacts of human interference in an area such as land use change, deforestation and other hydraulic structures such as dams and reservoirs (Moreda, 1999). The fact that the world faces a water crisis has become increasingly clear in recent years. Challenges remain widespread and reflect severe problems in the management of water resources in many parts of the world. These problems will intensify unless effective and concerted actions are taken (WWAP, 2003). However, from a water resource assessment point of view, the primary objective of modeling is often to generate a long representative time series of stream flow volumes for the purpose of planning and management of water resources.

Developing the basic relationships between the different hydrologic systems like rainfall, runoff, soil moisture, ground water level and land use land cover are crucial for effective and sustainable water resources planning and management activities with the support of hydrological models (Birhane et al.2013).

Rainfall-runoff models have been under a continuous state of development. Models used in the earlier days did not integrate the different phases of the hydrological cycle. Instead, they implemented simplified mathematical relationships between precipitation and certain attributes of the final catchment responses. However, estimation of runoff is essential in various kinds of water resources studies. Runoff estimation is normally based on rainfall runoff process. In order to model rainfall-runoff process, a variety of hydrological models have been applied (Hundecha, 2005).

Appropriate assessment of runoff amount is essential for design, planning, and management of river basin projects that deals with conservation and utilization of water for the various purposes. To determine accurately the quantity of surface runoff that takes place in a river basin, understanding of the complex relationships between rainfall and runoff process, which depend upon many geomorphologic and climate factors, is necessary**.** In recent years, new demands have been placed on rainfall-runoff models that require more physically based or complex methods. (Todini, 1988) recognizes three such demands: the use of models for simulating long continuous records; the application of models to complex watersheds with a variety of land uses, soil types, and storm water management facilities; and the transfer of the models for use on similar un gagged catchments. So generally aim of this study is to develop Hydrological modeling in order to simulate rainfall runoff relationships and to determine the watershed characteristics and runoff generation of Dabus River watershed using SWAT hydrologic model for sustainable watershed management systems.

1.2 Statement of the problem

Water resources play a crucial role in the economic development of the developing countries with plentiful of water resources like Ethiopia. The region's explosive population growth and resulting new demands on limited water resources require efficient management of existing water resources and building new facilities to meet the challenge. In water resources management system, it is well known that to combat water shortage issues, maximizing water management efficiency based on hydrological modeling is crucial (Ibrahim,2014).

Abay basin is one of the largest basin in Ethiopia which has a large volume of water resource and a source of life for several peoples living in the basin and for downstream country. The rapidly increasing population, deforestation, over cultivation, overgrazing, and other social, economic and political factors are the major problem in the basin and in its tributaries (Getnet, et al., 2011). Dabus river watershed is one of the tributaries of this basin, which faces land and water resources degradation, which promote losses of soil fertility in most of the watersheds because of lack of effective land and rainwater management practices in Abbay river basin, particularly in Dabus river watershed. This land degradation also affects basin hydrology and water resources availability in the watershed.

So Sustainable water resources management in the basin, particularly in Dabus river watershed is necessary that in-depth understanding of the basin hydrology can be achieved through assessment of hydrological variability, investigating the interaction between land use on hydrologic responses and detail understanding of rainfall-runoff processes (Sirak, 2015).

The derivation of relationships between the rainfall over a catchment area and the resulting flow in a river is fundamental problem for the hydrologist. In most developing countries, like Ethiopia there are usually no plenty of rainfall records. However, the more elaborate and expensive stream-flow measurements are often required by design engineer for the assessment of water resources or flood hazards. But, river flows recorded data are often limited and rarely available for specific sites under investigation (Beven, 2012). Thus, evaluating river discharges from rainfall has stimulated the imagination (mind's eye) and ingenuity (cleverness) of engineers for many years, and more recently has been the inspiration of many research workers(Tufa, 2011).

Rainfall-runoff models are useful tools where data are scarce and resources are under development. It is possible to generate runoff discharges from rainfall and other meteorological data where river flow data is not available (Beven, 2002). Hence Rainfall-runoff modeling is essential for effective rainwater management strategy in watershed.

However such studies were not yet done in this sub basin, therefore this research focus on Rainfall Runoff modeling for simulating monthly and annual runoff and to determine runoff potential which is used for planning and designing of water resources projects on Dabus watershed.

1.3 Significance of the study

The result of this study gives valuable first-hand information to improve effective watershed management for planning and designing of water resources projects within the selected watershed. The research finding may help implementers, policy makers, planners and donors in water sector and as starting data for any further investigation. It will also be helpful to understand the different barriers, which can affect the watershed management practice.

1.4 Objectives of the Study

1.4.1 General objective

The General objective of this study is to develop Rainfall-Runoff modeling at Dabus river watershed.

1.4.2 Specific objectives

1. To check the performance of SWAT model for simulating monthly surface runoff at Dabus river watershed
2. To investigate rainfall-runoff relationship at Dabus river watershed using SWAT hydrologic model
3. To determine Runoff potential in Dabus river watershed using SWAT hydrologic model

1.4.3 Research questions

1. What is the performance of SWAT hydrological model for monthly simulation of runoff at Dabus River watershed?
2. What is the relationship between rainfall and runoff at Dabus river watershed?
3. How much is the runoff potential of Dabus river watershed?

2. LITERATURE REVIEW

2.1 Hydrological Process

The hydrologic cycle is defined as “the pathway of water as it moves in its various phases through the atmosphere to the Earth, over and through the land, to the ocean, and back to the atmosphere” (National Research Council, 1991). It begins at the surface of large water bodies; oceans and lakes when direct solar radiation vaporizes these large reservoirs. This part hydrologic cycle is very important in water distribution in the form of precipitation over the global terrestrials provided that the moisture is driven away by wind currents.

As the term rainfall-runoff model suggests, the major input into the model is rainfall, and the output is an estimate of runoff. The intermediate steps that transform rainfall to runoff are the model processes. Among the hydrologic processes typically modeled are: precipitation, interception, infiltration, evapotranspiration, surface flow and stream flow. It is evident that before any modeling effort can be performed, one has to understand the above physical processes, their extent of effect on the abstraction from or addition of water to a catchment (Beven, 2002).

2.1.1 Precipitation

The term precipitation denotes all forms of water that reach the earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost and dew. Of all these, only the first two contribute significant amounts of water. Rainfall being the predominant forms of precipitation causing stream flow, especially the flood flow in the majority of rivers, unless otherwise stated the term rainfall synonymously with precipitation (Chow *et al*., 1988).

The magnitude of precipitation varies with time and space. Differences in the magnitude of rainfall in various parts of a country at a given time and variations of rainfall at a place in various seasons of the year are obvious and. This variation is responsible for many hydrological problems such as floods and droughts. A given drainage basin is divided into various parts or sub-basins, and rain gauge stations are evenly distributed over that basin. The rain catch at one station in a basin may be different from that of second station in the same basin. An average value of these rain catches is worked out, so as to get an idea of average precipitation on the entire basin. The following methods are generally used to work out the mean rainfall on an area, such as thiessen polygon, arithmetical mean and isohytal method. (Singh and Chowdhury, 1986) after comparing the various methods for calculating areal average, concluded that all methods are gives comparable result, especially when the time period is long.

2.1.2 Interception

The portion of a rain fall intercepted by the vegetation and roof of before reaching the ground is referred to as interception (Chow *et al*., 1988). The water is intercepted by the leaves of vegetation and roofs eventually evaporate into atmosphere. The amount of interception could be significant in densely vegetated areas such as tropical rain forests. Such forests maintain a relatively consistent canopy and do not generally exhibit the seasonal range of interception encountered in areas where deciduous trees are dominant. It is commonly understood that if the density of vegetation cover is spares then this loss is significant (Chow *et al*., 1988).

2.1.3 Infiltration

Infiltration is as the entry or the passage of water into the soil through soil surface. It is a major loss of precipitation affecting runoff of a basin. This term should be properly understood and quantified. Infiltration is one of the most difficult hydrological processes to quantify. The difficult arises due to many physical factors affecting the rate of infiltration such as rainfall intensity, initial moisture content soil property, etc. some experimental and empirical formulas such as (Horton, 1939 and Phiilp, 1975), and other are available to compute infiltration rates during a rainfall event. Depending on the soil strata, the infiltrated water gradually percolates to the ground or either flows as sub surface flow supplying river within the catchment.

2.1.4 Evaporation and Transpiration

Evaporation is the process in which water changed from liquid state in to vapour through the transfer of heat energy. The process of evaporation of water is one of the basic components of the hydrologic cycle and consists that phase in which precipitation reaching earth's surface is returned to the atmosphere in the form of vapor.The two main factors influencing the evaporation from an open water surface are the supply of energy to provide that latent heat of vaporization and the ability of to transport the vapour away from the evaporative surface: solar radiation and wind. Evaporation and transpiration together is called evapotranspiration, which the total water is lost to atmosphere over a period of time as water vapor from a watershed. As already defined, evapotranspiration is the total loss of water from land as evaporation and from plants as transpiration from a watershed. Obviously potential evapotranspiration (PET) means the rate of evapotranspiration from a fully vegetated watershed when sufficient moisture is always available to completely meet the, which is obtained by using empirical equation (Thornthwaite,1948).

Some potential evaporation and evaporation from pans are governed by the same meteorological factors they have strong correlation. The relation between them is often giving as a simple ratio. Using seasonal coefficient for converting pan data to potential evaporation rather than a single coefficient. In conceptual rainfall- runoff modelling one of the two terms, pan evaporation and potential evapotranspiration are equally used as input, which exerts energy to extract water from open surface or soil moisture storage (Burnash, 1995).

2.1.5 Runoff

The rain fall that exceeds the interception requirement and infiltration starts to accumulate on the surface. Initially the excess water collects to fill depressions, until the surface detention requirement is satisfied. There after water begins to move down slope as a thin and film and tiny streams which eventually join to form bigger and bigger channel. This part of stream flow is termed as surface runoff (Chow *et al*., 1988). The infiltrated part of rain may sometimes come as subsurface runoff, constitutes the Stream flow. Hence the direct runoff is the result of the immediate response of a catchment to the input rainfall. The stream flow consists of the direct runoff (which lasts for hours or days depending up on the catchment size) and the base flow (that emerges from ground water resources and also delayed subsurface runoff). The overall schematic representation of hydrologic processes is presented in figure below (Chow *et al*., 1988).

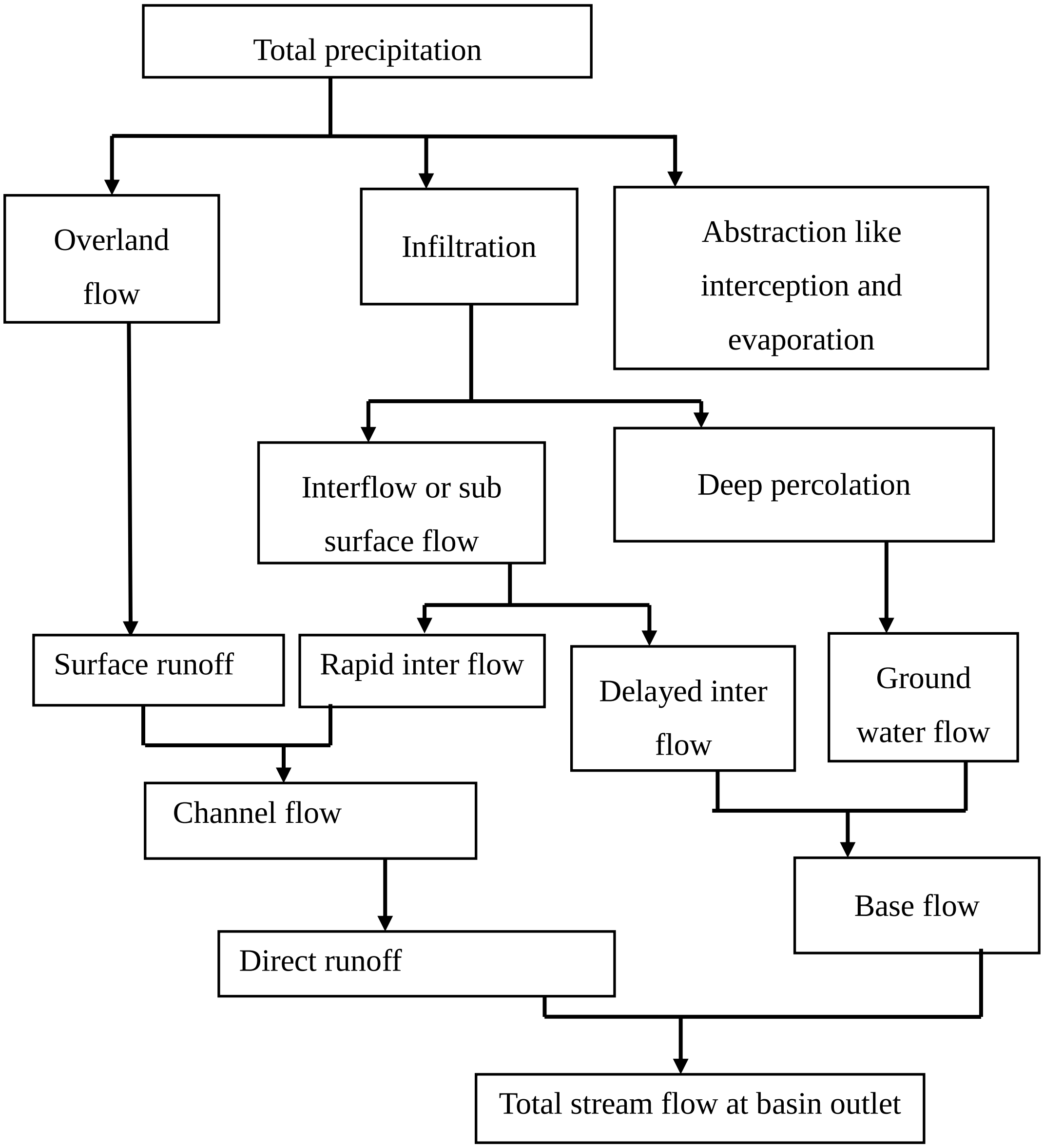


Figure 2.1: Schematic representation of runoff processes

2.2 Hydrological modelling

Hydrological models are mathematical formulations which determine the runoff signal which leaves a watershed basin from the rainfall signal received by this basin. They provide a means of quantitative prediction of catchment runoff that may be required for efficient management of water resources. Such hydrological models are also used as means of extrapolating from those available measurements in both space and time into the future to assess the likely impact of future hydrological change.

There are many different reasons why modelling of the rainfall-runoff processes of hydrology is needed. The main reasons behind are a limited range of hydrological measurement techniques and a limited range of measurements in space and time (Beven, 2002). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to ungauged watersheds and into the future to assess the likely impact of future hydrological change.

Hydrological models are characterizations of the real world system. A wide range of hydrological models are used by the researchers, however the applications of those models are highly dependent on the purposes for which the modeling is made. Beven (2002) stated that many rainfall-runoff models are carried out purely for research purposes as a means of enhancing knowledge about hydrological systems. He also added that other types of models are developed and employed as tools for simulation and prediction aiming ultimately to allow decision makers to improve decision making about hydrological problems. Before developing the hydrological models it is vital to understand how the watershed responds to rainfall under different conditions.

A watershed is an area of land in which all rain and snow runoff and small tributaries drain into a common outlet (Chow *et al*., 1988).Watersheds are usually delineated from surface topography, which include area that provide water to the point through lateral flow over the surface and underground. Watershed is the most acceptable units for the purpose of planning for optimum use and conservation of natural resources (Verma*et al*., 1995). Hydrological models are mathematical descriptions of components of the hydrologic cycle and are designed to meet a better understanding of the hydrologic processes in a watershed (Chow *et al*., 1988).

2.3 Classification of Hydrological Model

There are a number of ways of classifying hydrological models. Classifications are generally based on the method of representation of the hydrological cycle or a component of the hydrologic cycle. Owing to the complex nature of rainfall-runoff processes, different hydrologists have different modeling approaches even to the same hydrological system.

Rainfall-runoff models are categorized into lumped or distributed and deterministic or stochastic (Beven, 2000). In lumped models the hydrologic parameters do not vary spatially with in the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins (Chuderlik, 2003). He added that the representation of hydrologic processes in lumped hydrologic models is usually very simplified; however they can often lead to satisfactory results, especially if the interest is in the discharge prediction only. The distributed models make predictions that are distributed in space by discretizing the catchment into a large number of elements or grid squares and solving the equations for the state variables associated with every element or grid square (Beven, 2001). Distributed models generally require large amounts of data parameterization in each grid cell. According to Chuderlik, (2003), if governing physical processes are modeled in detail and properly applied, distributed models can provide the highest degree of accuracy.

There is a third type of model in this category called semi-distributed model. In semi distributed model, the parameters of the model are allowed to vary partially in space by dividing the basin into a number of smaller sub-basins. The main advantage of semi distributed models is that their structure is more physically based than the structure of lumped models, and that they are less demanding an input data than fully distributed models. Deterministic models permit only one outcome from a simulation with one set of inputs and parameter values while stochastic models allow for some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions or model parameters (Beven, 2002). Conceptual and physically based models are the other forms of model classification.

Conceptual models are based on limited representation of the physical processes acting to produce the hydrological outputs; it modifies the theoretical back ground and its Primary approach is to transfer rainfall to stream flow through a number of interconnected mathematical functions each responding a certain component of hydrologic cycle. Example: the Soil Moisture Accounting and Routing (SMAR), HBV among many other models.

Physically based models are based more solidly on understanding of the relevant physical processes (Ward and Robinson, 2000). Nowadays it is a best model since expresses real world and particularly advantage for study of basin change impact assessment. They offer physical data input and parameters have physical meaning that can be measured in the field. A good example for this model is SWAT, HEC HMS etc.

2.4 Rainfall-Runoff modelling

Rainfall-Runoff models, in the broader sense, hydrologic models are simplified characterizations of the real world system (Beven, 2002). Understanding the basic relationship between the rainfall over the catchment and the resulting runoff is important to know water resource potential and proper management of water resources in the catchment. Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. Whenever data is not available, hydrological models are important to establish baseline characteristics and determine long term impacts which are difficult to calculate (Lenhart et al., 2002).

A wide range of rainfall runoff models are currently used by researchers, however the applications of these models are highly dependent on the purposes for which the modelling is made. Runoff is the draining or flowing of the precipitation from the catchment area through a surface channel when evapotranspiration demand is fulfilled. It thus represents the output from the catchment in a given unit of time. Considering a catchment area receiving precipitation and for a given precipitation on a catchment area, the evapotranspiration, the initial loss, infiltration and detention storage requirement will have to be satisfied before the commencement of runoff. The excess precipitation is flow overland form drain lines enter into small channel and detention storage of water (K. Subramanya, 2008).

Rainfall-runoff modelling is essential for sustainable watershed development and reliable estimates of the various hydrological parameters. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices; a hydrological cycle is a complex system. As a result, use of mathematical models and geospatial analysis tools for studying hydrological process and hydrological responses to rainfall runoff relation is the current trend (Sanjay *et al*., 2010).

To quantify the variability of hydrologic fluxes and flow of water, a distributed watershed model with a high resolution of space and time is necessary. Human health and welfare, food security and industrial development are dependent on adequate supplies of suitable quality and quantity of water. The liveliness of natural ecological system is dependent on mankind's stewardship of water resources and proper utilization of these resources necessitates assessment and management of the quantity and quality of water resources both spatially and temporally (Alamirew, 2006).

A model used in water resources management should be sufficiently accurate to be used for the intended purpose. The existence of observations determines the validity of the model. Model prediction is compared with field measurement to evaluate its performance without any adjustment to the model parameters (Ward and Benaman, 1999). This process is termed as model validation or verification.

Why We Need Hydrologic Models?

Significance of the modeling in the hydrological process are: to generate useful information from limited data due to limitation in hydrological measurement technique, to extrapolate measurements in space and time, to neutralize flow, to analysis impact assessments and to define water resource related goals and objectives etc.

2.5 Hydrologic Model Selection

There are a range of possible model structures within each class of models. Hence, choosing a particular model structure for a particular application is one of the challenges of the model user community. Beven (2000) suggested four criterions for selecting model structures as below. Consider models which are readily available and whose investment of time and money appeared worthwhile, decide whether the model under consideration will produce the outputs needed to meet the aims of a particular project, prepare a list of assumptions made by the model and check the assumptions likely to be limiting in terms of what is known about the response of the catchment. This assessment will generally be a relative one, or at best a screen to reject those models that are obviously based on incorrect representations of the catchment processes and make a list of the inputs required by the model and decide whether all the information required by the model can be provided within the time and cost constraints of the project. For choice of models the main driven question is research problems or the main thing that initiate to do the thesis. If we need data reconstruction it is possible to use linear models LM, LPM, SMAR and HBV. For flow forecasting LPM, SMAR and also for impact assessment and prediction SWAT, MIK SHE and the like and also different criteria's are set by (Beven, 2000).

Make a list of the inputs required by the model and decide whether all the information required by the model provided within the time and cost constraints of the project. Therefore SWAT model is selected rather than the other model for this hydrological component relationship is for the following reasons: uses readily available inputs for weather, soil, land, and topography, allows considerable spatial detail for basin scale modeling, it is capable of simulating change in watershed characteristics using different scenarios, capability for application to large scale watersheds (>100km^2), capability for interface with a geographical information system (GIS) and the model simulates the major hydrological process in the watersheds.

2.6 SWAT Hydrological model

Soil and Water Assessment Tool (SWAT) is a river basin scale model developed by Dr. Jeff Arnold for the US Department of Agriculture (USDA) - Agricultural Research Service (ARS) (Neitsch et al., 2005). It is a conceptual, physically based, basin scale, daily time step, semi-distributed model that functions on a continuous time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in complex watersheds with varying soil, land use and management condition over a long period of time(Neitsch, *et al*., 2005).The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. It is capable of simulating a wide range of hydrological processes with different management scenarios (Zeleke and Partha, 2015). SWAT watershed modelling is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman*et al*., 2005).

SWAT model (Arnold *et al*., 1998) is a semi-distributed, continuous watershed simulator operating on a daily time step. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. In SWAT, a watershed is divided into multiple sub watersheds, which are then further subdivided into hydrologic response units (HRUs) that consist of homogeneous land use, management, and soil characteristics. The HRUs represent percentages of the sub watershed area and are not identified spatially within a SWAT simulation (Arnold *et al*, 2012).

2.6.1 Hydrological components of SWAT model

The simulation of the hydrology of a watershed is separated into two divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loading to the main channel in each sub-basin. Hydrological components simulated in land phase of the hydrological cycle are canopy storage, infiltration, redistribution, evapo-transpiration, lateral subsurface flow, surface runoff, ponds, tributary channels and return flow. The second division is routing phase of hydrologic cycle that can be defined as the movement of water, sediment, nutrients and organic chemicals through the channel network of the watershed to the outlet (Neistch*et al*., 2002)

In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \text{…………………………………}(2.1)$$

Where; SWt is the final water content (mm H_2O), SWo is the initial soil water content on day i (mm H_2O), t is time, days, R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), Ea is the actual evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose (unsaturated) zone from the Soil profile on day i (mm H_2O), Q_{gw} is the amount of return flow on day i (mm H_2O).

