JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Runoff and Sediment Yield Modeling and the Evaluation of Best Management practices Using Arc SWAT. A Case of Meki River Watershed, Rift Valley Basin, Ethiopia.

By: Genemo Barso Jatano

A thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillments of the Requirement for the Degree of Masters of Science in Hydraulic

January, 2020

Jimma, Ethiopia

JIMMA UNIVERSITY
INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR
MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

Runoff and Sediment Yield Modeling and the Evaluation of Best Management practices Using Arc SWAT. A Case of Meki River Watershed, Rift Valley Basin, Ethiopia.

By: Genemo Barso Jatano

A thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillments of the Requirement for the Degree of Masters of Science in Hydraulic Engineering.

Main Advisor: Dr.Ing Tamene Adugna (PhD)

Co-Advisor: Fayera Gudu (MSc)

January, 2020

Jimma, Ethiopia

DECLARATION

I declare that this thesis research is my own original work and I retain ownership rights to the copy rights of this work including but not limited to the right to use all or part of this work in the future works such as articles or book.

Any copying or publication of this thesis for commercial purposes or for financial gain is not allowed without my written permission.

Researcher's Name

Genemo Barso Signature ………………… Date ……................

As thesis research advisors, we hereby certify that we have read and evaluated this thesis, and prepared under our guidance, by Genemo Barso, entitled "Runoff and Sediment yield modeling and the Evaluation of Best Management practices using Arc SWAT" and we recommend that it can be submitted as fulfilling the thesis requirement.

Advisors' Name	Signature	Date
Main Advisor		
Dr.Ing. Tamene Adugna (PhD)	…………………….	………………..
Co-Advisor		
Mr. Fayera Gudu (MSc)	………………………	………………..

APPROVAL PAGE

As members of the Board of Examiners of the MSc Thesis Open Defense Examination, we Certify that we have read, evaluated the Thesis prepared by Genemo Barso and examined the candidate. We recommended that the Thesis be accepted as fulfilling the requirement for the degree of Master of Science in Hydraulic Engineering.

Members of Examining Board

Chairperson	Signature	Date
…………………………	…………………	…………………
Internal Examiner	Signature	Date
……………………..	………………	……………….
External Examiner	Signature	Date
…………………….	…………………….	………………..

Final approval and acceptance of the thesis is contingent upon the submission of final copy of the thesis to council of graduate studies through the departmental or school graduate committee of the candidate.

ABSTRACT

Runoff and sediment yield modeling was important in the Meki river watershed. Runoff and sediment yield modeling and the evaluation of best management practices is important to alleviate soil erosion and reservoir sedimentation. The general objective of this study was to model the runoff and sediment yield and to assess best management options to control soil erosion and sedimentation problems of the Meki River Watershed. The main materials and data used for input data preparation, analysis were, Arc GIS, Arc SWAT, SWAT CUP, Rainbow, excel stat and hydrological, meteorological, spatial data. The methodology of this work were the following: data collection, data preparation and quality assurance, data analysis and model setup, running model, model performance evaluation and model result interpretation. The total drainage area of the watershed was 2060.792 km^2. Simulation of the streamflow of Meki River watershed situated in central rift valley basin for the period from 1993 – 2010 and sediment yield was computed by developing sediment rating curve for the comparison of sediment yield produced from rating curve and sediment produced by SWAT simulation. The model was calibrated by adjusting sensitive parameters for observed stream flow data from 1993 – 2003 and validation was done using observed data from 2004 – 2010. The highest flow sensitive parameter was the curve number (CN2), Available water capacity of the soil layer (SOL_AWC) and Manning's "n" value for overland flow (OV_N). The model performance was checked by statistical model performance evaluation such as the coefficient of determination (R^2), Nash – Sutcliffe model efficiency (NSE) and percent bias. From the results of stream flow calibration and validation R^2 = 0.81, NSE = 0.76, Pbias =18 and R^2 = 0.81, NSE = 0.74 Pbias =17.1 respectively. The total annual runoff and sediment yield produced by SWAT simulation was 367.95mm and 75.896 ton/ha/yr. respectively. The simulation results showed that applying scenario USLE_P, conservation structure (contour ploughing and terracing with contour) reduced the current sediment yield by 25.84% and 13.97% respectively and using scenario filter strips reduced the current sediment yield by 68.47%. More research was necessary to forecast sediment yield and runoff of each sub-basin for daily and monthly time step under different land use/land cover scenario to improve decision making of the stake holder.

Key Words: *Meki River watershed, Runoff, Sediment yield, Validation and Calibration.*

ACKNOWLEDGEMENT

First, I would like to thank to my GOD who made it possible, to begin and finished this work successfully. My gratitude and appreciation also goes to my advisor, Dr.Ing. Tamene Adugna (PhD) and Co-advisor Mr. Fayera Gudu (MSc) for their giving general constructive comment and suggestion to implement this study.

I like also to say thanks to Federal ministry of education to give this enjoyable chance with cooperative to Jimma University on the behalf of ministry of education giving great dedication, the development and completion of this study would have been impossible.

Moreover, I wish to express my deepest gratitude to my wife Shage Buku for providing financial supporting and strength motivation to success in my study. In addition all friends and professional collogues thanks for your collaboration and motivation.

Finally, my deepest gratitude and humble thanks go to my immediate parents particularly my lovely mother Ramate, my sister and brothers for their never-ending support, encouragement and motivation.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONOMYS AND ABBREVIATIONS

Arc SWAT	Arc GIS interface soil and water assessment tool
CN	Curve number
DEM	Digital elevation model
GIS	Geographic information system
HRU	Hydrologic Response unit
LULC	Land use land cover
MRS	Mean Relative sensitivity
MUSLE	Modified universal soil loss equation
MoWIE	Ministry of water, irrigation and Electricity
NMSA	National meteorological service agency
PcpSTAT	Precipitation statistical parameter calculator
SCS	Soil conservation service
USDA	United state Department of agriculture
USLE	Universal soil loss equation
UTM	Universal Transverse Mercator
WEPP	Water Erosion Prediction project
WXGEN	Soil and Water Assessment tool Weather Generator model

1. INTRODUCTION

1.1 Back Ground

Runoff and sediment yield modeling was important in the watershed. Even though watershed has only one outlet point, it is characterized by different socio-economic activities, spatial, hydrological and climatic variability. Modeling the hydrological process such as runoff and sediment yield of the watershed is useful to manage the natural resources. In turn, this can help for sustainable soil and water management, which are key resources of the community lived in the watershed (Daniel *et al.*, 2011). During rainfall, part of the precipitation is intercepted (Chandler *et al.*, 1998) or infiltrates into the ground, and the remainder flows over the land surface as runoff run to the nearest stream or river. Runoff has different characteristics and affected by natural and man-made activities. For instance, in paved areas, storm-water runoff is much larger than non-paved areas. As runoff flows over the land surface, it picks up and transports potential pollutants and soil materials. Sometimes runoff occurs based on the degree of soil infiltration capacity. Erosion rates are frequently measured in small fractional-hectare plots and it can be affected by different factors, for example, rainfall intensity; these factors have a dynamic role in the erosional behavior of soil (Wainwright and Brazier , 2011).

Soil erosion accelerated by human activity has a serious ecological impact that costs a nation due to on-site effects such as soil nutrient and economic loss and off-site effects due to reservoir sedimentation. Additionally, in the downstream, irrigation and water resources project may be damaged. Furthermore, erosion also reduces the products of crops which resulting from soil fertility reduction (Upadhya *et al.*, 2012) and this, has further problems of water availability, water quality, food security and food supply. At farming land, erosion problem initiated by tillage practice in which the soil surface destructed, overgrazing, deforestation and poor land management practice; especially on slope land. Erosion and sedimentation are a sequential phenomenon, first occurred in the upstream of the watershed. Then, due to one of soil erosion agent that is water, after passing the erosion process, it is deposited at plain or mouth of the stream channels as sedimentation. They affect sustainable water resource planning and management and reservoir life (Daniel *et al.*, 2011).

Runoff and sediment yield can be estimated using different watershed models (Lelis and Calijuri , 2010). Several studies have reported using SWAT to predict surface runoff, soil erosion, sediment yield and assessment of best management practices. The model is calibrated and validated with good performance on the hydrological process and management practices (Jha & Gassman , 2014). Therefore, in this paper, SWAT was used to accomplish the general objectives of this study which was modeling of runoff and sediment yield and the evaluation of best management practices by SWAT model of the Meki River watershed. Emphasis should now be given to either directly modeling the high level, or emergent, properties of watersheds, or producing models that can reproduce these high-level properties (Ogwo *et al*., 2012). Different hydrological model uses certain application, and the choice of a suitable model relies heavily on the function that the model needs to serve. The model was tested for prediction of runoff and sediment in Meki with satisfactory results and good performance of Meki River watershed.

1.2 Statement of the Problem

Ethiopia has been described as one of the most seriously affected nation in the world by soil erosion (Gizachew *et al*., 2015). Soil erosion and sediment yield from catchments are therefore key limitations to achieve sustainable land use and maintaining water quality in rivers, lakes and other water bodies. The degradation of large part of the Ethiopian highlands has reached a scale where it has become increasingly difficult even to maintain the current level of production of basic food which is already insufficient in many regions of the country. Soil erosion by water has been a longstanding environmental problem in Ethiopia and is considered to be a critical economic problem. The annual rate of soil loss in the country is greater than the annual rate of soil formation (Tamene and Vlek, 2008).

The study of area Meki River watershed was characterized by a significant runoff, sedimentation and soil fragility, resulting thereby in soil erosion and there was a knowledge gap with respect to the interdependence between the runoff and sediment yield. The runoff and sediment yielding the area were a current phenomenon, the severity of their effects on hydrology of Meki River watershed might pose serious concern on the future functioning of this fragile resource if urgent action was not taken into consideration. Even though assessment of soil erosion, transport and deposition of sediments in the Meki River watershed, runoff and sediment yield and management systems were needed for land and water management, these were not studied in-depth in the Meki River watershed. The magnitude of sediment transported and the runoff in Meki River watershed had become a serious concern for planning, designing and implementing of the projects in the area. Deforestation, overgrazing of the forest lands and expansion of the agricultural area are activities of the people performed in the watershed. The watershed is also faced high erosion by the effects of intense rainfall of the watershed which aggravates the land cover change of the watershed (Aga *et al*., 2018).

Uncontrolled soil erosion, Poor land use practices, improper mitigation management systems and land degradation resulting in heavy sediment transport and runoff in streams and rivers causes significant reduction of the capacity of the Lake Batu. This alarming situation requires urgent interventions in order to preserve water and soil resources, imply the need for a decision tool for proper integrated management of the watershed. The continuous change in land cover has impacted the water balance of the watershed (inflow) by increase the runoff and sediment yield, which results increased the extent of the runoff and sediment yield management problem. On other hand sediment, deposition propagates upstream and up tributaries raised local ground water table, reduces channel flood capacity and affect water division and withdrawal. Therefore, unless the upstream flow of river and surrounding area are managed the Meki River watershed will be affected by runoff and sediment problem. Furthermore, reduction in the soil production capacity, change in river bank, sediment yield and runoff are problems call for estimation of annual runoff and sediment yield in the Meki River watershed (Tesfahunegn and Tamene, 2012).

Outlined the relationship between runoff and sediment yield modeling in the hydrological condition of the area enables us to evaluate the possible best management option through future development progress for appropriate measure. Specifically, this research was addressed to model the runoff and sediment yield to contribute a lot on the way toward tackling the above problems. Depending on research problem, SWAT was selected to assess and model internal state variables concerned runoff and sediment yield and its mitigation measures. The model had been widely applied for modeling of runoff and sediment yield from watersheds in different geographical locations, conditions and management practices (Feven, 2017).

1.3 Objective of the Research

1.3.1 General objective

The general objective of this study was to model the runoff and sediment yield and to assess best management options to control soil erosion and sedimentation problems of the Meki River watershed.

1.3.2 Specific objectives

The specific objectives of this study were:

- To model runoff and sediment yield of the Meki River watershed.
- To evaluate spatial distribution of sediment source areas and identify hot spot areas.
- To assess best management practices to reduce the runoff and sediment yield of the watershed.

1.4 Research Questions

The study was focused on the analysis of runoff and sediment yield modeling on Meki River watershed and the study would attempt to answer the following questions:-

- How much runoff and sediment yield were produced at the outlet from the watershed?
- How to identify the sediment source areas and its hot spot areas within the watershed?
- What are best management practices to reduce the runoff and sediment yield of the watershed?

1.5 Scope of the Research

In this study, analysis was carried out at watershed scale to describe the runoff, sediment yield and best management practices of the study area over time, measure the rate of change, and relate these changes to the hydrologic processes of the watershed and put directions to indicate the amount of runoff and sediment transport in to the River from the watershed which can be calibrated and validated by SWAT CUP, identify erosion prone areas and to mitigate the sediment problem of Meki River watershed by developed different sediment and runoff mitigation measure scenarios using Arc SWAT. Effective management strategies and policies, and implementation of best management practices with an active involvement of all stake holders to combat soil erosion problem were the call of the time. However, even before the adoption of soil conservation can be attempted, the extent and rate of soil erosion hazard and the causes of land degradation have to be assessed.

1.6 Significance of the study

In upper Meki River watershed land use change, occur at faster rate than unexpected and information about the magnitude and rate of these change, resources degradation, runoff and sediment yield was urgently needed. The present status of soil erosion founded in Meki River watershed would lead to further degradation of the area and in the long run aggravate the poverty of farmers lived in the watershed. Moreover, the reliable estimates of the various hydrological processes of a watershed were tedious and time consumed by the use of conventional methods especially in remote and inaccessible areas. Therefore, there was an urgent need for developing integrated watershed management plan based on hydrological simulation study used suitable modeling techniques. Thus, the results obtained from this paper would help: To provide information on runoff and soil erosion at watershed level that would help in identifying and designing conservation measures for controlling water and soil losses from the study area; To integrate water resource management across sub-watershed. Generally, the output of this study would support planners and decision makers in prioritizing time and limited available resource to control runoff and sediment yield and soil erosion from the watershed. Considering the hydrological behavior of the watershed and applicability of the existed models for the solutions of aforementioned problems, this study was undertaken using the Soil Water Assessment Tool (SWAT) model.

1.7 Limitation of the study

Though, the study has a significant role in provided the information about the status of runoff, sediment yield and best management of the study area in order to plan and implement an environmental protection programs on time, it has also some limitations. Among the limitations, there were getting the most recent digital elevation model difficulties and these limitations solved through download the digital elevation model from website https://vertex-retired.daac.asf.alaska.edu/ and the model step up difficulties that solved through discussion with advisors, through reading and video following. The other problems were the spatial data was not updated with the current status of technology so that this achieved through obtained the downloading the recent and updated data.

2. LITERATURE REVIEW

2.1 Runoff and Sedimentation

2.1.1 Soil Erosion Processes

Soil erosion involves detachment, transport and deposition of soil particles by water or wind. The process may be natural or accelerated by human interference in the environment. As the study by (Rijn , 1993) the two major types of erosion are geologic erosion and accelerated erosion. Geologic erosion, usually referred to as natural erosion acting over long geological periods, occurs when the soil was in its natural environment. Usually under natural geologic erosion rates, soil properties and soil profiles develop to approach an equilibrium condition. Accelerated erosion was soil loss in excess of geologic erosion. The forces involved in accelerated erosion are attacking forces, which remove and transport the soil particles and resisting forces, which retard erosion (Chekol , 2006).

Detachment of individual soil particles may occur when water strikes the surface by overcoming the interconnecting forces holding the soil particles together. This was commonly referred to as raindrop splash or a single drop of rain. As the inducing events of rainfall continue, water infiltrates into the soil at a rate controlled by the intensity of water hitting the surface and the infiltration capacity of the vertical soil profile. Water that was not infiltrated begins to pond on the surface. When sufficient depth is achieved at the surface, water flow would begin in the direction of the steepest slope that is unimpeded. This begins the hydrologic process referred to as overland flow or runoff (Chekol , 2006).

According to study by (William *et al*., 1999) the removal of a uniform thin layer of soil by raindrop splash or water runoff is called sheet erosion. Watersheds are commonly divided into the upland areas and channels. In the upland areas, overland flow is conceptually divided between rill flow mechanisms and inter-rill flow mechanisms, which occur on hill slopes. As overland flow converges from various portions of the upland area and becomes more concentrated, it becomes sufficiently erosive to form shallow channels, referred to as rills. In the inter-rill areas, runoff occurs as a very thin, broad sheet, sometimes referred to as sheet flow. Both detachment and transport may occur in the rill and inter-rill areas. As erosive power increases, the small rills may converge to form larger surface channels, called gulley (Chekol , 2006).

2.2 Types of Soil erosion by water

The process of Soil erosion by water starts from detachment of soil particles by raindrop impact then transportation by the force of flowing water (Wischmeier & Smith, 1978). And when the flowing water losses its transportation energy, deposition occurs. Depending on the stage of progress in the erosion process and the position in the landscape, there were various forms of soil erosion by water. Splash erosion, sheet erosion, rill erosion and gully erosions were the major ones (Mitiku, 2006). Rain splash is the first stage of erosion process. It occurs when rain falling directly on to the ground during rainstorms or intercepted by the canopy and make contact with the ground. Some of the water infiltrates into the soil, while some water stays on the surface, saturating it and weakens the natural soil aggregates and breaks them down so that facilitated to move with flowing water. Sheet erosion is characterized by removal of thin uniform uppermost surface layer of soil particle by surface runoff (sheet flow of water). This Surface runoff forms when the rainfall intensity of a storm exceeds the infiltration capacity of the soil (Morgan & R, 1995).

During sheet erosion, the entire surface of the field was gradually eroded uniformly. According to Hurni (1998) sheet and rill erosions are the most hazardous forms of soil erosion in which resulting steady degradation of large areas under cultivation. When the sheet flow of water becomes more and more, it starts to concentrate and forms a rill flow. Rills are micro-channels which would develop when surface water concentrates in a depression. Thus, rill erosion was the removal of soil particle by this concentrated flow of water along the formed small channels. It is more common in bare agricultural land, particularly overgrazed land, newly cultivated soil; where the soil structure has been loosen. The rills are shallow drainage line and can usually be removed with farm machineries and tools. Rill erosion can be reduced by reducing the volume and speed of surface water with grassed waterways and filter strips, and contour drains. Such erosion was often described as the intermediate stage between sheet erosion and gully erosion. Gully erosion is formed when runoff water accumulates and often recurs in narrow channels and removes the soil from this narrow area to considerable depth. It can be formed from rill erosion through gradual deepening and expansion (Nyssen, 2006).

2.3 Factors affecting soil erosion

The magnitude of rate of soil erosion is affected or controlled by different factors. Broadly these factors are two types, human induced factors and natural factors. Climatic factor, topographic factors and soil properties factors are categorized under natural factor affecting soil erosion. Vegetative cover factor and watershed management practice factors are categorized under human activities factors. However, these factors are dependent on each other, as geology affects topography, which can influence the climate as well (Costick, 1996b).

2.3.1 Climatic factor

Different climatic variables including rainfall, wind and temperature have influence on soil degradation. From these variables, rain fall amount and intensity is one of the major climatic factors that contribute for soil degradation (Kosmas, 1997). When raindrops act upon the soil particles, the soil particle would detached from the parent granular surface of the earth and starts to move with over land flowing water. Therefore, as the intensity of rain drop increase, the resulting soil loss would increase by the detaching power (kinetic energy) of raindrops striking the soil surface and through the contribution of rainfall to runoff (Bekele, 1998). Thus, Erosivity was the capacity or capability of rain drops to produce detachment and movement of soil particle, due to kinetic energy of the rain drops on the soil surface (Renard *et al*., 1997). A period of above 30 years average rainfall data of five selected rainfall stations in the watershed is recommended to compute the average erosivity factor (Farhan *et al*., 2013). Difference in the R-factor values reflects difference in rain fall intensity patterns between different regions. Different research has been attempted to conduct on rain fall intensities and erosivity for Ethiopian highlands. For instance, the study by (Nyssen, 2006) shows the relations between the rain fall intensities and erosivity for Northern Ethiopian highlands.

2.3.2 Soil properties factor

Due to naturally inherent property of soil, different soil types affected by erosion differently. Thus, Soil properties such as soil texture, structure, soil roughness, organic matter content and chemical and biological characteristics of soils make differ in erosion resistance capacity (Vrieling, 2007). Hence, this capacity is termed as soil erodibility factor which refers to the resistance or capability of the soil against erosion by different erosion agents (Morgan & R, 1995). According to (Sonneveld *et al*., 1999) soils having faster infiltration rates, higher levels of organic matter and improved soil structure, have a greater resistance to erosion. It means, such soil characterize with low K-factor values. Generally, Soils with high clay content have low K-factor values, because they are resistant to detachment. And Soils which are coarse textured, such as sandy soils also have low K-factor values, this is because of low transportability even though these soils are easily detachable. Medium textured soils, such as silty-loam soils, have moderate K-factor values, because they are moderately susceptible to detachment and transport. Soils having high silt content are the most erodible of all soils as they are easy to detach the particle and cause a decrease in infiltration and easy to transport. Generally, soil erodibility (K-factor) values rated from 0 to 1. Zero refers to soils with least susceptible to erosion, whereas 1 refers to soils which are highly susceptible to erosion by water (Houghton, 1994).

2.3.3 Topographic factor

Topographic factor that influence soil erosions are slope length, slope steepness and shape (concavity and convexity). Erosion would normally be expected to increase with increase in slope steepness and slope length as a result of respective increases in velocity and volume of surface runoff (Zeleke & Hurni, 2001). Accordingly, Steeper surface slope causes higher runoff velocities, more splashes downhill and faster flow and therefore, contributes greater soil erosion. The topographic factors or slope length and slope steepness factor have been considered as one of the major erosion contributing factor and represented as LS-factor.

2.3.4 Land use land cover factor

Land cover and human activities on the land cover, was one of the most crucial factors in reducing or increasing soil erosion. The vegetation cover reduces soil erosion by protecting the soil against the action of direct falling and contact of raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil particles by the roots of the cover plants and maintaining the roughness of the soil surface and improving the physical; chemical and biological properties of the soil (Asis and Omasa, 2007).

To consider this ground cover effect in soil erosion calculation, land use land cover factor has been included and it is one of the factor affecting soil erosion and represented by C-factor. Land use land cover changes takes two forms; conversion from one category of land use to other type of land use and modification of condition within a category. Hence, changes in land use reflect the history of human kind and linked with economic development, population growth, technology, and environmental condition of society (Houghton, 1994). Now a day, land use land cover change was a significant driving agent of global environmental change. Such large scale land use changes through deforestation, expansion of agricultural land as well as other human activities, are inducing changes in global systems and cycles. But the major change in land use, historically, has been observed to increase worldwide in agricultural lands. Thus, the increase in human population and distribution is the major cause of land cover change through time, rendering the soil to be left bare and more susceptible to erosion (Silva and A., 2008).

2.4 Impacts of soil erosion

Soil erosion problem has various effects on the environment. The effects are broadly of two type; on-site effect and off-site effect. Some of on-site effects of soil erosions were; removal of top fertile soil, minimizing infiltration and water holding capacity of the soil, and loss of chemicals and fertilizers. Off-site effect of soil erosions includes; water resource disturbance, river sedimentation, siltation of water storage structures like dams and weirs, disruption of lake ecosystems, contamination of drinking water and increased downstream flooding (Tesfahunegn & Tamene, 2012). Removal of top fertile soil leads to nutrient depletion such as Nitrogen, Phosphorus, Potassium and Calcium and organic matter which are vital for plant growth. When the top soil is removed crop roots are exposed to soil with low organic matter, phosphorous and nitrogen, and high pH contents. On the other hand soil moisture (water) is crucial for plant growth and if the top soil is eroded the infiltration and water holding capacity would decrease and loses its moisture (Morgan & R, 2005).

Consequently, the plant struggle to obtain the required water and nutrients in soils with low nitrogen and phosphorous availability and all this leads to inhibited plant growth and overall productivity declines. Sedimentation is the end product of soil erosion. The eroded soil particles transported through the processes of sheet, rill, and gully erosion and joins streams and rivers. Once transported by these streams, sediment particles are transported through a river system and are eventually deposited in water bodies such as reservoirs and lakes. This portion of the eroded material that transported through the stream network to some point of interest is referred to as the sediment yield and subsequent sedimentation leads to decrease the carrying capacity of water bodies. According to FAO (1998), one-fourth of the soil lost through erosion in a watershed actually reaches to ocean as sediment. The remaining three-fourths are deposited on foot hill slopes, in reservoirs, in river plains and other low-lying areas or in the river-bed which often causes channel shifts.

