JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

ESTIMATING RUNOFF AND SEDIMENT YIELDS AND EFFECT OF BEST MANAGEMENT PRACTICES: A CASE STUDY ON BILATE WATERSHED

BY: ASFAW CHINASHO

A Thesis Submitted to the School of Post graduate Studies of Jimma University in Partial fulfillment of the requirements for the Degree of Masters of Science in Hydraulic Engineering.

January, 2021

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Main Advisor: Fayera Gudu (M.Sc, Assistant prof.)

Co-Advisor: Mohammed Hussen (M.Sc.)

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DECLARATION

I, the undersigned, declare that a thesis entitled "Estimating Runoff and Sediment yields and Effect of best management practices" (A Case study on Bilate watershed) is my original work and has not been presented by any other person and will not be presented by me for an award of degree in this or any other University.

Submitted by:

Asfaw Chinasho

Signature: --------------------------------------Date: --------------------------------

This thesis has been done under my guidance and submitted for examination with my approval as a university supervisor.

Main advisor

Fayera Gudu (M.Sc,Assistant Prof.)

Signature: --- Date: ------------------------

Co-advisor

Mohammed Hussen (M.Sc.)

Signature: --- Date: ------------------------

External Examiner

Signature: --- Date: ------------------------

Internal Examiner

Signature: --- Date: ------------------------

ABSTRACT

Watershed runoff which is highly influenced by watershed characteristics (LULC, Hydrologic soil group, slope, and Climate condition) plays an important role in designing hydraulic structures, controlling soil erosion, and assessing the water yield potential of the watershed. Surface runoff and sediment loading are immense problems that have threatened water resources development in the Bilate watershed. The main objective of this study was estimating runoff and sediment yields and effect of best management practices in Bilate watershed. DEM, LULC, Soil and Weather data are inputs to the SWAT Model. The consistency and homogeneity of data were checked by using double mass curve and Rainbow respectively. Simulation was carried out for the period of 30 years (1986 to 2015) and divided the watershed in to 29 sub basins and 478 Hydrologic Response Units (HRUs). The flow calibration and validation were carried out for the period of (1989-2003) and (2004-2015) respectively. The calibration and validation of sediment yield was carried out for the period of (1990-1998) and (1999-2004) respectively. The SWAT-CUP with the Sequential Uncertainty Fitting (SUFI-2) algorithm was used for calibration and validation of both flow and sediment. The average annual runoff simulated in the watershed was 292mm/ha/y and that of sediment was 59.8t/ha/y. The maximum runoff took place in the month of August and the minimum runoff took place in the month of January The highest sediment yield was observed during the months of August and whereas the lowest sediment yield was observed during the month of December The Model performance evaluation was checked by using a coefficient of determination (R^2), Nash-Sutcliffe model efficiency (NSE), Root mean Square Error Standard Deviation Ratio (RSR) and Percent bias (PBIAS) for both flow and sediment. The result showed that R^2=0.82 for calibration and 0.77 for validation. NSE= 0.7 for calibration and 0.65 for validation. RSR= 0.6 for calibration and 0.54 for validation. *PBIAS= -15.4% for calibration and -14.1% for validation for flow. The Model performance evaluation of sediment yield showed that R^2= 0.74 for calibration and 0.71 for validation, NSE= 0.71 for calibration and 0.68 for validation, RSR= 0.6 for calibration and 0.62* for validation *and PBIAS= -34.8% for calibration and -31.3% for validation. The average annual runoff simulated in the watershed was 292mm/ha/y and that of sediment was 53.48t/ha/y. Runoff varies from place to place in this watershed. The average yearly maximum runoff generated from Sub basin 14 was 426mm and the minimum average yearly runoff was generated from Sub basin 20 was 49mm.The result also showed that, runoff varies randomly in the catchment and the maximum runoff took place in the month of August and the minimum runoff took place in the month of January. Sediment yield varies both spatially and temporally. The Sub basin 23 has small amount of sediment yield which was 4t/ha/y and that of 9 has high sediment yield (83t/ha/y). It was witnessed that the highest sediment yield was observed during the months of August and whereas the lowest sediment yield was observed during the month of December. Three management scenarios were carried out in this study and the result showed that the average annual sediment yield at the entire watershed and Sub basin after application of grassed waterway, filter strips, and contouring was highly reduced. After comparing the scenarios results, contouring was more effective than the others to reduce sediment yield entering in to the catchment (59.8 to 6.4t/ha/y). The result showed that the calibration and validation results of both flow and sediment have good correlation with observed data.*