2.6.2 Surface Runoff simulation

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration. When water is initially applied to a dry soil, the application rate and infiltration rates may be similar. However, the infiltration rate will decrease as the soil becomes wetter. When the application rate is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once all surface depressions have filled, surface runoff will commence. SWAT provides two methods for estimating surface runoff: the SCS curve number method (SCS 1972) and the Green & Ampt infiltration method (1911). Even though the latter method is better in estimating runoff volume accurately, its sub-daily time step data requirement makes it difficult to be used for this study. Hence, the SCS curve number method was adopted.

The SCS run- off equation is an empirical model that came into common use in the 1950s. It was the product of more than 20 years of studies involving rainfall-runoff relationships from small rural watersheds across the U.S. The model was developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types:

The SCS curve number equation:

$$Q_{surf} = \frac{\left(R_{day} - I_a + \mathrm{S}\right)^2}{\left(R_{day} - I_a + \mathrm{S}\right)} \quad \text{(2.2)}$$

Where: Q_{surf} is the accumulated runoff or rainfall excess (mm H2O), R_{day} is the rainfall depth for the day (mm H2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and S is the retention parameter (mm H2O).

The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as: $S = 25.4\left(\frac{100}{CN} - 10\right)$ ……………………………………………………………………… (2.3)

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition.

Commonly, Ia is approximated by 0.2S and the above equation can be rewrite as follow:

$$Q_{surf} = \frac{\left(R_{day} - 0.2\mathrm{S}\right)^2}{\mathrm{R}_{day} + 0.8\mathrm{S}} \quad \text{(2.4)}$$

Runoff will only occur when $R_{day}>$ Ia. The detailed and complete description about CN is given in the SWAT theoretical documentation (Neitsch (a) *et al*., 2002).

2.7 Related literature and Research gaps on different studies

There are so many rainfall runoff models which are applied for different catchment under different climate characteristics. For example: TOP MODEL, HEC HMS, SWAT, HBV, SMAR, ARNO, MIKSHE and the like. Among these models HEC-HMS and SWAT is commonly used models in case of Ethiopian catchment. But identifying of models which represent realistic simulation for the catchment is important for proper management of water resources.

Climate and Land use are two key factors controlling the hydrological behavior of the watersheds. Previous studies (Abdo, 2008, Emeru, 2009 and Habtom, 2009, Andualem 2010, Kirubel 2011) have addressed the impact of climate and land use change on the hydrological response of Gilgel Abbay Watershed independently, mostly focusing on seasonal to long term impacts on stream flow. However, there is a lack of combined climate and land use change impact studies especially concerning impacts on hydrology; the importance of this research gap has been pointed in recent reviews (Pose et al., 2003; Boardman, 2006). The expression of the changed land-use conditions for the spatial and temporal scale is relevant for this study. Today, an attribution of occurrence probability to the various scenarios of land-use is still absent.

Despite the above fact, however, little is known on the rate and spatial distribution of rainfall runoff in the Gilgel Abbay watershed. Therefore, an anticipated quantification of stream yield in the watershed is vital for implementing appropriate management practice that reduce run off in the watershed and sediment deposition in the reservoir.

White, et al.(2008) used a Water Balance-Based and Water Assessment Tool (SWAT) for improved Performance in the Ethiopian Highlands of Gumera watershed with an area of 1270 km2. The model uses the CN and water balance based approach. The author compares the efficiency of the model prior to any calibration. They reported SWAT can accurately model saturation-excess process without using the curve Number technique.

Sirak (2008) assessed the application of SWAT model in the Lake Tana basin Ethiopia The model for stream flow prediction in Tana Basin .The model was calibrated and validated on four tributaries of Lake Tana: Gumera, Gilgel-Abbay, Megach, and Ribb Rivers. They reported that SWAT 2005 model was successfully calibrated and validated in the Lake Tana Basin using different algorithm and give good simulation result for daily and monthly time steps.

Ashenafi (2013) studied watershed modeling and uncertainty analysis by using swat model and swat cup for uncertainty through SUFI 2 uncertainty routine from the result P factor shows the percentage of observations covered by the 95PPU and as a result the value of p factor. 31% of the observation data matches with the simulated data. In addition, the small P-factor and relatively large R-factor values for these stations represent there is some uncertainties. In addition, D factor of 0.26 also shows small relative width of 95% probability band which represents to greater uncertainties.

Kealeab et al. (2013) conducted runoff and sediment modeling using SWAT in Gumera catchment, Ethiopia The performance of the model was evaluated using statistical and graphical methods to assess the capability of the model in simulating the runoff and sediment yield for the study area. The coefficient of determination (R^2) and NSE values for the daily runoff by using Parasol optimization technique was obtained as 0.72 and 0.71 respectively for the calibration period and 0.79 and 0.78 respectively for the validation period, R^2 and NSE values of monthly flow calibration using SUFI2 are 0.83 and 0.78 respectively for validation it was 0.93 and 0.93.

Kumela (2011). Try to compare SMAR and HBV light models on catchment. The discrepancy occurred between simulated and observed runoff may be due to in adequacy of model structure, human intervention, incorrect estimation of parameters especially in case of manual optimization, if there is an interflow between catchments, the quality of data and the absence of any substantial, consistent , or coherent relationship in the data used to calibrate the model.

3. MATERIALSAND METHODS

3.1 Description of the study area

Dabus River is one of the biggest tributary of Abbay River which is located in Western Ethiopia which contributes high percent of water to the Abbay basin next to Dedesa sub basin. It originate in the south-western and central parts of Wollega and flows generally northwards into a large and flat basin known as the Dabus swamp then continuous northward to the Blue Nile River.The study area is bounded between latitudes 10°36'38" and 9°8' 34"North and longitudes 35°8'58" and 34°28'54" East (MoWR, 2002). This research focused on Dabus watershed which covers area about 14738.92km^2.

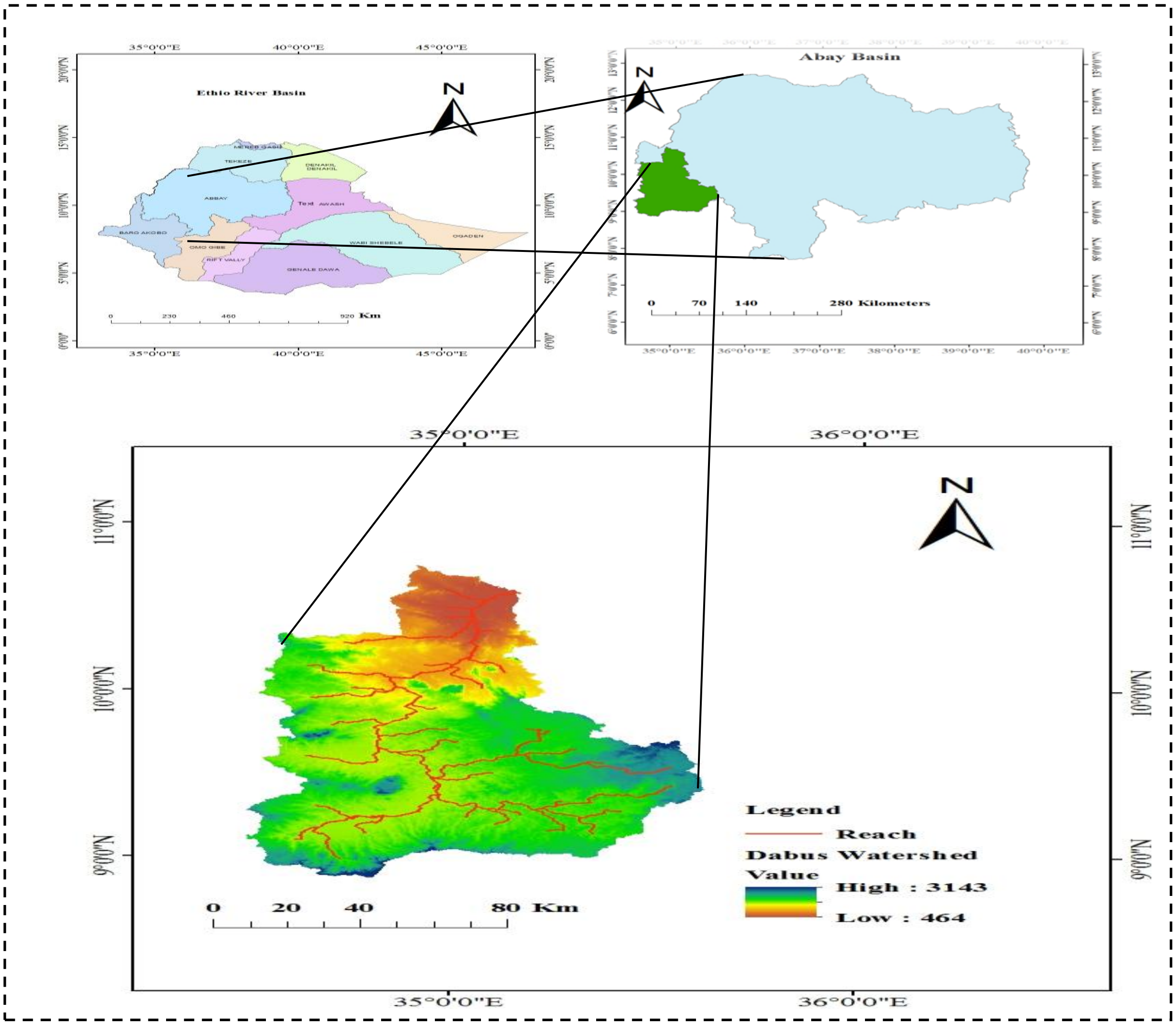


Figure 3.1: Location map of the study area

3.1.1 Climate

The basin falls within the climatic classification of tropical climate II according to the modified copen system. The climate is characterized by a mean annual rainfall between 680 to 1200 mm. The rainfall distribution in the Dabus basin is monomial, with the length of the wet season decreasing as one goes to the north and north-west in the basin. The South-western part of the basin experiences longer rainy season extending from April/May to October/November (Ibrahim, 2014).

3.1.2 Geology

The river Dabus originates from a high range of mountains composed mostly of volcanic rocks overlying precambrian granitic and metamorphic rocks. The upstream part of the drainage system flows northward into large and flat basin (Dabus swamp) which was formed primarily by flows of basaltic lava which filled in the drainage system and dammed off previously eroded valleys. These younger volcanic rocks underlie the major portion of the Dabus swamp area. Downstream from the Dabus swamp area the river is eroding into Precambrian metamorphic rocks. The river gradient is steep from the outlet of the swamp to the junction of the Blue Nile (MoWIE, 2002).

3.2 Data Collection

3.2.1 Meteorological Data

For this study, daily data of precipitation, temperature (Max & Min), sunshine hours, relative humidity and wind speed of all synoptic stations around and in the Dabus watershed were collected from National Meteorological Agency (NMSA). Six meteorological stations were used for this study (table 3.1), where Asossa station was selected as a weather generator stations, to generate for the missing data of the other stations.

3.2.2 Hydrological data

The daily stream flow data for gauged stations were collected from Ministry of Water, Irrigation and Electricity from the period 1996–2016 with some missed value. The high flows concentrated on the months of the rainy season (mid July, August and September).

Table3.1: List and location of the Hydro- Meteorological stations with in and around the dabus watershed.

S.No	Station Name	Latitude in Degree	Longitude in Degree	Elevation in (m)	Record Length in Year
A	Dabus Nr:Asossa	10.024	34.849	1650	1996-2016
1	Asossa	10.000	34.517	1600	1994-2016
2	Mendi	9.780	35.100	1650	1994-2016
3	Nedjo	9.500	35.450	1800	1994-2016
4	Abadi	9.617	34.750	1410	1994-2016
5	Begi	9.333	34.533	1650	1994-2016
6	Gulliso	9.200	35.517	1600	1994-2016

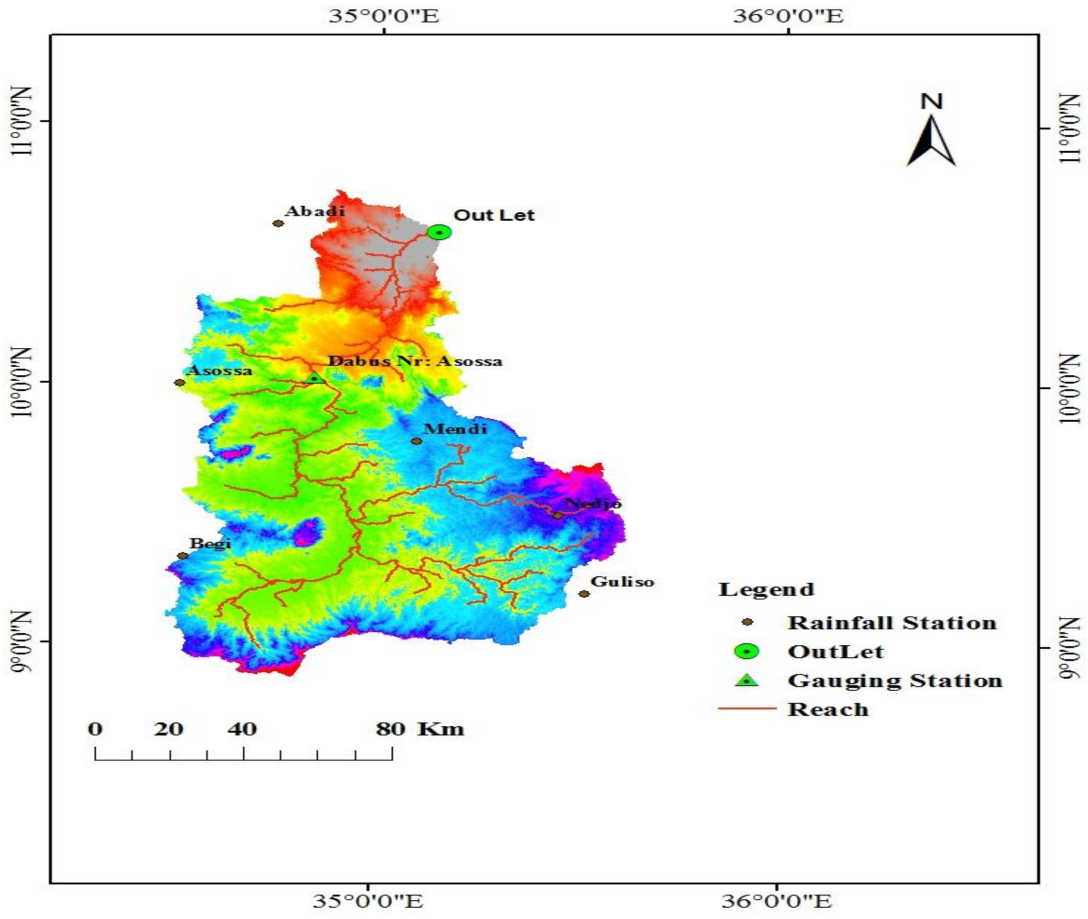


Figure 3.2: Location of Hydro-meteorological stations

3.2.3Digital Elevation Model

Topography is defined by digital elevation model (DEM) that describes the elevation of any point in a given area at specific spatial resolution. DEM of Abay Basin was collected from Ministry of Water, Irrigation and Energy of Ethiopia and Dabus watershed DEM was extracted from this Abay basin DEM.

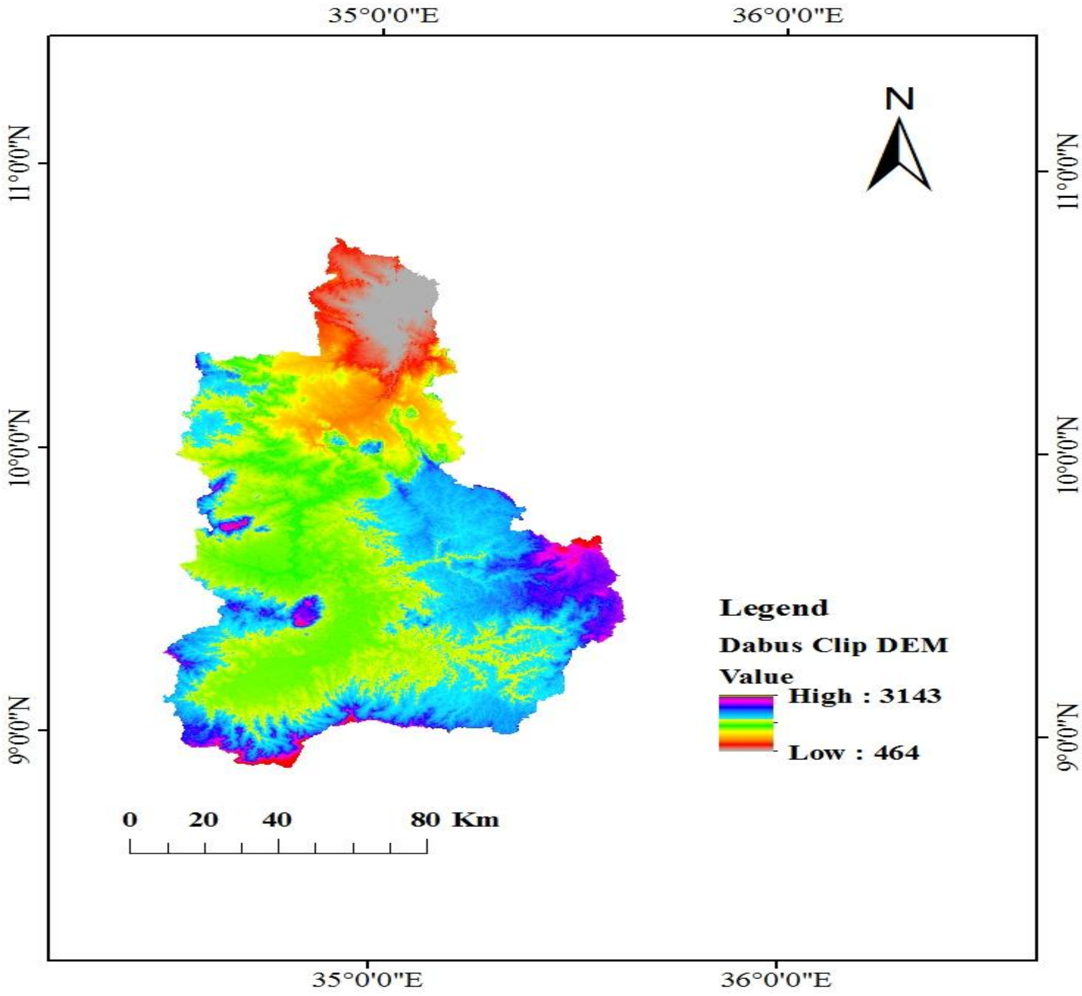


Figure 3.3: DEM of Dabus watershed

3.2.4 Land Use Land Cover data

The land use/land cover 2013 map of the study area was collected from Ethiopian mapping agency (EMA). It is spatial dataset in the model defines the densities and types of land use found within a given area. The dominant land use condition in the Dabus watershed in includes mainly moderate forest, agricultural land and grassland. Land use is one of the most important factors that affect runoff, evapotranspiration and surface erosion in a watershed. Land use land cover data which is very essential for SWAT input for determining the watershed characteristics, and also used for comparison of impacts on stream flow of the catchment.

3.2.5 Soil Data

The soil data has been collected from the MoWIE, where it had been prepared on a 1:250,000 scale during the 1997/98 master plan period [BCEOM, 1998]. But many additional hydrological attributes, such as the saturated hydraulic conductivity, the bulk density, available water capacity, and particle size distribution, required by SWAT were collected from Water Base, National Engineering Handbook [USDA, 1972], International Soil Reference and Information Center (ISRIC) which developed a World Inventory of Soil Emission potential (WISE) and harmonized global soil information [Batije, 2002 and 2008], FAO and the American Soil Survey and Soil Taxonomy.

3.3 Hydro-Meteorological Data Analysis

Hydrological modeling to a large extent depends on hydro-meteorological and hydrological data. Reliability of the collected raw hydro-meteorological data significantly affects quality of the model input data and, consequently, the model simulation. This subchapter sequentially presents, rough data screening of raw hydro-meteorological and hydrological data, completion of identified missing data, estimation of areal rainfall and analysis done to check consistency and homogeneity of the estimated a real data sets. Engineering studies of water resources development and management depend heavily on hydro- meteorological data. These data should be stationary, consistent and homogeneous when they are used for frequency analyses or to simulate a hydrological system.

Rough screening of the data will allow visual detection of whether the observations have been consistently or accidentally credited to the wrong day, whether they show gross errors (e.g. from weekly readings instead of daily ones) or whether they contain misplaced decimal points. In this study no data detected in this procedure since there are no outcropping daily data in entire stations and period of records.

3.3.1 Meteorological data analysis

The meteorological data used for this study should be stationary, consistent and homogeneous to say that the simulation is efficient. So, it’s mandatory to check the data

against these parameters. For this study, daily data of precipitation, temperature (Max & Min), sunshine hours, relative humidity and wind speed of all synoptic stations around and on the Dabus watershed were collected. Six meteorological stations were used for this study, where as Asossa station was selected as weather generator stations, to generate for the missing data of the other stations.

3.3.1.1 Filling in Missing meteorological Data

Measured precipitation data are important to many hydrologic analysis and design. Because of the cost associated with data collection, it is very important to have complete records at every station. Obviously, conditions sometimes prevent this. For gages that require periodic observation, the failure of the observer to make the necessary visit to the gage may result in missing data. Vandalism of recording gages is another problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the precipitation record.

A number of methods have been proposed for estimating missing rainfall data. The station-average method is the simplest method. The normal ratio methods provide a weighted mean, with the former basing the weights on the mean annual rainfall at each gage and the latter having weights that depend on the distance between the gage where recorded data are available and the point where a value is required. The isohytal and linear regression methods are the third and fourth alternative to fill missed data.

For this study linear regression method and station average method were used for filling missed rainfall data values for all station. Where as for station average method the general formula for computing the missed data is given in equation 3.1.

$$Px = \frac{1}{N}(P_A + P_B + P_C + \cdots + P_N) \quad \text{..........3.1}$$

Where, PX is the precipitation for the station with missed record, PA, PB, PC+.....+ PN are the corresponding precipitation at the index stations.

Filling of missing other metrological parameters was done with the same procedure and method as that of precipitation data.