2.5 Runoff and sediment transport

Water erosion is one of the major geomorphological processes on hill slopes. Erosion consists of three phases: particle detachment, transport and deposition. Gully erosion occurs by the combined action of splash, sheet wash and rill-wash (inter rill and rill erosion). These erosion processes have a great influence on both sediment production and sediment transport. The relation between rainfall, runoff, erosion and sediment transport is highly variable. Their relation can be modified by land use changes and climate oscillations that, ultimately, would control water and sediment yields. The rate of soil erosion depends mainly on the detachment of soil particles and on the transporting capacity of overland runoff (Kilinc & M, 1972). The sediment transport capacity depends on many factors, including runoff velocity, sediment grain size, and the specific gravity of sediment practices in a particular river. Sediment moves in the stream as suspended load (fine particles) in the flowing water, and as bed load (large particles), which slides or rolls along the channel bottom. Sometimes, the particles (small particles of sand and gravel) move by bouncing along the bed, which is termed as siltation, which is a transitional stage between bed and suspended load (Jain *et al*., 2010).

2.6 Relationship of soil erosion and sediment yield

The relationship between the amount of soil eroded at upstream point and waterborne sediment delivered to a downstream location is important for designing hydrological facilities, planning water resource development and determining water pollution loadings (Lane & Kidwell , 2000). The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), the soil characteristics, the local climatic conditions, and the land use and management practices implemented on the watershed. MUSLE uses the amount of runoff to model erosion and sediment yield. The main strength of MUSLE is the prediction accuracy and the possibility of estimating the sediment yields of single event storms. The soil susceptibility to erosion is expressed by a soil erodibility factor (Neitsch *et al*., 2005).

2.7 Hydrological Modelling

Comprehensive and physically based watershed models have the capability of simulating hydrologic, sediment and water quality processes at a watershed scale. Different types of watershed models are summarized below differentiating between models representing long term simulation (continuous time step) and single event based simulation (Borah & Bera, 2003).

2.7.1 Continuous time step simulation models

Continuous time step models are characterized by their capability of simulating stream flow and sediment fluxes on a long-term time basis. In the following, some of the most popular continuous time step simulation models are (Annualized Agricultural Nonpoint Source), (Areal Nonpoint Source Watershed Environment Response Simulation), (Hydrologic Simulation Program Fortran), Water Erosion Prediction Project (WEEP) and Soil Water Assessment Tool (SWAT): SWAT is a non-point source pollution model with the capability of simulating hydrology, missing weather elements, sediment and pollutants transport (Borah & Bera, 2003).

2.7.2 Single event based simulation models

The common single event based simulation models are: Agricultural Non-Point Source (AGNPS): This model has the capability to simulate hydrology, land erosion and sediment transport. It simulates single storm events. The watershed was analyzed based on a uniform square area. Nevertheless, the model does not simulate subsurface flow. Overland sediment transport, including channel sediment transport is computed using the USLE. Cascade of planes in 2-dimensions (CASC2D): The model can be used to analyze the flow and the sediment of a storm event as well as on a long-term basis. Similarly, to the transport at a watershed scale using spatially varying input parameters. 2-D square grids for the overland flow and 1-D for the channel flow represent watershed. The 2-D diffusive wave equation solved by the finite difference method is used to compute overland flow. Kinematic Runoff and Erosion Model (KINEROS): In this model, the watershed is represented as planes for surface runoff and conduits or channels. Overland and channel sediment is computed based on the raindrop detachment and scour, while deposition of sediment is based on the sediment transport capacity and a mass balance equation. Precipitation Runoff Modeling System (PRMS). The model developed to evaluate the watershed response to various parameters: for example, precipitation, climate and land use. The watershed s represented as flow planes and channel segments (Arnold *et al*., 1998).

2.8 SWAT to estimate runoff and sediment yields

Sediment yield refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which would enter a reservoir located at the downstream limit of its tributary watershed (Arnold & Allen, 1999). The most common unit for sediment yield is tone/year. The specific sediment yield is the yield per unit of land area, which is most commonly given in tones/km^2/year. Sediment yield is affected by geology, slope, climate, drainage density and patterns of human disturbance and therefore, no single parameter or simple combination of parameters explains the wide variability in sediment yields (Abbaspour, 2013). A considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the water that moves over the land in undefined channel is termed as runoff, (Chow, 1988). During precipitation, some of the rainfall is intercepted by vegetation before it reaches the land surface. This may later fall to the ground or evaporate. Meteoric water, which is not intercepted by the vegetation cover falls on the ground surface, where it evaporates, infiltrates into pervious soils, lies in the ground depression or flows down giving rise to runoff. The runoff process is strongly influenced by infiltration capacity. The infiltration capacity varies not only from soil to soil, but also different for dry versus moist conditions in the same soil. After a certain time it reaches a regime value, which is called equilibrium infiltration capacity (Chow, 1988).

2.9 Effect of Land use/land covers change on runoff and sediment yields

The effects of land use/land cover change on sediment and runoff dynamics of a river basin has been an area of interest for hydrologists in recent years. Land degradation and erosion hazard induced by water erosion, human and physical factors, particularly the denudation of vegetation by human and domestic animals, and the infrequent and irregular distribution of precipitation are becoming a major problem worldwide. The unsustainable agricultural practices along with many other physical, socioeconomic and political factors have been the driving forces to a series of land degradation problems in the country. SWAT is a river basin scale model developed to quantify the impact of land management practices on water, sediment, and agricultural chemical yields, can adequately simulate the effects of land use on runoff volumes, sediment yield and stream flows. A study conducted by (Arnold & Fohrer, 2005) in the watersheds to simulate the effects of land use on runoff volumes, sediment yield, and stream flows shows that Arc SWAT adequately predicted peak flows and temporal variation of runoff volumes and sediment yields. Sediment loading is highly dependent on precipitation within the watershed.

2.10 Surface Runoff

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. Excess water from precipitation, that is not stored within depressions in the ground or infiltrated into the ground, is classified as runoff. This overland flow caries nutrients and sediment as it travels towards the stream channel. Runoff increases stream flow and must be estimated accurately in order to model stream flow and sediment transport within in a watershed. Using daily or sub daily rainfall, SWAT offers two methods for estimating surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (Green & Ampt, 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. SWAT simulates surface runoff volumes and peak runoff rates for each HRU. For the definition of hydrological groups, the model uses the U.S. Natural Resource Conservation Service (NRCS) classification. The classification defines a hydrological group as a group of soils having similar runoff potential under similar storm and land cover conditions. Thus, soils are classified into four hydrologic groups (A, B, C, and D) based on infiltration which represent high, moderate, slow, and very slow infiltration rates, respectively (Neitsch *et al*., 2012).

2.11 Factors affecting surface runoff

As the rain continues, water reaching the ground surface infiltrates into the soil until it reaches a stage where the rate of rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled with water (depression storage), and after that overland flow as runoff is generated. The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration. The flow of any stream is determined by two major groups of factors. The first set belongs to the geomorphological factors of the drainage basin. The second set of factors depend on the climatological variables (Neitsch *et al*., 2012).

Meteorological factors affecting runoff: type of precipitation, rainfall intensity, rainfall amount, rainfall duration, distribution of rainfall over the watersheds, direction of storm movement, antecedent precipitation and resulting soil moisture, other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season. physical characteristics affecting runoff: land use, vegetation, soil type, drainage area, basin shape, elevation, slope, topography, direction of orientation, drainage network patterns, ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or alter runoff from continuing downstream. The climatological factors are: rainfall intensity and type, duration of rainfall, distribution of rainfall, direction of storm movement, soil moisture conditions. The geomorphological factors include land use land cover, type of soil, area, shape, elevation, slope, network of drainages and indirect influences for runoff (Neitsch *et al*., 2005).

2.12 Best management practices (BMPs) to reduce runoff and sediment

Best management practices (BMPs) are commonly used to control runoff and sediment yields. The pretension of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system and to reservoirs. Most common standard technical solutions for soil and water conservations adopted in different parts of the world can be terracing, contour ploughing, trench excavation, strip cropping, stone buds, crop rotations and stabilization of critical areas by their return to grasslands or forests. Terracing is a piece of sloped plane that has been cut into a series of successively receding flat surface, which resemble steps for the purpose of more effective farming. Such graduated terrace stapes are commonly used to farm on hilly or mountainous terrain. A terraced field decreases both erosion and surface runoff (Vanost *et al*., 2006).

Contour ploughing is a farming practice of ploughing and planting across a slope following its elevations contour line. These contour lines create a water break which reduces the formations of rills and gullies during times of heavy water runoff which a major cause of soil erosion. In contour ploughing the ruts made by the plow run perpendicular rather than parallel to slope and allows more time for water to settle in to the soil (Vanost *et al*., 2006). Bunds are among the most common techniques used in agriculture to collect surface run off, increase water infiltration and prevents soil erosion. The principle is comparably simple; by building bunds along the contour lines, so that water runoff is slow down, which leads to increased water infiltrations and enhancing soil moisture. Contour bunds can either be made of stones or soil (sometimes with crop remains). Strip cropping is a method of farming which involves cultivating a field into long, narrow strips which are alternated in a crop rotation system. It is used when a slope is too steep and or when ether is no alternative method of preventing soil erosion. The most common crop choices for strip cropping are closely sown crops such as wheat, corn soybeans cottons and others. In certain systems, strips in particularly eroded areas are used to grow permanent protective vegetation; in most systems, however, all strips are alternated on an annual basis (Frederick *et al*., 2003). Crop rotation is the practice of growing a series of dissimilar or different types of crops in the same area in sequenced seasons. It is done so that the soil of farms is not used for only one set of nutrient. It helps also in reducing soil erosion and increases soil fertility and crop yield (Frederick *et al*., 2003).

2.13 Model selection Criteria for SWAT

Thus for the problems to be considered in choosing a suitable model in general have to be discussed. In most situations, however, absolute objective methods of choosing the best model for a particular problem have not yet been developed, so this choice remains a part of the art of hydrological modeling. (Dawdy & Lichty, 1968) Suggested four criteria that can be used to choose between alternative models: 1) Accuracy of prediction, 2) Simplicity of the model, 3) Consistency of parameter estimate, 4) Sensitivity of results to change in parameter values. Accuracy of prediction of system output is obviously very important; it is desired when all other factors being equal, the model with minimum error variance would be superior. Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be explained to clients or public bodies. When all other factors are being equal, one should choose the simplest model. Consistency of parameter estimation is an important consideration in developing hydrological models using parameters estimated by optimization techniques. Finally, models should not be extremely sensitive to input variables that are difficult to measure (Dawdy & Lichty, 1968).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The study area of the Meki River watershed lies in the Western Rift Valley Lakes Basin and this watershed was shared by East Shoa and Arsi Administrative Zones. It was administratively located in Dugda Bora Wareda, East Shoa Zone of Oromia Regional State. A total watershed area of 2060.792 km^2 and the highlands at altitude of 3,607 m to 1626m. The Meki River Watershed lies in between 7^{0}59'23" to 8^{0}27'23" N Latitude and 38^{0}14'49" to 38^{0}59'32"E Longitude (Dereje, 2011).

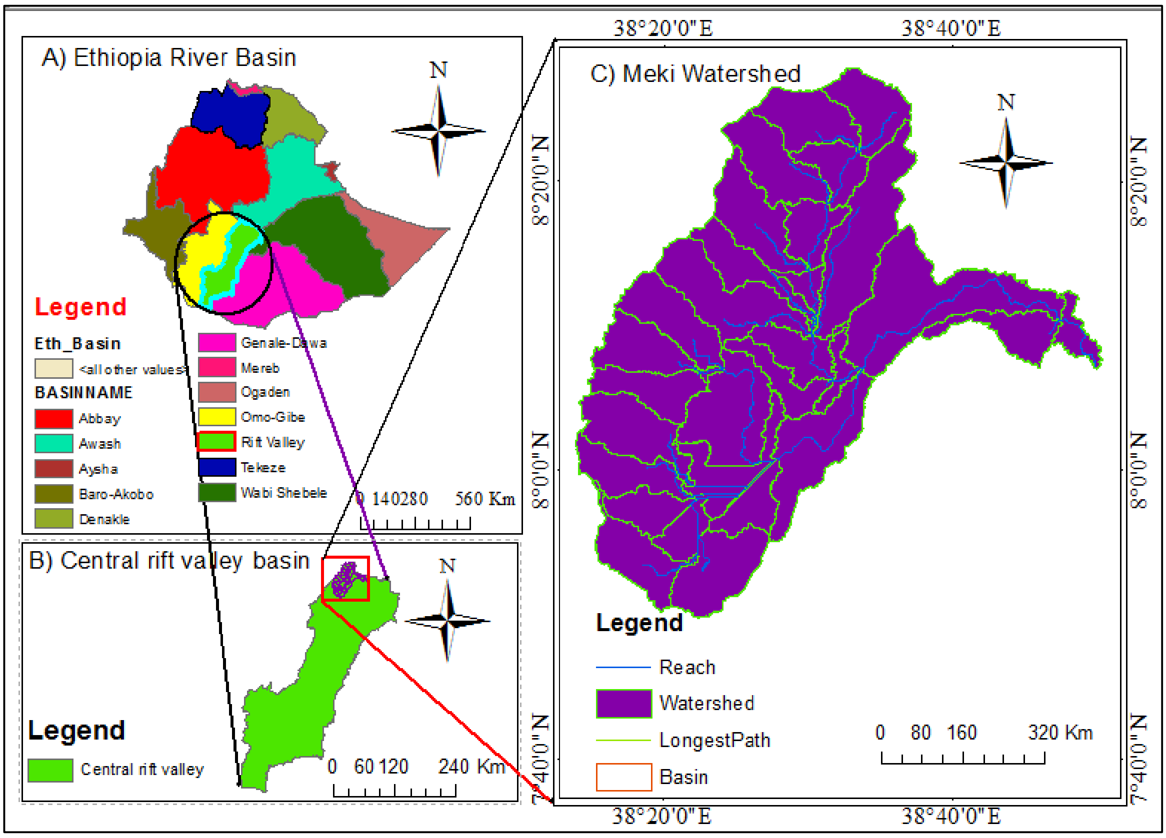


Figure 3.1: Location Map of the Study Area.

3.1.2 Climate and Topography

The study area, which was a sub basin of central rift valley basin consists of variety of landscape with various topographical features (flat to mountainous) with elevation variation from 1626 to 3607 m above mean sea level (Figure 3.2). The climate in the study area and around the lakes was arid or semi-arid. However, it was humid to dry sub-humid in the River watershed areas in the highlands, west of Butajira and East of Assela.

According to Hurni (1988) description of Agro climatic zones of Ethiopia, the watershed consists of three agro-climatic zones "kola, weynadega and dega" with elevation variation of 500-1500, 1500-2300 and above 2300 m respectively. The climatic condition varies depending up on the variation in elevation. The average annual precipitation of the five stations was about 2030.924mm. The mean annual temperature of two stations was about 20.78 ^{0}C while monthly minimum temperature was 6.1 ^{0}C in December and monthly maximum temperature was 27.6 ^{0}C in March. Humidity values vary between 37.2% in November and 40.16% in July. Average monthly solar radiation were 22.02 $Jm^{-2}day^{-1}$. Wind speed was reportedly low minimizing potential evapo-transpiration values between 77.41mm in July and 96.5mm in May and the calculated parameter using Arc SWAT user manual were shown in appendix D.

Table 3.1: The selected observed maximum and minimum temperatures from the higher and lower parts of the study area.

Average monthly Temperature (^{0}C) of Bui station												
Max	25.7	26	27.6	26.9	27.4	26.6	23.9	23.8	24.4	24.8	24.5	23.9
Min	7.6	7.9	10	10.7	10	10.2	9.8	9.7	9.2	7.6	6.7	6.1
Average monthly Temperature (^{0}C) of Butajira station												
Mo	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Max	23	24	24	24	23.8	23.7	22.6	22.7	23.6	24.5	24.5	22.6
Min	9.5	10.	10.8	10.8	10.7	11	10.4	10.7	11.1	10.9	10	8.9

3.2 Data collection and analysis

Engineering studies of water resources development and management depends heavily on Hydro-meteorological data. These data should be stationary, consistent and homogeneous when they were used to simulate a hydrological system. If it does not fulfill these criteria's, it would result in a big problem that contradicts the actual situation. Therefore, using different methods, the inconsistency, homogeneity, infilling for missed data and extension of short records encountered in the actual data processing activity should be done.

3.2.1 Spatial data

The spatial data which were Digital Elevation Model (DEM) was downloaded from website https://vertex-retired.daac.asf.alaska.edu/and Soil map and land use map was obtained from Ministry of Water, Irrigation and Electricity (MoWIE).

3.2.1.1 Digital Elevation Model (DEM)

The spatial variability of the basins physiographic factors can be extracted from different digital maps which were the main building blocks of watershed configuration parameters in SWAT model. Topography was defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. In other words, the DEM was any digital representation of a topographic surface and specifically to a raster or regular grid of spot heights. It was the basic input of the Arc GIS integrated SWAT hydrologic model to delineate the watershed, to extract information about the topography/elevation of the watershed and to analyze the drainage patterns of the land surface terrain. Sub-basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics were also derived from the DEM. For this study 12.5m by 12.5m DEM of the Meki River watershed was downloaded. The DEM downloaded were in different layers which was mosaic ked into one raster data set and further Meki River watershed DEM were extracted from this mosaic ked data using Arc GIS 10.1.

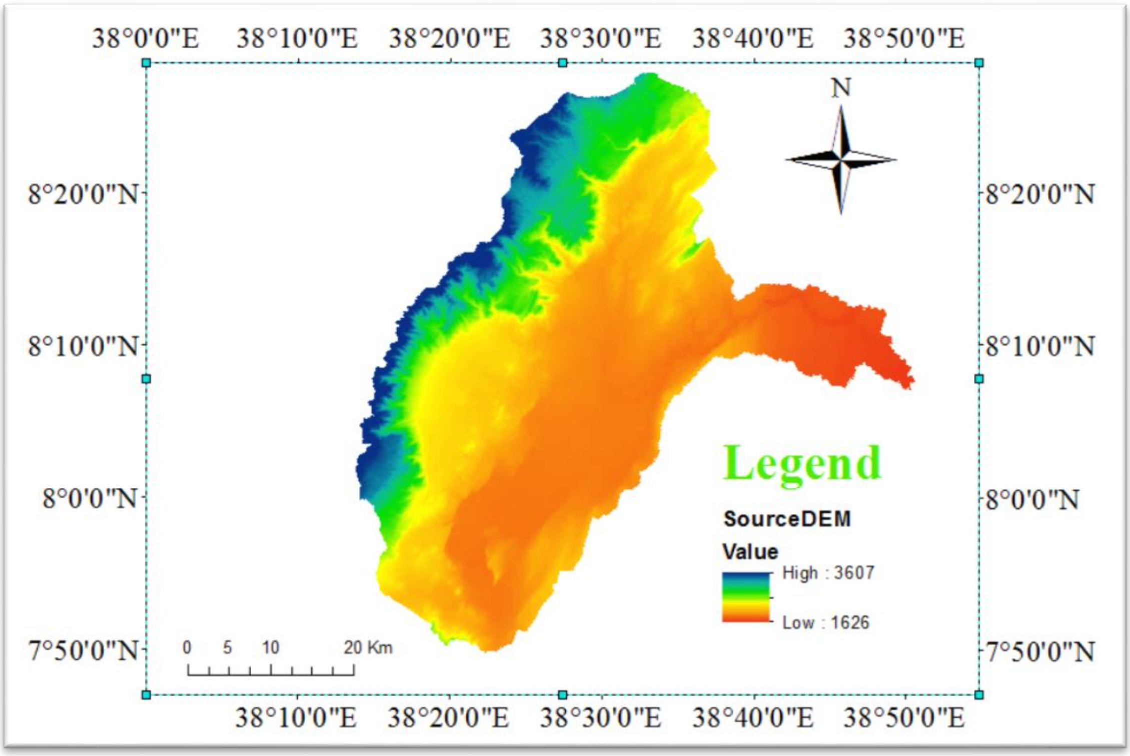


Figure 3.2: Meki River Watershed DEM

3.2.1.2 Land use/land cover data

The land use land cover map gives the spatial extent and classification of the various land use land cover classes of the study area. Land use and cover affect surface erosion, water runoff and Evapo-transpiration in a watershed. The LULC data of 2013 combined with the soil cover data generates the hydrologic characteristics of the watershed or for the study area, which in turn determines the excess amounts of precipitation, recharge to the ground water system and the storage in the soil layers. Land use land cover was one of the main input data of the SWAT model to describe the Hydrological Response Units (HRUs) of the watersheds which affect runoff, evapo transpiration and surface erosion in a watershed. It was also used for comparison of impacts on stream flow of the watershed with in time. The land use condition in the Meki River watershed includes mainly of wood land, grassland, Moderate cultivated land and forestland, intensive cultivated land, Shrub land, Wetland, Settlement and Water Bodies. It was estimated that 64520.76ha (31.31%) was intensive cultivated land, 17709.62ha (8.59%) was Moderate cultivated land, 31145.44ha (15.11%) was grass land, 2363.86ha (1.15%) was wood land, 22311.42ha (10.83%) was Barren land and the remaining 67489.74ha (33.01%) was under Settlement, forest, shrub land, wetland and water bodies. The most coverage land use land cover of the study area was intensive cultivated land. Meki watershed LULC and Percentage of area coverage were shown in appendix B.

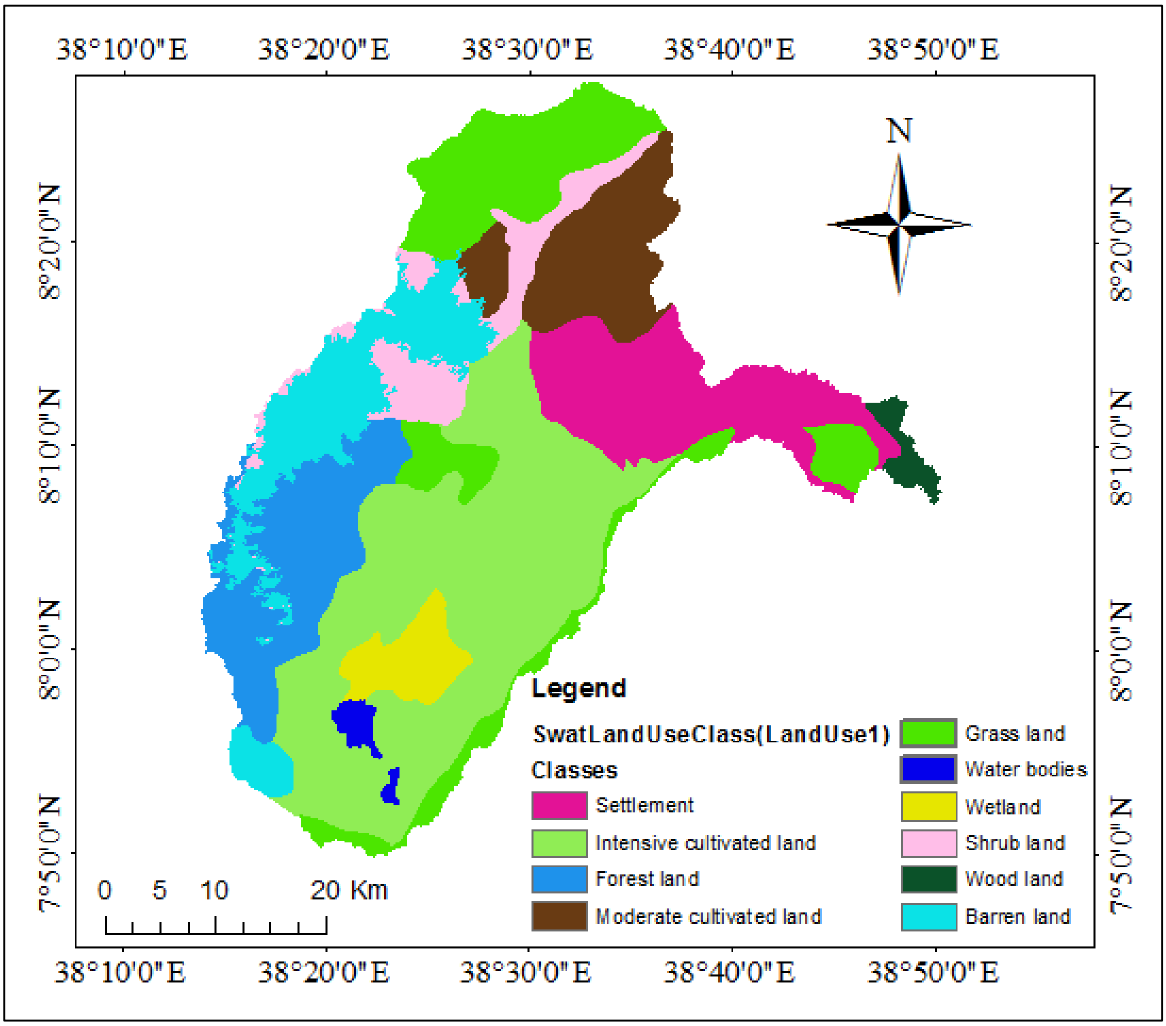


Figure 3.3 Meki Watershed Land Use Land Cover (LULC).