***Key words**: ArcGIS, Arc SWAT, calibration, Sediment yield, BMPs, and SUFI.*

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LIST OF ACRONYMS

ARS	Agricultural Research Service
BMPs	Best management practices
CN	Curve Number
DEM	Digital Elevation Model
FAO	Food and Agricultural Organization
GIS	Geographical Information System
HRU	Hydraulic Response Unit
MoWIE	Minster of water, irrigation and electricity
M.a.s.l	Meter above Sea Level
MUSLE	Modified universal soil loss equation
NMSA	National meteorology service agency
NSE	Nash Sutcliff Efficiency
PBIAS	Percent bias
RSR	Root mean Square Error Standard Deviation Ratio
SCS	Soil Conservation Service
SUFI2	Sequential Uncertainty Fitting Version2
SWAT	Soil and Water Assessment Tool
USDA	United State Development of Agriculture
USLE	Universal soil loss equation
UTM	Universal Transverse Mercator
WGEN	Weather Generator

1. INTRODUCTION

1.1 Back ground

Runoff and sediment yield modeling is important in the watershed (Abebe and Gebremariam, 2019a). Runoff and sediment load changes are affected by climate change and human activities in an integrated way (Wang,2013). Watershed runoff which is highly influenced by watershed characteristics (LULC, Hydrologic soil group, slope, and Climate condition) plays an important role in designing hydraulic structures, controlling soil erosion, and assessing the water yield potential of the watershed(Hussein and Ahmed,2020). Degradation of agricultural land as a result of soil erosion is a worldwide phenomenon leading to loss of nutrient-rich surface soil and increased runoff from the most impermeable subsoil that leads to lowering agricultural productivity (Keesstra *et al.*, 2016). Soil erosion which is widespread and global phenomenon is regarded as a severe environmental threat to soil quality, thus hindering soil ecosystem services in many regions of the world, particularly in ecologically fragile areas (Olson *et al.*, 2016). The loss of sediments caused by soil erosion not only deteriorates the quality of surface water, nearby water bodies, and wetlands but also reduces the productivity of agricultural land (Issaka and Ashraf, 2017). Land and water resources degradation are the major problems in developing countries like Ethiopia. Poor land use land cover practices, improper management systems and deforestation have played a significant role in causing high soil erosion rates, sediment transport and loss of agricultural nutrients (Krishna *et al*.,2014). Because of the irregular ground, the rates of soil erosion and land degradation are high in Ethiopia (Tamene and Vlek, 2008). Soil erosion intensity has a strong correlation with land use, even stronger than that of soil erosion and rain fall variability and it is a major problem in Ethiopia (Degu *et al.,* 2019). Deforestation, overgrazing, and poor land management accelerates the rate of erosion. Runoff and Sediment yield estimations are required for studies of reservoir sedimentation, river morphology, soil and water conservation planning, water quality modeling and design of efficient erosion control structures. Appropriate assessment of runoff and sediment yield amount is vital for the design, planning, and management of river basin projects that deals with conservation and utilization of water for the various purposes. Estimation of runoff and Sediment yield and applying suitable management practices in a watershed, as well as any other natural phenomenon requires an understanding of the factors affecting it. Since erosion and Sediment yield is one of the most complex natural processes and many factors are involved in it, the full knowledge of the factors influencing this phenomenon is very difficult (Ahmadi *et al.*,2005). Therefore, to estimate the quantity of runoff and sediment yield that takes place in a catchment, it is important to understand the complex relationships between rainfall-runoff and sediment yield process, which depend upon many geomorphologic and climate factors. Bilate River contributes a large quantity of flow to Lake Abaya. Visual assessment of the river hewed high turbidity of the flow which has reddish brown color throughout the year. This indicates that a large amount of sediment from the basin is transported to the lake through the river flow. Due to this it is important to develop management options in order to reduce the amount of sediment entering into the catchment. Models are generally used as service in various areas of water resource development, in assessing the available resources, in studying the impact of human interference in an area such as, climate change, deforestation, farm practice and change of watershed management (intervention of watershed conservation practices). There have been several models developed to estimate sediment yield and runoff such as Revised Universal Soil Loss Equation (RUSLE), Erosion Productivity Impact Calculator (EPIC), Areal Nonpoint Source Watershed Environment Response Simulation (ANSWERS), Water Erosion Prediction Project (WEPP) Geo-spatial Erosion Prediction mode (GeoWEPP) and Soil and Water Assessment Tool (SWAT) (Mohammad *et al*.,2016).