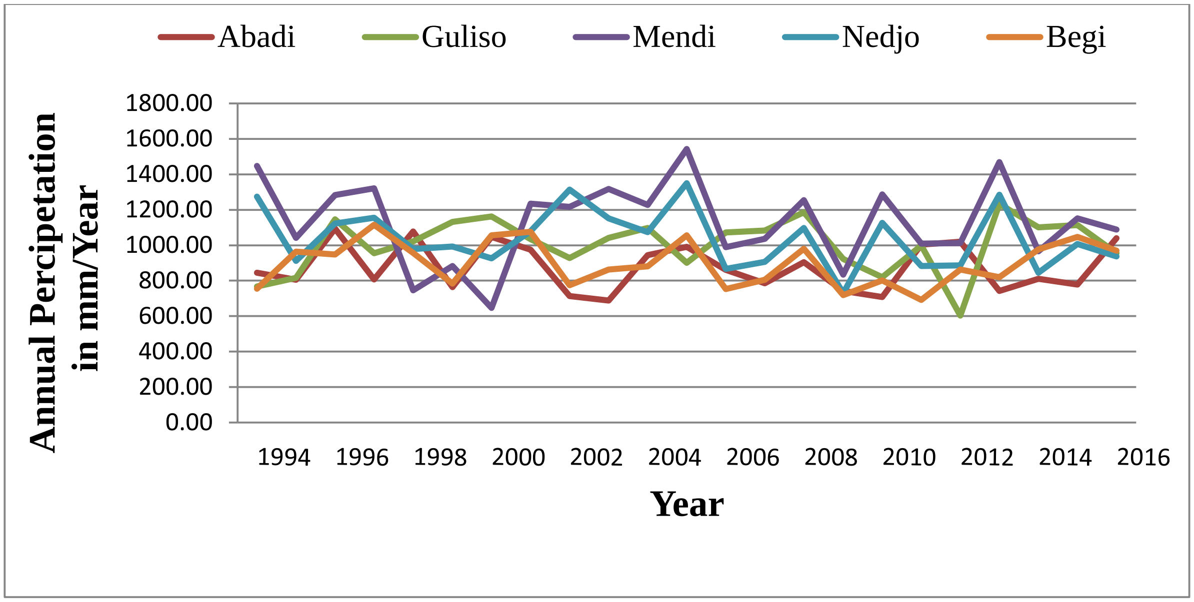


Figure 3.4: Annual precipitation variability for selected metrological stations

3.3.1.2 Estimation of areal rainfall

Areal rainfall was calculated by thiessen polygon method. This method gives weight to stations in proportion to the space between the stations (IHMS, 2006). The daily areal rainfall is calculated from the daily point measurement of precipitation inside the catchment by thiessen polygon method. A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. Average depth of precipitation over the area under the area of considerations is one of the most important parameter in hydrological analysis.

Arithmetic average method: When rainfall is uniformly distributed over the area, average rainfall may be taken as the arithmetic average of the recorded rainfall, thiessen polygon method: Rainfall varies in intensity and duration from place to place. Hence, rainfall recorded by each rain gauge station should be weighted according to the area it is assumed to represent and isohytal method: - isohyets are a line joining places of equal rainfall intensities on rainfall map of the basin. An isohytal map represents an accurate picture of the rainfall distribution over the basin. If the network rainfall stations within the storm sufficiently dense, the isohytal map will give a reasonably accurate indication of rainfall distribution zones.

For this research study, a method called thiessen polygon was used due to the rainfall variation in intensity and duration from station to other. The thiessen polygons were generated with the help of ARC GIS 10.4.1 tools using all six selected meteorological stations. The areal precipitation is calculated using the following equation of thiessen polygons method:

$$p_{Total} = \frac{A1}{A_{Total}} * P1 + \frac{A2}{A_{Total}} * P2 + \frac{A3}{A_{Total}} * P3 + \cdots \ldots \ldots .. + \frac{A6}{A_{TotalL}} * P6 \ldots \ldots .... (3.2)$$

Where A_{Total} = Total area, A1, A2…… A6 = Area of each station, P = precipitation and p_{Total} = The sum of precipitation for six meteorological station.

Table 3.2: Thiessen gauge weight for Dabus watershed

Dabus Watershed			
S.NO.	Rainfall station	Area (km^2)	Gauge Weight
1	Abadi	1730.44	11.7%
2	Asossa	2006.83	13.6%
3	Begi	3403.93	23.1%
4	Guliso	1514.12	10.3%
5	Mendi	4070.64	27.6%
6	Nedjo	2012.98	13.7%
Total 14738.9 Km^2			

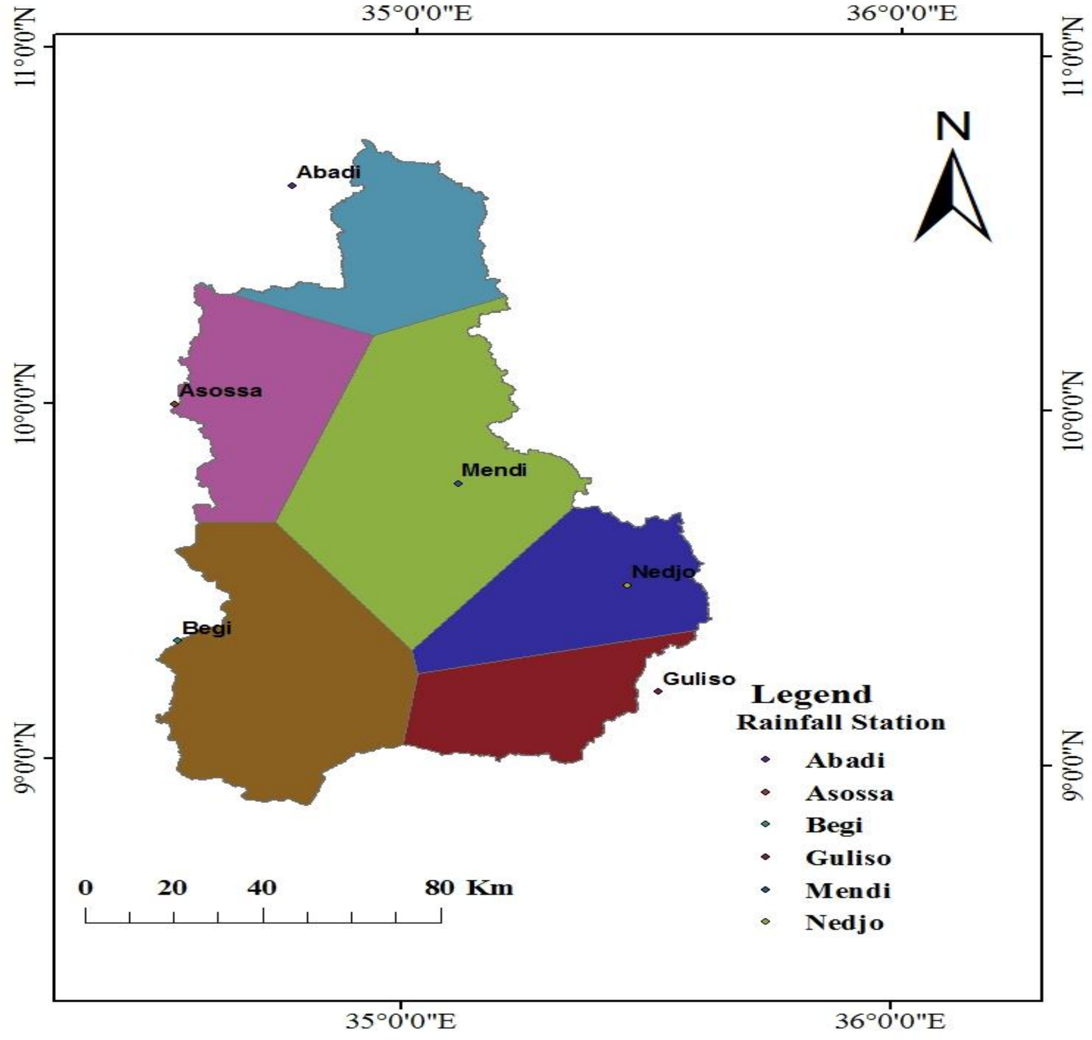


Figure 3.5: Thiessen polygon developed for Dabus watershed

3.3.1.3 Test for consistency of record and Homogeneity

Estimating missing data is one problem that hydrologists need to address. A second problem occurs when the catch at rain gages is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record. A consistent record is one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result from any one of a number of events; specifically, adjustment may be necessary due to changes in observation procedures, changes in exposure of the gage, changes in land use that make it impractical to maintain the gage at the old location, and where vandalism frequently occurs.

Double-mass-curve analysis is the method that is used to check for an inconsistency in a gauged record. A double-mass curve is a graph of the cumulative catch at the rain gage of interest versus the cumulative catch of one or more gages in the region that has been subjected to similar hydro-meteorological occurrences and is known to be consistent. If a rainfall record is a consistent estimator of the hydro meteorological occurrences over the period of record, the double-mass curve will have a constant slope.

A change in the slope of the double mass curve would suggest that an external factor has caused changes in the character of the measured values. If a change in slope is evident, then the record needs to be adjusted, with either the early or later period of record adjusted. Conceptually, adjustment is nothing more than changing then values so that the slope of the resulting double-mass curve is a straight line. The rainfall records of the station X are adjusted by multiplying the recorded values of rainfall by the ratio of slopes of the straight lines before and after change in environment.

$$Y_{2X} = Y_{1X}\frac{S2}{S1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.3)$$

Where: Y_{2X}= corrected precipitation at station x,

Y_{1X}=original recorded precipitation at station x,

S2=slope of double mass curve to be corrected and

S1= original slope of double mass curve

In order to check the consistency of all the rainfall stations the double mass curve is used. According to the double mass curves, all the stations were found to be consistent.

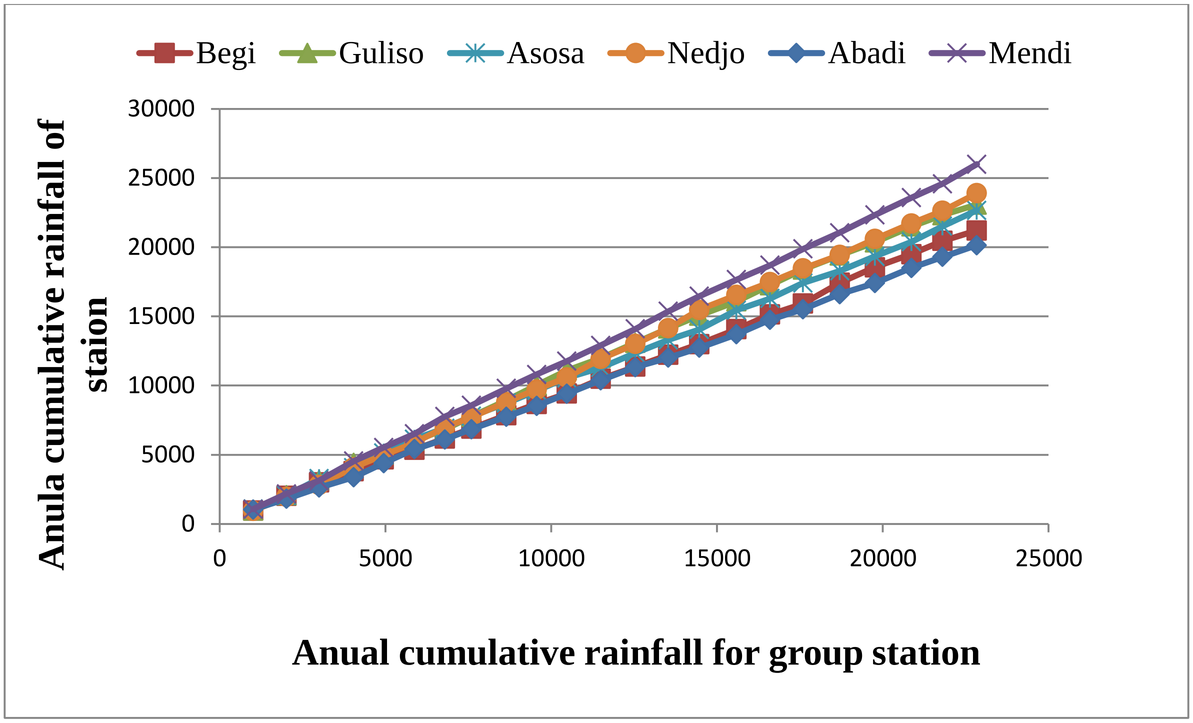
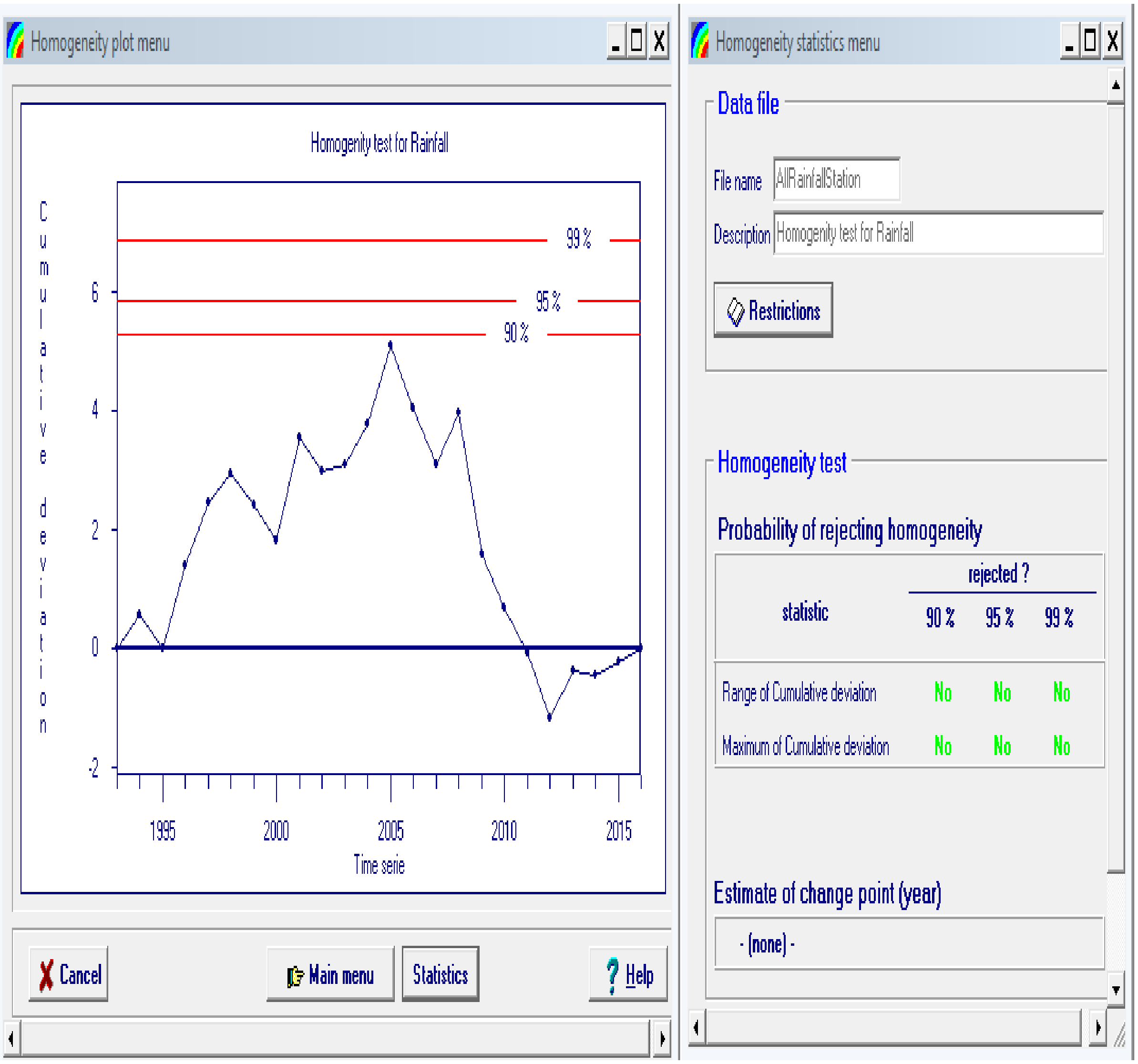


Figure 3.6: Double mass curve plots for the selected metrological stations.

Also rain fall stations were tested for homogeneity with the help of the RAINBOW software package**.** Critical values for the test-statistic which test the significance of the departures from homogeneity are plotted in the Homogeneity plot menu as well (3 horizontal lines). If the cumulative deviation crosses one of the horizontal lines the homogeneity of the data set is rejected with respectively 90, 95 and 99% probability. The probability of rejecting the homogeneity of the data set is reported in the homogeneity statistics menu. The menu is displayed by clicking on the ‘Statistics’ button in the homogeneity plot menu. If as a result of a homogeneity test, the homogeneity of the data set is rejected, the user can restrict the analysis to the fraction of the time series which is homogenous. For this study the data was found to be homogenous as indicated in figure 3.7.



Data file

File name: AllRainfallStation

Description: Homogenity test for Rainfall

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure 3.7: Homogeneity test of Rainfall data of all station

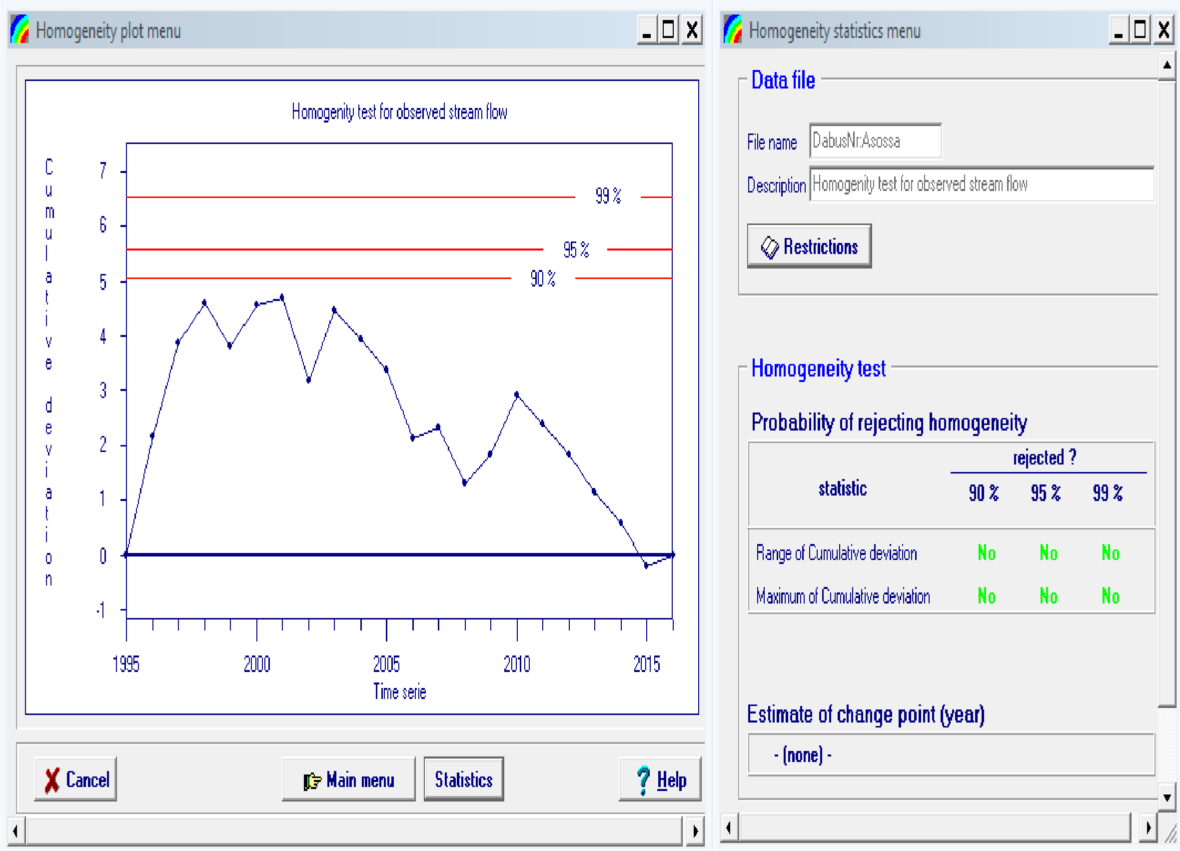
3.3.2Hydrological Data Analysis

Like metrological data, the initial step taken during the hydrological data analysis was quick visual scan of the data time series to detect gross errors such as untrue peak flow, missed recordings, and flows of constant rate. It helps to detect the year with magnitude change in the data, long periods of missing records and short-term missing data. Because unlike rainfall, stream flow shows strong serial correlation; the value on one day is closely related to the value on the previous and following days especially during periods of low flow or recession.

Dabus watershed has a number of streams, where some of the streams having seasonal flow, while the focus of this study is on the flow of the Dabus River which flows throughout the year. The selected gauging stations of Dabus river for this case is Dabus Nr: Asossa near to the outlet of watershed, because this stations is the only station installed on the main river and represent the area of the watershed. The only other station that has concurrent record is that on Haffa river near Assosa. The data from this station was then used to fill the gaps in the records of the station Dabus near Assosa using linear regression method.

Flow data was required for performing calibration and validation of the model from 1996 to 2016 for the period of 21 years. The flow data was also collected from Ministry of Water, Irrigation and Energy of Ethiopia. The homogeneity of flow data was also checked using RAINBOW (a software package for hydro meteorological frequency analysis and testing the homogeneity of historical data sets).

RAINBOW offers a test of homogeneity which is based on the cumulative deviations from the mean. By evaluating the maximum and the range of the cumulative deviations from the mean, the homogeneity of the data of a time series was tested. For this study the hydrological data was found to be homogenous as indicated in figure 3.8.



Data file

File name: DabusNr.Asossa

Description: Homogenity test for observed stream flow

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure 3.8: Homogeneity test of flow data

3.4 General Methodology

For any research, identifying clear and efficient material and methodology used is crucial for the effectiveness of the study not only from time budget point of view, but also from the quality of the research result expected. In this research, Arc SWAT2012 was used for the simulation which was integrated with Arc GIS 10.4. Arc SWAT breaks preprocessing in to following steps: - watershed delineation, hydraulic response unit (HRU) analysis and weather data definition, model simulation with that of sensitivity analysis calibration and Validation.

In order to understand how each section works within the modeling process. It is important to understand the conceptual framework of each step, as well as what data are used and how they are integrated in to Arc SWAT. There for the major steps of Arc SWAT preprocessing will be covered in figure below.

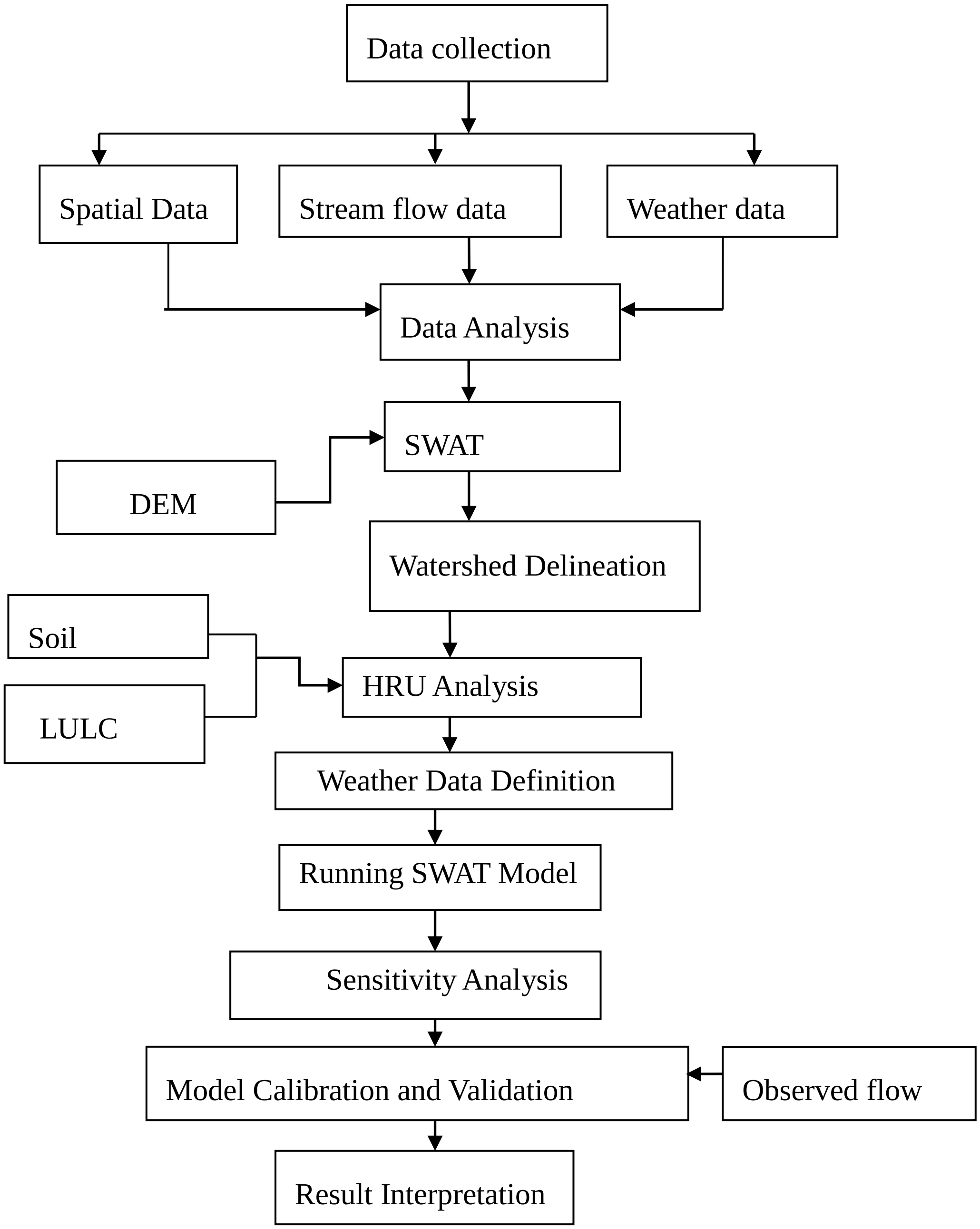


Figure 3.9: Flow charts of Arc SWAT preprocessing step

Model set up: The model setup involves the following steps: (a) Watershed delineation and Sub basin discretization, (b), HRU Definition, (c) Weather data definition, (d) Model running and (e) Sensitivity analysis, Model calibration and Validation.