3.2.1.3 Soil data

Like the Digital Elevation Model, soil data resolution has also a significant impact on the modeling of stream flow, sediment load and nutrient content. This on the other hand affect the runoff and sediment prediction. If the low resolution soil data was used to generate the HRUs it assigns same soil type for larger area of the watershed that actually may have different soil types. Different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity etc. that affects the water balance and sediment yield from the watershed. Therefore, all required soil properties were adopted from database since there was no possibility of measuring all soil properties in the field due to time constraint. The soil was projected to WGS-1984 UTM Zone 37N using the raster projection in Arc Map before it was imported to Arc SWAT. Soil of Ethiopia was not available in SWAT databases. The physical properties of the soils in Meki River watershed have been extracted from FAO (1998) world soil database. The soil map and classification of Meki

River watershed used in the HRU definition in this study was shown in figure 3.4. Soil data was one of the major input data for the SWAT model with inclusive and chemical properties. Twelve major soil groups were identified in the watershed of Meki River. SWAT model requires soil physical and chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of each soil type. To integrate the soil map with SWAT model, a user soil database which contains textural and chemical properties of soils was prepared for each soil layers and added to the SWAT user soil databases using the data management tool in Arc GIS. The most coverage soil of the study area was Haplic Cambisols. Meki watershed soil and percentage of area coverage were shown in appendix C.

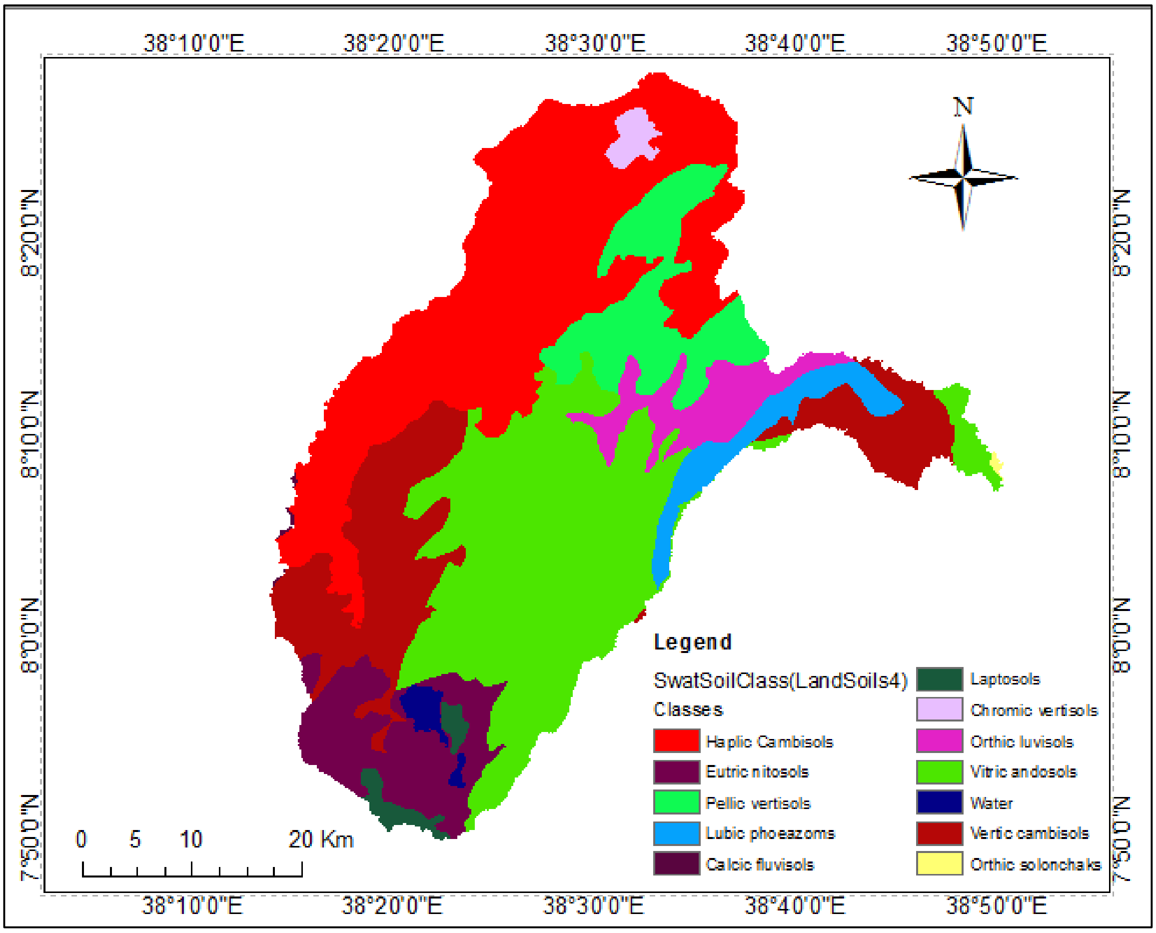


Figure 3.4: Soil Map of the Meki River watershed.

3.2.2 Hydrological data

3.2.2.1 Stream flow

The hydrological data was required for performing sensitivity analysis, calibration and uncertainty analysis and validation of the model. The steam flow from (1993-2010) used for calibration and validation. The hydrological data collected was daily flow for the Meki River feeding into Lake Batu at Meki flow station (8.151 N Lat, 38.817 E Long). It was the only hydrological data used for sensitivity analysis, calibration and validation because of it had long term and reliable stream flow data and also located at the outlet of River to the Lake.

3.2.2.2 Sediment

There were few sediment data which have measured suspended sediment data in the Meki River watershed. The sediment rating curve is a relationship between the river discharge and sediment concentration or load (Morris & Fan, 1998). It is widely used to estimate the sediment load being transported by a river. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over daily, monthly or other time periods. So that using rating curve, the records of discharges are transformed into records of sediment concentration or load. Commonly, the relation is the following form (Morris and Fan, 1998).

$Q_s = aQ^b$……………………………………………………………………………….3.1

Qs = is the Suspended sediment concentration (ton/day), Q = is the discharge (m^3/s), a and b are constants. The most commonly used sediment rating curve is power function. The Sediment flow measurement in the Meki River watershed was not in continuous time step; so that by using stream flow and measured sediment data can generate sediment rating curve (Morris and Fan, 1998). The measured suspended sediment concentration data of Meki River watershed from MoWIE was shown in Appendix J.

3.2.3 Meteorological data

The climate data was among the most prerequisite parameter of SWAT model. The data collected were based on their homogeneity of the pattern, which can be representative to the Meki River watershed. The meteorological data collected includes, Precipitation, maximum and minimum temperature, solar radiation, Wind speed and relative humidity. The collected data covers a period of (1993-2017). Solar radiation, relative humidity, and wind speed data were available only for principal station (Bui). These data for the rest of the stations were generated by SWAT weather generator model (WGEN). The SWAT weather generator model (WGEN) was used to fill missed values in weather data of relative humidity, wind speed and solar radiation. As a consequence of, NMSA was not directly measured solar radiation instead the sunshine hour data was found, it can be calculated with the Angstrom formula which relates solar radiation to extraterrestrial radiation and relative sunshine duration (Feven, 2017). $R_s = (a_s+b_s\, n/N)R_a$…………………………………….3.2

Where; R_s solar or shortwave radiation [J m-2 day-1], n actual duration of sunshine [hour], N maximum possible duration of sunshine or daylight hours [hour], n/N relative sunshine duration [-], Ra extraterrestrial radiation [J m-2 day-1], as regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n = 0), a_s+b_s fraction of extraterrestrial radiation reaching the earth on clear days (n = N). Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month), the Angstrom values a_s and b_s would vary. Where n = 0 actual solar radiation data were available and n = 0 calibration has been carried out for improved a_s and b_s parameters, the values a_s = 0.25 and b_s= 0.50 were recommended. The daylight hours, N and the extraterrestrial radiation, R_a. Meteorological stations also geo-referenced using latitude, longitude, and elevation data.

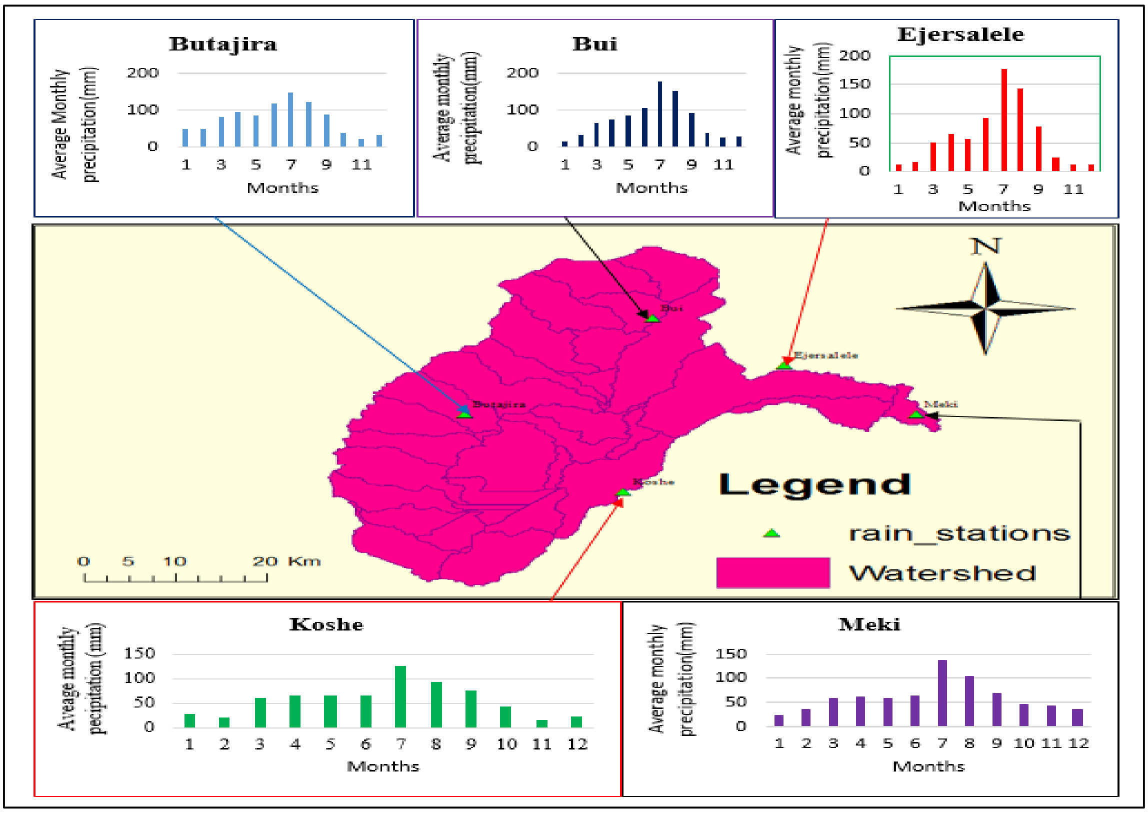


Figure 3.5: Selected Meteorological Stations of the Meki River Watershed with their average Monthly Rainfall.

3.2.3.1 Rainfall

The data of 25 years (1993 - 2017) monthly recorded data from each meteorological station were used for SWAT simulation. The rainfall data for selected representative rainfall stations in the study area were shown in table 3.4. These rainfall stations were Bui, Butajira, Ejersalele, Koshe, and Meki stations.

Table 3.2: The locations and yearly average rainfall for each station.

Stations Name	Locations		Altitude (m)	Yearly Average Rainfall(mm)
	Lat (N)	Long (E)		
Bui	8.33	38.55	2054	91.48
Butajira	8.15	38.37	2000	94.63
Ejersalele	8.24	38.69	1797	75.69
Koshe	8.01	38.53	1878	70.25
Meki	8.151	38.82	1662	74.12

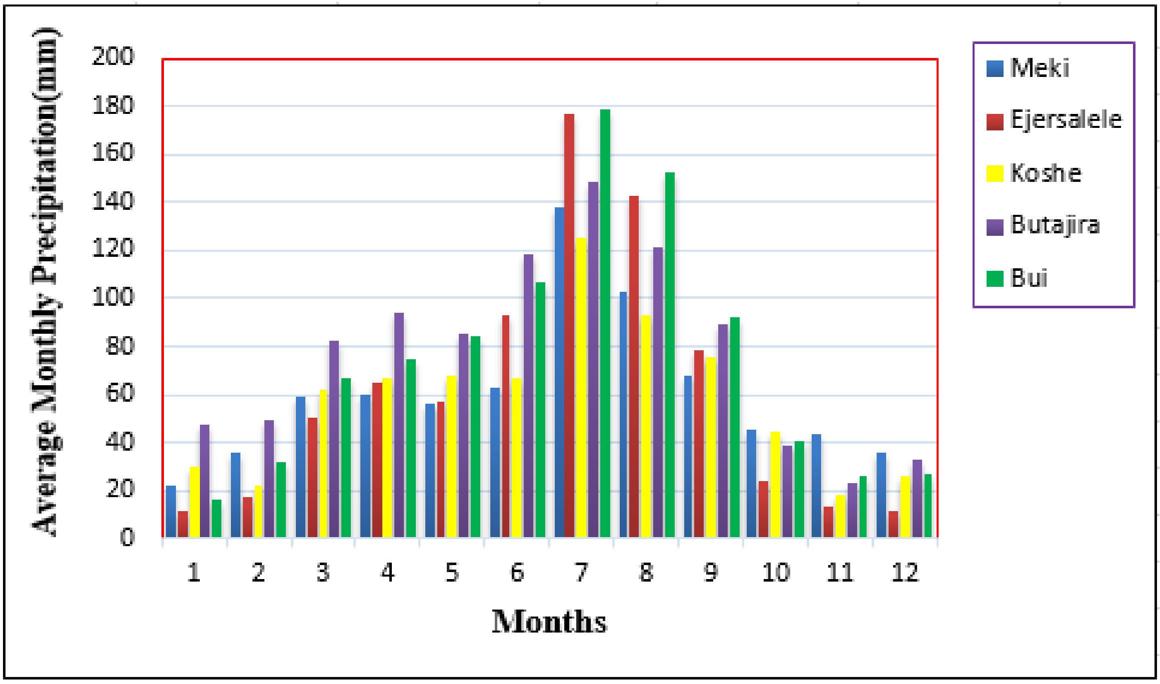


Figure 3.6: Average Monthly Precipitation of the Meki River Watershed.

3.2.3.2 Temperature

Temperature in the study area shows that strong variations with altitude. Mean annual temperature ranges from about 8.8 ºC to around 25.5 ºC in the highlands.

The minimum temperature 6.1 ºC in December and maximum temperature 27.6 ºC in March. The temperatures of two meteorological stations in the study area were shown on figure 3.7.

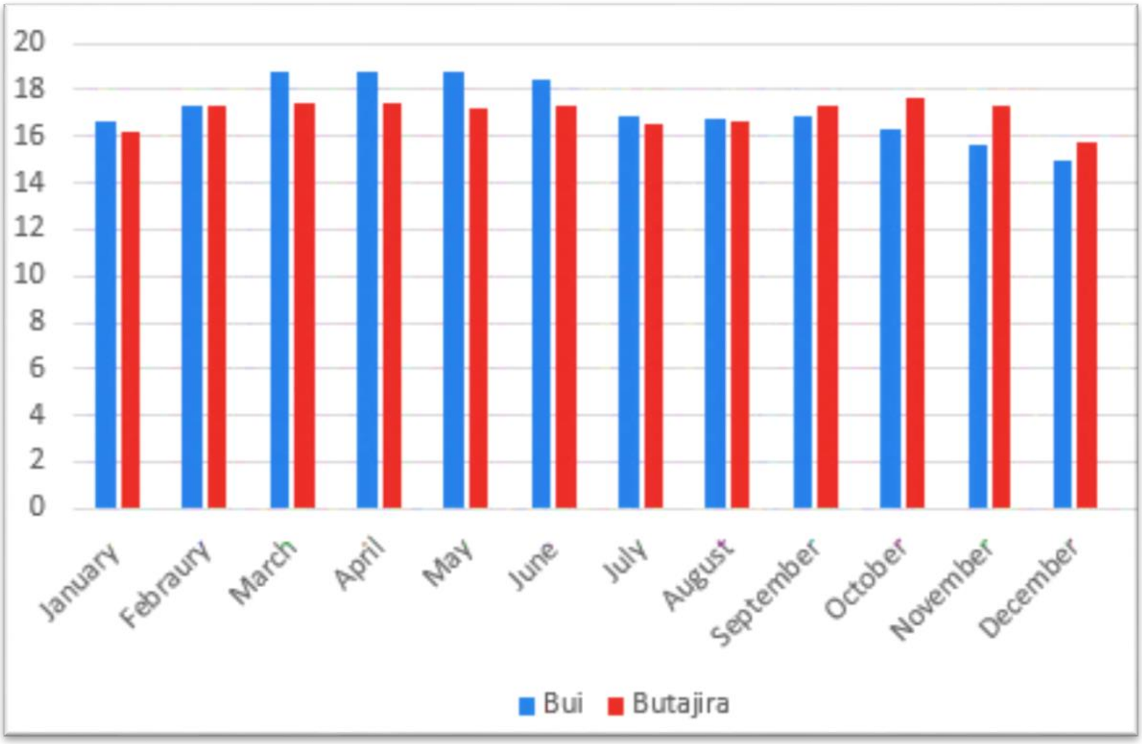


Figure 3.7: Average Temperature Observed in the Meki River Watershed (1993-2017).

Before using these data the quality of each data recorded at each station was evaluated using homogeneity test by non-dimensional parameterization and consistency test by double mass curve.

3.3 Data consistency Checking

Data continuity checking, avoiding wrong rainfall, stream flow, river stage readings, and suspended sediment weights i.e., negative values, and deleting dates with empty data recordings which affect data sorting process were done to exclude poor quality data from modeling purpose. Wrongly written starting and ending times for stream flow recordings and sediment samplings were also adjusted so that the total data calculations were not affected.

3.3.1 Filling Missed Rainfall Data by Regression

Although complete hydro-meteorological data was a pre-requisite for successful water resource planning and management, significant data sets were usually missing due to interruption of measurements caused by natural and/or human-induced factors. Some precipitation stations may have short breaks in the records because of absence of the observer or instrumental failures. Some techniques of filling missed rainfall data were simple linear interpolation, arithmetic mean method, inverse distance and normal ratio method. For this study, arithmetic mean method for one station which have least percentage of missing and regression/excel stat was used to fill the missing data of rainfall and temperature from nearest stations for other stations. The arithmetic mean method formula applied for filled the missing data (Nash and Sutcliffe, 1970).

$$Px = \frac{P1+P2+P3+\cdots+P_N}{P} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.3)$$

Where: Px is the precipitation from station with missed record, P_1, P_2, P_3… P_N are corresponding index station, N = Number of index station.

3.3.2 Checking consistency of selected stations by double mass curve

Numerous factors could affect the consistency of rainfall record at a given station. Inconsistency is a change in the amount of systematic error associated with the recording of data. It can arise from the use of different instruments and methods of observation. A time series observational data was relatively consistent and homogeneous if the periodic data were proportional to an appropriate simultaneous period. This proportionality can be tested by double mass analysis in which accumulated rainfall/hydrological data was plotted against the mean value of all neighborhood stations. Double mass curve method helped in determining the best realistic correlation of stations located near or within watershed. This technique was based on the principle that when each recorded data comes from the same parent population, they were consistent. It should be corrected as (Weiss & Wilson, 2001)

$$\frac{Pa}{Pd} = \frac{\frac{Y}{X}}{\frac{Yd}{Xd}} = \frac{\text{Slope of original line}}{\text{Slope of deviated line}} = \text{Correction factor} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots (3.4).$$

Where, Pa = adjusted amount, Pd = deviated amount for the concurrent period for which Pa is desired. Correction was performed when, $\frac{\text{Slope of deviated line} - \text{Slope original line}}{\text{Slope of deviated line}} * 100\% \ldots (3.3)$ greater than 10%. But for this study correction was not needed.

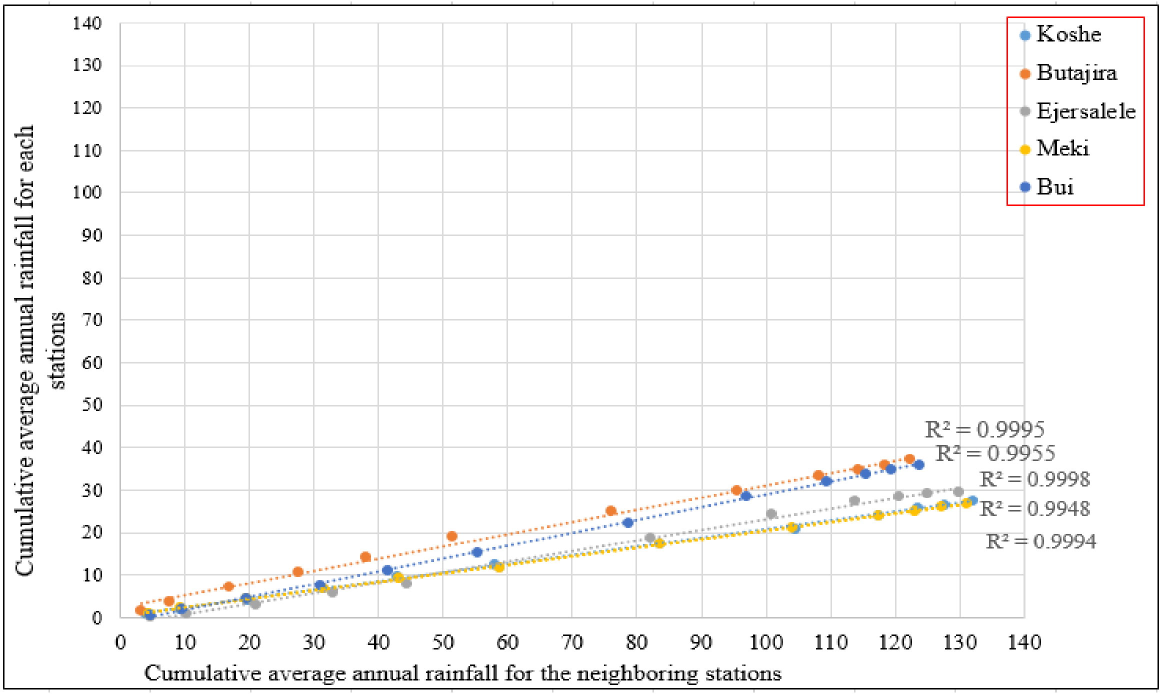


Figure 3.8: Double Mass Curve Plot for Selected Meteorological Stations.

3.3.3 Checking homogeneity of stations by non-dimensional parameterization

Homogeneity analysis is used to identify a change in the statistical properties of the time series. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation station. Therefore, in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations was essential and the homogeneity of the selected gauging stations monthly rainfall records were carried out by non-dimensional (Yevjevich & Jeng, 1969).

$$\text{Pi}= \frac{\overline{\text{Pi}}}{\overline{\text{P}}} * 100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3.5)$$

Where: Pi = Non dimensional value of precipitation for the month i, $\overline{\text{Pi}}$ = over year average monthly precipitation for the station i, $\overline{\text{P}}$ = the over years average yearly precipitation of the station. The selected stations were also plotted for comparison with each other; for illustration figure 3.9 shows the result of homogeneity analysis and Same-mode and pattern of the stations were observed and hence group stations selected were homogenous.

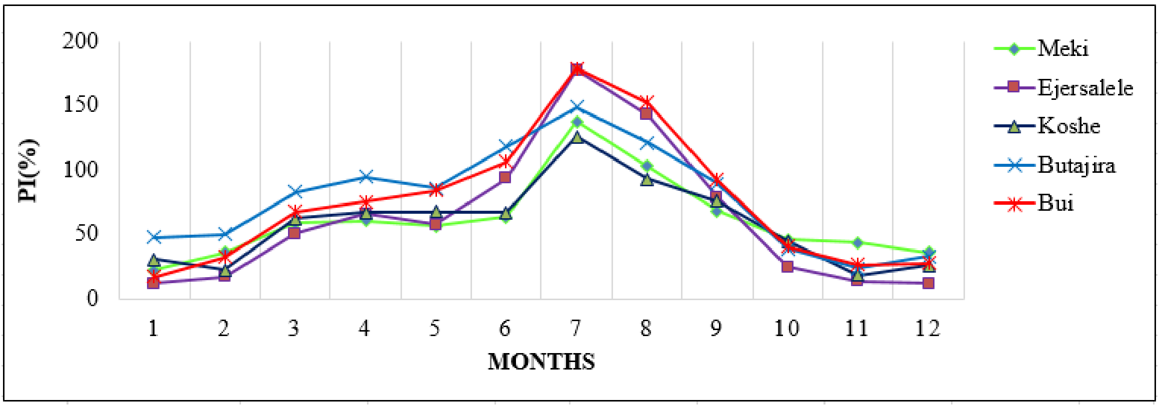


Figure 3.9: Homogeneity Test for Selected Meteorological Stations.