1.2 Statement of problems

Soil erosion and unconstrained runoff alter the stream flow regime and generate Considerable amount of sediment yield, which leads to a serious environmental impacts on water quality and aquatic habitat (Akay *et al*., 2008)**.** According to Tesfalem(2009), surface runoff and sedimentation has been a very serious problem for water resource schemes in Ethiopia and this is mainly due to most of the schemes are located at the foot of mountains characterized by high runoff and sediment yield. Deposition of sediment yield in reservoirs reduces the storage capacity of the reservoir, life expectancy of Hydraulic structures and they can cause serious problems concerning the operation and stability of the structure and may increase operation and maintenance cost. According to Tamene and Vlek (2008), Ethiopia loses about 1.5

billion metric tons of fertile top soils from high lands every year and the degradation of land through soil erosion is increasing at high rate. Land degradation in Ethiopia is especially severe in the highlands where the annual soil loss from farmland is estimated to 100 to 300 t /ha/ y (Girmay *et al*., 2020).This shows for most Ethiopian watersheds were affected by erosion and sedimentation. Bilate watershed is one of the sub basin of Ethiopian Rift valley basins and intensively used for irrigation and other developmental activities was highly affected by sedimentation so, understanding of the hydrological characteristics of the watershed is considerably important because of the country's interest in the utilization of its water resources, the need to improve and enhance development and management activities of these resources, and the potential danger from destructive impacts of runoff and sediment yield. The Bilate watershed was highly affected by runoff and sedimentation and the maximum suspended and deposited bed loads settled at the conveyance system of Bilate Tobacco development farm through the intake were 366,605.6 and 227248.8 t/y respectively (Tessema,2006) .Deforestation, overgrazing, and poor land management accelerated the rate of erosion in the watershed.

1.3 Objective of the study

1.3.1 General objective

The general objective of this research is estimating runoff and sediment yields and effect of best management practices in the Bilate watershed.

1.3.2 Specific objectives

- ❖ To calibrate and validate the SWAT model based on a stream flow and sediment data on Bilate watershed.
- ❖ To evaluate the spatial and temporal variability of runoff and sediment yield and identify the most prone sediment yielding Sub basin in the watershed.
- ❖ To identify best management option to reduce sediment yield entering to the bilate catchment.

1.4 Research questions

1. How to calibrate and validate SWAT model based on stream flow and sediment data?

2. What causes spatial and temporal variation of runoff and sediment yield in the Bilate watershed?

3. What management option is best to reduce sediment yield in Bilate watershed?

1.5 Significance of the study

The result of this study has valuable information for planning and designing of different water resource projects (like reservoir, dam, irrigation schemes and etc) on Bilate watershed. It also, informs to the government to use best management options to reduce sediment entering into this watershed and the result is used as precondition for someone who wants to conduct research on this watershed.