Data Preparation

The required spatial data sets were projected to the same projection called Adindan UTM Zone 37, which is the transverse Mercator projection parameter for Ethiopia, using Arc GIS

10.4.1. The land use / Land cover special data were decalcified in to SWAT land cover/plant types. A user lookup table was created that identified the SWAT code for different categories of Land cover/Land use on the map as per the required format. The soil map is linked with the soil data base which is designed to hold data for soils not included in the U.S.

3.4.1 Watershed Delineation

The first step in initializing a watershed simulation in SWAT model to have SWAT model input is watershed delineation from digital elevation model. For modeling purposes, a watershed may be partitioned into a number of sub watersheds or sub basins. The use of sub basins in a simulation is particularly beneficial when different areas of the watershed are dominated by land uses or soils dissimilar enough in properties to impact hydrology. By partitioning the watershed into sub basins, the user is able to reference different areas of the watershed to one another spatially (Neitsch et al., 2005).

The watershed and sub watershed delineation was done using 30m x 30m DEM data. The watershed delineation process include five major steps, DEM setup, stream delineation, outlet and inlet definition, watershed outlet selection and definition and calculation of sub basin parameters. For the stream definitions the threshold based stream definition option was used to define the minimum size of the sub basins. The Arc SWAT interface allows the user to fix the number of sub basins by deciding the initial threshold area. The threshold area defines the minimum drainage area required to form the origin of a stream. Subdividing the sub watershed in to areas having unique land use, soil and slope combinations makes it possible to study the differences in evapotranspiration and other hydrological conditions for different land covers, soil and slopes. Stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation.

The size and number of sub-basins and details of stream network depends on this threshold area (Winchell et al., 2007). In this study the threshold area was taken 12000 ha and the watershed outlet is manually added and selected for finalizing the watershed delineation. With this information the model automatically delineates a watershed area of 14738.92km^2 with 75 sub basins which is shown in figure below.

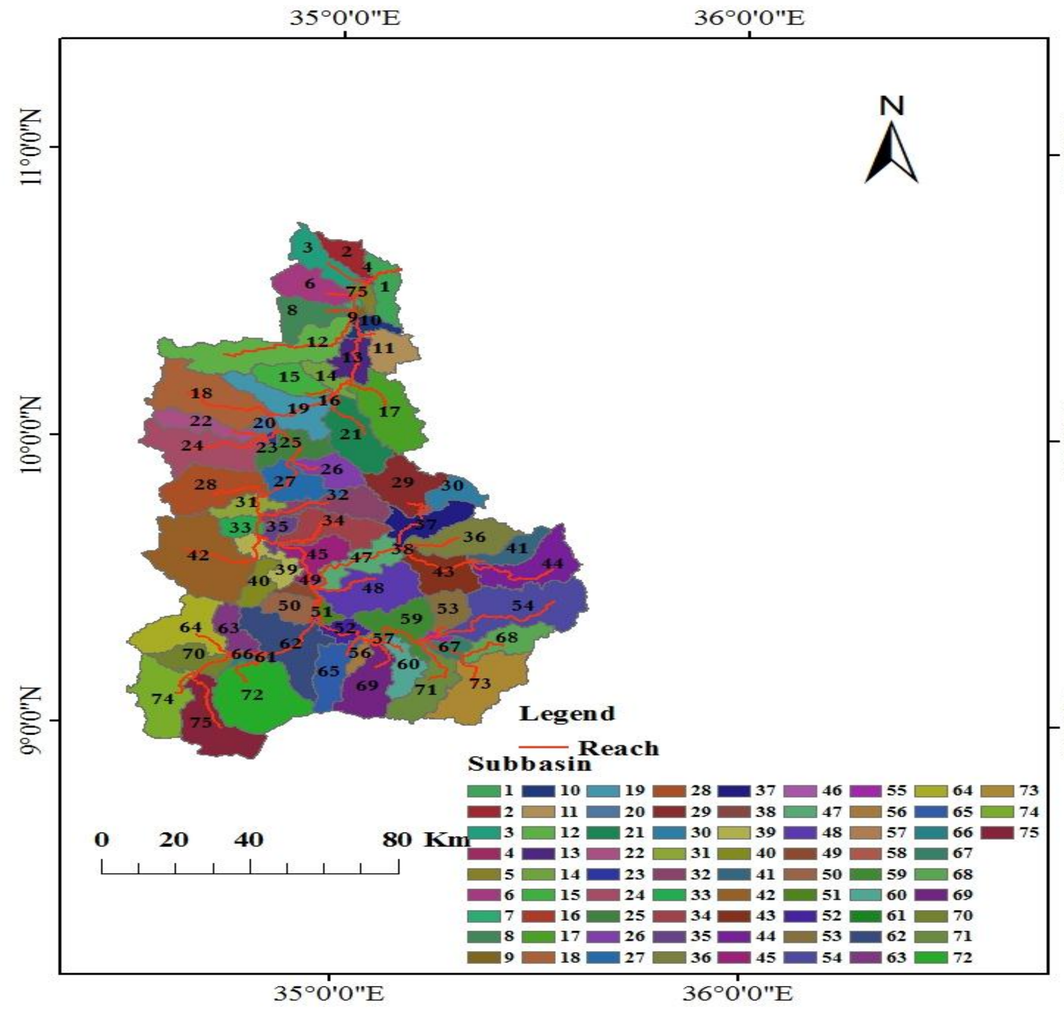


Figure 3.10: Sub basin discretization of Dabus watershed

3.4.2 Hydrologic Response Unit Determination

After watershed delineation, the watershed was partitioned in to hydrologic response units (HRU), which are unique land use, soil and slope combinations within in the watershed to be modeled. There are two options: HRUs can be determined either by assigning only one HRU for each sub watershed considering the dominant soil/land use combinations. The second way is by assigning multiple HRUs for each sub watershed considering the sensitivity of the hydrologic process based on a certain threshold values of soil/land use combinations; in this study multiple HRU was used.

Land use/cover map that was collected from EMA was not directly used by the SWAT model. SWAT has predefined land uses identified by four-letter codes and it uses these codes to link land use map of the study area to SWAT land use databases in the GIS interface. So, well preparation of the lookup-table of the land use/cover types in the SWAT compatible way is basic for the loading of the land use/cover of the study area. Information collected from the digitalized land use/cover map shape file was used in renaming the land uses/cover or to prepare the look up table. The land use map overlapped to the delineated watershed as shown in figure below.

Table 3.3: Land use/land cover types, their area coverage in the study area and redefinition according to SWAT Code

Original Land use/ Landover	Redefined Land use according to SWAT	SWAT Code	Area (km^2)	% of Area Watershed
Dense forest	Ever-forest green	FRSE	1588.07	10.77
Moderate forest	Forest-mixed	FRST	6044.77	41.01
Wood land	Forest-deciduous	FRSD	1.09	0.01
Swamp/wetland	Wetland-non forest	WTEN	2.68	0.02
Settlement	Residential	URBN	8.98	0.06
Bare land	Barren	BARR	29.42	0.2
Cropland	Agricultural land generic	AGRL	4503.35	30.55
Grass land	Range grasses	RNGE	213.84	15.92
Shrub land	Range brush	RNGB	2346.70	1.45

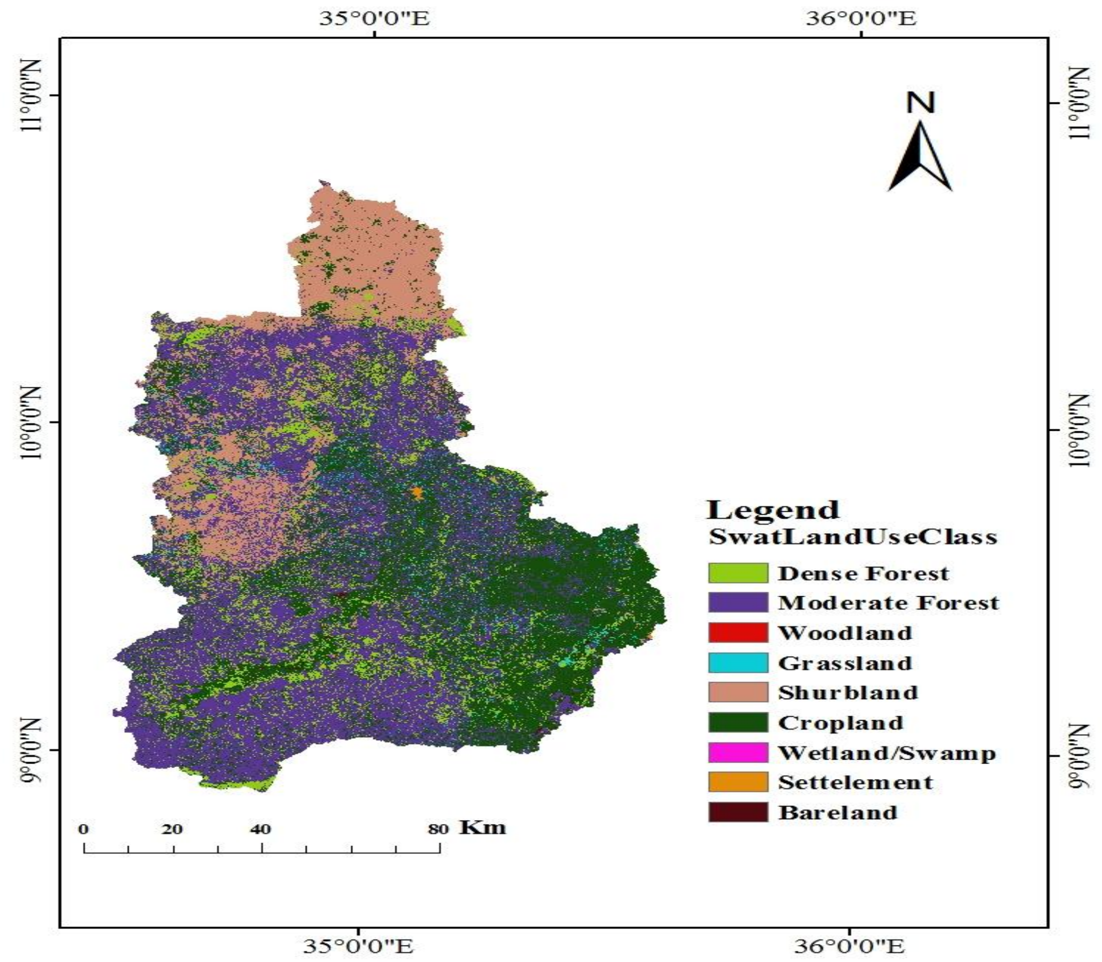


Figure 3.11: Land cover map of Dabus watershed

After add the land use map into the model, the next is the soil map of the watershed. Like the land use map, the soil map that was collected from MoWIE was not directly used by the SWAT model. In order to integrate the soil map within the SWAT model, it is necessary to make a user soil database that contains physical and chemical properties of each soil of the study area. Finally the soil class in the input soil map is linked to SWAT data base by using lookup table. Soil map wasoverlapped to the delineated watershed as shown in figure below.

Major soil types in the Dabus watershed are Haplic Alisols, Rhodic Nitosols, Haplic Nitosols, Euteric Vetisols, Haplic Acrisols, Marsh, Dystric Cambisopls, etc.

Table 3.4:Soil of the Dabus watershed with their aerial coverage (based on FAO soil classification)

Soil type	BECOM	Symbol	Area (km^2)	% of Area Watershed
Haplic Acrisols	S/RhAc	Ach	804.27	5.46
Haplic Alisols	V/ShAl	ALh	5428.36	36.83
Dystric Cambisols	RdCm	CMd	174.29	1.18
Euteric Cambisols	ReCm	CMe	109.95	0.75
Euteric Flivosols	ReVr	FLeS	91.68	0.62
Dystric Leptosols	RdLp	LPd	99.84	0.68
Euteric Leptosols	ReLp	LPe	115.29	0.78
Marsh	HSf	MA	474.28	3.22
Haplic Nitosols	RhNt	NTh	4523.72	10.78
Rhodic Nitosols	V/SrNt	NTr	1327.81	30.69
Euteric Vertisols	VeVr	VRe	1547.79	9.01

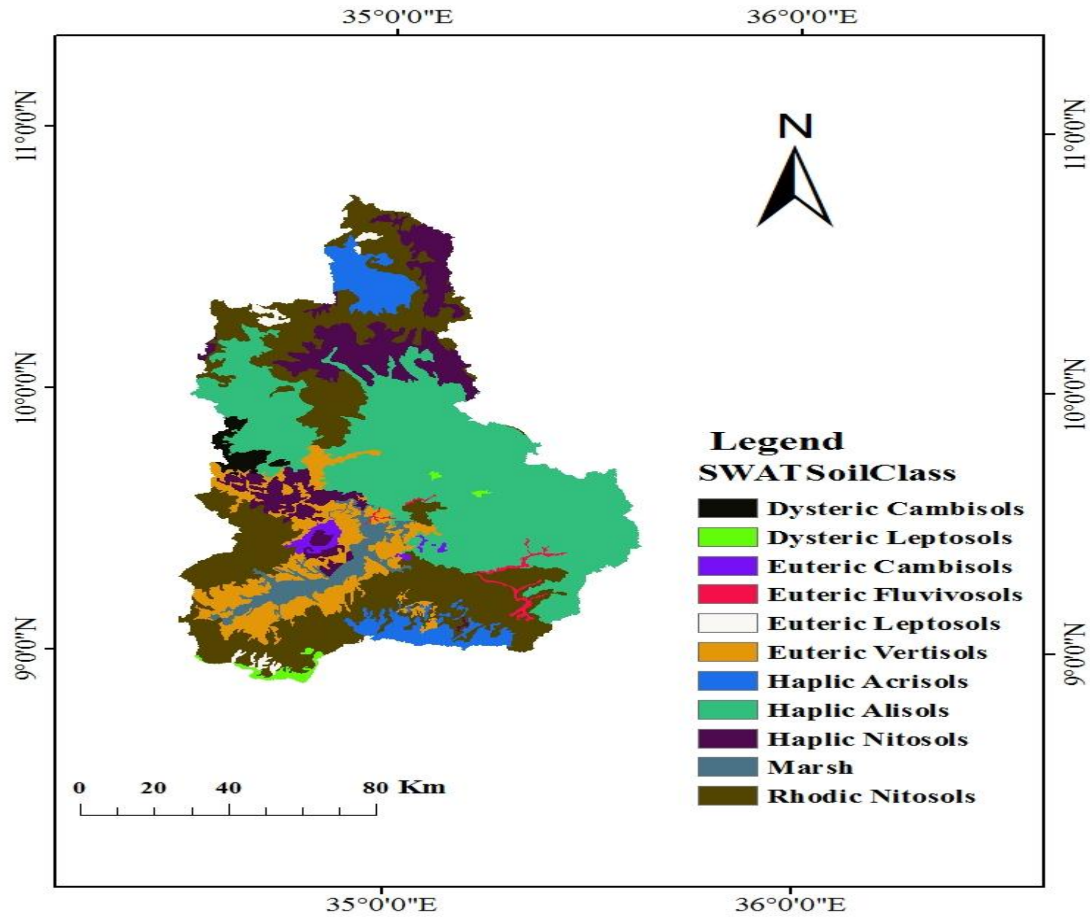


Figure 3.12: Major soil map of Dabus watershed

The third step in HRU definition is selection of slope classification option (single or multiple) and if multiple slope option is select then defines the range of the slope. For this study multiple slope option (an option for considering different slope classes for HRU definition) was selected and the slope class was classified to four and the range was 0-5%, 5-15%, 15-45% and above 45%. This classification was used to account lower slope ranges and it is best discretization option in considering deposition of soil materials during sediment transport.

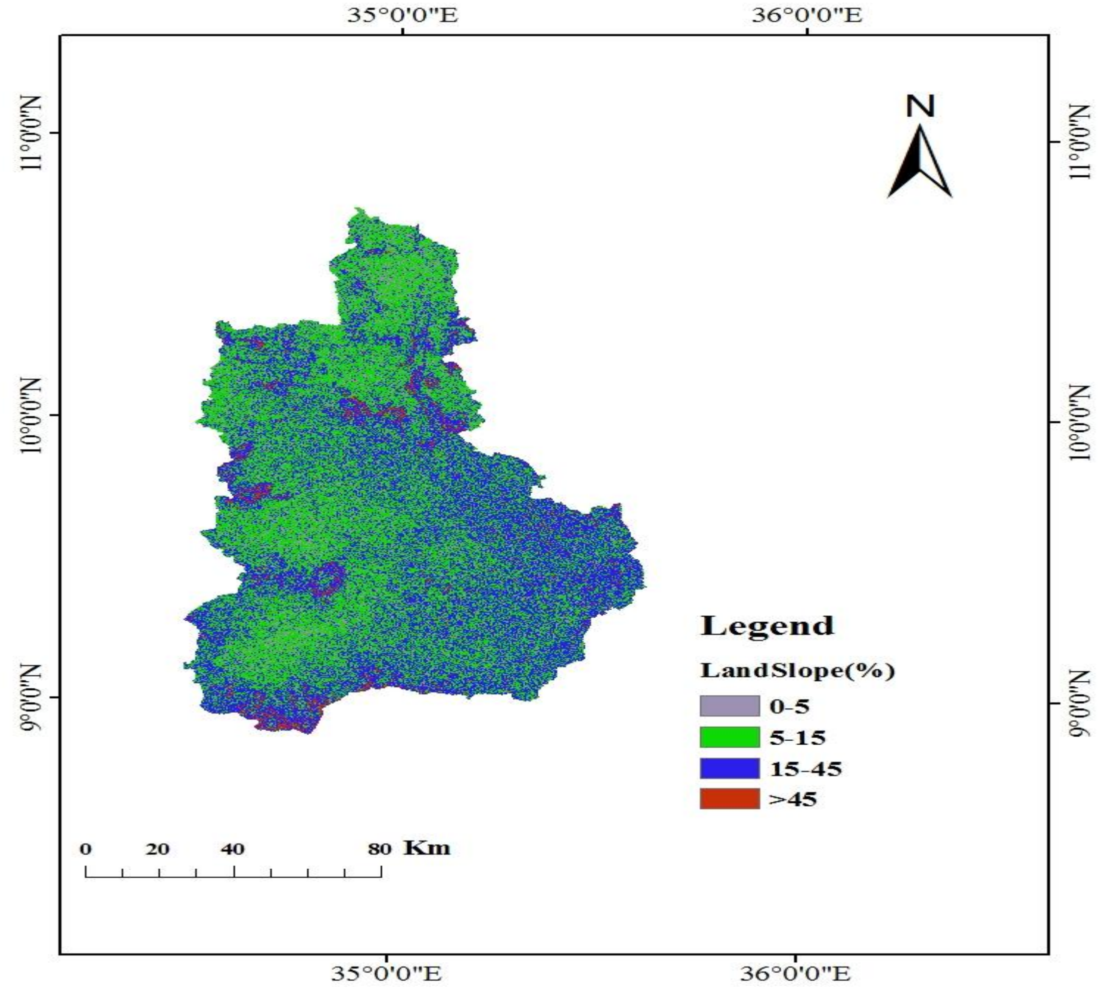


Figure 3.13: Slope classification of the Dabus watershed in SWAT model

Lastly by overlaying the three classifications and defining the HRUs within a sub-basin HRU setup was completed. The Arc View SWAT interface user's manual suggests that a 20 percent land use threshold, 10 percent soil threshold and 10 percent slope threshold are adequate for most modeling applications. In this study, multiple HRU with 15 percent land use threshold, 10 percent soil threshold and 10 percent slope threshold were adopted. Threshold values indicate that land uses which form at least 15 % of the watershed area, soils which form at least 10% of the area and slope which form at least 10 % of the area within each of the selected land uses will be considered in HRU. With this information the model automatically created 323 HRU for a watershed area of 14738.92km^2 with 75 sub-basins.

3.4.3 Weather Data Definition

Another major section of Arc SWAT is weather data. Weather generator model included in SWAT was used to fill missing values in measured records and also to simulate the data if simulation option is selected. WXGEN was provided with all the necessary statistical information from the meteorological records of the watershed to fill the missing portion properly. The parameters needed for the weather generator are listed in Appendix A (for definition of each parameter listed, look at (Neitsch et al., 2005)

These statistical values were calculated from the metrological data available in Asossa station. The number of years for calculating the statistical values depends on the availability of data in the station. Monthly dew point temperature was additional parameter required for weather generator which was calculated by using DEW02 (Ms.dos software) (Liersch 2003). Statistical analysis of daily precipitation data was calculated by using PCPSTAT. Finally available data of sunshine hour was converted to solar radiation by using angstrom empirical equation.

Then loading this WXGEN parameter and location table was the last step for weather generator data. After loading this WXGEN parameter and location table, the daily meteorological data (daily precipitation, daily minimum and maximum air temperature, daily relative humidity, daily solar radiation and daily wind speed) including the corresponding location table ware prepared according to SWAT mode format and integrated in to the model using weather data input wizard.

Once data base setup was completed in Arc SWAT, the designated weather stations wear added to the monitoring point layer created during watershed delineation. The last step before SWAT simulation run was to write all of the input files required by SWAT and produced from the preprocessing data from Arc SWAT. Once they were written, individual files can be edited through ARCSWAT or externally, and automatically update based on predetermined queries. Making edits to a section of these files is crucial to produce more accurate SWAT simulation result.