In this study, the Rainfall-homogeneity test was also carried out using Rainbow software. Rainbow is a software package developed by the Institute for Land and Water Management of the K.U.Leuven. The programme is designed to test the homogeneity of hydrologic records and to execute a frequency analysis of rainfall and evaporation data. The program is especially suitable for predicting the probability of occurrence of either low or high rainfall amounts, both of which are important variables in the design and management of irrigation systems, drainage network, and reservoirs. Homogeneity test is based on the cumulative deviation from the mean as expressed using the mathematical equation proposed by (Raes *et al*., 2006)**.**

$$S_K = \sum_{i=1}^{K} (X_i - \overline{X}) k = 1, -n \quad \ldots\ldots 3.6$$

Where; X_i = the record for the series X_1, X_2 --- X_n, $\overline{X}$ = the mean, Sks = the residual mass curve. For a homogeneous record, one may expect that the Sks fluctuate around zero in the residual mass curve since there is no systematic pattern in the deviation Xi’s from the average values $\overline{X}$. To perform the homogeneity test, annual cumulative rainfall data of the stations were computed and analyzed using the Rainbow software and the result of the homogeneity test were presented in figure 3.10.

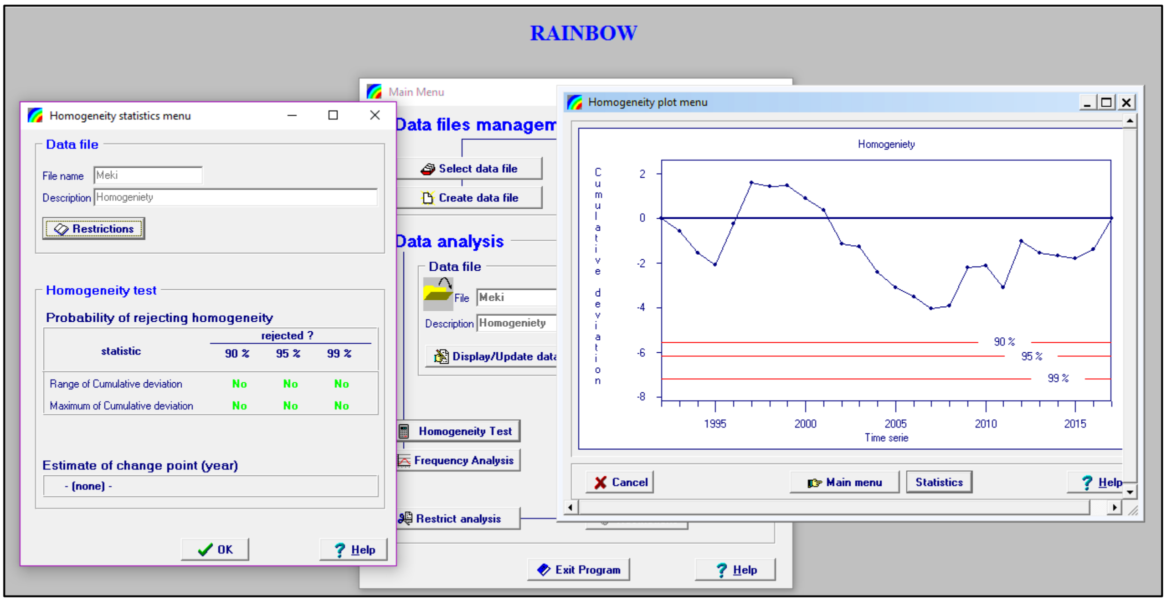


Figure 3.10: Homogeneity Test and Statistics of Meki Station Rainfall Data.

Results of figure 3.10 shows that the data point fluctuate around the zero centers line an indication that the rainfall data were statistically homogeneous. To further confirm that the rainfall data were statistically homogeneous, test of hypothesis was done as follows; H0: Data were statistically homogeneous H1: Data were not homogeneous. The null and alternate hypothesis were tested at 90%, 95% and 99% confidence interval that is 0.1, 0.05 and 0.01 degree of freedom and results obtained were presented in figure 3.10. From the result of the null hypothesis (H0) was accepted, and it was concluded that the rainfall data collected from Meki station was statistically homogeneous at 90%, 95% and 99% confidence interval that was 0.10, 0.05 and 0.01difference. In this study the homogeneity of the other stations were also analyzed in the same manner and presented in appendix E.

3.4 Statistical parameters calculation for precipitation data

After the precipitation data was checked for quality and the appropriate station selected the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programme PcpSTAT.exe. This programme calculates the statistical parameters of daily precipitation data by the weather generator of the SWAT model (Liersch, 2003) to reduce the amount of time required for the computations a minimum of seventy two parameters. The statistical parameters for precipitation were calculated using the programme PcpSTAT was shown in Appendix D.

3.5 Statistical parameters calculation for temperature data

The temperature data record was available from one weather station Bui. The daily maximum and minimum air temperature was available with some missing data. The missing data was filled using regression formula for checking the trend of the air temperature over time. Dew02.exe is used to calculate the dew point temperature using minimum and maximum daily temperature and the average daily humidity (Neitsch *et al*., 2005). The data must be an ASCII text file format with three columns. The first column stores the maximum daily temperature data the second column the minimum temperature data and the third column the average daily humidity data used to generate maximum and minimum temperature and relative humidity and dew point. The statistical parameters for temperature were calculated using the programme Dew02.exe was shown in Appendix D.

3.6 SWAT Model description

The Soil and Water Assessment Tool (SWAT) (Arnold *et al*., 1998) model is a river basin model developed by US Department of Agriculture - Agricultural Research Service (ARS) in Temple, Texas. The SWAT model is a physically based, continuous time, long-term simulation, lumped parameter, deterministic, and originated from agricultural models with spatially distributed parameters operating on a daily time steps (Arnold & Fohrer , 2005). SWAT incorporates features of several ARS models and was a direct outgrowth of the Simulator for Water Resources in Rural Basins (SWRRB) model. Specific models that contributed significantly to the development of SWAT were Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS), Ground Water Loading Effects on Agricultural Management Systems (GLEAMS) and Erosion-Productivity Impact Calculator (EPIC) (William *et al*., 1999).

SWAT is an operational or conceptual model that operates on a daily time step. The main objective of model development is to predict the impact of land management practices on water, sediment and agricultural chemical yields (nutrient loss) in large and complex watersheds with varying soils, land uses and management conditions over a long period of time (Arnold & Fohrer, 2005). To satisfy the intended objective, the model (a) is physically based (calibration is not possible on ungagged watersheds); (b) uses readily available inputs; (c) is computationally efficient to operate on large basins in a reasonable time; and (d) is continuous in time and capable of simulating long periods for computing the effects of management changes (Neitsch *et al*., 2005). Therefore, the model is a computationally efficient simulator of hydrology and water quality at various scales. The model is semi-physically based, and allows simulation of a high level of spatial detail by dividing the watershed into large number of sub-watersheds (Abbaspour *et al*., 2007). It simulates evapo-transpiration, snow and runoff generation, and is used to investigate climate change impacts. Using the routing command language, the model can simulate a basin sub-divided into sub-watersheds and further into hydrological Response units (HRUs) (Arnold, 1998).

3.6.1 Hydrologic Processes in SWAT

The hydrology component of the SWAT model is based on water balance equation. The water balance in the SWAT model relates soil water, surface runoff, interception, daily amount of precipitation, evapo-transpiration, percolation, lateral subsurface flow, return flow or base flow, snowmelt, transmission losses and ponds. According to (Arnold *et al*., 1998) the water in the stream is contributed by surface runoff, lateral flow from soil profiles and return flow/base flow from shallow aquifer. In SWAT, the water balance is computed from the soil water content, which is described by the following equation.

$$S_{Wt} = S_{Wo} + \sum_{i=1}^{t} (R_{day} - Q_{surf} - Ea - W_{seep} - Q_{gw}) \quad 3.7$$

S_{Wt} final soil water content (mm), S_{Wo} initial soil water content (mm), t time (days), R_{day} amount of precipitation (mm), Q_{surf} amount of surface runoff (mm), Ea amount of evapo-transpiration (mm), Wseep amount of water entering vadose zone (mm), Q_{gw} amount of return flow in day (mm).

3.6.2 Surface runoff/overland flow

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 infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When the rate of application is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once the all surface depressions have filled, surface runoff would commence. SWAT provides methods for estimating the surface runoff: the SCS curve number procedure (SCS, 1972) and (Green and Ampt, 1911).

$$Q_{surface} = \frac{(Rday - Ia)^2}{(Rday - Ia + S)} \quad 3.8$$

Where: $Q_{surface}$ is the accumulated runoff or rainfall excess (mm H_2O), R_{day} is the rainfall depth for the day (mm H_2O), I = initial abstraction (mm), S = retention parameter (mm). The retention parameter (S) is defined as:

$$S = 254\left(\frac{100}{CN} - 1\right) \quad \text{.......... 3.9}$$

Where: CN is the curve number for the day. The SCS curve number is a function of the soils permeability, land use and antecedent moisture conditions: I- dry (wilting point), II- (average moisture), and III- wet (field capacity). The moisture condition I, curve numbers the lowest value that the daily curve number can assume in dry conditions. The curve numbers II and III are calculated as:

$$CNI = CNII - \frac{20*(100-CNII)}{(100-CNII+\exp(2.533-0.0636*(100-CNII))} \quad \text{.......... 3.10}$$

Where, CNI is the moisture condition 1-curve number, CNII is moisture condition 2-curve numbers, and CNIII is the moisture condition 3-curve number. SWAT uses a modified rational method to calculate the peak runoff rate.

$$Q_{peak} = \frac{\alpha\kappa*Qsurf*Area}{3.6\ tconc} \quad \text{.......... 3.11}$$

Where, Q_{peak} is the peak runoff rate (m^3/s), ακ is the fraction of daily rainfall that occurs during the time of concentration, Q_{surf} is the surface runoff (mm), Area is the sub-basin area (km^2), t_{conc} is the time of concentration for the sub basin (hr) and 3.6 is a unit conversion factor.

3.7 SWAT Model set up

SWAT model needs the digital elevation model (DEM) that used to analyze the drainage patterns of the land-surface by determining slope, slope length, channel slope and length of the Meki watershed. The first step was SWAT project setup creating new swat project then selecting project directory where to save the project. Then the project setup was done.

3.7.1 Watershed delineation

The first step in creating SWAT model input was delineation of the watershed from a DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition the threshold based stream definition option were used to define the minimum size of the sub-basins. The Meki River watershed was delineated with an outlet point at Meki which was the gauge station. The overall watershed was further classified into sub-basins based on the algorithms provided by the SWAT model. As a consequence these sub-basins influence the level of spatial complexity that was represented in the SWAT model. A sub-basin in SWAT was defined as the hydrologic area contributing to only one stream channel. Stream channels were defined as DEM cells having 206079.2 hectare contributing area. The contributing area resulted in 35 sub basin for Meki River watershed being delineated.

3.7.2 Hydrological Response Units (HRUs)

For simulation, a watershed was subdivided into a number of homogenous sub-basins (hydrologic response units or HRUs) having unique soil, slope and land use properties. Before going in hand with spatial input data i.e. the soil map, LULC map and the DEM were projected into the same projection called UTM Zone 37N, which was a projection parameters for Ethiopia. The HRU analysis tool in Arc SWAT helps to load land use, soil layers and slope map to the project. The delineated watershed by Arc SWAT and the prepared land use and soil layers were overlapped. HRU analysis in SWAT includes divisions of HRUs by slope classes in addition to land use and soils. The multiple slope option (an option which considers different slope classes for HRU definition) was selected.

The LULC, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties made to be overlaid for HRU definition. The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub-basin. Subdividing the sub-watershed into areas having unique land use, soil and slope combinations makes it possible to study the differences in evapo-transpiration and other hydrologic conditions for different land covers, soils and slopes. The land use, soil and slope datasets were imported overlaid and linked with the SWAT 2012 databases. The HRU analysis report was shown in Appendix A. For multiple HRU definition 10 percent land use, a 10 percent soil and 5 percent slope threshold were used. Finally, 284 HRU for Meki River watershed was created.

Table 3.3: The slope classes of the Meki River watershed.

Classes	Slope range	Area	
		Ha	%
I	0-6	71326. 57	34.61
II	6-20	89004.67	43.19
III	>20	45747.98	22.2

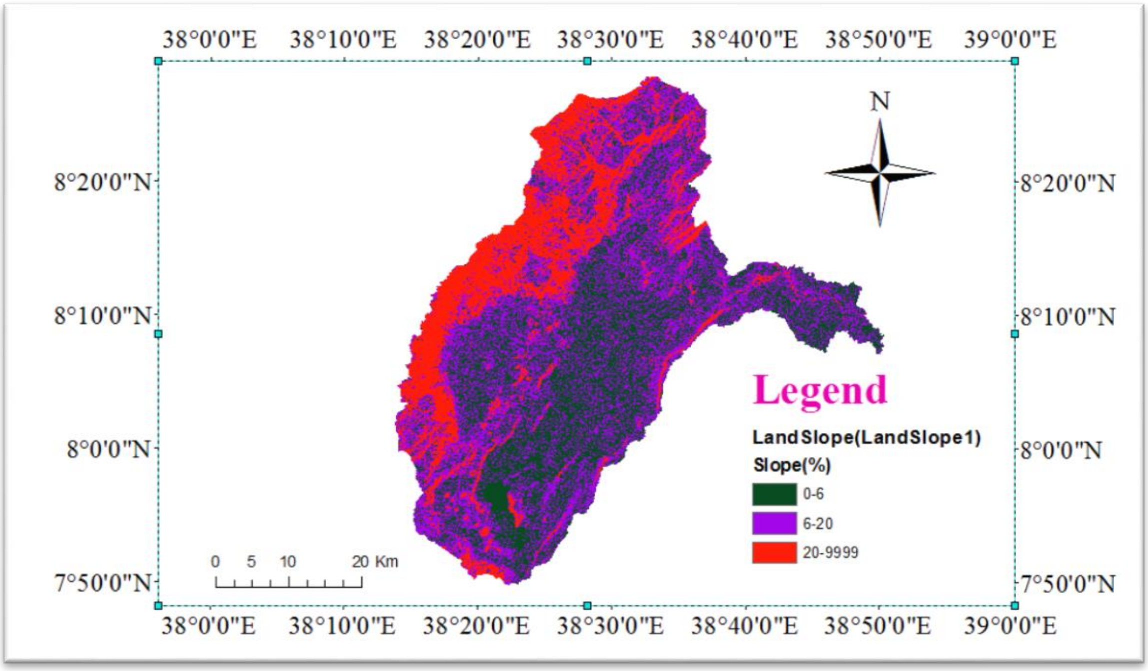


Figure 3.11: The slope classes of the Meki River watershed.

3.7.3 Write input tables

The input data needed include weather data and river discharge for prediction of stream flow and calibration purposes. Weather data filled with as per SWAT intake form prepared data of rainfall, temperature, wind speed, solar radiation, and relative humidity data. Weather generator**:** The weather generator used to fill the missed values in measured records and also to simulate the data if simulation option was selected. The WXGEN was provided with all the necessary statistical information from the meteorological records of the watershed to fill the missed portion properly. After loading this WXGEN parameter and location table, daily values for weather were generated from average monthly values. The model generates a set of weather data for each sub-basin. The parameters needed for the weather generator were listed in Appendix B. In this study, Bui meteorological stations were added to the WXGEN with their statistical values to use as weather generator to fill the missed data of Meki meteorological station. SWAT model takes data of each climatic variable for each sub-basin from the nearest weather station in the weather generation process.

3.7.4 Edit SWAT input

This step of model set up used to modify soil parameters, land use type and slope etc. It was used this step to get simulated stream flow at Meki after fixed sensitive parameters.

3.7.5 SWAT simulation

Running the model, sensitivity analysis, calibration and validation was carried out.

3.8 SWAT-CUP

SWAT-CUP is Soil and Water Assessment Tools, Calibration and Uncertainty Procedures. It incorporates sensitivity and uncertainty. The model output files compared with the measured data using five types of uncertainty algorithms (SUFI-2, PSO, MCMC, Parasol and GLUE) which are applied in SWAT-CUP. SWAT-CUP provides a link between the input and output of the SWAT model for optimizing the output of SWAT model. It provides iteration statistics between auto calibration runs for goodness-of-fit. SWAT CUP is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources determines best-fit parameters (Abbaspour *et al*., 2015). In this work SWAT CUP 5.1.6 version, and SUFI-2 algorithm, has been used for calibration and validation.

3.9 Model Sensitivity analysis, Calibration and Validation

The main function of an interface was to provide connection between the output/input of a calibration program and the model. Using this generic interface, any calibration, and validation/uncertainty or sensitivity program can easily be linked to SWAT.

3.9.1 Sensitivity Analysis

The sensitivity analysis tool in Arc SWAT has the capability of performing two types of analyses. The first type of analysis uses only modeled data to identify the impact of adjusting a parameter value on some measure of simulated output, such as average stream flow. The second type of analysis uses measured data to provide overall “goodness of fit” estimation between the modeled and the measured time series. The first analysis helps to identify parameters that improve a particular process or characteristic of the model, while the second analysis identifies the parameters that are affected by the characteristics of the study watershed. After a thorough preprocessing of the required input for SWAT model, flow simulation was performed for 25 years of recorded periods. When a SWAT simulation is taken place there is a discrepancy between measured data and simulated results. So, to minimize this discrepancy, it is necessary to determine the parameters which were affected the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step ordered to analysis. It can increase the accuracy of calibration by reducing uncertainty (Abbaspour, 2013). Two types of sensitivity analysis were allowed when using SUFI-2 (Sequential Uncertainty Fitting version 2). Global Sensitivity and One-at-a-time sensitivity analysis. The two aforementioned sensitivity analysis methods may yield different results since the sensitivity of one parameter depends on the value of other related parameters. In this study global sensitivity analysis were performed and the ranking of the parameters was compared. Twelve parameters were considered for the model parameterization sensitivity analysis and effective for monthly flow simulation analysis. The one-at-a-time (OAT) sensitivity analysis was performed for one parameter at a time only by keeping the value of other parameters constant. OAT sensitivity analysis shows the sensitivity of a variable to changes in a parameter if all other parameters are kept constant at some reasonable value. This constant value can be the value of parameters from the best simulation (simulation with the best objective function value) of the last iteration. The drawback with the OAT sensitivity analysis is that the correct value of other parameters that are fixed never known (Lenhart *et al.*, 2002).

Global sensitivity analysis. Global sensitivity analysis performs the sensitivity of one parameter while the value of other related parameters are also changing. Global sensitivity analysis uses t-stat and p-values to determine the sensitivity of each parameters. The t-stat provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity. A p-value close to zero has more significance. This type of sensitivity can be performed after an iteration. The main problem related to global sensitivity analysis is that it needs a large number of simulations (Abbaspour, 2013).

3.9.2 Model calibration

Model calibration is a means of adjusting model parameters to match with the observed data as much as possible, with limited range of deviation accepted. It is also the modification of parameter values and comparison of predicted output of interest to measured data until a defined objective function is achieved. Parameters for modification are selected from those identified by sensitivity analysis. Additional parameters other than those identified during sensitivity analysis are used primarily for calibration due to the hydrological processes naturally occurring in the watershed. Sometimes it is necessary to change parameters in the calibration process other than those identified during sensitivity analysis because of the type of miss match of the observed variables and predicted variables The graphical and statistical approaches are also be used to evaluate the SWAT model performance a number of times until the acceptable values are obtained for surface runoff and sediment independently (Lenhart *et al*., 2002).

3.9.3 Model Validation

Validation is the comparison of the model outputs with in independent data set without making any adjustment. The purpose of model validation is to check whether the model can predict flow for another range of period. In order to utilize the calibrated model for estimating the effectiveness of future potential management practices, the model is tested against an independent set of measured data. As the model predictive capability is demonstrated as being reasonable in both the calibration and validation phases, the model is used for future predictions under different land use scenarios. The statistical model performance measure will be used in calibration as percent difference between simulated and observed data (Abbaspour, 2013).

3.10 Model Performance Evaluation

In order to evaluate the performance of the model such as its quality and reliability of prediction compared to the observed values the methods for goodness-of-fit measures of model predictions used during the calibration and validation periods. These numerical model performance measures are coefficient of determination (R^2), Nash-Sutcliffe simulation efficiency (NSE) and Percent bias (PBIAS) (Moriasi *et al*., 2007).

3.10.1 Nash-Sutcliffe Coefficient (NSE)

Nash-Sutcliffe coefficient measures the efficiency of the model by relating the goodness-of-fit of the model to the variance of the measured data. Nash-Sutcliffe efficiencies can range from $-\infty$ to 1. An efficiency of 1 corresponds to a perfect match of modeled discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < NSE < 0$) occurs when the observed mean is a better predictor than the model. The evaluation of hydrologic model behavior and performance is commonly made and reported through comparisons of simulated and observed variables. NSE indicates how well the plot of observed versus simulated data fits the 1:1 line.

The formula for Nash-Sutcliffe (NSE) is: (Nash and Sutcliffe, 1970).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Qosi - Qsi)^2}{\sum_{i=1}^{n}(Qoi - \overline{Q})^2} \quad \ldots\ldots 3.12$$

Where: Q_{osi} = observed stream flow in m³/s, Q_{si} = simulated stream flow in m³/s, and $\overline{Q}$ = mean of observed values, and n = number of observations.

3.10.2 Coefficient of Determination (R^2)

The coefficient of determination, denoted R^2, it provides a measure of how well observed outcomes were replicated by the model. The range of R^2 lies between 0 and 1 which described how much of the observed desperation is explained by the prediction. A value of zero means no correlation at all; whereas one means that the desperation of the prediction is equal to that of the observation (Nash and Sutcliffe, 1970).

$$R^2 = \frac{[\sum_{i=}^{n}(Qsi-\overline{Qs})(Qoi-\overline{Qo})]^2}{\sum_{i=1}^{n}(Qsi-\overline{Qs})^2\sum_{i=1}^{n}(Qoi-\overline{Qo})^2} \quad \text{......3.13}$$

Where: $\overline{Qs}$ = mean of simulated values, $\overline{Qo}$ = mean of observed values, Qsi = simulated stream flow in m³/s, Qoi = observed stream flow in m³/s, and n = number of observations.

3.10.3 Percent Bias (PBIAS)

As introduced by *(Moriasi et al*., 2007) it measures the average tendency of the simulated data to be larger or smaller than their observed data. The PBIAS low-magnitude values show accurate model simulation. A positive value of PBIAS indicates model is an under estimation and negative values indicate model is overestimation bias.

$$PBIAS = \frac{\sum_{i=1}^{n}(Qi^{ob}-Qi^{Sim})*(100)}{\sum_{i=1}^{n}(Qi^{ob})} \quad \text{......3.14}$$

Where: Qi^{ob} = mean of observed values in m³/s, Qi^{sim} = simulated stream flow in m³/s, and n = number of observations

Table 3.4: Performance Evaluations for Monthly Time Step

Performance rating	R^2	NSE	PBIAS
Very good	$0.75< R^2<1.00$	0.75< NSE<1.00	PBIAS ≤ ±10
Good	$0.65< R^2<0.75$	0.65< NSE <0.75	±10 ≤ PBIAS≤ ±15
Satisfactory	$0.5< R^2<0.65$	0.5< NSE <0.65	±15 ≤ PBIAS≤ ±25
Unsatisfactory	$R^2≤0.5$	NSE ≤0.5	PBIAS≤ ±25

3.11 Assessment of management practices

Best management practices (BMPs) are commonly used to control runoff and sediment yields. The pretension of watershed management and soil conservation measures is to substantially reduce erosion and thereby decrease the sediment input to the stream system and to reservoirs. These measures include practices such as contour farming and terracing; strip cropping, crop rotation, no-till farming, grassed drainage ways, gully erosion control, and stabilization of critical areas by their return to grasslands or forests (William *et al*., 1999). Overall combination of land management strategies such as planting of trees and grass strips, waterways, contour plough and agro forestry may be suitable for these sites to reduce soil erosion, reduce environmental damage, pre-serve the fertility of the soil and maximize the productivity level of the watershed. The erosion values reflected by these factors can vary considerably due to varying weather conditions (Farhan *et al*., 2013). The greater the intensity and duration of the rain storm, the higher the erosion potential. The soil erodibility factor: It is the average soil loss in tones/hectare for a particular soil in cultivated, continuous fallow with arbitrarily selected slope length and slope steepness. The soil erodibility factor is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting soil erodibility, but structure, organic matter and permeability also contribute. The slope length-gradient factor: The slope length-gradient factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness. The steeper and longer the slope, the higher the risk for erosion (Farhan *et al*., 2013). The crop/vegetation and management factor: It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The crop/vegetation and management factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land. The crop/vegetation and management factor can be determined by selecting the crop type and tillage method that corresponds to the field and then multiplying these factors together (Lulseged *et al*., 2006).