1.6 Scope of the study

This study was conducted on Bilate watershed for estimation of runoff-sediment yield and evaluating mitigation measures for sediment reduction using Arc SWAT used LULC and Climate data as input but it did not comprises the effect of LULC and Climate change on runoff and sediment yield and among different BMPs rather than Filter trips, Grassed waterways and Contouring were not addressed to evaluate their effect on sediment reduction.

2 LITERATURE REVIEW

2.1 Runoff

Runoff is drainage or flowing of precipitation from a catchment area through a surface channel after satisfaction of evapotranspiration, initial loss, infiltration and detention storage requirements for given precipitation(Subramanya,2008). According to Abebe and Gebremariam (2019b), runoff refers to the portion of rain water that is not lost to interception, infiltration, and evapotranspiration. As the U.S. Geological Survey (USGS), runoff is that part of the precipitation, snow melt, or irrigation water that appears in uncontrolled surface streams, rivers, drains, or sewers. in the study area. Depending up on the source from which the flow is derived, runoff may consist of surface runoff, subsurface runoff and ground water runoff and its process is strongly influenced by infiltration capacity(Tewodros,2011). Runoff is generated by a combination of two mechanisms which are saturation excess and infiltration excess and Saturation excess occurs when the soil becomes fully saturated with water and exceeding the water holding capacity of the soil and infiltration excess occurs when rainfall intensity exceeds the maximum rate that water can infiltrate into the soil, and water must flow over land to a different area (Yang *et al*., 2015). Runoff plays a central role in water resources assessment and computed by means of multiyear data and long and continuous runoff data at required spatial and temporal scales are generally not available in many regions around the world, due to the costs involved in measurements, difficulty in accessing the locations of interest, and malfunctioning of the measurement devices and these affects accuracy of annual runoff (Tongho *et al*.,2019). Runoff is an important area of interest for monitoring water resources, as well as solving water quality and quantity problems such as flood forecasting and ecological and biological relationships in the water environment (Kokkonen *et al*., 2003). Based on this, assessment of the runoff which mainly depends on the meteorology, topography, geology, soil and land use pattern is required for proper planning of the hydraulic structures as well as mitigation of natural hazards in watershed.

2.2 Soil erosion

Soil erosion refers to a process of detachment and transportation of soil particles from their original place to further downstream by erosion agents such as rainfall and wind

(Dotterel *et al*., 2016). In the water erosion process, rain drops mechanically breakdown soil particles into finer particles, and soil nutrients dissolve in water. The generated runoff can transport soil particles and their associated nutrients and then redistribute sediment and nutrients across the landscape (Sun *et al*., 2019). Studies suggested that high rates of soil erosion in Ethiopia is mainly caused by extensive deforestation due to the prevalence of high demand for fuel wood collection and grazing into steep land areas (Haile and Fetene ,2013). Poor land use land cover practices and improper management systems have played a significant role in causing high soil erosion rates (Krishna *et al*.,2014). Soil erosion intensity has a strong correlation with land use, even stronger than the relation between soil erosion and rain fall variability (Garcia,2008). According to (Berhe *et al.*, 2018),soil erosion can cause soil physical, chemical and biological property degradation, resulting in decreased crop productivity. Soil erosion causes worldwide environmental problems leading to degraded soil productivity and water quality, causes sedimentation in the reservoirs and increases the probability of floods as a result of reduction of flood storage capacity (Fasil,2012). In Ethiopia soil erosion and the consequent land degradation are recognized as major constraints to agricultural productivity and food security and the severity increases from the lower lying areas to the highlands of Northern Ethiopia (Jemberu *et al*., 2017). Soil erosion by water has been a longstanding environmental problem in Ethiopia and is considered to be a critical economic problem (Bewket *et al.*,2003). The annual rate of soil loss in the country is greater than the annual rate of soil formation (Sewnet *et al.*, 2016)**.**