3.4.4 Model Simulation

SWAT simulation run was carried out on the 1994-2016 weather data. The first two years taken for warm up period. The warm up period is important to make sure that there are no effects from the initial conditions in the model. The lengths of warm up period differ from watershed to watershed. It is mainly depend on the objective of the study. The simulate output data imported to database and the simulation results were saved in different files of SWAT output format. The file that saved in table out Microsoft access format contains different SWAT parameters output. It is used for SWAT model calibration since most of the observations of the watershed behavior are obtained by measuring these parameters.

3.4.5 Sensitivity Analysis

SWAT- CUP is a SWAT Calibration Uncertainties Program, which is developed to analyze the prediction uncertainty of SWAT model calibration and validation results. The SWAT-CUP can integrate various calibration/uncertainty analysis procedures for SWAT in one user interface. It is a public domain program that links Sequential Uncertainty Fitting ver.2 (SUFI-2), Particle Swarm Optimization (PSO), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (ParaSol), and Markov Chain Monte Carlo (MCMC) algorithms to SWAT model. The SWAT-CUP enables sensitivity analysis, calibration, validation, and uncertainty analysis of SWAT models (Abbaspour, 2009).

The sensitivity analysis of the Dabus watershed of the SWAT model input parameter utilized 21 number of SWAT input parameters. These parameters were selected from various references (White,et al, 2005). The analysis was including the global sensitivity analysis and local sensitivity analysis. In a global sensitivity analysis, parameter sensitivities are determined by calculating the following multiple regression systems, which regresses the Latin hypercube generated parameters against the objective function values.

In SUFI-2, the assessment of the sensitive parameters is measured using the t-stat values where the values are more sensitive for a larger in absolute t-stat values. P-values are used to determine the significance of the sensitivity where the parameter becomes significance if the P-values is close to zero. The sensitivities given above are estimates of the average changes in the objective function resulting from changes in each parameter while all other parameters are changing. This gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters. The local sensitivity analysis or one-at-a-time sensitivity shows the sensitivity of a variable to the changes in a parameter if all other parameters are kept constant at some value.

3.4.6 Model Calibration and Validation

The calibration is the modification or adjustment of model parameters, within the recommended ranges, to optimize the model output so that it matches with the observed set of data. The calibration provides several different parameters for adjustment through user intervention. These parameters can be adjusted manually or automatically until the model output best matches with the observed data. This study is done by applying SWAT-CUP for calibrating outlet stream flow. The validation is the process of determining the degree in which a model or simulation is an accurate representation of the observed set of data from the perspective of the intended uses of the model. The discharge data were recorded during the years 1996-2016 at Dabus Nr:Asossa station, and the daily discharges from 1996-2008 are used for calibration and the daily discharge from 2009-2016 are used for validation, but for the years 1994-1995 it was skipped for model warm-up**.**

3.4.7 Uncertainty Analysis in SWAT model

Most important issue with calibration of watershed models is that of uncertainty in the predictions. Watershed models suffer from large model uncertainties. These can be divided into: conceptual model uncertainty, input uncertainty, and parameter uncertainty (Abbaspour, *et al*. 2009).

Another uncertainty worth mentioning is that of “modeler uncertainty”. It has been shown before that the experience of modelers could make a big difference in model calibration. Like SWAT-CUP (is an interface that was developed for SWAT) can help decrease modeler uncertainty by removing some probable sources of modeling and calibration errors. On a final note, it is highly desirable to separate quantitatively the effect of different uncertainties on model outputs, but this is very difficult to do. The combined effect, however, should always be quantified on model outputs (Abbaspour *et al*. 2009).

Even though there is overall great uncertainty, to check parameter uncertainty independently SWAT CUP interface SUFI-2 (sequential uncertainty fitting version 2) among GLUE (generalized likelihood uncertainty estimation) and parasol method of uncertainty analysis) due to the fact that its simplicity to carry out iteration.

Conceptual Basis of the SUFI-2 uncertainty analysis routine In this study SUFI2 used because it converges with relatively smaller number of iterations, and possibility of restarting an unfinished iteration and splitting iteration into several runs. SUFI-2 algorithm, in particular, is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources (e.g., data, model and etc.) (Yang et al., 2008).

In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty is driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU).

As all the processes and model inputs such as rainfall and temperature distributions are correctly manifested in the model output (which is measured with some error)-the degree to which we cannot account for the measurements the model is in error; hence uncertain in its prediction. Therefore, the percentage of data captured (bracketed) by the prediction uncertainty is a good measure to assess the strength of our uncertainty analysis.

The 95PPU is calculated at the 2.5% and 97.5% levels of the cumulative distribution of an output variable obtained through Latin hypercube sampling, disallowing 5% of the very bad simulations. As all forms of uncertainties are reflected in the measured variables (e.g., discharge), the parameter uncertainties generating the 95PPU account for all uncertainties. Breaking down the total uncertainty into its various components is highly interesting, but quite difficult to do (Abbaspour et al., 2009).

Another measure quantifying the strength of a calibration/uncertainty analysis is the R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data with the smallest possible uncertainty band. Theoretically, the value for P-factor ranges between 0 and 100%, while that of R-factor ranges between 0 and infinity. A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data.

The average thickness of the 95PPU band ($\bar{r}$) and the r-factor are computed by Equation 3.4 and 3.5 respectively.

$$\bar{r} = \frac{1}{n}\sum_{ti}^{n}\left(Y^{M}{}_{ti,97.5\%} - Y^{M}{}_{ti,2.5\%}\right) \ldots\ldots (3.4)$$

$$\text{r- Factor} = \frac{p-factor}{\sigma_{obs}} \ldots\ldots (3.5)$$

Where:$(Y^{M}{}_{ti,97.5\%}$ and $Y^{M}{}_{ti,2.5\%})$ represent the upper and lower boundaries of the 95PPU and σ_{obs} is the standard deviation of the measured data.

3.4.8 Model Evaluation

The performance of SWAT model was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2), Percent bias (PBIAS), RSR and Nash-Sutcliffe simulation efficiency (ENS) were the goodness of fit measures used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the observed and simulated values.

Percent bias (PBIAS): This measures the average tendency of the simulated data to be larger or smaller than the observed values. PBIAS is expressed in percentage see equation 3.6; the lower the absolute value of the PBIAS is the better will be the model performance.

$$\text{PBIAS} = \left[\frac{\left(\sum_{i=1}^{n} Q_{oi} - \sum_{i=1}^{n} Q_{si}\right)}{\sum_{i=1}^{n} Q_{oi}}\right] * 100 \ldots\ldots (3.6)$$

Where: Q_{si} is the simulated discharge and Q_{oi} is the measured discharge. A value close to 0% is best for PBAIS. A negative value indicates model over estimation and a positive value indicate model under estimation.

Root mean square error observation standard deviation ratio (RSR)

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Q_{oi}-Q_{si})^2}}{\sqrt{\sum_{i=1}^{n}\left(Q_{oi}-\overline{Q}_O\right)^2}} \ldots\ldots (3.7)$$

Where: Q_{si} is the simulated value, Q_{oi} is the measured value, and $\overline{Q}_o$ is the average obseved flow.

Nash-Sutcliffe efficiency: The Nash-Sutcliffe efficiency (E_{NS}) is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. E_{NS} measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. E_{NS} can be defined according to the following (Equ.3.8)

$$E_{NS} = 1 - \frac{\sum_{i=1}^{n}(Q_{oi}-Q_{si})^2}{\sum_{i=1}^{n}(Q_{oi}-\overline{Q}_{oi})^2} \ldots\ldots (3.8)$$

Where: Q_{si} is the simulated value, Q_{oi} is the measured value, and $\overline{Q}_{oi}$ is the average obseved flow.For an acceptable model performance, NSE should be close to 1.

Besides, due to frequent use of this objective function, it is known that when values between 0.60 and 0.80 are generated, the model performs reasonably well. Values between 0.80 and 0.90 indicate that the model performs very well and values between 0.90 and 1 indicate that the model performs extremely well (Deckers, 2006).

Finally, **Coefficient of determination (r^2):** it expresses the measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. The range of values for r^2 is 1.0 (best) to 0.0

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(Q_{si}-\overline{Q}_s\right)(Q_{oi}-\overline{Q}_o)\right]^2}{\sum_{i=1}^{n}(Q_{si}-\overline{Q}_s)^2 \sum_{i=1}^{n}(Q_{oi}-\overline{Q}_o)^2} \ldots\ldots (4.8)$$

Where: Q_{si} is the simulated discharge, Q_{oi} is the measured, $\overline{Q}_s$ is the average simulated discharge and $\overline{Q}_o$ is the average measured discharge (m3/s).

Based on the values of the performance parameters above, the following guideline table for a performance rating of a general watershed simulation model, is set up (Moriasi et al., 2007).

Table 3.5: Model performance ratings based on the range of values for RSE, NSE and PBIAS for for monthlystream flow)

Performance Rating	R^2	NS	PBIAS	RSR
Very Good	$0.85 \leq R^2 \leq 1.00$	$0.75 < NSE \leq 1.00$	$PBIAS \leq \pm 1.00$	$0.00 \leq RSR \leq 0.50$
Good	$0.70 \leq R^2 \leq 0.85$	$0.65 < NSE \leq 0.75$	$\pm 10 \leq PBIAS < \pm 15$	$0.50 < RSR \leq 0.60$
Satisfactory	$0.60 \leq R^2 \leq 0.70$	$0.50 \leq NSE \leq 0.65$	$\pm 15 \leq PBIAS < \pm 25$	$0.60 < RSR \leq 0.70$
Unsatisfactory	$R^2 < 0.60$	$NSE < 0.50$	$PBIAS \geq \pm 25$	$RSR > 0.70$

3.5 Rainfall-Runoff Relationship of watershed

The derivation of relationships between the rainfall over a watershed area and the resulting flow in a river essential for sustainable watershed development and reliable estimates of the various hydrological parameters. Due to the spatial and temporal heterogeneity in soil properties, vegetation and land use practices; a hydrological cycle is a complex system. As a result, use of physical models and geospatial analysis tools for studying hydrological process and hydrological responses to rainfall- runoff relation is the current trend (Sanjay *et al.*, 2010).

This study shows the structure of the SWAT-based model used in modeling of the Rainfall Runoff process. SWAT simulation is done for monthly and yearly basis. The runoff analysis for the Dabus watershed focuses on the time span 1996-2016.The relation between rainfall and the resulting runoff is quit complex and is influenced by a host of factors relating the catchment and climate. Further, there is the problem of paucity of data which forces one to adopt simple correlations for the adequate estimation of runoff. One of the most common methods is to correlate runoff, R with rainfall, P values. Plotting of R values against P and drawing a best fit line can adopted for very rough estimates (K. Subramanya, 2008).

A better method is to fit a linear regression line between R and P and to accept the result if the correlation coefficient is nearer unity. The equation for straight-line regression between runoff R and rainfall P is

$$R = a\times P + b \quad (3.9)$$

and the values of the coefficients a and b are given by

$$a = \frac{N\left(\Sigma P R\right) - \left(\Sigma P\right)\left(\Sigma R\right)}{N\left(\Sigma P^2\right) - \left(\Sigma P\right)^2} \quad (3.10)$$

and

$$b = \frac{\Sigma R - a\,\Sigma P}{N} \quad (3.11)$$

in which N = number of observation sets R and P. the coefficient of correlation r can be calculated as

$$r = \frac{N(\sum PR)-(\sum P)(\sum R)}{\sqrt{[N(\sum P^2)-(\sum P)^2)]\times[N(\sum R^2)-(\sum R)^2]}} \quad (3.12)$$

The value of r lies between 0 and 1 as R has only positive correlation with P. A value of $0.6 < r < 1.0$ indicates good correlation. Further it should be noted that $R \geq 0$.

3.6 Water balance of watershed

The water balance was derived from SWAT model, which was calibrated and validated with measured stream flows. The water balance estimation was consisting of precipitation; actual evapor transpiration, runoff, ground water flow and water yields. Then the spatial results of water balance were mapped at the sub basin level.

4. RESULTS AND DISCUSSIONS

4.1 Sensitivity Analysis

SWAT-CUP program with SUFI-2 algorithm was used for model calibration and validation, which can read output data from Arc SWAT interface.

The optimization process that reflects the sensitivity of the SWAT input parameters (Table 4.1) were conducted in two sets; local and global sensitivity. The processes of the local sensitivity analysis were only allowing a single change in the input parameters and other parameters be kept constant at some value. About 100 iterations were conducted for every change of the SWAT input parameters. On the global setting procedures, 500 numbers of iterations were selected in gaining the most sensitive input parameters. In this study, it is observed that only 200 simulations were performed to get sensitive parameters.

Sensitively analysis was performed and its results indicated the most sensitive parameters that illustrated in Table 4.1. From Table 4.1, most sensitive parameters are SCS curve number for moisture condition II (CN_2), ALPHA_BF, GW_DELAY, CANMX and SOL_AWC because of P-value close to 0 and t-stat bigger than other parameters.

Since land use and antecedent soil water conditions (CN2) was the most sensitive of the model parameters the identification of parameter should be surface dominance in case of SWAT model.

Note: the t-Stat provides a measure of sensitivity (larger absolute values are more sensitive); the p-value determines the significance of the sensitivity (a value close to zero has more significance).

Table 4.1: Summary of sensitivity analysis on the 12 input parameter.

Parameters	Definition	P-Value	t-stat	Processes	Global Sensitivity
R_ CN2.mgt	Initial SCS runoff curve number for moisture condition II	0.00	9.09	Runoff	Very high ↕ Very Low
V_ALPHA_BF.gw	Base flow alpha factor (1/day)	0.00	6.78	Groundwater	
V_GW_DELAY.gw	Groundwater delay (days)	0.01	2.65	Groundwater	
V_CANMX.hru	Maximum Canopy Storage	0.02	2.27	Runoff	
R_SOL_AWC(1).sol	Available water capacity of the soil layer (mm H2O/ mm soil)	0.03	-2.14	Soil	
V_ESCO.hru	Soil evaporation compensation factor	0.09	1.72	Soil	
R_SOL_K(1).sol	Saturated hydraulic conductivity (mm/hr)	0.11	-1.60	Soil	
V_REVAPMN.gw	Threshold depth of water for revap to occur	0.23	-1.20	Groundwater	
V_EPCO.hru	Plant uptake compensation factor	0.25	1.15	Plant	
V_CH_N2.rte	Manning roughness for main channel	0.52	0.64	Channel	
V_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0.76	-0.31	Groundwater	
V_GW_REVAP.gw	Threshold depth of water in the shallow aquifer for "revap" to occur	1	0.00	Groundwater	

4.2 Model Calibration

Calibration is the process whereby model parameters are adjusted to make the model out put match with the observed data. Therefore, in this study the hydrologic component of the model was calibrated at Dabus Nr: Asossa gauging station in order to make the simulation result more realistic for independent calibration period. Flow calibration for the watershed was conducted in the outlet for the total of thirteen years (from January 1, 1994 to December 31, 2008) which includes two years of warm up, (from January 1, 1994 to December 31, 1995). The model was calibrated automatically by changing the parameters itself iteratively 200 times. The best fit of the flow parameters were seen at the 125 simulation number.

Table 4.2: Recommended and finally fitted parameter values of flow calibration

Parameters	Description	Recommended value	Fitted Value
R_CN2.mgt	Initial SCS runoff curve number for moisture condition II	-0.2-0.2	0.055
V_ALPHA_BF.gw	Base flow alpha factor (1/day)	0-1	0.9675
V_GW_DELAY.gw	Groundwater delay (days)	30-450	49.95
V_GWQMN.gw	Threshold depth of water in the shallow aquifer required for return flow to occur (mm)	0-2	0.275
V_GW_REVAP.gw	Threshold depth of water in the shallow aquifer for "revap" to occur	0-2	0.305
V_ESCO.hru	Soil evaporation compensation factor	0.8-1	0.9075
V_CH_N2.rte	Manning roughness for main channel	0-0.3	0.12975
R-SOL_AWC(1).sol	Available water capacity of the soil layer (mm H2O/ mm soil)	-0.2-0.4	0.1555
R_SOL_K(1).sol	Saturated hydraulic conductivity (mm/hr)	-0.8-0.8	0.076
V_CANMX.hru	Maximum Canopy Storage	0-100	54.25
V_EPCO.hru	Plant uptake compensation factor	0-1	0.2725
V-REVAPMN.gw	Threshold depth of water for revap to occur	0-10	3.125

The performance of the model was tested at every stage of the model simulation with the parameters printed out at the respective stages. Adjusting the parameters values as stated above and simulating the model, the model goodness of-fit was evaluated on monthly basis to test the performance of the model. The result of the model test shows that the R^2, NSE, RSR and PBIAS of 0.88, 0.80%, 0.45 and -3.80% respectively. Therefore the objective functions were satisfied.

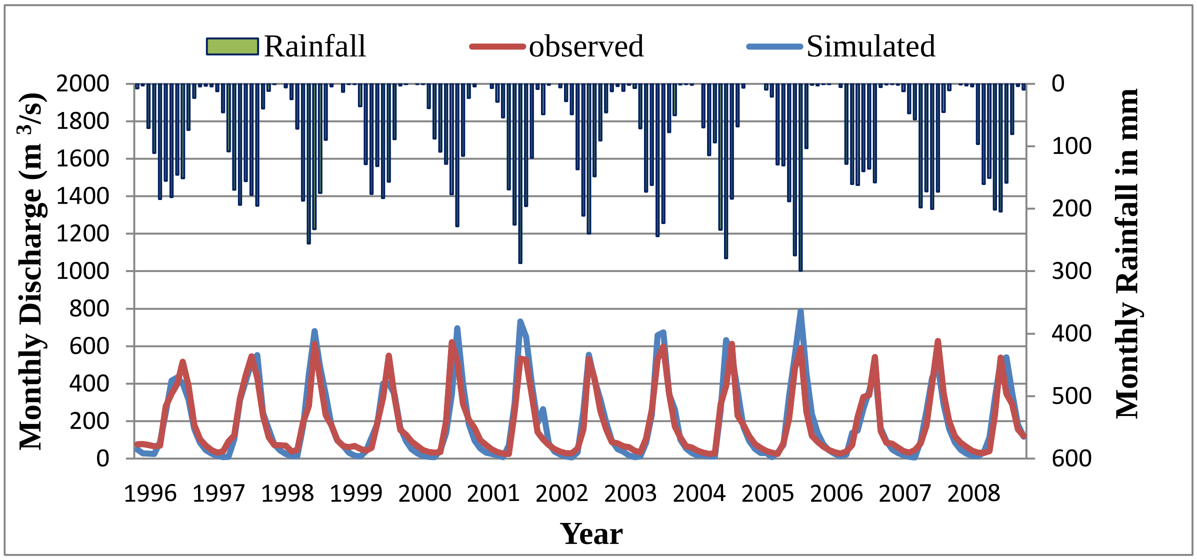


Figure 4.1: Graphical comparison of measured and simulated flow at DabusNr:Asossa during Caliberation period (1996 - 2008).

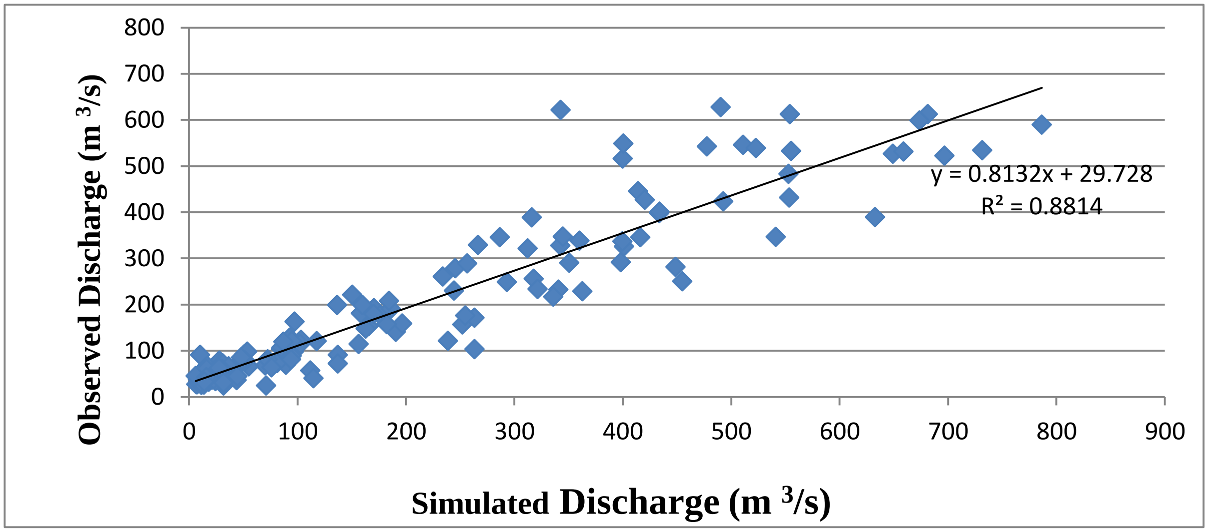


Figure 4.2: Scatter plot of observed and simulated stream flow for Dabus watershed during Calibration period (1996-2008).

The performance of the model was tested at every stage of the model simulation with the parameters printed out at the respective stages.

4.3 Model Validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Thus, the model was validated with observed flow data at Dabus Nr: Asossa gauging station, but different time period from January 1, 2009 to December 31, 2016, without further adjustment of the parameters of flows. The overall performance of the model during validation has been tested using R^2, Nash-Sutcliffe (NSE), RSR and PBIAS. The statistical values in monthly time base of R^2, NSE, RSR and PBIAS are 0.88, 0.76, 0.49 and -3.2% respectively. This indicates the objective functions that used for evaluation were in the acceptance range for the validation time period.

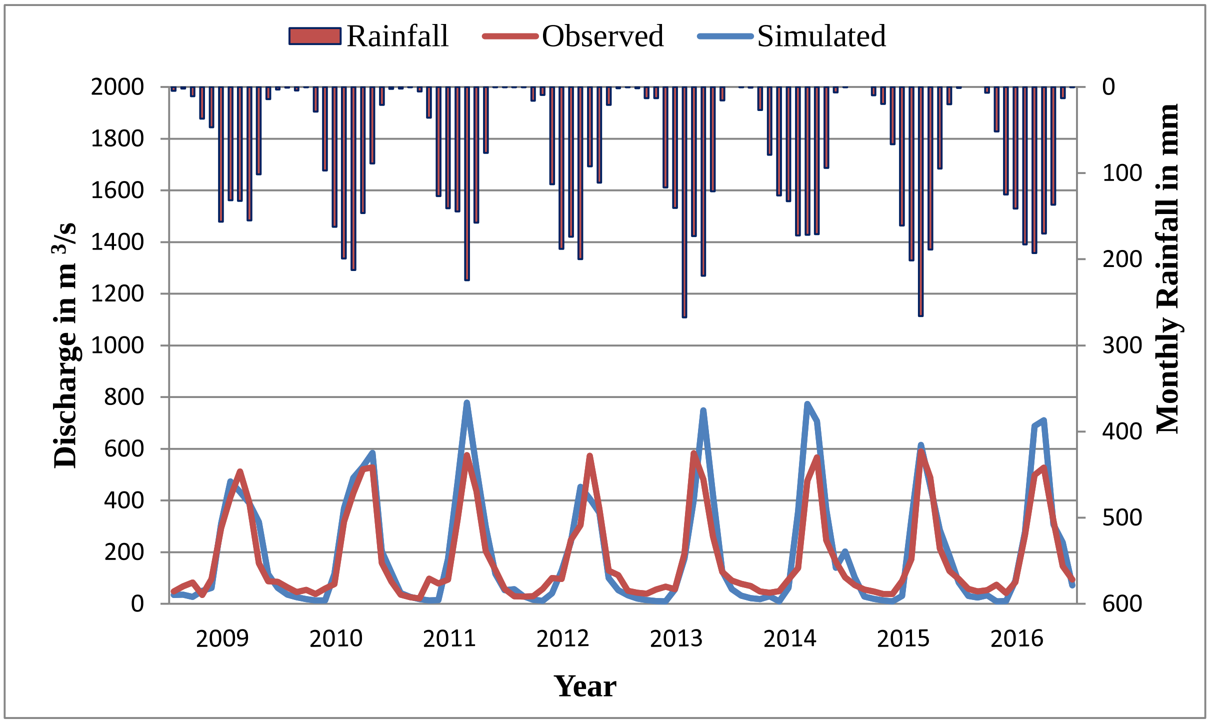


Figure 4.3: Graphical comparison of measured and simulated flow at DabusNr: Asossa during validation period (2009 - 2016).