The support practice factor: It reflects the effects of practices that would reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The support practice factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. SWAT estimates the erosion and sediment yield for each HRU with the Modified Universal Soil Loss Equation (MUSLE). MUSLE uses the amount of runoff to model erosion and sediment yield. The main strengths of MUSLE were the prediction accuracy and the possibility of estimating the sediment yields of single storm events (Neitsch *et al*., 2012).

The MUSCLE was: $Sed = 11.8\ [Q_{Surf} * q_{peak} * Area_{hru}]^{0.56} * K_{usle} * P_{usle} * C_{usle} * LS_{usle} * CFRG$ ……………………………………………………………..………………..3.15

Where: Sed is sediment yield on a given day (tons), Q_{Surf} = the surface runoff volume (mm water/ha), Q_{peak} =the peak runoff rate (m^3/sec), $Area_{hru}$ area HRU=the area of the HRU (ha), K_{usle} = the USLE soil edibility factor, C_{usle} = the USLE cover and management factor, P_{usle} = the USLE support practice factor, LS_{usle} = the USLE topographic factor and CFRG = the coarse fragment factor.

3.12 Over all frame work of the research

The conceptual frame work which present on Figure 3.12, serves to describe the overall research steps describing the methodology applied to carry out the research.

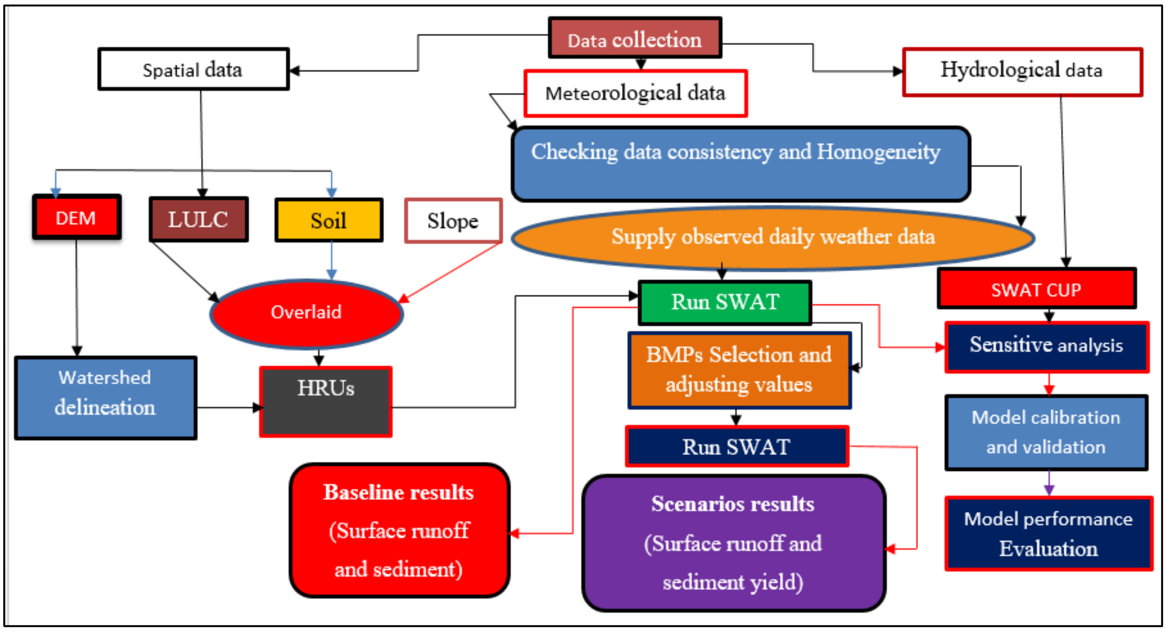


Figure 3.112: Flow Chart of the Research.

4. RESULT AND DISCUSSION

4.1 Flow Sensitivity Analysis

Initially twelve parameter were identified to select the most sensitive parameters during flow calibration. Those selected sensitive parameters were, Available water holding capacity of the soil layer (SOL_AWC), curve number (CN2), Ground water delay (GW_DELAY), Base flow alpha factor (ALPHA_BF), Threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), Threshold depth of water in the shallow aquifer for “revap” (REVAPMN), Base flow alpha factor for storage (ALPHA_BNK), Soil evaporation compensation factor (ESCO), Exponent parameter for calculating sediment re-entrained in channel sediment routing (SPEXP), Ground water revap coefficient (GW-REVAP), Manning's "n" value for overland flow (OV_N) and Average slope length (SLSUBBSN).

Monthly streamflow input data from 1993 to 2010 was used for flow sensitivity parameter identification. From 100 iteration output, eight parameters were selected as sensitive parameters for further calibration process. Table 4.1 shows the most flow sensitive parameters. The highest flow sensitive parameter was the curve number (CN2), Ground water revap coefficient (GW-REVAP), Manning's "n" value for overland flow (OV_N), maximum canopy storage (CANMX), Threshold depth of water in the shallow aquifer (REVAPMN), Base flow alpha factor (ALPHA_BF), Soil evaporation compensation factor (ESCO), Available water capacity of the soil layer (SOL_AWC). Figure 4.1 shows the identification of significant sensitive parameters using p-value and t-stat.

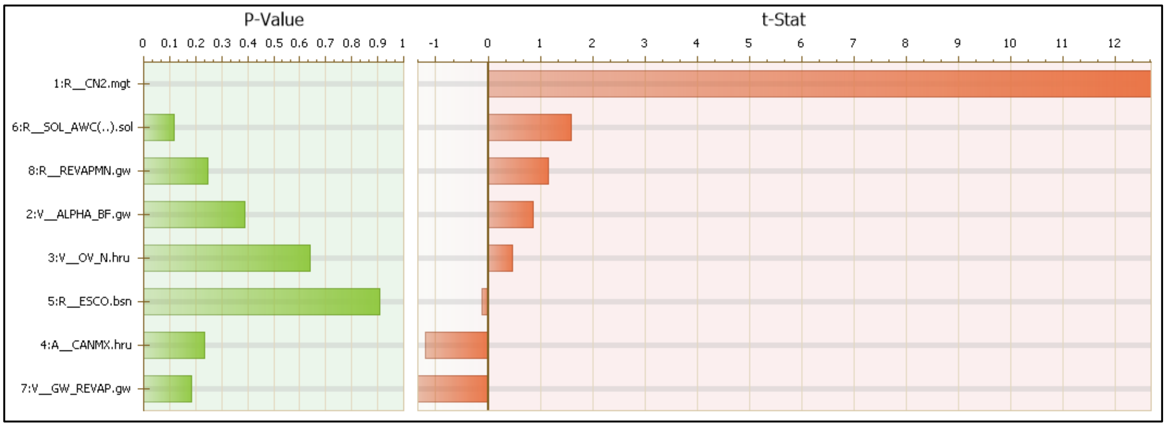


Figure 4.1: P-value and t-stat for Streamflow Sensitive Parameters.

Table 4.1: Grid view of Streamflow sensitive parameter.

So	Parameter	Description of parameter	P-Value	t-Stat	Range		Fitted value	rak
					Min	Ma		
1	R-CN2.mgt	SCS curve number II	0	12.7	-0.1	0.8	0.34	1
2	V-GW_REVAP gw	Ground water revap coefficient	0.18	-1.34	0.1	0.2	0.17	3
3	V-OV_N.hr	Manning's "n" value for overland flow	0.64	0.46	0.1	1	0.69	7
4	R-REVAPMN. gw	Threshold depth of water in the shallow aquifer	0.24	1.16	0	0.2	0.04	5
5	A-CANMX.hr	maximum canopy storage	0.23	-1.19	0	1	0.33	4
6	V-ALPHA_BF. gw	Base flow alpha factor	0.38	0.86	0	0.3	0.07	6
7	R-ESCO.bsn	Soil evaporation compensation factor	0.89	0.90	0	0.6	0.08	8
8	R-SOL_AWC. sol	Available water capacity of the soil layer	1.58	0.12	1	1.6	1.52	2

This was evaluated by the values of t-stat and p-value. The higher the absolute value of t-stat and smaller the value of p-value, the more sensitive is the parameter (Abbaspour *et al*., 2007). The t-stat is the regression coefficient of a parameter divided by its standard error. If the coefficient value is greater than its standard error, the value of t-stat is greater than zero, so the parameter is sensitive (Abbaspour *et al*., 2015). The p-value for each parameter tests the null hypothesis that the regression coefficient is equal to zero. A small value of p-value (<0.05) indicates that reject the null hypothesis. This means that the parameter exerts influence on the dependent variable, thus it is sensitive. The value of 0.05 indicates that there is a 95% probability that a parameter change would affect the dependent variable. R-relative that implies multiples the existing value with (1+ the given value) and V-replace the existing value with the given value, A- absolute that implies adds the given value to the existing value. The mean of the variations in the objective function estimates the sensitivity.

It is computed by altering each parameter, one by one, while all other parameters remain the same (Abbaspour *et al*., 2018).

4.2 Calibration and Validation

4.2.1 Flow Calibration

The model results were compared with the observed monthly Streamflow data at Meki gauging station for calibration process. The value of R^2 greater than 0.6 and close to one is the higher of the agreement between the simulated (flows and sediment load) with the observed (flows and sediment load). NSE ranges between $-\infty$ and 1 (1 inclusive), NSE > 0.5 is a good model performance; NSE equal to 1 is being the optimal value. The PBIAS low-magnitude values show accurate model simulation. A positive value of PBIAS indicates model is an underestimation and negative values indicate model is overestimation bias (Moriasi *et al*., 2007). The calibration process is done until the acceptable agreement happens between observed and simulated data (Neitsch *et al*., 2005). This activity determined in the monthly time basis. Moreover, the fit between observed and simulated streamflow data was checked by statistical techniques provided in Table 4.2.

Streamflow hydrographs were developed to compare observed and simulated streamflow values for the calibration periods in monthly time step in figure 4.2. Statistical model performance evaluator of calibration result shows a good agreement between the observed and simulated streamflow parameters and the model recommended for the monthly time basis. The available Streamflow data from the period January 1993 to December 2003 used for calibration (eleven years) and the obtained results for coefficient of determination ($R^2 =$ 0.81$>$ 0.8) was very good, Nash Sutcliffe Efficiency ($\text{NSE} = 0.76 > 0.75$) was very good and Percent bias ($\text{Pbias} = 18$) which was between $\pm 15 \leq \text{pbias} < 30$ was good. The observed and simulated average streamflow of Meki gauging station during calibration period was 4.68 m^3/sec and 3.83 m^3/sec respectively. Moreover, previously SWAT was not applied in the study area; following this fact, the calibrated results indicate that the model recommended for predicting watershed process of the Meki River watershed and the time series trend of the gauged flow was well fitted for monthly time steps.

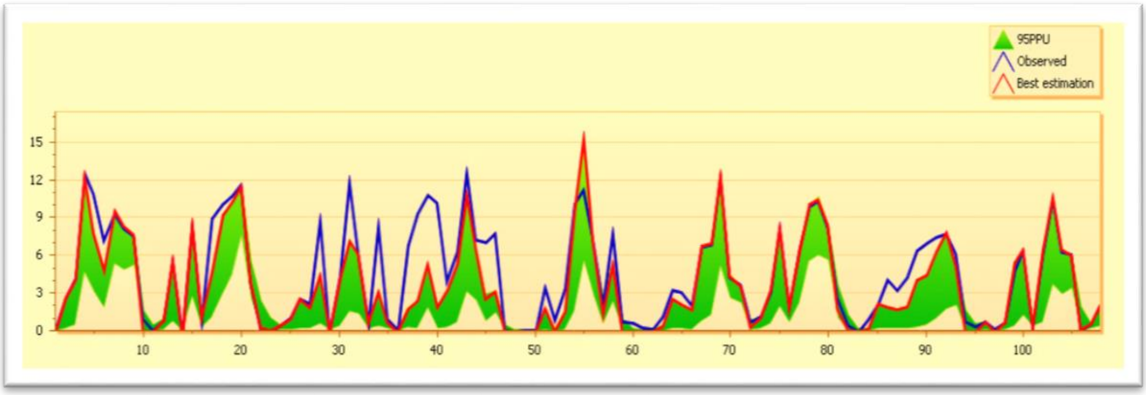


Figure 4.2: Measured and Simulated Monthly Streamflow for Calibration.

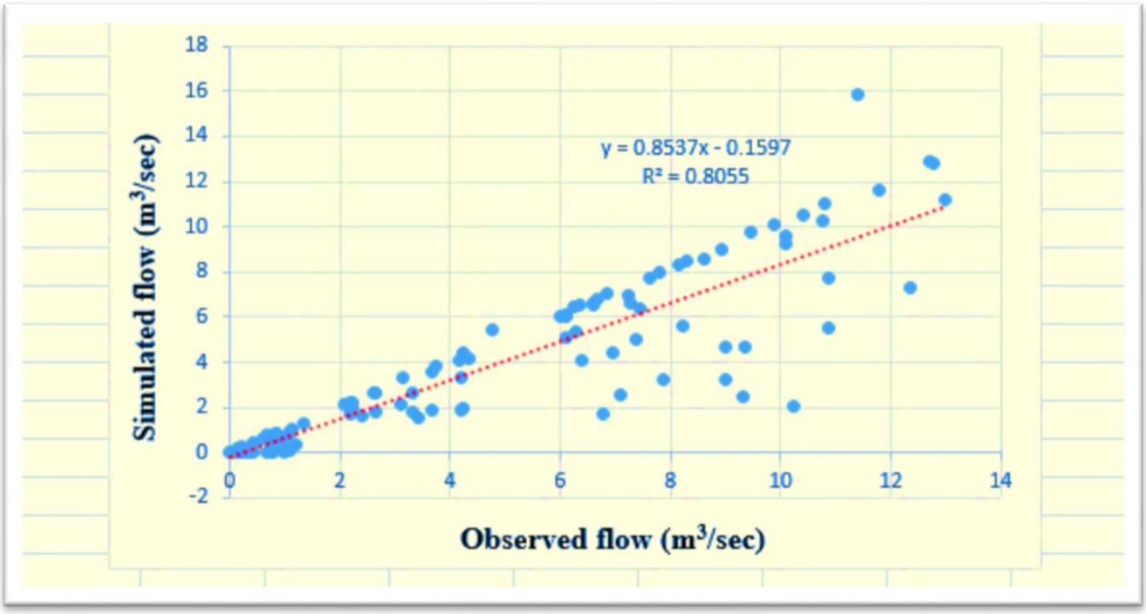


Figure 4.3: Scattering plot of Measured and Simulated Streamflow for Calibration.

Table 4.2: Observed and simulated flow at the calibration period.

Time (year)	Average Streamflow (m^3/s)		Model Efficiency (Monthly)		
1993-2003	Observed	Simulated	R^2	NSE	PBIAS(%)
	4.68	3.83	0.81	0.76	18

Figure 4.4 Shows flow calibration dotty plots; these were plots of parameter values vs objective function (NSE). The main purposes of these graphs were to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. CN2, SOL_AWC, GW_REVAP and CANMX were the most sensitive parameters at the calibration.

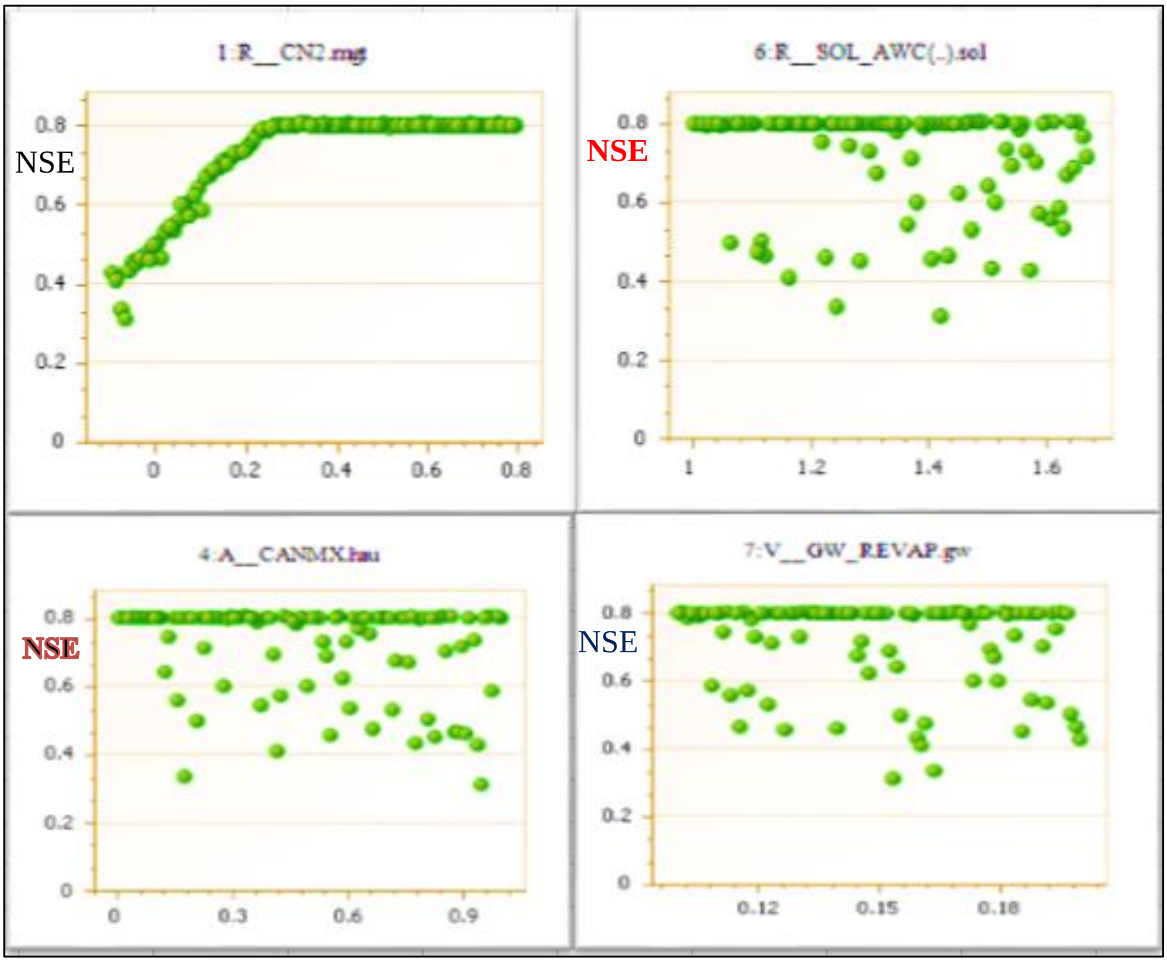


Figure 4.4: Distribution of Sampling Points; Parameter Values Vs Nash-Sutcliffe Efficiency (NSE) for Calibration.

4.2.2 Flow Validation

The model was re-run without any adjustment of calibration parameters using different time and monthly Streamflow input data from the calibrated period which increase the model reliability on the calibrated result. The model validation carried out from January 2004 to December 2010 and the obtained results for coefficient of determination ($R^2 = 0.81 > 0.8$) was very good, Nash Sutcliffe Efficiency ($NSE = 0.74 < 0.75$) was good and Percent bias ($Pbias = 17.1$) which was between $\pm 15 \leq pbias < 30$ was good. The observed and simulated average streamflow of Meki gauging station during calibration period was $5.3m^3/sec$ and $4.4m^3/sec$ respectively. An agreement between measured values of streamflow and simulated outputs of streamflow on monthly time steps was shown by R^2, NSE, and PBIAS in table 4.3, the model parameters represent the processes happen in the Meki watershed. Figures 4.5 clearly show a reasonably good agreement between observed and simulated streamflow hydrographs for monthly time steps during the validation period.

Figure 4.5 and 4.6 shows graphical comparison between observed and simulated monthly stream flow. Table 4.3 shows observed and simulated average streamflow and model efficiency results of the validation.

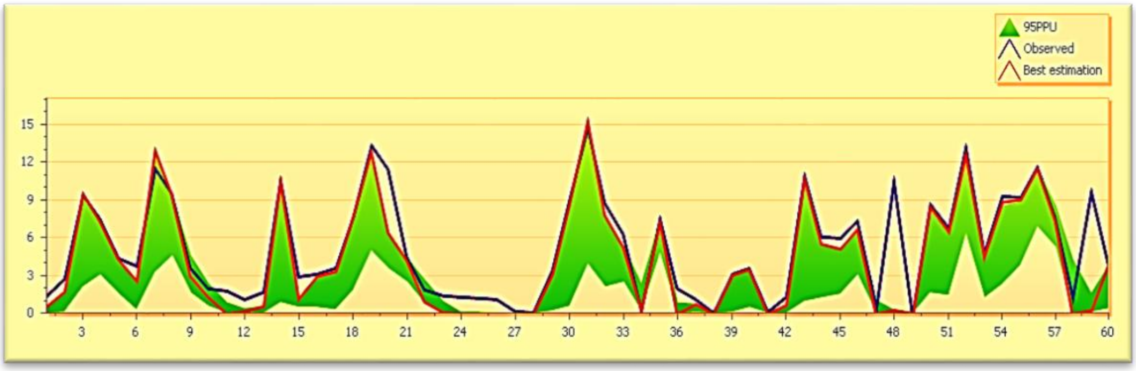


Figure 4.5: Measured and Simulated Monthly Streamflow for Validation

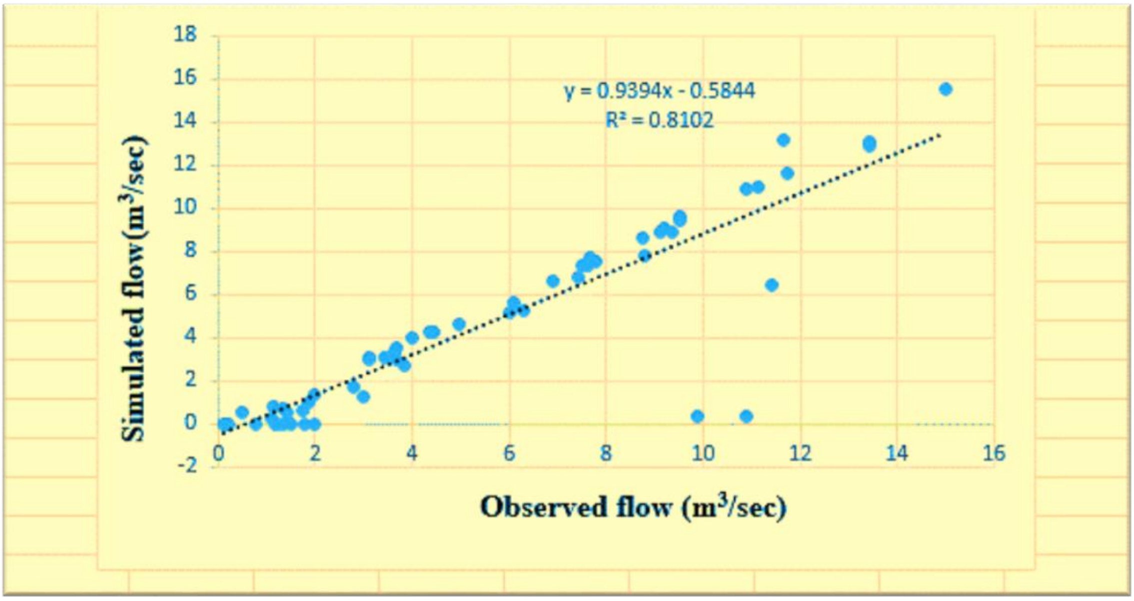


Figure 4.6: Scattering Plot of Measured and Simulated Streamflow for Validation.

Table 4.3: Observed and simulated flow at the validation period.

Time (year)	Average Streamflow (m^3/s)		Model Efficiency (Monthly)		
2004-2010	Observed	Simulated	R^2	NSE	PBIAS(%)
	5.3	4.4	0.81	0.74	17.1

Figure 4.7 Shows flow calibration dotty plots; these were plots of parameter values vs objective function (NSE). The main purposes of these graphs were to show the distribution of the sampling points as well as to give an idea of parameter sensitivity. CN2, SOL_AWC, GW_REVAP and REVAPMN were most sensitive parameters at the validation.

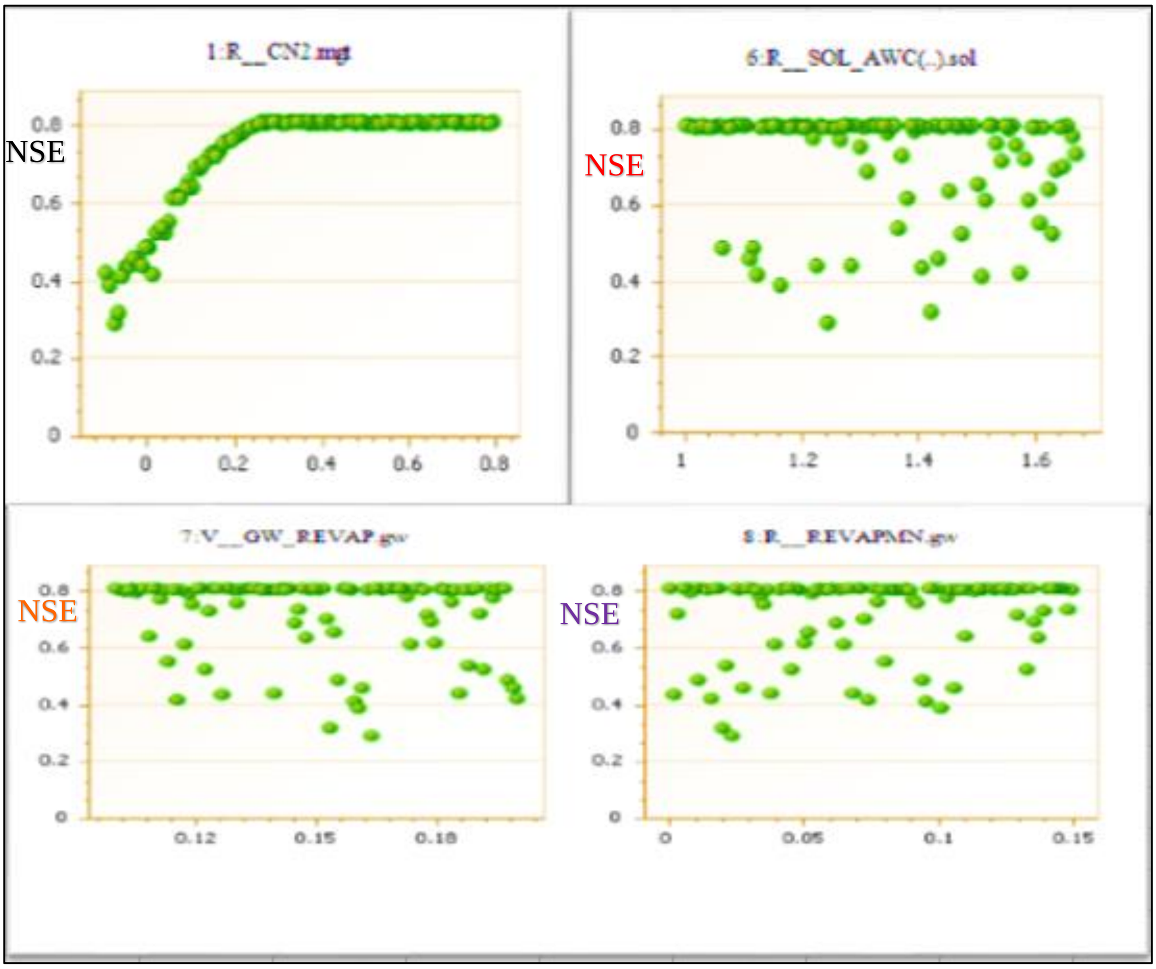


Figure 4.7: Distribution of Sampling Points; Parameter Values Vs Nash-Sutcliffe Efficiency (NSE) for Validation.

4.3 Sediment Rating Curve Development

The sediment rating curve is a relationship between the river discharge and sediment concentration. It is widely used to estimate the sediment load being transported by a river. Commonly, the relation of Suspended sediment concentration and the discharge computed using the equation 3.1. The most commonly used sediment rating curve is power function (Morris & Fan, 1998). The Sediment flow measurement in the Meki River is not in continuous time step; so that by using stream flow and measured sediment data can generate sediment rating curve. Generally, a sediment rating curve may be plotted showing average sediment concentration or load as a function of discharge averaged over different periods. Since the sediment measurement in the watershed is less, a rating curve is developed to estimate sediment yield from flow measurement (Aga *et al*., 2018). The comparison plots between measured and computed data with rating curves, namely rating curve developed by normal linear log–log regression was shown in figure 4.8. In a plot between, discharge and sediment concentration there will be a large scatter in points. One reason behind this scatter is that soil erosion rates in a watershed are not the same during different seasons of the year. If the scatter is large, it might be necessary to develop separate rating curves for different seasons or according to stream flow generation mechanisms, such as rainfall, snowmelt, etc. The data pertaining to rising and falling limbs of the hydrograph may also be separated to improve the relationship. A sediment rating curve is mainly applied to obtain the value of sediment concentration for a given discharge. Along with the flow duration curve at a given location, the sediment rating curve can also be used to estimate the amount of sediment transport over a period of time, say a year. Another important use of sediment rating curve is in estimation of the impact of land use changes and watershed management on sediment yield (Aga *et al*., 2018). Suspended sediment rating curves for the Meki River was described by graphs of sediment load versus discharge in Figure 4.8.

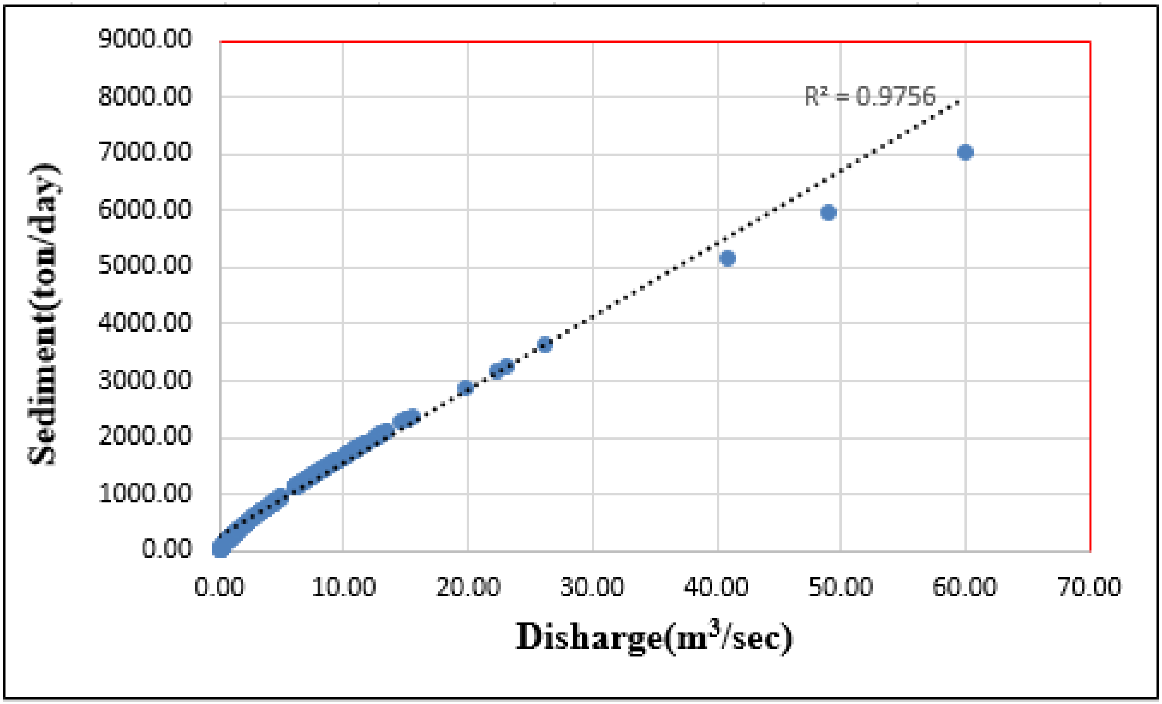


Figure 4.8: Sediment Rating Curve for the Meki River Watershed.

4.4 Sediment Computation for the model performance evaluation

While the underlying theory is well known, the measurement of sediment transport requires that many simplifying assumptions were made. This is largely because sediment transport is a dynamic phenomenon and measurement techniques cannot register the ever-changing conditions that exist in water bodies, particularly in river systems. Arc SWAT model was calibrated for sediment by comparing model simulated yield with measured yield. However due to the absence of daily measured sediment yield for Meki River watershed and it was not well for auto calibration, the monthly computed sediment data from rating curve used as measured sediment yield to compare with sediment simulated from SWAT for the model performance evaluation. The SWAT model is found to simulate well on monthly basis of sediment yield (Lemma *et al*., 2017).

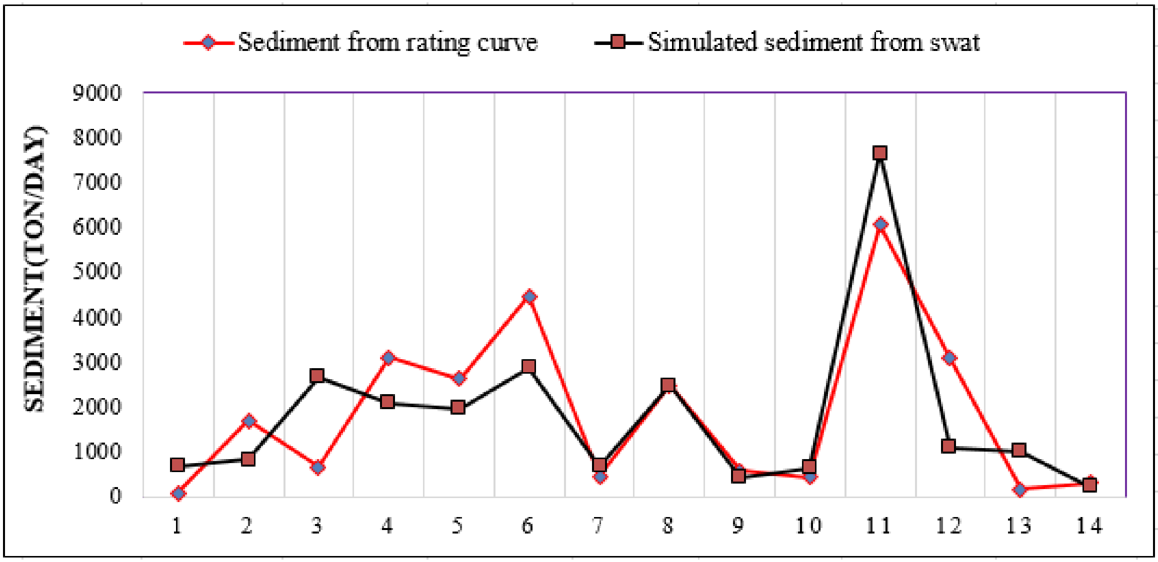


Figure 4.9: Comparisons between Sediment from Rating Curve and Simulated Sediment Yield from SWAT Simulation of Meki River Watershed.

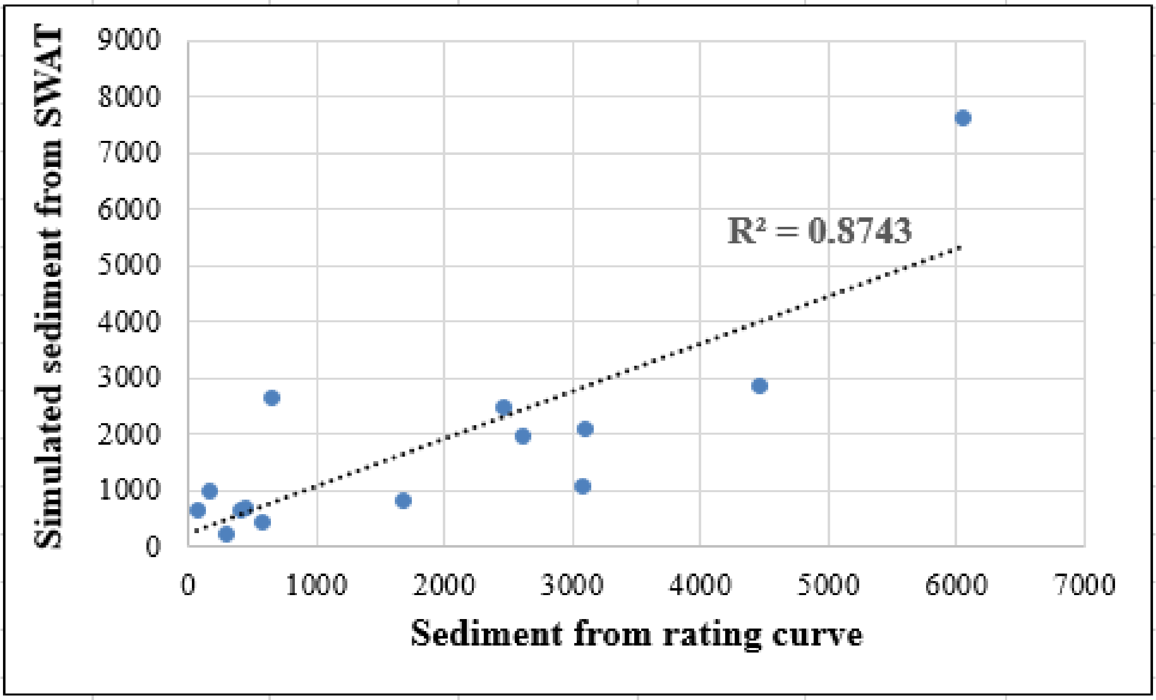


Figure 4.10: Scattering Plot of Simulated Sediment from SWAT and Sediment from Rating Curve.

From the graph 4.9 and 4.10, the results show that model performance was very good ($R^2 = 0.8743 > 0.8$) and well agreement between sediment obtained from rating curve and simulated sediment obtained from SWAT. The total annual sediment yield from watershed in to the Lake Batu during Simulation period was estimated by using SWAT model was 75.896 ton/ha/yr.

4.5 Runoff and sediment yield spatial distribution

Runoff and sediment yield of each sub-basin is not uniform. This is as a result of rainfall distribution and its intensity. In fact, only rainfall amount and its distribution have not impact on runoff and erosion rather the intensity. Actually, good LU/LC cover has positive effects on the reduction of runoff and sediment yield. Study on LU/LC can be controlled erosion by covering the soil surface by the canopy and reduce the mechanical action happen at the soil surface by intercepting the raindrop (Nearinga *et al*., 2005).

4.5.1 Runoff Spatial Distribution

Figure 4.11 shows the different surface runoff within all 35 sub-basins as annual averages over the 25-year simulation period (1993–2017). The result shows not only the streamflow at the gauge was an important variable for analyzing the water balance of a watershed, but also the spatial patterns within the entire watershed was important. Study of Hurni (1988) confirmed that sub basins can be classified as none to slight (< 80), slight (80-130), medium (130-220), high (220-612), and very high (> 612) mm for runoff. From SWAT simulation the runoff produced at the Meki River Watershed was 367.95 mm. As shown in figure 4.11, runoffs have no impact on sediment yield at some sub basin. For instance, in sub-basins (1-8), 10, 11,12,13,18, 20-26, 31 and 34 there was high runoff but less sediment yield. This was may be the response of LU/LC, soil resistance to erosion, slope and other management practice founded in the watershed. The sub-watersheds that produce moderate surface runoff were 9, 14, 19, 28, 32, 33 and 35. The sub-watersheds that produce slight surface runoff were 16, 17, 27 and 30 and also none to slight surface runoff were in 15 and 29. These simulation results show the relative variations of Runoff level within a sub-basin. Moreover, these results showed that Runoff to Meki River watershed was mainly from sub-basins of (1-8), 10,11,12,13, 18, 20-26, 31 and 34.These sub-basin which fall under high Runoff was characterized by intensive cultivated land which leads to high Runoff susceptibility of the watershed.

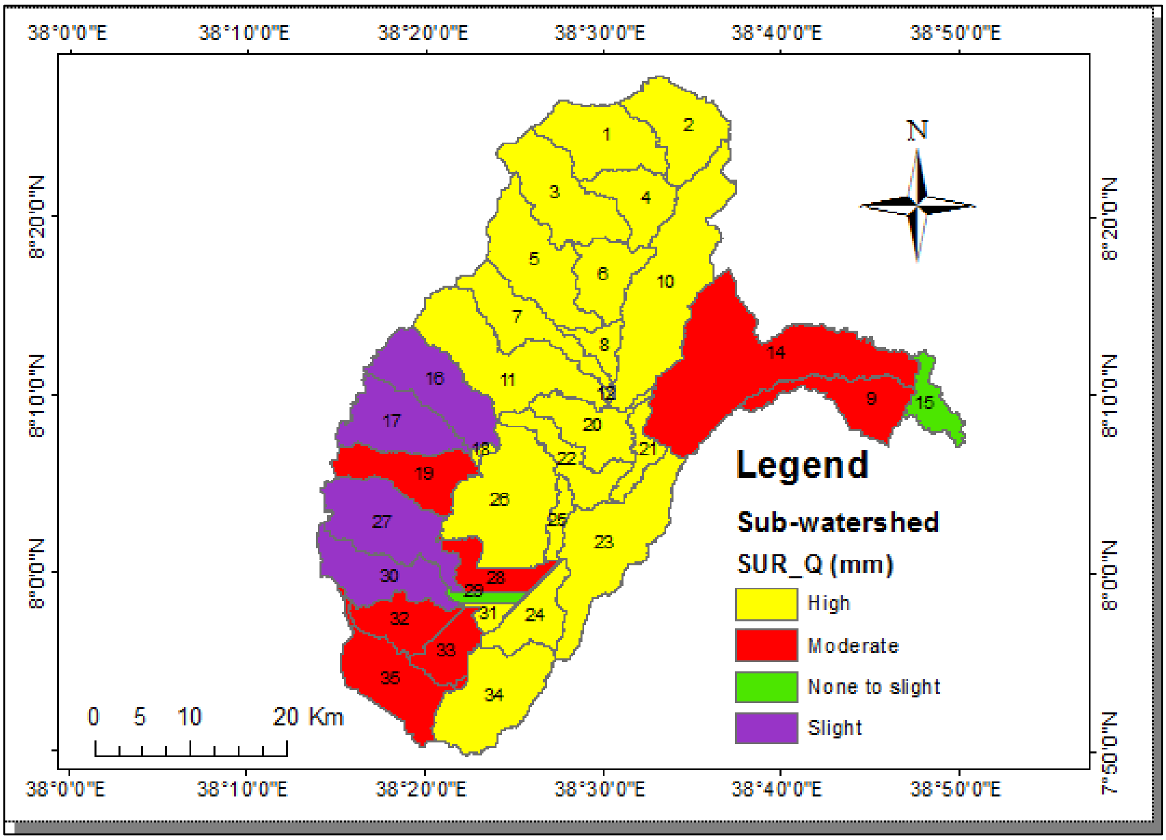


Figure 4.11: Spatial Distribution of Annual Surface Runoff in Meki Watershed.

4.5.2 Sediment Yield Spatial Distribution

The sediment yield of all 35 sub-basins, represented as annual values over 25 years (1993–2017) was shown in figure 4.12. From SWAT simulation the sediment yield produced at the Meki River watershed was 75.896 ton/ha/yr. These simulation results show the relative variations of soil erosion level within a sub-basin. Study of Hurni (1988) confirmed that sub basins can be classified as none to slight (< 9), slight (10-21), medium (22-61), high (62-109), and very high (> 109) ton/ha/yr. for sediment. The moderate sediment yielding sub-basins were (1-8), 10, 11, (14-27) and (32-34) of Meki River watershed corresponds to moderate erosion level (22–61 ton/ha/yr.). These sub-basins were covered most areas by intensive cultivated lands followed by moderate cultivated land. The sediment yield distribution, for instance, sub-basins 9, 30 and 35 were high and characterized by maximum sediment yield distribution to Meki River watershed. The slight sediment yielding sub-basins were 12, 28, and 31. They deliver least sediment may be due to well-covered land use/cover. The erosion level which were indicated as none to slight sediment in sub-basins 29. These sub-basins 9, 30 and 35 which fall under high erosion class was leads to high sediment susceptibility of the watershed.

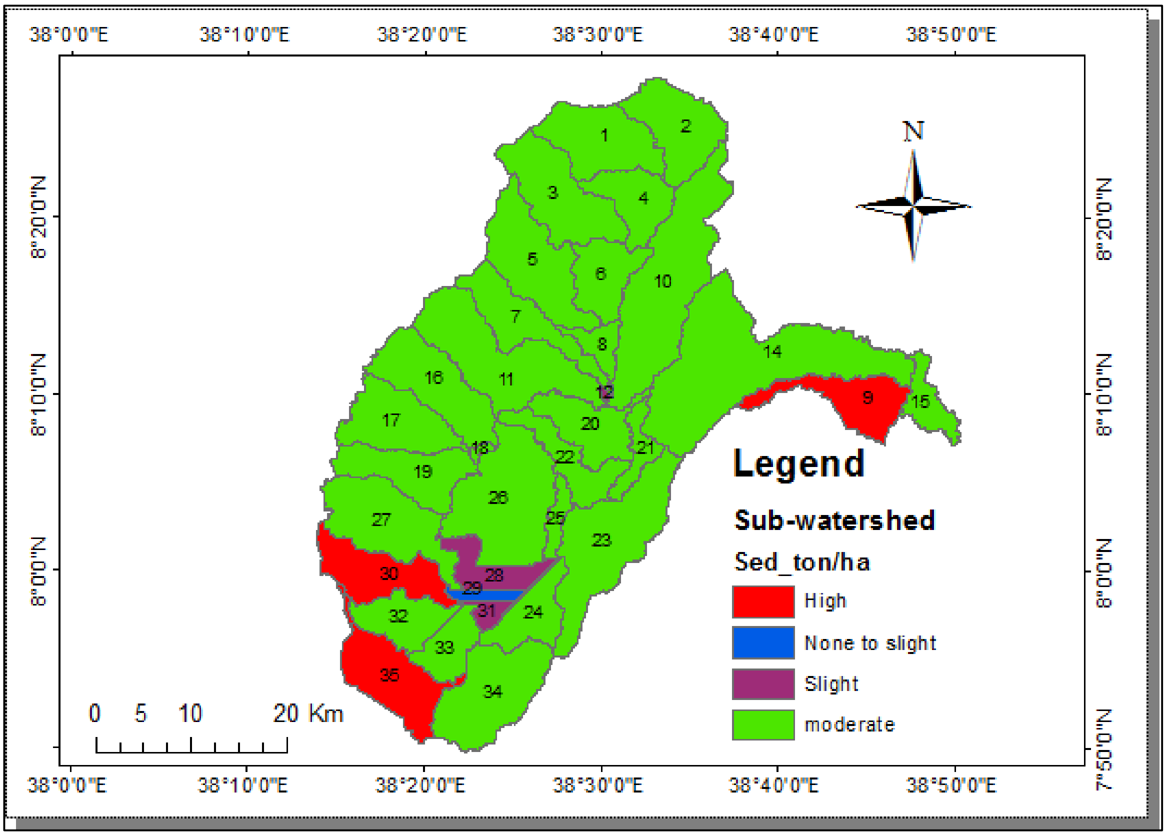


Figure 4.12: The Spatial Distribution of Annual Sediment Yield in Sub-Basins of Meki Watershed.

4.6 Identification of hot spot areas from the critical sub-basins of Meki watershed

Identifying erosion prone areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield and is an important input for policy makers and researcher's to implement short and long term management strategies. Spatial analysis of sediment prone areas is one of the many tasks SWAT can do while modeling sediment. SWAT is powerful in spatial visualization of sub basin or HRU level detail so that one can see which area produces high sediment and which area produces less. From the model simulation output, sediment source areas were identified in the Meki Watershed. The spatial visualization of sub basin wide sediment yield in tons/ha is given in appendix I. These sub-basins 9, 30 and 35 which fall under high erosion class was leads to high sediment susceptibility of the watershed. A study of soil formation rates and tolerable soil loss level for each sub basins were 82.86, 83.22, 81.34 ton/ha/yr. respectively. On the other hand, sub-watershed 9, 30 and 35 were the most erodible area and needs rehabilitation. Out of the total watershed area 2060.792km², 182.66 km² areas was eroded area that means

8.86% of the total Meki watershed area was eroded. Thus from 35 critical sub basins these sub watershed need well watershed management practices to reduce the sediment yield and priority should be given to the high erosion prone areas in order to minimize runoff and sedimentation problems of Meki river watershed.

4.7 The Evaluation of Best Management to Reduce the Runoff and Sediment

The conservation practice factor expresses the effects of soil conservation practices that reduce the amount and rate of water runoff, increase infiltration and subsequent reduction of the amount of erosion. In MUSLE model, the P-factor is considered as the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation. Therefore, the effects of this factor is depends on the actual agricultural activity held on the given area by the stake holders or farmers. The major erosion control practice such as contouring, strip cropping and terracing which reduces the eroding power of rainfall-runoff and increase infiltration by reducing slope steepness and slope length are the main controlling factors. These activities have a great advantage against erosion by letting the surface runoff to be not concentrated in a channel and to have less flow velocity. Different management practice shows different capability of soil erosion reduction. Related to this, different researcher attempts to evaluate the most common physical management practice like; contouring during farming and contouring with terracing both at a time (Wischmeier and Smith, 1978). Table 4.4 shows the P- factor values for corresponding conservation practice for two cases (if only contouring practice was commonly practiced and if both contouring and terracing practice was fully developed), with in a given range of slope gradient in percent.