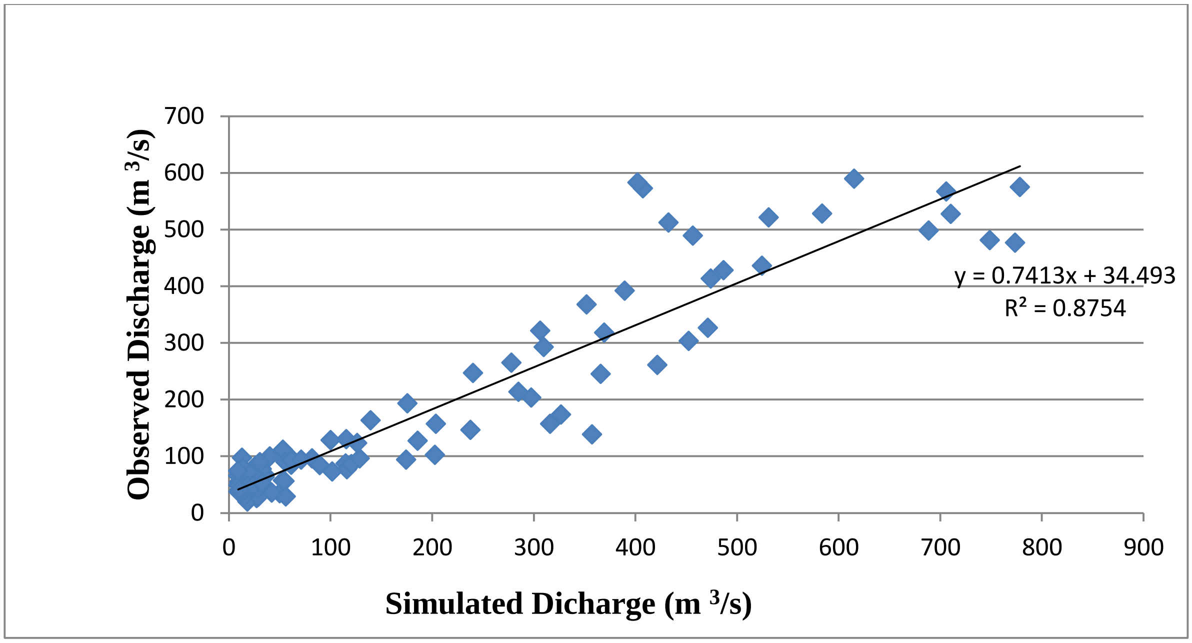


Figure 4.4: Scatter plot of observed and simulated stream flow for Dabus watershed during Validation period (2009-2016).

4.4 Uncertainty Analysis

The uncertainty of the calibrated model in SUFI-2, 95PPUs, is the combination of the uncertainties in the input data, model structure, model parameters, and the measured data (which was not separately evaluated). The uncertainty was represented by the p-factor and the r-factor. In terms of monthly stream flow, the p-factor and the r-factor was 94 % and 50% for calibration. This indicated about 94 % (Out of a perfect 100 %) of the measured monthly stream flow could be bracketed by the 95PPU with a very narrow 95PPU band of 0.5 (close to a perfect 0) in the calibration period.

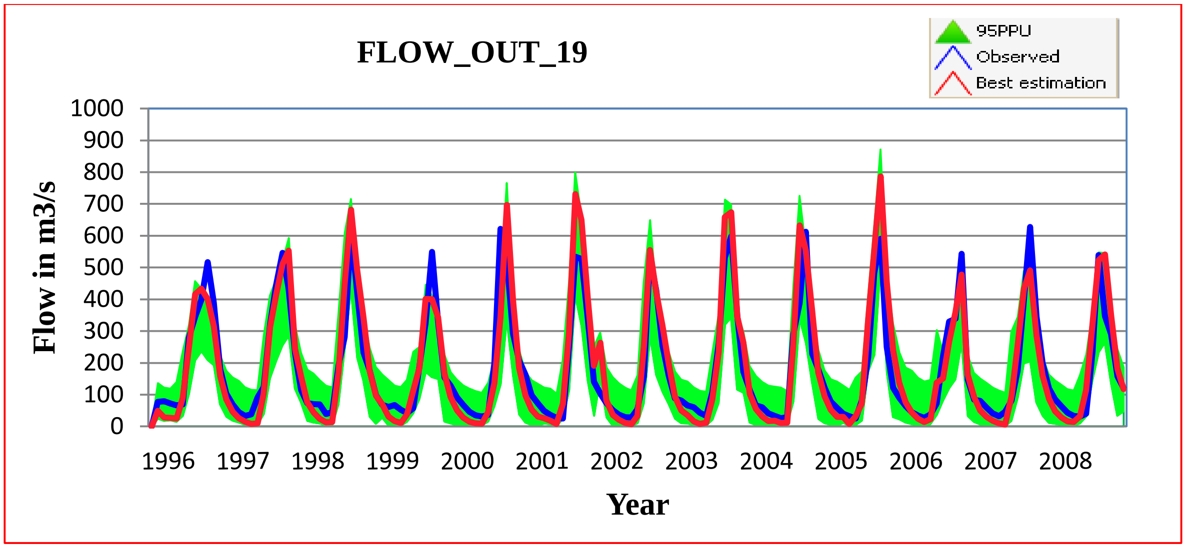


Figure 4.5: Uncertainty plot for SWAT model

Table 4.3: Model Performance Evaluation for flow calibration and validation period

Variable		Calibration	Validation	Performance Remarks	
				Calibration	Validation
R^2		0.87	0.88	V.G	V.G
NS		0.80	0.76	V.G	V.G
PBIAS		-3.8	-3.2	V.G	V.G
RSR		0.45	0.49	V.G	V.G
Average Monthly Flow in m^3/s	Measured	182.79	178.70		
	Simulated	189.77	184.46		

4.5 Rainfall-Runoff Relationship of Dabus watershed

This study shows the structure of the SWAT-based model used in modeling of the rainfall runoff process. SWAT simulation is done for monthly and yearly basis. The runoff analysis for the Dabus watershed focuses on the time span 1996-2016. The runoff depends on total precipitation, evaporation and soil water storage. It is clearly seen that for high potential of evapotranspiration, there is corresponding low runoff coefficient indicating the effect of evapotranspiration on runoff. The average annual runoff in the Catchment is variable. For a variation of precipitation from 792.2mm/yr to 1111.1mm/yr there is a variation of annual average runoff from 121.6mm/yr to 349.19mm/yr.

The variability of the runoff can be primarily attributed to the patterns of precipitation. The largest portion of the runoff is derived from south and south west part of the Dabus watershed where the high elevation promotes greater precipitation. The annual rainfall and runoff diminishes toward the north and east of Dabus sub basin. This revealed that the runoff of the basin is highly controlled by topography and precipitation. The runoff increases during rainy season and drops when the rainfall is decreased. Generally the highest flows are typically during the mid July, August and September and the lowest flows are occurred during April and May. So Dabus river has the highest discharge in 2005.

The observed discharges at the river gauging station has an intra-annual bimodal distribution with a small peak discharges in April and may and a large peak during the rainy seasons in mid July, August and September. Like rainfall, runoff is highly variable in the Dabus watershed. The rainfall runoff correlation has also been done for 21 years data and a good correlation is found with r^2 value 0.9. Average runoff for average yearly rainfall is shown in figure below from which it can be seen that the maximum runoff occurred in the year 2001.

Table 4.4:Yearly average rainfall-runoff Correlation

Year	Rainfall P (mm)	Runoff R (mm)	P^2	R^2	PR
1996	1111.1	237.57	1234543.21	56439.50	263964.03
1997	1121.1	237.57	1234543.21	56439.50	263964.03
1998	1047.54	282.71	1097340.05	79924.94	296150.03
1999	917.84	170.63	842430.27	29114.60	156611.04
2000	911.78	189.51	831342.77	35914.04	172791.43
2001	1142.27	349.18	1304780.75	121926.67	398857.84
2002	969.14	208.86	939232.34	43622.50	202414.58
2003	1026.06	271.31	1052799.12	73609.12	278380.34
2004	1051.43	287.23	1105505.04	82501.07	302002.24
2005	1159.25	330.59	1343860.56	109289.75	383236.46
2006	897.09	188.84	804770.47	35660.55	169406.48
2007	916.7	186.34	840338.89	34722.60	170817.88
2008	1073.03	222.55	1151393.38	49528.50	238802.83
2009	792.93	121.6	628737.98	14786.56	96420.29
2010	961.82	213.69	925097.71	45663.42	205531.32
2011	913.44	187.01	834372.63	34972.74	170822.41
2012	925.09	195.19	855791.51	38099.14	180568.32
2013	1079.86	255.92	1166097.62	65495.05	276357.77
2014	979.24	180.07	958910.98	32425.20	176331.75
2015	1028.53	240.09	1057873.96	57643.21	246939.77
2016	1018.87	244.51	1038096.08	59785.14	249123.90
	$\sum p$ = 21034.1	**$\sum R$ = 4800.9**	**$\sum P^2$ =21247858.5**	**$\sum R^2$ =1157563.3**	**$\sum PR$ =4899494.7**

$$r = \frac{N(\sum PR) - (\sum P)(\sum R)}{\sqrt{[N(\sum P^2) - (\sum P)^2] * [N(\sum R^2) - (\sum R)^2]}} = 0.9$$

The values of the coefficients a and b are given by:

$$a = \frac{N(\Sigma PR) - (\Sigma P)(\Sigma R)}{N(\Sigma P^2) - (\Sigma P)^2} = 0.5$$

and

$$b = \frac{\Sigma R - a\Sigma P}{N} = -272.0$$

Where N = number of observation

The equation for straight-line regression between runoff R and rainfall P is

R = a×P + b = 0.5×P-272

SWAT also gives mean monthly maximum runoff for corresponding mean monthly maximum rainfall value throughout the year. Here the graphical representation of mean monthly maximum rainfall-runoff values for each year for 21 years period has been shown in Figure 4.6 from which it can be seen that the monthly maximum runoff occurred in the year 2005.

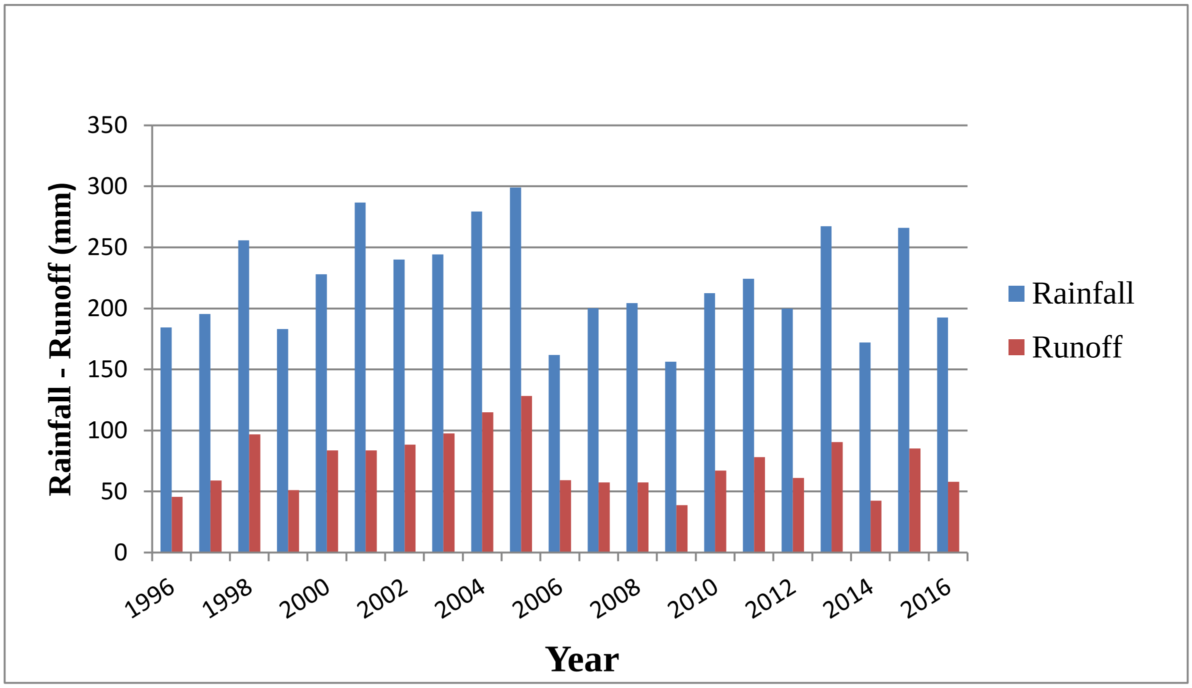


Figure 4.6: Mean monthly maximum rainfall-runoff.

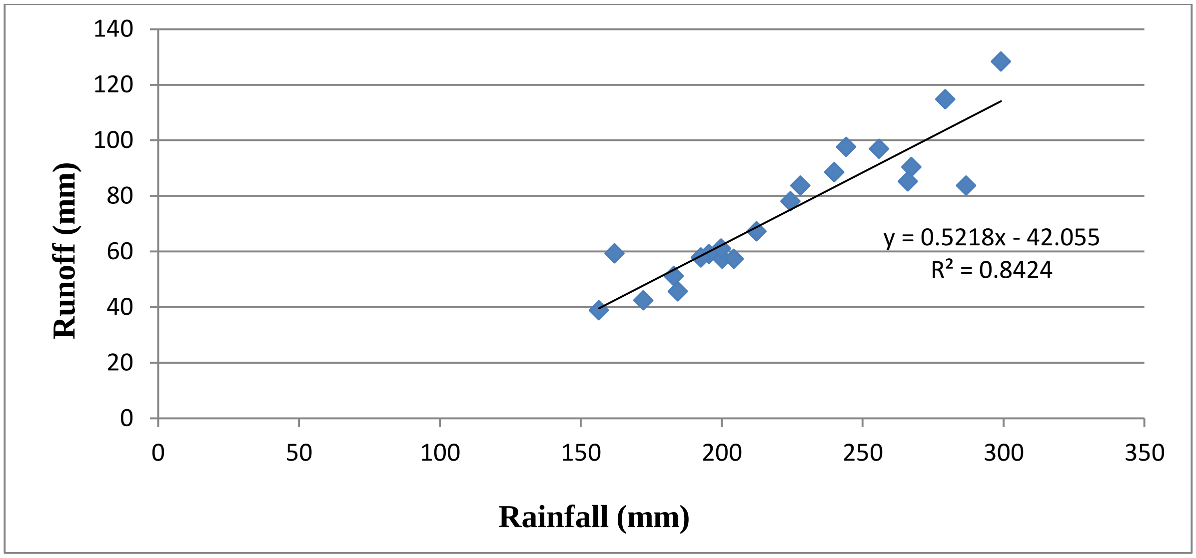


Figure 4.7: Scatter plot for mean monthly maximum rainfall-runoff correlation

4.6 Simulated Water Balance components for Dabus watershed

The main water balance components of the watershed includes: the total amount of precipitation reaching a sub basin and corresponding runoff during the time step, actual evapotranspiration from the watershed and the net amount of water that leaves the watershed and contributes to stream flow in the reach (water yield). The water yield includes surface runoff contribution to stream flow, lateral flow contribution to stream flow; groundwater contributes to stream flow minus the transmission losses. More interesting are the numbers, relative to the incoming precipitation, which is the ultimate source of all water in a watershed. Thus, one can infer that only 52.8% of the precipitation in the watershed contributes to the stream flow, whereas 44.7% of the precipitation is lost by evapotranspiration. Moreover, one can read from Table 4.5 that 43% of the water yield is generated by the surface runoff, 3.5% from lateral flow, and about 57% of yield is contributed from base flow. This shows that the contribution of Base flow to water yield is considerably higher than that of the other water balance components.

The results of the calibration and validation analysis reveal that for the calibration period (1996-2008) the simulated mean monthly stream flow of the Dabus watershed at DabusNr: Asossa station is 189.77m^3/s. For the validation period (2009-2016), the simulated mean monthly stream flow of the Dabus watershed at DabusNr: Asossa station is 184.46m^3/s.

The various annual SWAT-simulated water balance components for the Dabus watershed which are part of the regular output of the model - for the total time period (1996-2016) the calibration- and the validation period are listed in Table 4.5.

The simulated annual water balance components for the catchment indicated that 43.9% of the annual precipitation is lost by evapotranspiration in the basin during calibration period as compared to 43% during validation period. Surface runoff contributes 44.9% of the water yield during calibration period and 37.8% of the water yield during validation period. Whereas the ground water contributes 59.4% and 56.9% of the water yield during calibration and validation period respectively.

Table 4.5: Dabus watershed simulated annual water balance components for total record time-, calibration and validation periods.

Hydrologic parameter	Total time (1996-2016)	Calibration period (1996-2008)	Validation period (2009-2016)
Precipitation (mm)	1001.6	1025.7	962.5
Surface runoff (mm)	228.74	243.3	204.8
Lateral flow (mm)	20.0	20.4	19.3
Ground water (base) flow (mm)	316.8	322.1	308.1
Total water yield (mm)	541.8	561.9	509.1
Evapotranspiration (mm)	436.3	439.8	430.7
Potential evapotranspiration (mm)	1163.9	1163.9	1137.7

The runoff analysis for the Dabus watershed focuses on the time span 1996-2016. Most runoff occurs during the rainy season, more than 70% of the total annual runoff.

Once parameters values were determined for stream flow using measured data at Dabus Nr:Asossa station, the parameters were extended to the rest of the watershed. The SWAT model produced spatial output by aggregating HRU output to the sub-basin level. Watershed maps of precipitation and runoff were derived for the annual average and are presented in Figures below.

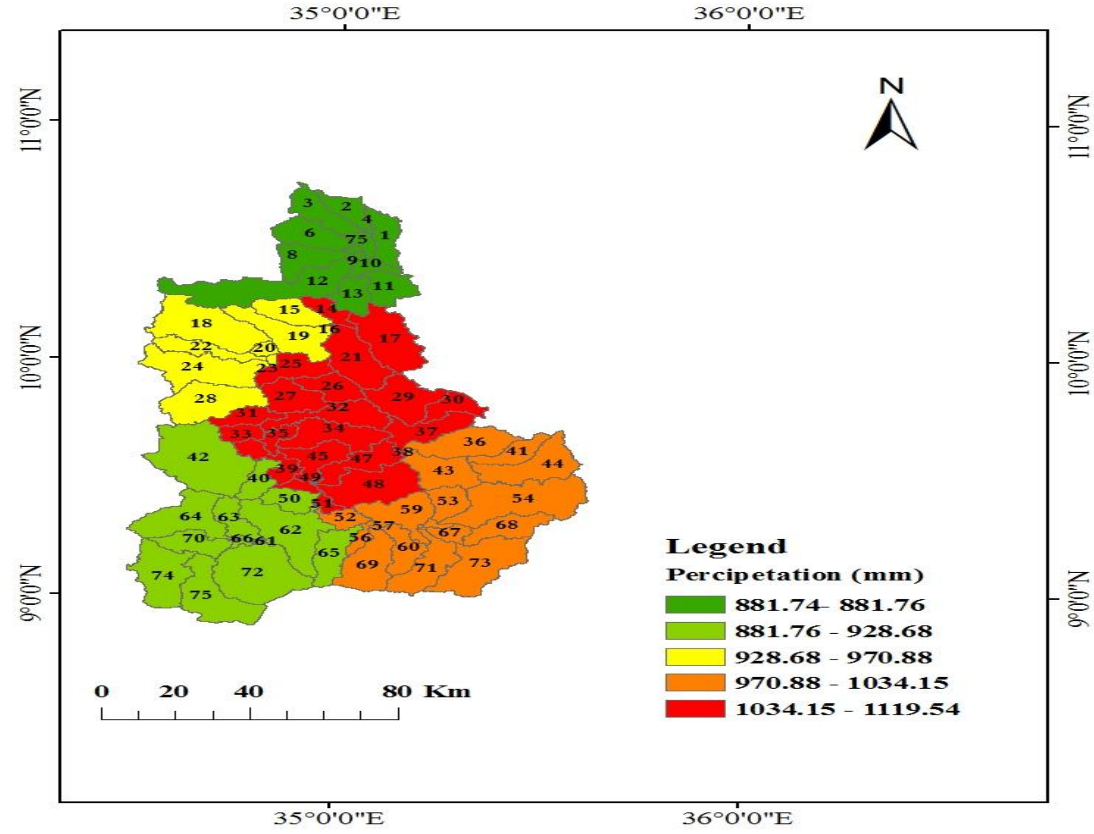


Figure 4.8**:** shows average rainfall for each sub basin.

The rainfall varied from 881.74 mm in the north to 1119.54 mm in south west. The highest precipitation was observed in high land (more than 1650m of elevation above mean sea level).

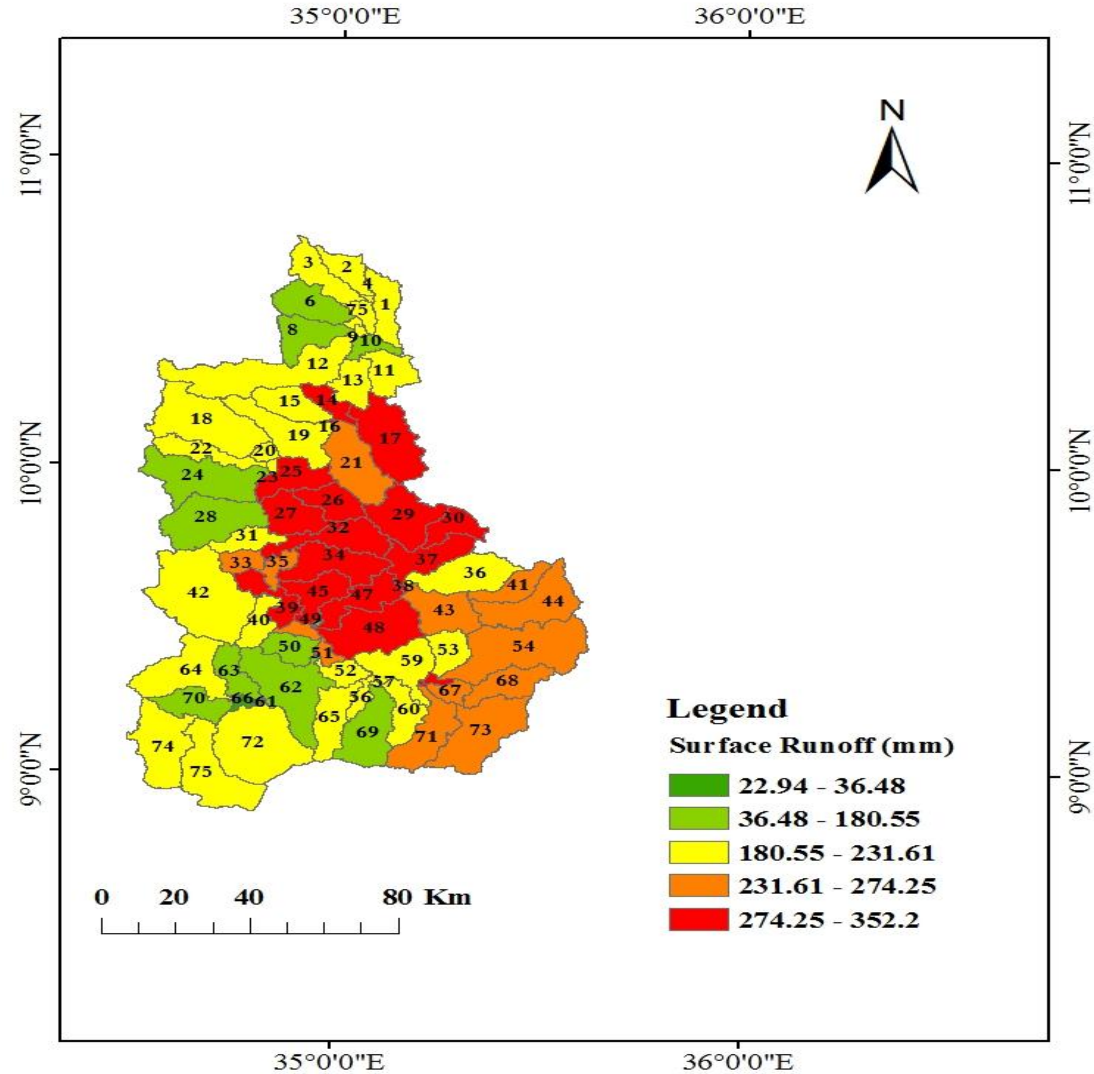


Figure 4.9: Average annual surface runoff over the watershed

The runoff map (Figure 4.9) shows that sub-basins with high precipitation correspond to high runoff. The max runoff could reach 352.20 mm while minimum was 22.94 mm; however the large part of the watershed (60%) had a runoff greater than 180mm.

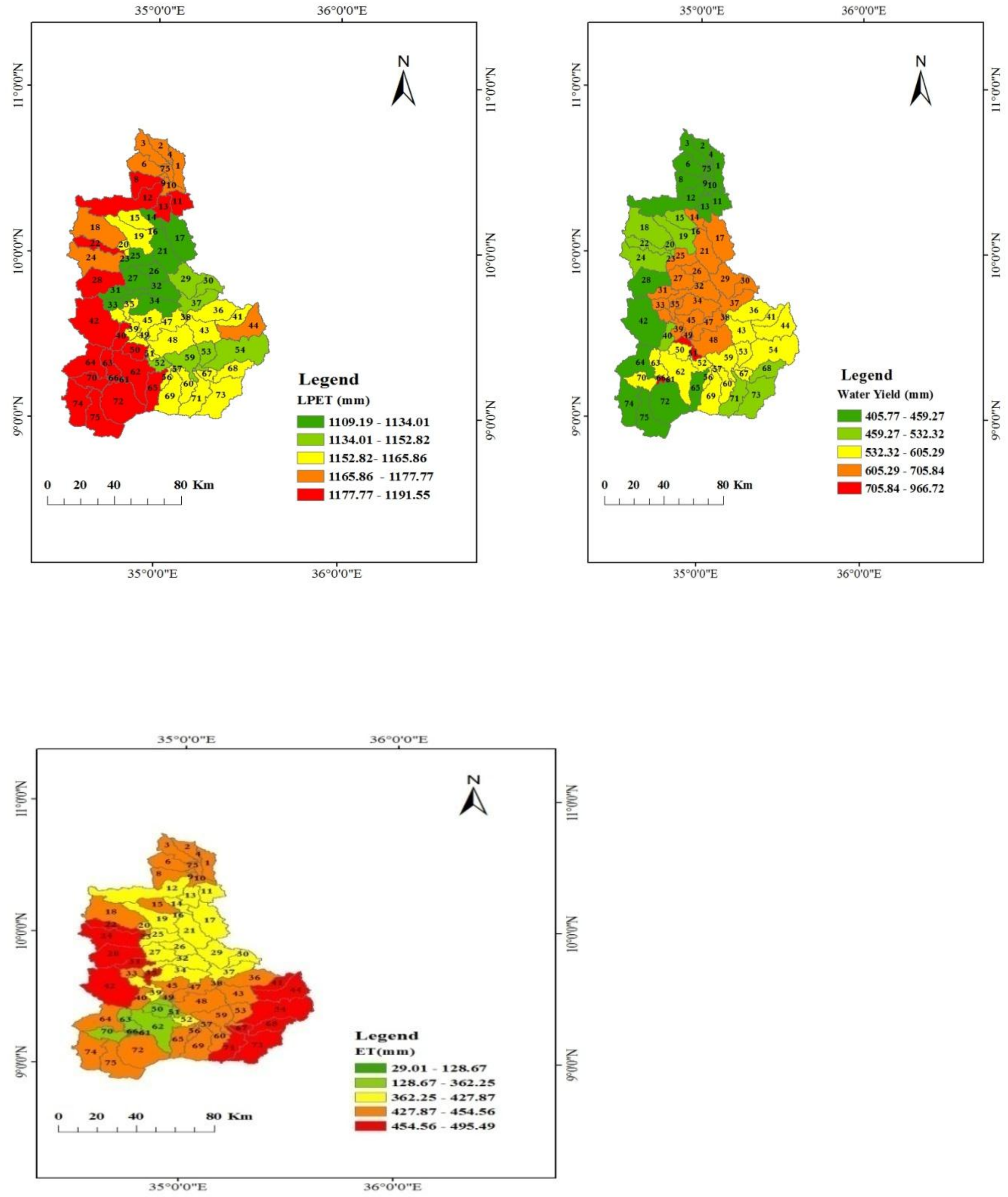


Figure 4.10: Simulated water yield, PET and ET across the Dabus watershed.

For a better understanding of the hydrology of the Dabus watershed the water yield, potential evaporation (PET) and actual evapotranspiration have been computed sub-basin wise. From this figure one may notice that in those areas of the Dabus watershed where the precipitation is low, such as in the north and south eastern sub-basins the potential evaporation (PET) is high because at this area there is high temperature. However, regardless of the prevailing conditions, the water yield in these sub-basins is also lower than in other sub-basins. On the other hand, the eastern highlands and the parts of the south -western parts have relatively high precipitation, water yield and evapotranspiration.

Though some spatial correlations between the distributions of precipitation, PET and water yield can be observed in most areas of the Dabus watershed, the correlations between precipitation and water yield appear to be, somewhat expectedly, the strongest. Hence special attention should be given to the future watershed management, as huge water losses due to PET will lead to corresponding decreases of the Dabus stream flow.

5. CONCLUSIONS AND RECOMONDATIONS

5.1 CONCLUSSIONS

SWAT model is applied to Dabus watershed in order to estimate runoff at this watershed and to investigate rainfall runoff relation in the area and to evaluate its simulating capacity through calibration and validation using Sequential Uncertainty Fitting (SUFI-2) algorithm of SWAT-CUP in monthly time series.

According to SWAT classification, the watershed was divided into 75 sub basins and 323 hydrological response units (HRUs). Then by using 23 years of daily weather data SWAT simulation was done for monthly basis to find out runoff volume and runoff for corresponding rainfall. Only one flow gauging station is found at the main Dabus river which is DabusNr: Asossa near to the out let of the watershed. Therefore, sensitivity analysis, calibration and validation of the model were performed at this gauging station.

The result of sensitive analysis showed that 12 parameters were sensitive; out of 21, the five most sensitive parameters are CN_2, ALPHA_BF,GW_DELAY, CNMAX and SOL_AWC. The SWAT model was calibrated from 1996 to 2008 and validated from 2009 to 2016 including warm up period on monthly basis to examine its applicability for simulating flows for the Dabus watershed. The average monthly simulated flows were compared with the average monthly observed values using graphical and statistical methods. Performance of the model for both calibration and validation watershed were found to be reasonably good with coefficient of determination (R^2) values of 0.88 and 0.88 and Nash-Sutcliffe values 0.80 and 0.76 for calibration and validation respectively. So, the values obtained from the coefficient of determination and Nash-Sutcliffe simulation efficiency values proved the SWAT is good to simulate the hydrological process of the catchments.

Rainfall-Runoff relationship investigation was performed using average annual rainfall and runoff data, So rainfall-runoff correlation was found to be 0.9 and simulated average annual surface runoff was 228.74 mm. Hence, it can be concluded that SWAT was able to fairly explain the hydrological characteristics of the Dabus catchment.

5.2 RECOMONDATIONS

There is need to explore the performance of other hydrologic models for the purpose of comparing catchment behavior and impacts statistics even best simulation result is get from each models.

It is suggested in future studies, SWAT model which can be used in further evaluation of land use change, climate change, as well as other different management scenarios apply on stream flows and soil erosion.

The applications SWAT 2012 models were very challenging and a lack of appropriate data was one of the biggest concerns throughout. Without proper data, model implementation is very difficult. The use of new data gathering techniques should be envisaged for developing countries like Ethiopia so that local and regional authorities can be involved in integrated and coordinated data compilation. In case of this study for flow gauging station there is only one gauging station is provided at the main Dabus river, the other one is located far away from the main river.

Even if Rainfall-runoff and Sediment modeling are the most essential modeling for study of watershed characteristics and to decide best management practice in the watershed. This study was conducted by taking only rainfall-runoff modeling for investigation the hydrological processes of the watershed. Therefore considering both Rainfall-runoff and Sediment modeling are likely to have more implication in the investigation of watershed characteristics to decide best management practice in the watershed.

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APPENDIX

APPENDIX A : Stastical Analysis

APPENDIX A 1: Statistical Analysis of Daily Precipitation Data (1994-2016) by PCP STAT

Input Filename = RFasosa.txt

Number of Years = 23

Number of Leap Years = 6

Number of Records = 8401

Number of No Data values = 1

Month	**PCP_MM**	**PCPSTD**	**PCPSKW**	**PR_W1**	**PR_W2**	**PCPD**
Jan.	1.95	0.6969	15.0343	0.0143	0.1667	0.52
Feb.	1.55	0.571	17.3249	0.0157	0.2857	0.61
Mar.	8.61	1.493	6.3857	0.043	0.2368	1.65
Apr.	68.14	6.6481	5.4603	0.1496	0.5	7.04
May.	185.04	12.1172	3.2372	0.3794	0.5698	14.96
Jun.	232.33	12.2173	2.3789	0.5738	0.648	19.39
Jul.	243.2	14.0541	3.277	0.628	0.7134	22
Aug.	245.09	12.2059	2.8733	0.6337	0.7241	22.22
Sep.	233.81	12.4677	2.7118	0.6316	0.6944	20.91
Oct.	172.61	10.8393	2.7224	0.4036	0.6117	16.35
Nov.	23.17	3.4498	6.3576	0.0736	0.3418	3.43
Dec.	1.77	0.7235	15.9202	0.0142	0.0909	0.48

PCP_MM = average monthly precipitation (mm)

PCPSTD = standard deviation

PCPSKW = skew coefficient

PR_W1 = probability of awet day following a dry day

PR_W2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

APPENDIX A 2 : Average daily Dew point temperature for the period (1994-2016) using Dew02

Input Filename = Tempasosa.txt

Number of Years = 23

Number of Leap Years = 6

Number of Records = 8401

Number of No Data values = 1

Month	**tmp_max**	**tmp_min**	**Hmd**	**Dewpt**
Jan	30.7	13.22	59.21	15.16
Feb	31.9	14.72	55.03	15.06
Mar	32.64	16.2	57.01	16.56
Apr	31.53	16.41	59.96	16.76
May	28.32	16.6	66.37	16.51
Jun	25.78	16.2	71.94	16.17
Jul	24.82	15.87	74.78	16.12
Aug	24.82	15.76	75.58	16.24
Sep	25.74	15.68	76.46	16.92
Oct	26.79	14.64	74.21	16.79
Nov	28.35	13.95	68.03	16.1
Dec	29.83	13.38	61.34	15.22

tmp_max = average daily maximum temperature in month (^{0}C)

tmp_min average daily minimum temperature in month (^{0}C)

hmd = average daily humidity in month (%)

dewpt = average daily dew point temperature in month (^{0}C)

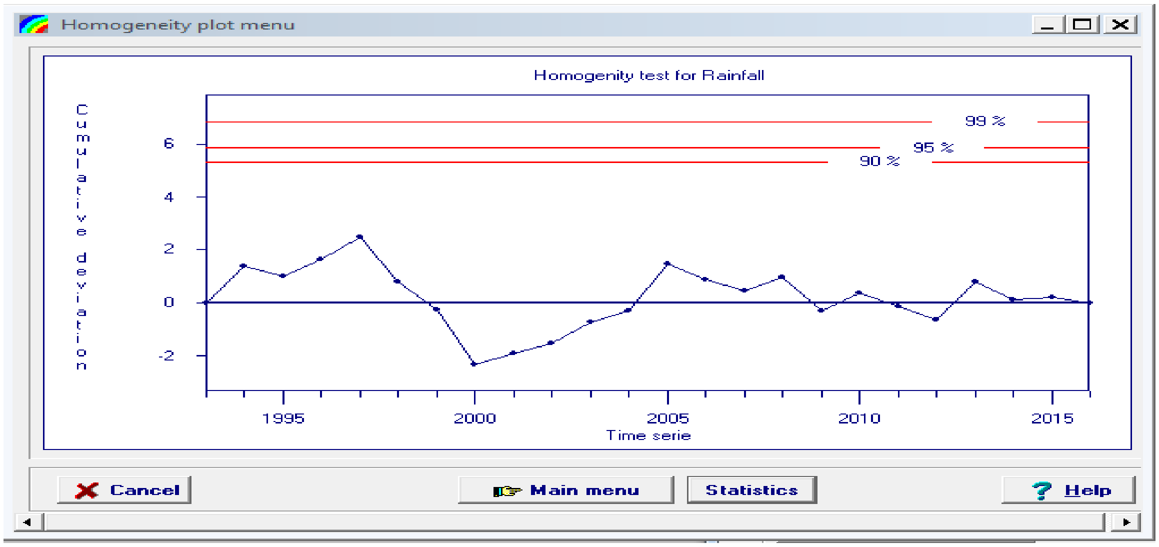
APPENDIX A3: Annual Mean Rainfall (mm)

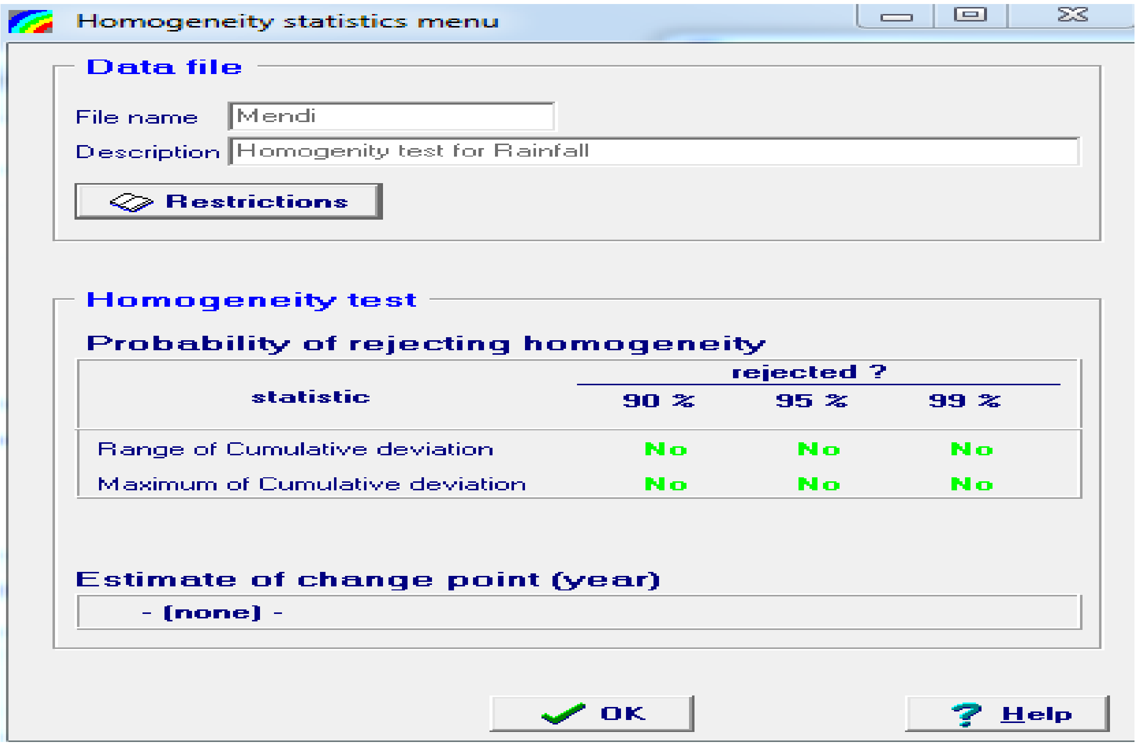
Year	Abadi	Asossa	Begi	Guliso	Mendi	Nedjo
1994	70.419	94.857	62.893	63.911	120.653	106.210
1995	67.119	94.642	80.356	67.963	86.828	75.974
1996	91.126	87.517	78.971	95.442	106.896	93.533
1997	67.294	92.010	92.907	79.598	110.028	96.273
1998	89.824	71.860	126.133	85.085	62.105	81.512
1999	63.681	94.642	65.379	94.239	73.530	82.720
2000	87.175	69.323	88.059	96.796	53.850	77.221
2001	81.250	115.828	89.695	86.168	102.859	90.000
2002	59.456	62.984	64.513	77.355	101.308	109.436
2003	57.281	77.968	71.885	86.818	109.745	96.026
2004	78.645	88.390	73.396	91.504	102.242	89.460
2005	82.649	62.666	88.059	75.102	128.491	112.428
2006	71.738	75.687	62.790	89.337	82.503	72.189
2007	65.525	74.659	67.075	90.290	86.314	75.524
2008	75.313	78.604	81.635	98.876	104.458	91.400
2009	61.919	72.085	59.838	76.868	69.512	60.822
2010	58.931	66.063	66.842	68.310	107.287	93.875
2011	83.624	83.690	57.709	83.135	84.133	73.616
2012	84.930	87.916	71.920	50.337	84.370	73.823
2013	61.881	65.421	68.320	102.722	122.392	107.091
2014	67.588	102.028	81.337	91.731	80.492	70.430
2015	64.919	79.564	87.296	92.782	95.952	83.957
2016	86.681	90.385	80.822	79.549	90.686	78.127

APPENDIX A4: Annual mean flow

Year	Mean Annual flow in m^3/s
1996	214.738
1997	207.544
1998	192.920
1999	168.660
2000	193.026
2001	183.259
2002	157.728
2003	201.297
2004	173.080
2005	172.362
2006	162.155
2007	184.073
2008	165.449
2009	189.175
2010	198.053
2011	173.380
2012	172.620
2013	170.144
2014	172.727
2015	169.172
2016	184.289
	Average mean annual flow 181.23 m3/s

Appendix B:- Homogeneity test result for Rain fall stations





Data file

File name: Mendi

Description: Homogenity test for Rainfall

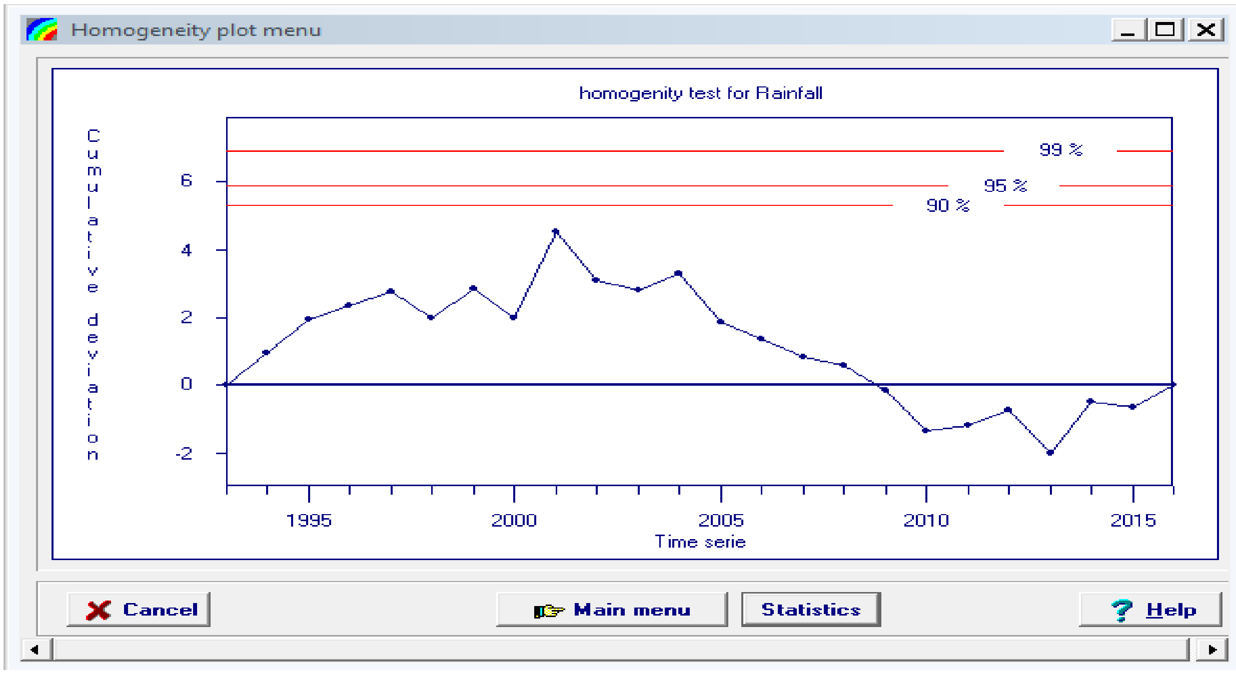
Homogeneity test

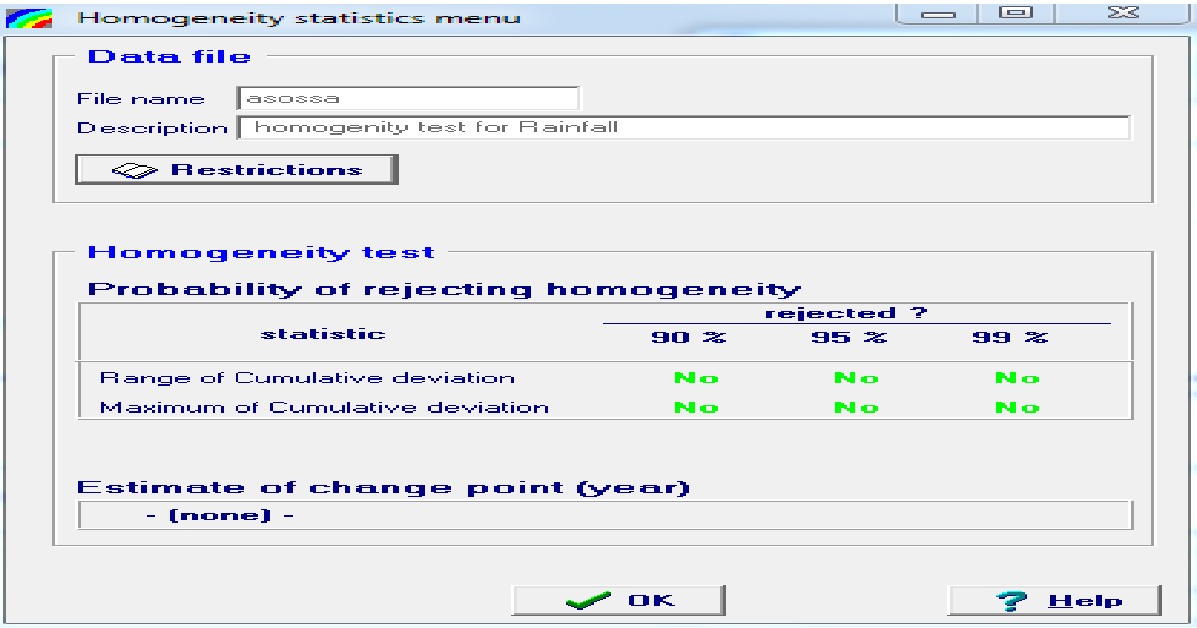
Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- [none] -