Table 4.4: P-factor values and slope-length (Wischmeier and Smith, 1978).

Slope in percent	P-factor values	
	For only contouring	For Contouring with Terracing
< 2	0.6	0.30
3-5	0.5	0.25
6-8	0.5	0.30
9-12	0.6	0.30
13-16	0.7	0.35
17-20	0.8	0.40
> 20	0.9	0.45

The specified method of soil conservation is the dominant soil erosion control practice among the farmers in the cultivated lands for a long period of time. This research also, shows the comparison of the soil erosion rate under the current soil management practice with the expected fully developed application of standard technical solutions like; terracing with contour ploughing in the study area. Since the expected amount of soil erosion from steep slope and gentle slope with the same management practice will not be equal, and conservation activities are highly dependent on the topographic condition (slope) of the land (Betrie *et al*., 2011).

Hence, the conservation practice factor values were given within the ranges of slope gradient of the study area. Depending on the land management practice employed in the study area currently on varied slope gradient, the value of P-factor ranges from 0.5 to 0.9. Considering an implementation of watershed management practice such as contouring with terracing fully developed, the P-factor values ranges from 0.25 to 0.45.

In Scenario 2 filter strips were placed on all land use land cover, all soil types and slope classes. The effect of filter strip is to reduce sediment, dissolved contaminants and sediment adsorbed organics in runoff. The FILTERW value was assigned based on local research experiences in the Ethiopian (Betrie *et al*., 2011). The filter width value, FILTERW, of 1 m was assigned to simulate the impact of filter strips on sediment trapping. In Scenario 1 stone/soil bunds were placed on all land use land cover, all soil types and slope classes. This practice has a function to reduce overland flow, sheet erosion and reduce slope length (Setegn *et al*., 2010). Appropriate parameters for representing the effect of stone/soil bunds were the USLE_P support practice factor (USLE_P). The SWAT assigned value of the USLE_P value of 1m was used prior to the application of BMPs (scenario 0). The modified value for USLE_P was assigned based on table 4.4.

The SWAT model simulation for the existing condition predicted the sediment yield and runoff at the Meki River watershed, which was an inlet to Lake Batu was 75.896 ton/ha/yr. and 367.95mm respectively. The simulation of scenario 1 for USLE_P only for contouring reduced the total sediment yield to 56.281ton/ha/yr. from current condition at the same outlet location, which was equivalent to 25.84% reduction and 346.63mm runoff were produced. The simulation of USLE_P for contour with terracing reduced the sediment yield to 65.293 ton/ha/yr. from the current conditions, which was equivalent to 13.97% reduction and 350.25mm runoff were produced. The simulation of scenario 2 for FILTERW reduced the total sediment yield to 23.929 ton/ha/yr. from current condition at the same outlet location, which was equivalent to 68.47% reduction and 329.7mm runoff were produced. From the result, scenario FILTERW were best management practices in the watershed as the dominant soil conservation. Percentage of runoff and sediment yield reduction by filter strips and soil/stone bund scenario were shown on figure 4.13 and figure 4.14 respectively. The model was capable of providing precise information for stake holders to prioritize ecologically sound feasible BMPs at fields that were capable of reducing overland soil erosion and sediment delivery to channels while increasing crop yield.

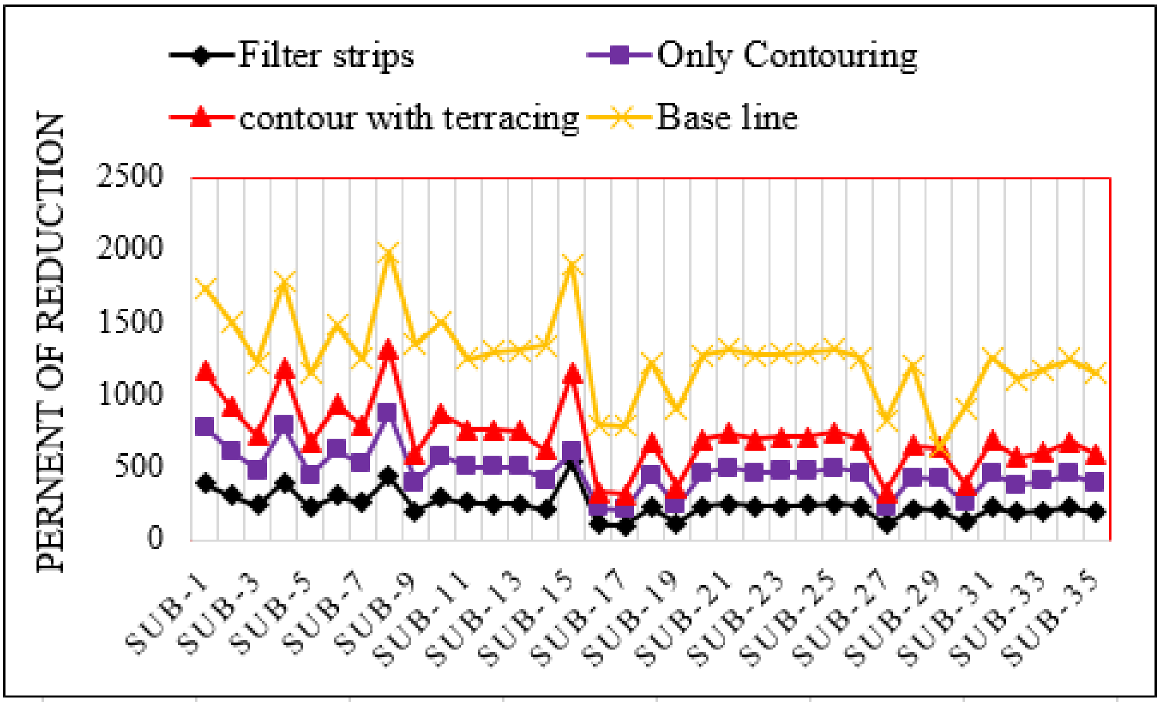


Figure 4.13: Percentage Runoff Reduction of Base line, Filter Strips and Stone/Soil Bund Scenario.

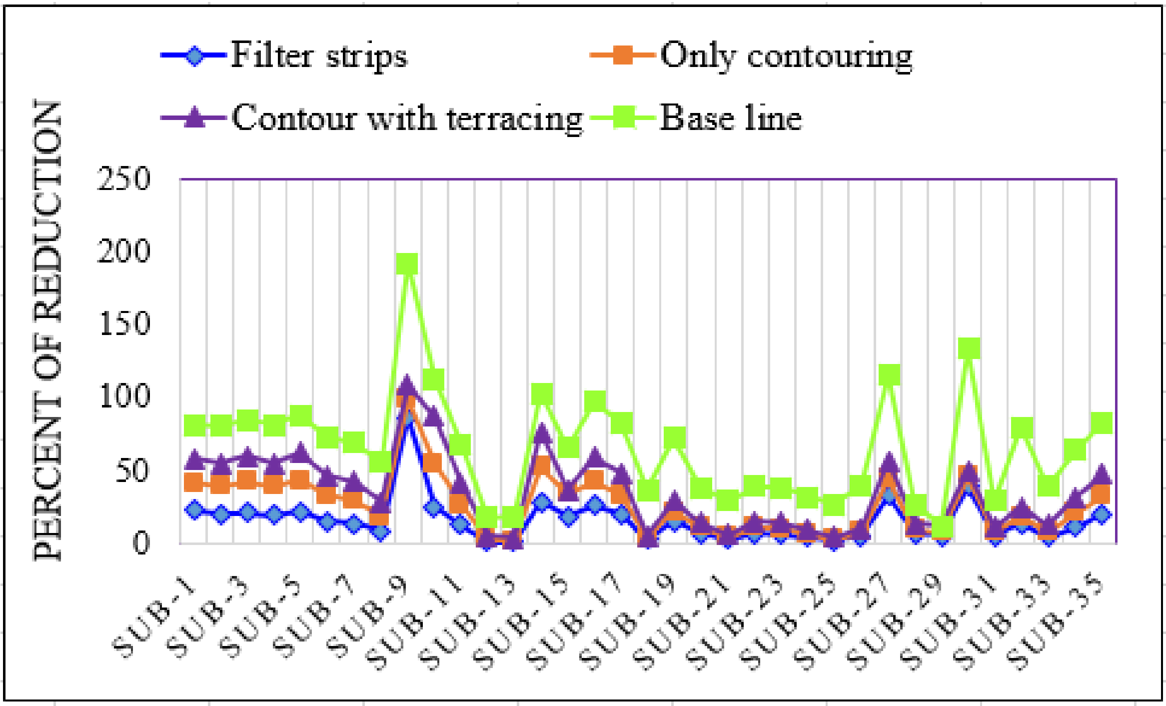


Figure 4.14: Percentage Sediment Yield Reduction of Filter Strips and Stone/Soil Bund Scenario.

4.8 Comparing the result with previous works

Mengist (2016) showed the spatial distribution of sediment in the Gelana catchment with an average annual sediment distribution ranges from 7.58 ton/ha to 53.17 ton/ha whereas Zelalem (2016) the runoff sediment yield modeling using Soil and Water Assessment Tool for management planning of Mojo watershed Ethiopia, showed that the estimated soil loss rate from different sub-watershed ranges from 2 ton/ha/year to 204 ton/ha/year. This study identified the average annual sediment distribution ranges from 0.4648 ton/ha to 75.896 ton/ha in the Meki watershed. The sub- watershed sediment yield of this study was different from others listed due to the combined effect of erodibility physiographical factors such as land use, soil type and slope, etc. Unlike the findings of this study, some studies however, report a rather higher rate of erosion in different parts of Ethiopian watersheds. For instance, Bewket and Teferi (2009) report high rate of erosion with an average soil rate of 93t ha-1 yr-1 for Chemoga watershed of Blue Nile Basin in North-Western highland.

Fasil (2012), prediction of sediment inflow to Gefersa reservoir using SWAT model and assessing sediment reduction measure indicated that: changing 53 % of forest land to agricultural land, result in 74.5 % of sediment reduced where as in Meki watershed reduced 25.84% after applying contouring and reduce to 13.97% in applying contour with terrace to reduce sediment entering the lake Batu. Further studies investigated the occurrence of runoff under coverage of Chinese cabbage. (Lee *et al*., 2010) conducted field experiments in a Korean mountainous area comparing different kinds of tillage. The modelling study reveals 265mm surface runoff of precipitation under cabbage cultivation with conventional tillage. This was comparable to the values of this study 367.95mm surface runoff of Meki river watershed. The result varies due to the percentage of erodible area availability varies from one catchment to another catchment. According to Haregeweyn (2012), analyzed Options to prolong the life of Angereb reservoir using multicriteria analysis approach and removing the sediment using machinery and undertaking watershed management interventions of runoff and sediment management options were proposed.

5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

In this study, attempts were made to model Meki River watershed in terms of sediment yield, runoff, and identification of potential sediment source areas and evaluation of alternative management interventions to reduce the impact of soil erosion in the watershed. Modeling the hydrological process such as runoff and sediment yield of the watershed is useful to manage the natural resources. The study of area Meki River watershed was characterized by a significant runoff, sedimentation and soil fragility, resulting thereby in soil erosion and there was a knowledge gap with respect to the interdependence between the runoff and sediment yield. The general objective of this study was to model the runoff and sediment yield and to assess best management options to control soil erosion and sedimentation problems of the Meki River watershed.

The model was applied on a monthly basis for twenty five years from 1993 to 2017. For stream flow, the model output was calibrated for eleven years from 1993 to 2003 and validated for seven years from 2004 to 2010. The highest flow sensitive parameter was the curve number (CN2), Ground water revap coefficient (GW-REVAP), Manning's "n" value for overland flow (OV_N), maximum canopy storage (CANMX), Threshold depth of water in the shallow aquifer (REVAPMN), Base flow alpha factor (ALPHA_BF), Soil evaporation compensation factor (ESCO) and Available water capacity of the soil layer (SOL_AWC).

After the most influential sensitive parameters were identified, the model was calibrated and validated using SWAT CUP optimization algorithm SUFI-2 and the performance was evaluated by coefficient of determination (R^2), Nash-Sutcliffe Efficiency (NSE) and Percent BIAS (PBIAS). Model calibration was performed for stream flow at Meki outlet for performance evolution during monthly stream flow calibration and validation period indicated that R^2 = 0.81, NSE = 0.76, PBIAS = 18 and R^2 = 0.81, NSE = 0.74, PBIAS = 17.1 respectively. The 25 years simulation result indicates that the simulated annual average suspended sediment yield and runoff of the Meki River watershed was 75.896 t/ha/yr. and 367.95mm respectively. The sub-watersheds that produce moderate erosion level which were classified as moderate in sub-basin (1-8), 10, 11, (14-27) and (32-34) of Meki river watershed corresponds to moderate erosion level (22 – 61 to/ha/yr.). The erosion level which were indicated as highest sediment yield in sub-basins 9, 30 and 35 were relative to remaining sub-basins and their erosion level (61 - 109 t/yr.). The sub-watersheds that produce high surface runoff was (1-8), 10, 11,12,13,18, 20-26, 31 and 34.

Following calibration and validation of SWAT model, also the model was applied to spatially distributed soil runoff and sedimentation processes at monthly time step and to assess the impact of different Best Management Practices (BMPs) scenarios on runoff and sediment reductions from critical sub-watersheds in the Meki River watershed. For existing conditions of base line, a reasonable agreement was obtained between the model runoff and sediment yields predictions and measured sediment yields at the watershed outlet. The simulation results showed that applying USLE_P, conservation structure (contouring ploughing and terracing with contour) reduced the current sediment yields by 25.84% and 13.97% respectively. The simulation of scenario FILTERW reduced the total sediment yield to 23.929 ton/ha/yr. from current condition at the same outlet location, which was equivalent to 68.47% reduction and 329.7mm runoff were produced. From the result, scenario FILTERW were best management practices in the watershed as the dominant soil conservation. These results indicate that applying BMPs could be effective in reducing runoff and sediment transport for sustainable water resources management in the watershed. Generally, the SWAT model performed well in predicting both the flow and sediment yields from the study watershed and the results were acceptable.

5.2 RECOMMENDATION

- Sediment reduces the life time of the reservoir. Therefore, sediment trap means should be exercised in upstream of the watershed and runoff reduction. This can be achieved through soil and water conservation program at critical sub-basin with vegetation screen upstream of watershed with continuous follow up by stake holders.
- Also, more research was necessary to forecast sediment yield and runoff of each sub-basin for daily and monthly time step under different land use/land cover scenario to improve decision making of the stake holder.
- The model result would be boost if the data quality and quantity was increased. However, there was sever data scarcity in Meki River watershed especially data on sediment concentration or load of the main reach. The gap should be bridged by increased the number and quality of climatological and hydrometric networks evenly over the river watershed.
- To get better model simulation, well-distributed meteorological station needed within the watershed.
- The concerned body must gauge continuously sediment and stream flow data at the outlets and avail the data for research input.
- Lack of appropriate soil-conservation measures and late application associated with intense rainfall and steep terrain topography had great contribute to soil erosion.
- When applying the recommended runoff and sediment reduction scenario, the following should be done.
  - ✓ Modified farming system should be applied on the land to optimize more crop yield to increase the crop production.
  - ✓ The people should be advised and facilitated to encourage crop production.
- Further analysis should be done on the runoff, sediment and specific soil erosion study with related to different management scenarios on Meki River watershed.

REFERENCES

Abbaspour, K. C., 2013. SWAT-CUP 2012: SWAT calibration and uncertainty programs user manual. Swiss: Eawag and Swiss Federal Institute of Aquatic Science and Technology.

Abbaspour, K. C, Rouho lahnejad, E. Vaghefi, S. Srinivasan, R. Yang, H. Kløve, B. (2015). A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology, v. 5.

Abbaspour, K. C., Vaghefi, S. A., Srinivasan, R (2018). A Guideline for Successful Calibration and Uncertainty Analysis for Soil and Water Assessment: A Review of Papers from the 2016 International SWAT Conference. Water, v. 10, n. 6, p. 1-18.

Abbaspour, K. C., Yang, J.; Maximov, I.; Siber, R.; Bogner, K.; Mieleitner, J. (2007) Modelling hydrology and water quality in the pre-alpine/alpine Thur watershed using SWAT. Journal of Hydrology, v. 333, n. 2-4, p. 413-430.

Aga, A.O.; Chane, B.; Melesse, A.M. (2018). Soil Erosion Modelling and Risk Assessment in Data Scarce Rift Valley Lake Regions, Ethiopia. Water 10, 1684, doi: 10.3390/w10111684.

Arnold JG, Srinivason R, Muttiah RR, Williams JR (1998) Large area hydrologic modeling and assessment part I: model development. J Am Water Resource Assoc 34(1):73–89. J. America Water Resource. Assoc, Volume 34(1), pp. 73-89.

Arnold, J. & Fohrer , N., 2005. SWAT2000: current capabilities and research opportunities in applied watershed modeling.. Hydro Process, Volume 19(3), p. 563–572.

Arnold, J. G. & Allen, P. M., 1999. Automated methods for estimating base flow and groundwater recharge from stream flow records.. J. Am. Water Resource.Assoc.

Asis De and Omasa (2007). Estimation of vegetation parameter for modeling soil erosion using linear Spectral mixture analysis of land SAT ETM Data. ISPRS Journal of Photo grammetry and remote sensing, 62, 309–324.

Bekele, D., 1998. Economics of Soil Erosion and Conservation. Review of Literature and a Dynamic Non-Linear Optimization Model with Risks and Uncertainties: . In: A Case Study for Ethiopia. M.Sc. Thesis In Environmental Economic,. Wageningen Agricultural University.

Betrie GD, Mohamed YA, van Griensven A, Srinivasan R (2011) Sediment management modeling in the Blue Nile Basin using SWAT model. Hydrol Earth Syst Sci 15(3):807–818.

Borah, . D. & Bera, M., 2003. Watershed-scale hydrologic and nonpoint-source pollution models:. review of mathematical bases. Trans ASAE, Volume 46(6), p. 1553–1566.

Chandler DG, (1998) Runoff responses among common land uses in the upland of Matalom, Leyte, Philippians. Trans ASAE 41:1635–1641.

Chekol D. A., 2006. "Modeling of hydrology and soil erosion of upper Awash River Basin". Doctoral thesis University of Bonn, Germany.

Chow V. T., 1988. Applied Hydrology.McGraw hill, New York.

Costick, 1996b. Spatial Information for Land Use Management.. Gorden and Breach Science Publishers. ISPRS Journal of Photogrammetry & Remote Sensing, , Volume 62,, pp. 309-324.

Daniel EB, Camp JV, Le Boeuf EJ, Penrod JR, Dobbins JP, Abkowitz MD (2011). Watershed modeling and its applications: a stateof- the-art review. Vanderbilt University, VU Station B 351831, Nashville, Tennessee 37235-1831, USA.

Dawdy & Lichty, 1968. Development and application of a physically based landscape water balance in SWAT, Msc theses, London England.

Dereje Birhanu, 2011. Numerical Ground Water Flow Modelling of the Meki River Catchment, Central, Ethiopia.

FAO, 1998. World Reference Base for Soil Resources," World Soils Report No.84, Rome.

Farhan, D. Z., Ibrahim Farhan (2013). Spatial estimation of soil erosion risk using Rusle Approach, Rs, and Gis techniques: A Case Study Of Kufranja Watershed, Northern Jordan. Journal of Water Resource and Protection, 2013, 5, 1247-1261.

Fasil, G. 2012, Prediction of Sediment Inflow to Gefersa Reservoir (Using SWAT Model) and Assessing Sediment Reduction Methods.

Feven G/Selassie (2017). Estimation of sediment yield using Arc SWAT for Kater watershed.

Frederick R. Troeh, J. Arthur Hobbs & Roy L. Donahue (2003). Soil and Water Conservation for Productivity and Environmental Protection (4th ed.). Prentice Hall: 226.

Gizachew, A. & Yihenew, G. Soil loss estimation for soil conservation planning using geographic information system in Guang watershed, Blue Nile basin. J. Environ. Earth Sci, 5: 126-134.

Green W. H. & Ampt C. A., (1911). Studies On Soil Physics: I. Flow Of Air And Water Through Soils, J. AGR. Sci. 4, 1-24.

Houghton R. A., 1994. The Worldwide Extent of Land-Use Change.. Bio Science, Global Impact of Land-Cover Change, Volume Vol. 44, No.5, pp. , 305-313.

Hurni, 1988. Degradation and Conservation of the Resources in the Ethiopian Highlands. Mountain Research and Development.

Jain , S., Tyagi , J. & Singh, . V., 2010. Simulation of runoff and sediment yield for a Himalayan watershed using SWAT model. J Water Resource Prot 2:267–281.

Jha M. & Gassman P., 2014. Changes in hydrology and streamflow as predicted by a modelling experiment forced with climate models. Hydrol Process 28(5):2772–2781.

Kilinc & M Y., 1972. Mechanics of soil erosion from overland flow generated by simulated rainfall.

Kosmas, 1997. The Effect of Land Use on Runoff and Soil Erosion Rates under Mediterranean Conditions. Catena, Volume 29, pp. 45-59.

Lane L. J. & Kidwell M. R., 2000. watershed sediment and rangeland health. International Journal of sediment research.

Lelis T. & Calijuri M., 2010. Hydro sedimentological modeling of watershed in southeast Brazil, using SWAT. Interdiscip J Appl Sci 2(5):158–174.

Lemma, H. Admasu, T. Dessie, M. Fentie, D. Deckers, J. Frankl, A.Poesen, J. Adgo, E. Nyssen, J (2017). Revisiting lake sediment budgets: How the calculation of lake life time is strongly data and method dependent. Earth Surf. Process. Landf. 43, 593–607.

Lenhart T. K., Fohrer. N., & Frede H. G., (2002). Comparison of two different approaches of sensitivity analysis”. Physics and chemistry of the earth 27(2002), Elsevier science ltd., p. 645–654pp.

Liersch S. (2003). The program PcpSTAT user’s manual. Lane L.J., Kidwell M.R., 2000: watershed sediment and rangeland health. International Journal of sediment research.

Lulseged T., Park, S., Dikau, R. And Vlek, P.L.G. (2006). Analysis of factors determining sediment yield variability in the highlands of Ethiopia. Geomorphology, vol. 76: pp.76-91.

Mitiku, 2006. Sustainable Land Management: A New Approach to Soil and Water Conservation in Ethiopia. Article.

Morgan & R.P.C., 1995. Soil erosion and conservation. Edinburgh: Addison-Wesley Longman. At the surface processes and landforms, vol. 23, 1998, pp. 527-544.

Morgan & R, P. C., 2005. Soil Erosion and Conservation. Book, Third Edition. Blackwell: Malden.

Moriasi DN, Arnold JG, Van Liew MW, Bingner RL, Harmel RD, Veith TL (2007). Model evaluation guidelines for systematic quantifcation of accuracy in watershed simulations. Soil Water Div ASABE 50(3):885–900.

Morris G. L., & Fan, J. (1998). Reservoir sedimentation handbook: design and management of dams, reservoirs, and watersheds for sustainable use (Vol. 9). New York: McGraw-Hill.

Nash JE, Sutcliffe JV (1970). River flow forecasting through conceptual models: part 1. A discussion of principles. J Hydro10 (3):282–290.

Nearinga Ma, Jettenb V, Baffautc C, Cerdand O, Couturierd A,Hernandeza M, Le Bissonnaise Y, Nicholsa MH, Nunesf JP, Renschlerg CS, Souchèreh V, van Oosti K (2005) Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena 6.

Neitsch S.L., Arnold, J.G., Kiniry, J.R., and Williams, J.R. (2005). “Soil and Water Assessment Tool Theoretical Documentation.” Version 2005. Grassland, Soil and Water Research Service, Temple, TX.

Neitsch S. R, N. S. L. &. W. J. R, Arnold J. G, Haney E. B. & Kiniry, J. . R (2012). Soil and water assessment tool theoretical documentation version 2012. Texas Water Resources Institute.

Nyssen, 2006. Modelling The Effect Of Soil And Water Conservation Practices In Ethiopia. Agriculture, Ecosystems and Environmental Modelling & Software, Agriculture, Ecosystems and Environment. Volume 105, pp. 29-40.

Ogwo K. N. Ogbu, C. J. Okoye, M. E. Okechukwu and C. C (2012). “Comparison of soil erosion models for application in the humid tropics,” special publication of the Nigerian association of hydrological sciences, pp. 266-278.

Raes D., Willens, P. & Gbaguidi, 2006. Rainbow – A software package for analyzing data and testing the homogeneity of historical data sets. Volume 1, pp. 1-15.