Data file

File name: asossa

Description: homogenity test for Rainfall

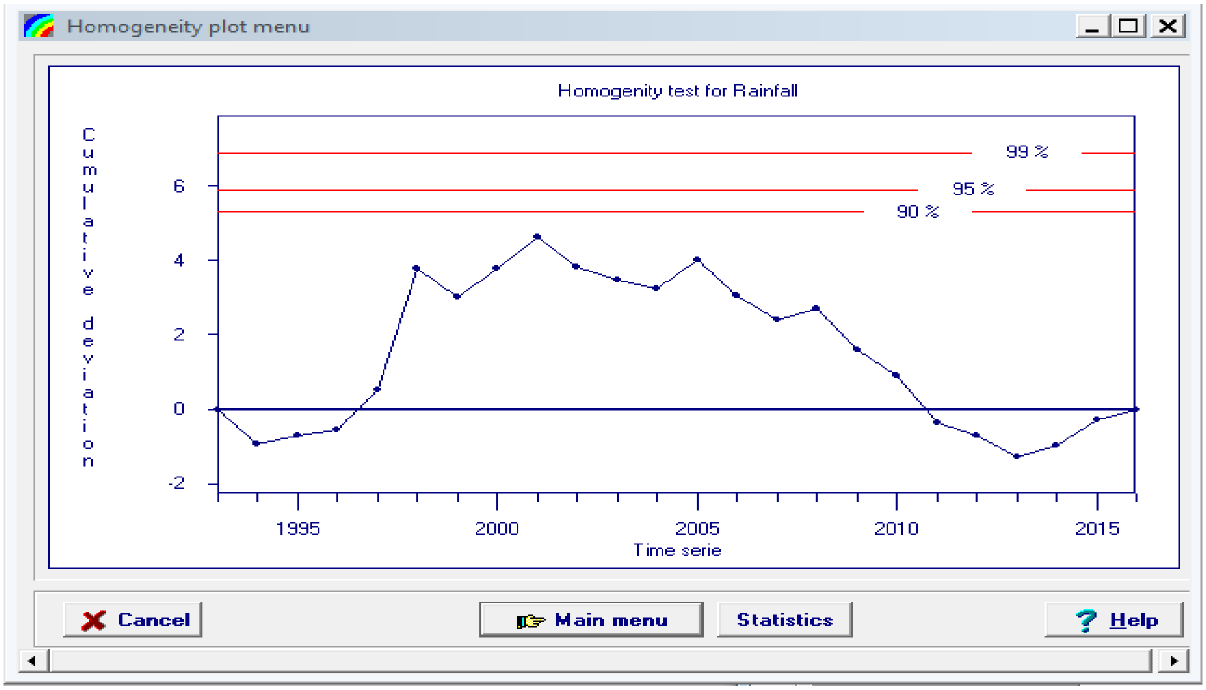
Homogeneity test

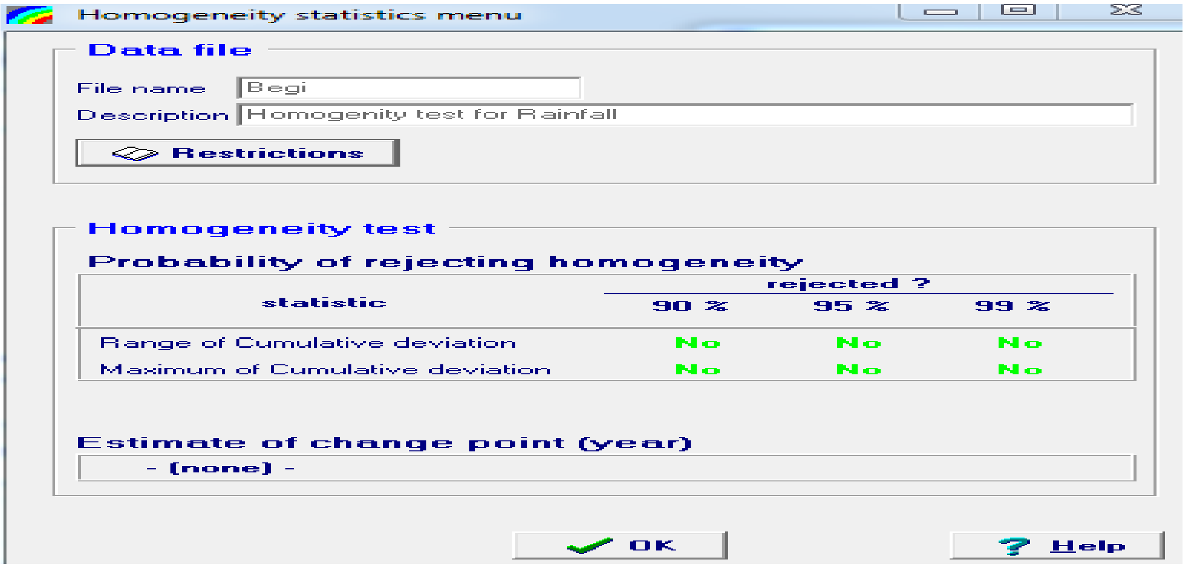
Probability of rejecting homogeneity

statistic	rejected ?		
	90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -





File name: Begi

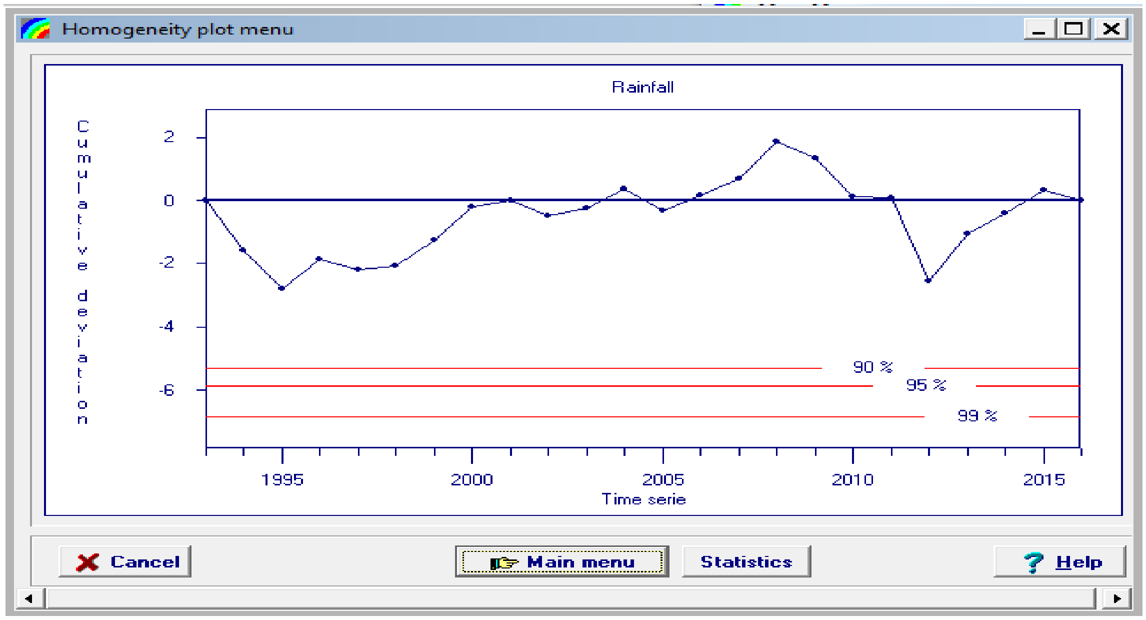
Description: Homogenity test for Rainfall

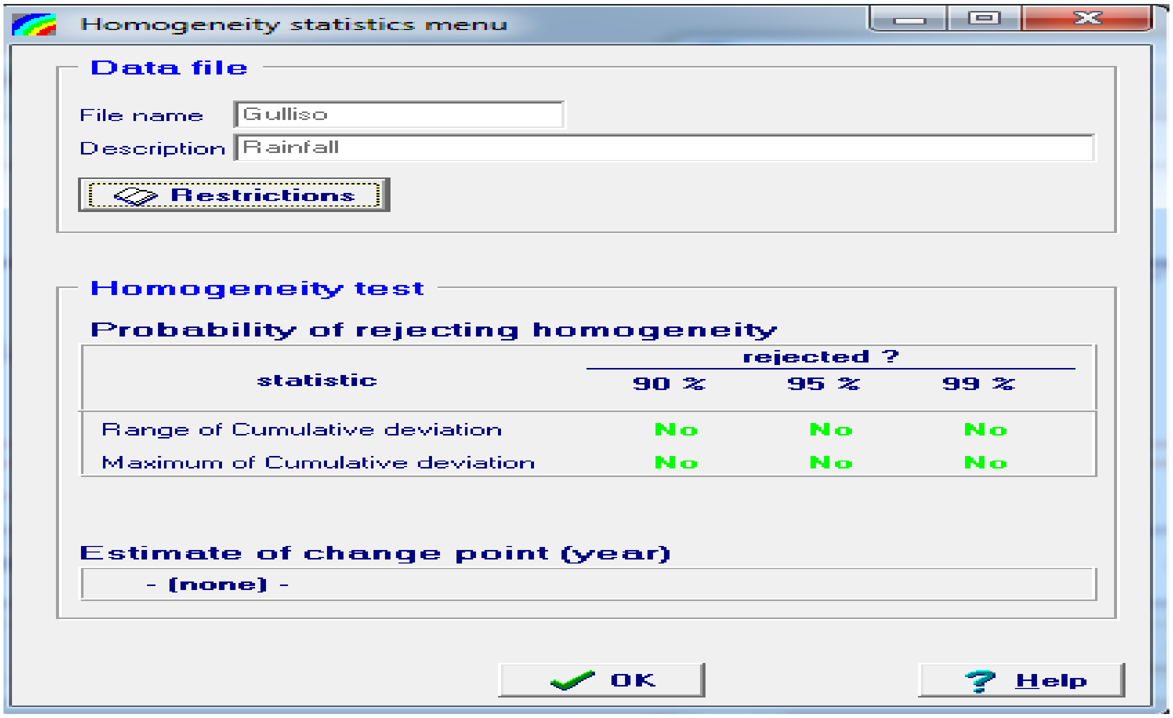
Probability of rejecting homogeneity

statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -





Data file

File name: Gulliso

Description: Rainfall

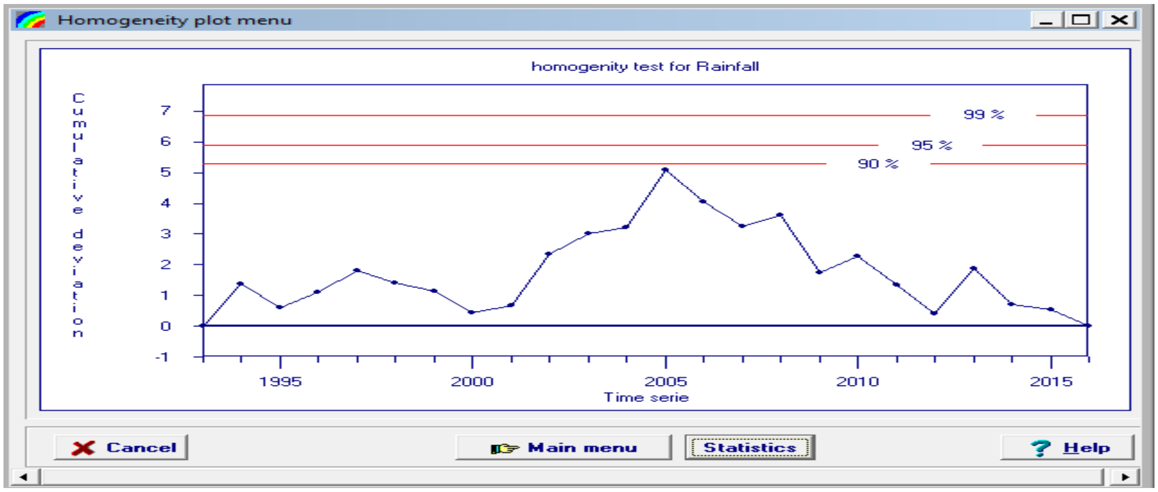
Homogeneity test

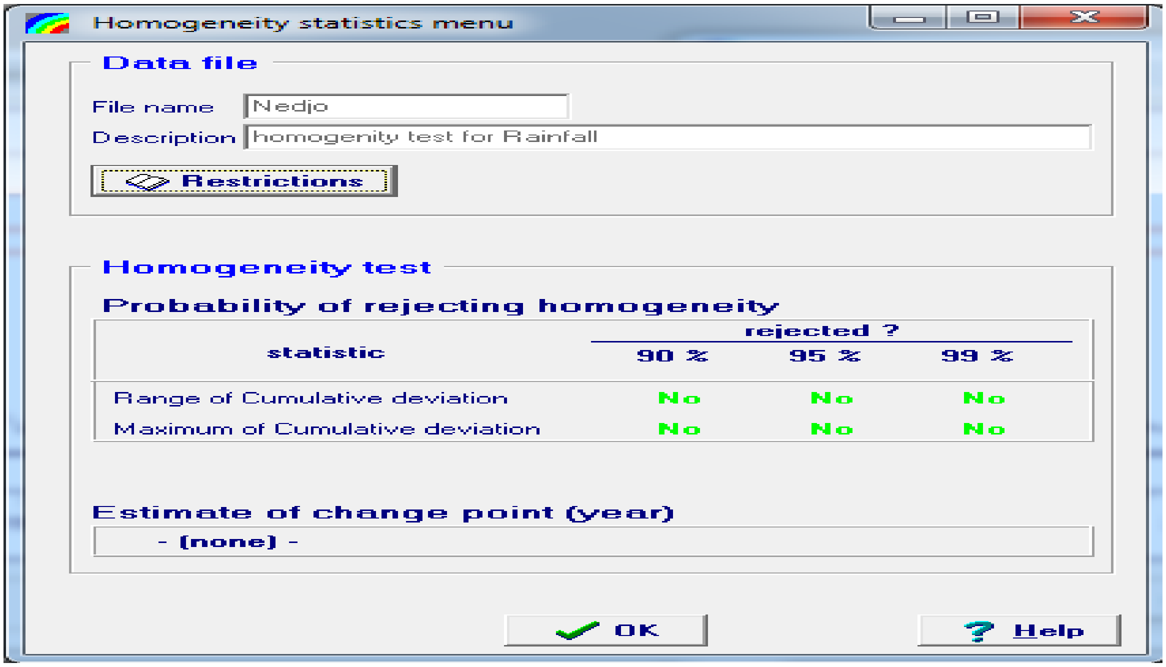
Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -





File name: Nedjo

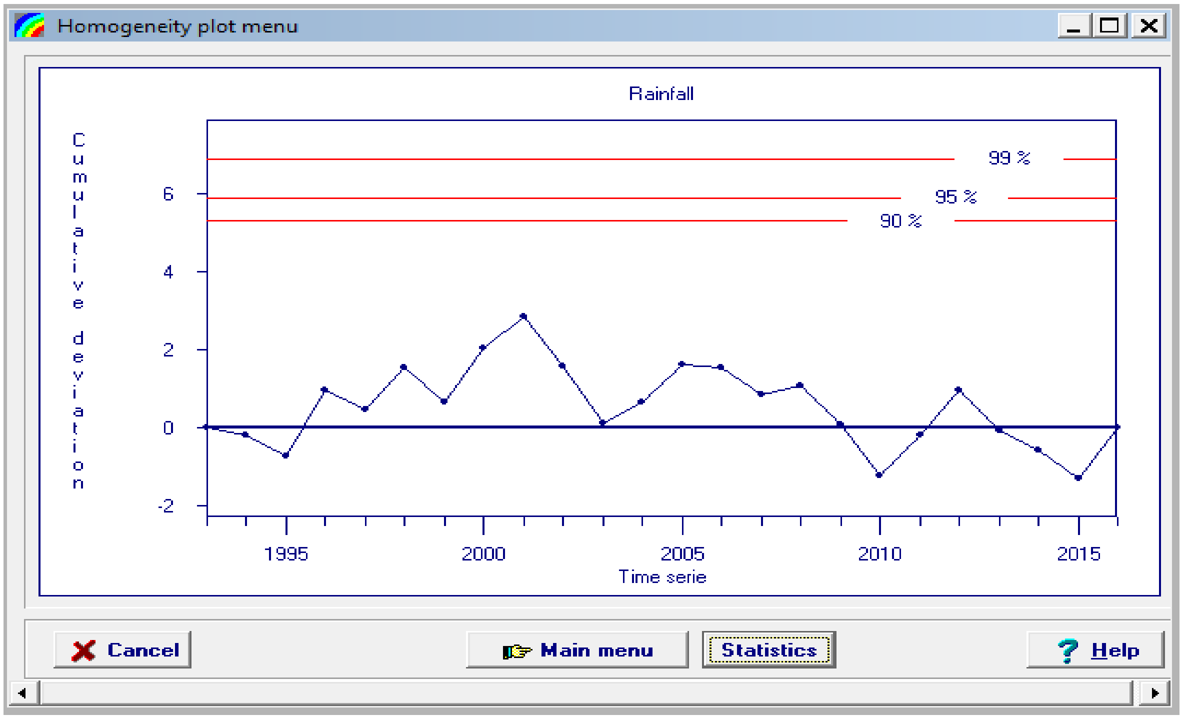
Description: homogenity test for Rainfall

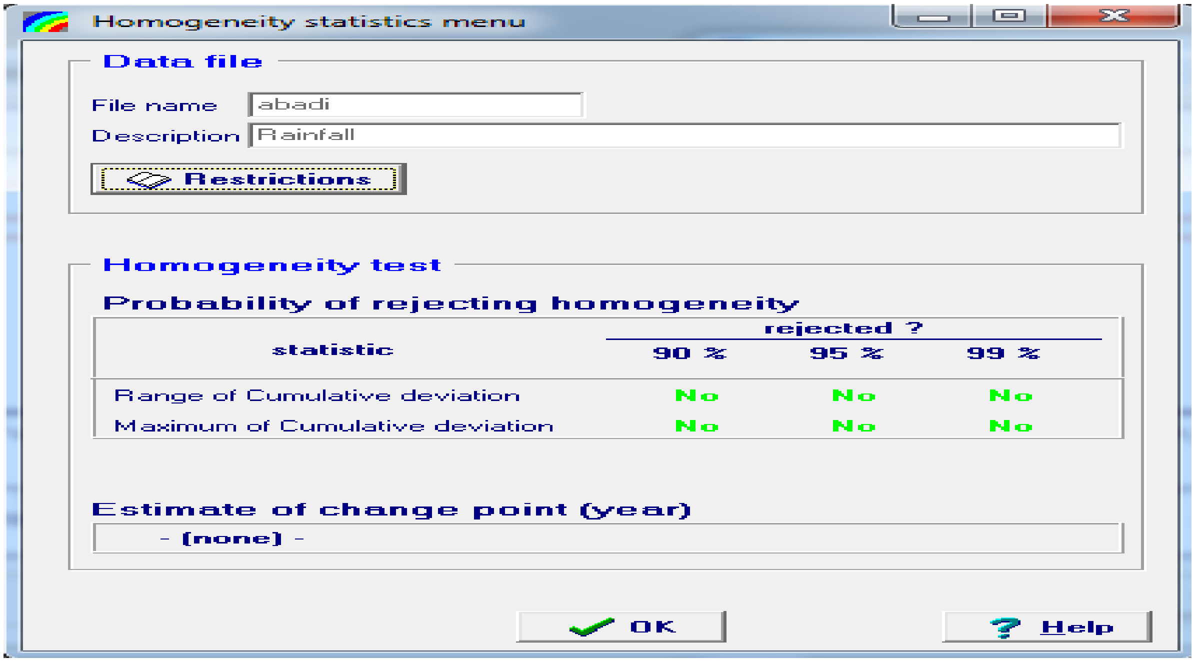
Probability of rejecting homogeneity

statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -





Data file

File name: abadi
Description: Rainfall

Homogeneity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

APPENDIX C: Soil parameters of the study area used in the SWAT database

SNAM	NLAYERS	HYDGRP	SOL_ZMX	TEXTURE	SOL_Z1	SOL_BD1	SOL_AWC1	SOL_K1	SOL_CBN1	CLAY1	SILT1	SAND1	ROCK1	SOL_ALB1	USLE_K1
FLe	3	D	1500	C	200	1.19	0.09	3.03	3.92	61.95	32.18	5.88	0	0.12	0.22
Ach	3	C	1800	C	300	1.21	0.13	6.15	6.98	45.32	29.03	22.24	3.41	0.04	0.15
ALh	3	C	1600	C	250	1.26	0.13	4.57	5.57	44.26	31.37	24.3	0.07	0.06	0.15
CMe	3	D	1400	C	250	1.3	0.12	2.44	4.2	47.07	28.29	24.62	0.03	0.11	0.15
CMd	3	B	550	C	200	0.92	0.06	52.54	20.35	51.95	39.51	8.54	0	0	0.21
LPe	2	C	350	CL	200	1.32	0.14	4.59	3.7	38.8	34.81	26.4	0	0.14	0.16
LPd	2	C	350	CL	200	1.32	0.14	4.59	3.7	38.8	34.81	26.4	0	0.14	0.16
NTh	3	D	1550	C	200	1.24	0.11	2.01	3.65	56.72	28.56	13.49	1.23	0.14	0.16
NTr	3	D	1700	C	250	1.25	0.11	1.79	3.42	56.45	27.61	14.51	1.43	0.15	0.15
VRe	3	D	1450	C	200	1.19	0.07	1.77	3.59	68.04	24.64	7.32	0	0.14	0.18
MA	1	D	25	C	25	0	0	260	0	0	0	0	0	0.23	0