Renard K.G., Foster, G.R., Weesies, G.A., McCool, D.K. &Yoder, D.C., (1997). Predicting soil erosion by water: a guide to conservation planning RUSLE, Agriculture Handbook No. (703), agricultural research service, washington DC.

Rijn Leo C.van (1993). "Principle of sediment transport in rivers, Estuaries, Coastal seas and oceans", Oldemarkt.

SCS (Soil Conservation Service) (1972). National Engineering Handbook, Section4: Hydrology. Washington, DC.

Setegn SG, Dargahi B, Srinivasan R, Assefa M (2010). Modeling of sediment yield from Anjeni-Gauged watershed, Ethiopia using swat model. J Am Water Resour Assoc 46(3):514–526.

Silva Da, A. M. (2008) Regional scale modeling of erosion related to land cover evolution: A Case study in Brazilian Southeastern region's. Suelo (Argentina). Article, 26(2), 153-160.

Sonneveld B. G., J. S., M.A., Keyzer and P.J. Albersen (1999). A Nonparametric Analysis of Qualitative and Quantitative Data for Erosion Modeling: A Case Study for Ethiopia.

Tamene, L. and Paul L.G. Vlek (2008). Soil erosion studies in Northern Ethiopia. In Ademola K. Braimoh and Paul L.G. Vlek (eds.), Land Use and Soil Resources, 73-100. Springer Netherlands.

Tesfahunegn G. B. & Tamene P. V., 2012. Management Strategies for reducing soil degradation through modeling in a GIS environment in Northern Ethiopia catchment, nutrient cycling in agro ecosystems 92, 255-272.

Upadhya R, Pandey K, Upadhyay SK, Bajpai A (2012). Annual sedimentation yield and sediment characteristics of upper lake, Bhopal, India. J Chem Sci 2(2):65–74.

Vanost K. K., Govers G. G., De Alba S. S., Quine T. A. (2006). "Tillage erosion: a review of controlling factors and implications for soil quality". Progress in Physical Geography, 30 (4): 443-466.

Vrieling A., 2007. Mapping Erosion from Space.Doctoral Thesis Wageningen University – With Ref. – With Summaries in English and Dutch. ISBN:. pp. 978-90-8504-587-8.

Wainwright J. & Brazier R., 2011. Slope systems. In: Thomas DSG (ed) Arid zone geomorphology: process, form and change in drylands. Wiley, Hoboken. ISBN 978-0-470-71076-0.

William W. Doe III, David S. Jones, and Steven D. Warren, (1999). "The soil erosion model guide for military land mangers: analysis of erosion models for natural and cultural resources applications". Tri-Service CADD/GIS Technology Center. Colorado state.

Wischmeier W. H. & Smith D . D., 1978. Predicting Rainfall Erosion Losses-A Guide to Conservation Planning. Predicting Rainfall Erosion Losses. A Guide to Conservation Planning.

Zeleke & Hurni H., 2001. Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands. Mountain Research and Development,. Volume 21(2):, pp. 184-191.

APPENDIX

Appendix A: HRU Analysis Report

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	Settlement --> RNGE	25529.0709	63083.6106	12.39
	Intensive cultivated land --> DWHT	64520.7641	159434.0341	31.31
	Forest land --> FRST	22465.7296	55513.9411	10.90
	Moderate cultivated land --> CORN	17709.6170	43761.3492	8.59
	Grass land --> PAST	31145.4404	76961.9404	15.11
	Water bodies --> WATR	1733.6303	4283.8871	0.84
	Wetland --> WETL	6527.0632	16128.6996	3.17
	Shrub land --> RNGB	11772.6348	29090.7692	5.71
	Wood land --> CRWO	2363.8626	5841.2226	1.15
	Barren land --> BARR	22311.4152	55132.6226	10.83
SOILS:				
	Calcic fluvisols	128.0658	316.4570	0.06
	Chromic vertisols	1724.4456	4261.1914	0.84
	Eutric nitosols	16027.1156	39603.8039	7.78
	Haplic Cambisols	62457.1949	154334.8514	30.31
	Laptosols	2371.6947	5860.5761	1.15
	Lubic phoeazoms	6916.6236	17091.3229	3.36
	Orthic luvisols	9242.9928	22839.8973	4.49
	Orthic solonchaks	1624.5785	4014.4148	0.79
	Pellic vertisols	17276.3825	42690.8049	8.38
	Vertic cambisols	30811.4753	76136.6960	14.95
	Vitric andosols	57367.1487	141757.0928	27.84
	Water	131.5101	324.9679	0.06
SLOPE:				
	0-6	71412.1929	176463.0993	34.65
	20-9999	45679.6290	112876.6473	22.17
	6-20	88987.4061	219892.3299	43.18

Appendix B: Meki watershed LULC and Percentage of area coverage.

Land use/ Land cover	Area (Ha)	Cover Percentage (%)
Intensive cultivated land	64520.76	31.31
Forest land	22465.73	10.90
Wood Land	2363.86	1.15
Wetlands	6527.06	3.17
Grassland	31145.44	15.11
Water bodies	1733.63	0.84
Settlement	25529.07	12.39
Moderate cultivated land	17709.62	8. 59
Shrub land	11772.63	5.71
Barren land	22311.42	10.83

Appendix C: Meki watershed soil and percentage of area coverage.

Soil Type	Area (Ha)	Percent of coverage
Vitric Andosols	57367.19	27.84
Orthic Luvisols	9242.99	4.49
Orthic Solonchaks	1624. 59	0.79
Pellic Vertisolos	17276.38	8.38
Calcic Fluvisols	128.07	0.06
Eutric Nitosols	16027.11	7.78
Lubic Pheaozems	6916.62	3.36
Haplic Cambisols	62457.19	30.31
Chromic Vertisols	1724.44	0.84
Leptosols	2371.69	1.15
Vertic Cambisols	30811.47	14.95
Water	131. 51	0.07

Appendix D: Calculated Weather parameter for Weather generator.

D1/ Parameter calculated using PcpSTAT.

```
Statistical     Analysis        of      Daily   Precipitation   Data    (1993 - 2017)
Input   Filename        =       pbui.txt

Number  of      Years   =       25
Number  of      Leap    Years   =       6
Number  of      Records =       9131
Number  of      NoData  values  =       1
```

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD	rainhhm
Jan.	20.74	3.8763	10.065	0.0458	0.3818	2.2	0.432
Feb.	35.98	4.9448	8.235	0.0467	0.6887	4.24	0.750
Mar.	81.65	8.4643	5.546	0.1258	0.471	6.2	1.701
Apr.	89.82	8.5559	5.3339	0.1388	0.5414	7.24	1.871
May.	98.3	7.613	4.6182	0.1782	0.5826	9.68	2.048
Jun.	127.52	8.2205	2.9563	0.3295	0.5032	12.4	2.657
Jul.	221.65	9.8471	2.2379	0.5188	0.6088	18.2	4.618
Aug.	188.6	9.2064	3.0071	0.5117	0.5543	17.32	3.929
Sep.	110.72	7.2065	3.1296	0.2766	0.5631	12.36	2.307
Oct.	50.05	5.1349	6.0697	0.0786	0.678	7.08	1.043
Nov.	31.39	3.8642	6.7534	0.0222	0.8487	4.76	0.654
Dec.	33.98	2.7218	4.7414	0.0321	0.8696	7.36	0.708

```
PCP_MM  =       average monthly precipitation   [mm]
PCPSTD  =       standard        deviation
PCPSKW  =       skew    coefficient
PR_W1   =       probability     of      a       wet     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
```

D2/ Parameter calculated using formula in the Arc SWAT user manual.

Month	TMPSTDMX	TMPSTDMN	SOLARAV	WNDAV
Jan	5.703	3.194	24.218	2.283
Feb	5.86	2.961	23.881	2.472
Mar	2.809	3.048	24.279	2.2
Apr	7.76	3.244	22.604	2.708
May	6.807	3.974	22	2.264
Jun	3.294	3.876	18.739	1.913
Jul	5.233	2.136	18.61	1.726
Aug	6.237	2.449	17.994	1.799
Sep	7.122	2.707	21.07	1.801
Oct	5.727	2.488	23.404	2.248
Nov	6.744	2.742	23.317	2.28
Dec	7.298	2.726	24.176	2.4

D3/ Parameter calculated using dew02 point.

This file has been generated by the program 'dew02.exe'
Input Filename = dewpoint.txt
Number of Years = 25
Number of Records = 9131

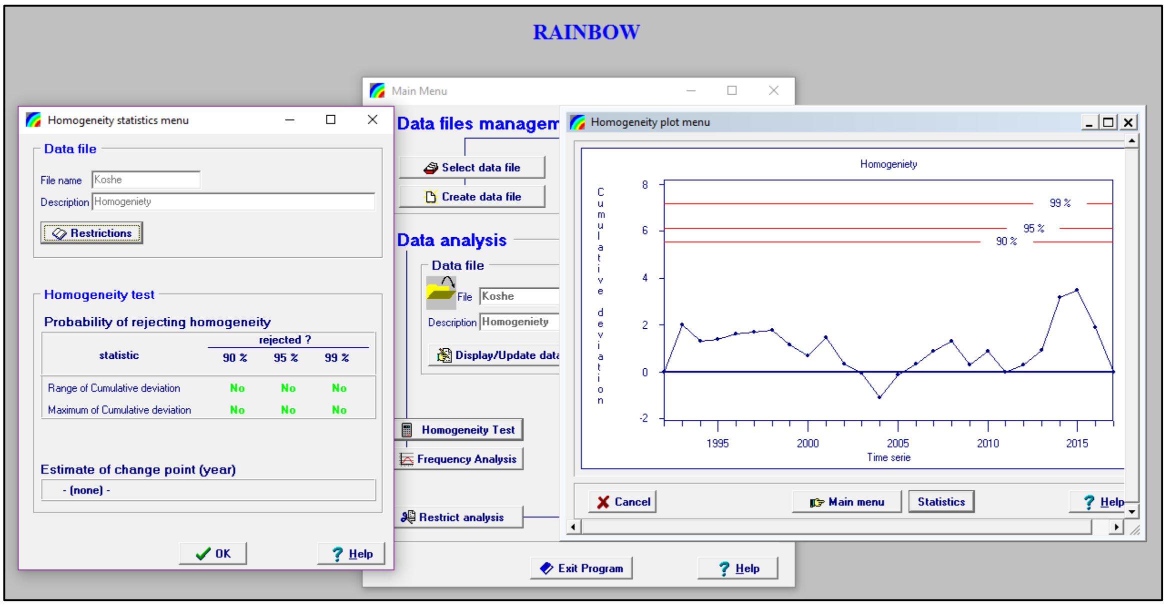
Number of NoData Values
tmp_max = 0
tmp_min = 0
hmd = 4

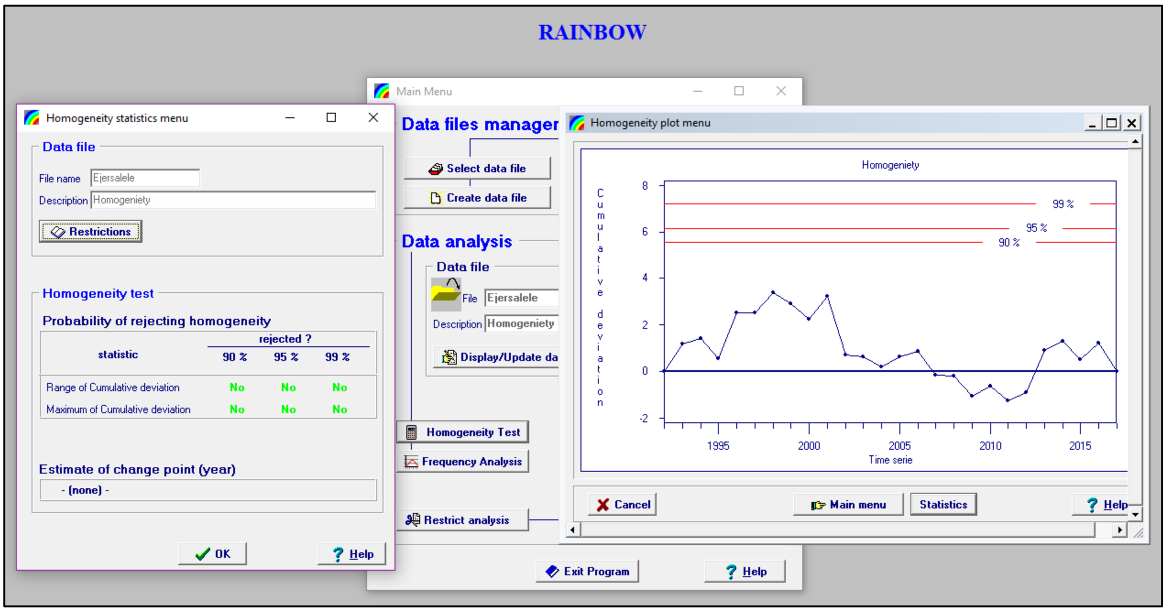
Average Daily Dew Point Temperature for Period (1993 - 2017)

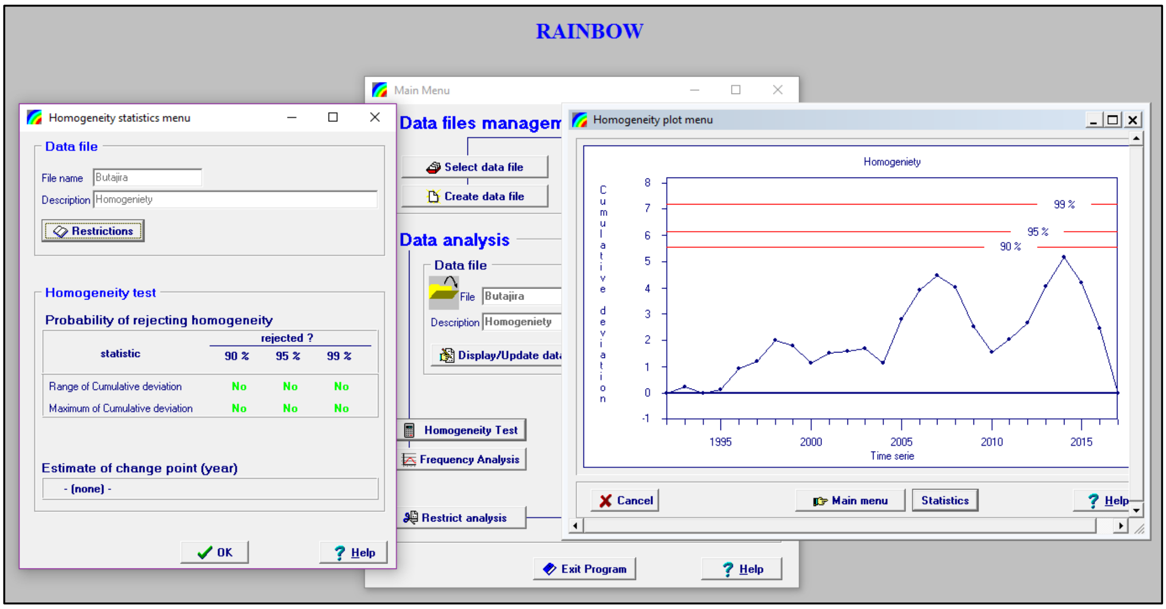
Month	tmp_max	tmp_min	hmd	dewpt
Jan	25.54	7.56	37.2	2.99
Feb	26.51	7.8	37.23	3.69
Mar	27.54	10.04	38.3	5.28
Apr	26.69	10.74	37.58	4.64
May	26.03	11.14	37.83	4.77
Jun	26.64	10.25	37.96	4.61
Jul	23.83	9.76	40.16	3.49
Aug	23.67	9.73	38.12	2.51
Sep	23.85	9.22	37.25	2.45
Oct	24.39	7.69	38.58	2.83
Nov	23.92	6.84	37.2	2.03
Dec	23.25	6.08	37.45	1.49

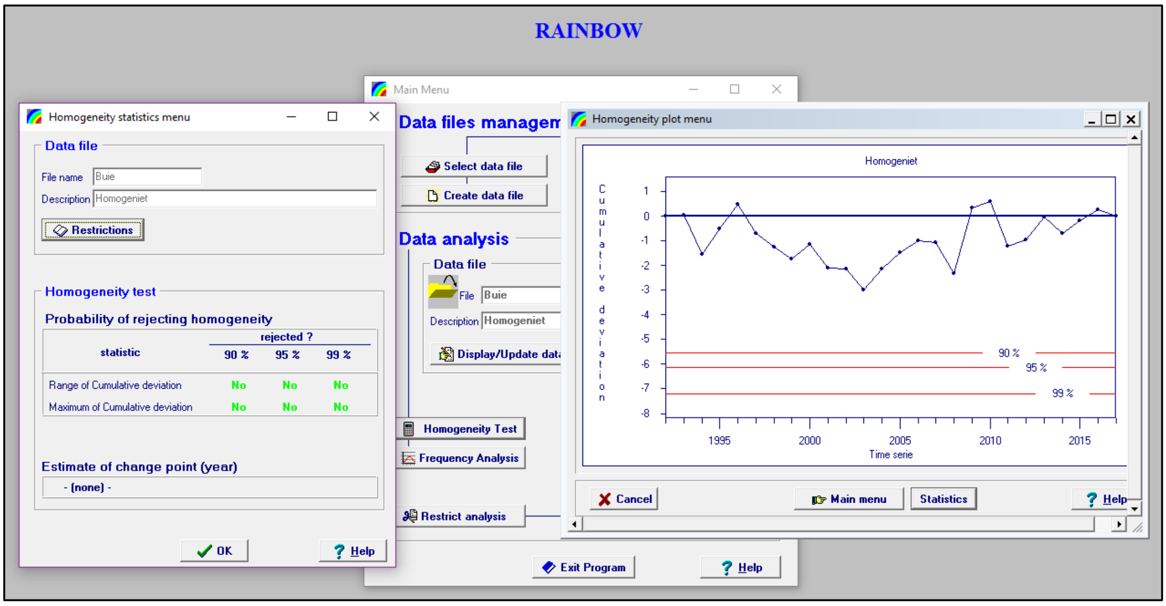
tmp_max = average daily maximum temperature in month [°C]
tmp_min = average daily minimum temperature in month [°C]
hmd = average daily humidity in month [%]

Appendix E: Homogeneity Test and Statistics of Meteorological Station Rainfall Data.









Appendix F: Sensitivity result of flow parameter with fitted values.

Parameter_Name	Fitted_Value	Min_value	Max_value
1:R__CN2.mgt	0.336500	-0.100000	0.800000
2:V__ALPHA_BF.gw	0.067500	0.000000	0.300000
3:V__OV_N.hru	0.688150	0.010000	1.000000
4:A__CANMX.hru	0.325000	0.000000	1.000000
5:R__ESCO.bsn	0.081000	0.000000	0.600000
6:R__SOL_AWC(..).sol	1.519250	1.000000	1.670000
7:V__GW_REVAP.gw	0.168500	0.100000	0.200000
8:R__REVAPMN.gw	0.042750	0.000000	0.150000

0.336500	0.067500	0.688150	0.325000	0.081000	1.519250	0.168500	0.042750

r__CN2.mgt	0.336500
v__ALPHA_BF.gw	0.067500
v__OV_N.hru	0.688150
a__CANMX.hru	0.325000
r__ESCO.bsn	0.081000
r__SOL_AWC().sol	1.519250
v__GW_REVAP.gw	0.168500
r__REVAPMN.gw	0.042750

Appendix G: Calibrated and validated average annual watershed values.

```
General Input/Output section (file.cio):
12/7/2019 12:00:00 AM ARCGIS-SWAT interface AV

     AVE ANNUAL BASIN VALUES

          PRECIP =   1159.8 MM
          SNOW FALL =    0.00 MM
          SNOW MELT =     0.00 MM
          SUBLIMATION =     0.00 MM
          SURFACE RUNOFF Q =   367.95 MM
          LATERAL SOIL Q =   32.04 MM
          TILE Q =     0.00 MM
          GROUNDWATER (SHAL AQ) Q =   27.77 MM
          GROUNDWATER (DEEP AQ) Q =    11.80 MM
          REVAP (SHAL AQ => SOIL/PLANTS) =   19.79 MM
          DEEP AQ RECHARGE =    11.95 MM
          TOTAL AQ RECHARGE =  239.01 MM
          TOTAL WATER YLD =   613.55 MM
          PERCOLATION OUT OF SOIL =  239.84 MM
          ET =    525.5 MM
          PET =   1003.3MM
          TRANSMISSION LOSSES =     0.00 MM
          SEPTIC INFLOW =        0.00 MM
          TOTAL SEDIMENT LOADING =   75.896 T/HA
          TILE FROM IMPOUNDED WATER =     0.000 (MM)
          EVAPORATION FROM IMPOUNDED WATER =     0.000 (MM)
          SEEPAGE INTO SOIL FROM IMPOUNDED WATER =    0.000 (MM)
          OVERFLOW FROM IMPOUNDED WATER =    0.000 (MM)
```

Appendix H: High and moderate runoff class of Meki River Watershed.

Sub-basins	Surface runoff (mm)	Runoff class	Rank
1	389.654	High	3
2	305.81	High	5
3	239.443	High	13
4	395.769	High	2
5	224.918	Moderate	23
6	311.98	High	4
7	261.376	High	7
8	439.311	High	1
9	198.871	moderate	28
10	291.495	High	6
11	254.967	High	8
12	254.306	High	9
13	251.804	Moderate	10
14	207.165	Moderate	26
18	225.941	High	22
20	232.902	High	17
21	247.405	High	12
22	232.642	High	18
23	237.64	High	15
24	238.789	High	14
25	247.751	High	11
26	232.918	High	16
32	190.971	Moderate	30
33	201.947	Moderate	27
34	226.557	High	21
35	196.175	Moderate	29

Appendix I: High and Moderate Erosion Class of Meki River Watershed.

Sub basins	Sediment (ton/ha/yr.)	Erosion class	Rank
1	23.078	Moderate	28
2	25.304	Moderate	21
3	24.329	Moderate	23
4	26.969	Moderate	13
5	25.044	Moderate	22
6	26.218	Moderate	20
7	26.408	Moderate	17
8	26.65	Moderate	16
9	82.858	high	2
10	26.236	Moderate	19
11	26.345	Moderate	18
14	26.744	Moderate	15
15	28.499	Moderate	12
16	37.632	Moderate	7
17	35.152	Moderate	8
18	32.095	Moderate	9
19	43.096	Moderate	6
20	23.811	Moderate	26
21	23.736	Moderate	27
22	23.839	Moderate	25
23	24.28	Moderate	24
24	22.56	Moderate	29
26	29.225	Moderate	11
27	58.832	Moderate	4
30	83.216	high	1
32	54.271	Moderate	5
33	26.925	Moderate	14
34	32.019	Moderate	10
35	81.341	Moderate	3

Appendix J: Suspended Sediment Data from MoWIE.

Station No	River/ Stream	Basin	Date of Sampling	Flow (m^3/s)	Depth (m)	Sediment load (tons/day)
081018	Meki	Rift Valley	23-Feb-90	13.53	3.57	4930.13
081018	Meki	Rift Valley	11-Apr-90	39.65	0.32	8247.60
081018	Meki	Rift Valley	27-May-90	3.60	6.83	239.01
081018	Meki	Rift Valley	13-Aug-90	55.03	0.52	56132.85
081018	Meki	Rift Valley	10-Oct-90	6.24	7.83	342.67
081018	Meki	Rift Valley	1-Oct-92	9.90	0.29	643.89
081018	Meki	Rift Valley	19-Nov-92	1.16	0.71	5.15
081018	Meki	Rift Valley	8-Aug-94	52.74	7.03	25679.41
081018	Meki	Rift Valley	12-Aug-94	68.77	9.20	13422.40
081018	Meki	Rift Valley	6-Feb-95	0.18	0.21	67.28
081018	Meki	Rift Valley	22-Sep-02	10.05	0.75	1680.24
081018	Meki	Rift Valley	27-Mar-03	3.12	0.57	658.44
081018	Meki	Rift Valley	7-Aug-03	21.52	1.48	3089.45
081018	Meki	Rift Valley	2-Sep-03	17.40	1.20	2606.86
081018	Meki	Rift Valley	16-Aug-04	34.07	1.39	4461.86
081018	Meki	Rift Valley	21-Aug-04	33.98	1.34	4452.85
081018	Meki	Rift Valley	16-Aug-07	16.24	4.35	2466.65
081018	Meki	Rift Valley	19-Aug-07	46.20	2.77	5693.15
081018	Meki	Rift Valley	21-Aug-07	31.45	2.13	4185.39
081018	Meki	Rift Valley	23-Aug-07	49.90	3.00	6055.07
081018	Meki	Rift Valley	27-Aug-07	21.42	1.60	3078.18
081018	Meki	Rift Valley	2-Dec-13	0.57	0.31	168.46
081018	Meki	Rift Valley	28-Jun-14	1.13	0.30	293.10