2.3 Sediment yield

Sediment yield is the amount of sediment exported from watershed over a period of time, which will eventually enter a lake, reservoir or pond located at the downstream limit of the watershed (Ndomba, 2013). According to Merten *et al (*2016),sediment yield from watersheds is the result of the balance between natural, scale-dependent erosion and deposition processes, but can be greatly altered by human activities and decreases along the course of a river as it trapped in alluvial plains and sinks on other case. It is the amount of eroded sediment discharged by a stream at any given point (Abraha,2009). Sediment yield reaching the stream channel is the sum of total sediment yield calculated by MUSLE minus the lag, and the sediment trapped in grassed waterway, vegetative filter strips and/or ponds (Neitsch *et al*., 2011). The current climate change occurs all over the World and leads to increase of air temperature, amount, intensity and frequency of precipitation, and rainfall erosive factor, and as a consequence to growth of severe floods and erosive events (landslides, mudflows) causing the increase of sediment yield, basin component of sediment yield, and channel transformations(Kuksina,2019). Global estimates of erosion and sediment transport in major rivers of the world vary widely, reflecting the difficulty in obtaining reliable values for sediment concentration and discharge in many countries, that are made by different researchers, and the opposing effects of accelerated erosion due to human activities (deforestation, poor agricultural practices, road construction, etc.) relative to sediment storage by dam construction (FAO, 2019). Most sediment is exported from watersheds during relatively short period of flood discharge and these events must be accurately monitored to provide information on the long term yield as well as the time wise variation in load needed to evaluate sediment routing strategies. Knowledge of the spatial variation in yield is required to focus yield reduction efforts on the landscape units that deliver most sediment to the reservoir.

2.4 Best management practices

It is important to coordinate measures involving vegetative planting, engineering practices, conservation tillage and sheet and gully erosion control so as to secure the best integrated benefits of various conservation measures (Dilnesaw,2006).
Different Researchers (*e.g.* (Betrie (2011), Andualem & Gebremariam (2015) were conducted research on the impact of Best management practices (BMPs) on sediment reduction in a number of watersheds in Ethiopia by using SWAT model. However, the scenarios modeled during their study differ from one researcher to the other. These BMPs were represented in the SWAT model by modifying SWAT parameters to reflect the effect the practice has on the processes simulated within SWAT (Bracmort *et al.,* 2006). Implementation of watershed management plan provides the necessary measures for protecting the catchments from sedimentation. Absence of such a plan and inappropriate development in watersheds can lead to widespread soil erosion and siltation of the reservoir. According to Betrie *et al* (2011), each of the BMPs has a different effect on flow and sediment with distinct representation of parameters. (Douglas *et al* (2010a), classified BMPs into two groups such as structural (e.g., grassed waterways, terraces, contouring, filter strips) and non-

structural (e.g. no tillage, contour farming, conservation tillage, strip tillage). Lal (2008), also classified the soil and water conservation measures into two broad groups as erosion preventive measures (conservation tillage, mulching, reforestation, contour farming, vegetative barriers, etc.) and erosion control measures (e.g. check dams, terraces, grassed waterways, filter strips, graded channel). However, selection of BMPs and their parameters values is site specific and should reflect the study area reality.

2.5 Hydrological modeling

According to (Devi *et al*, 2015)**,** a model is a simplified representation of real world system. Even physically based models, solving complex systems of differential equations describing the occurring physical processes, need simplifications related to the identification of the parameter values, the uncertainties in input/output observations, the point-scale nature of physically based equations. Hydrological models are tools that describe the physical processes controlling the trans-formation of precipitation to stream flows. They are primarily developed for better understanding of the hydrologic processes and prediction of hydrologic phenomena in a watershed (Beven, 2019)**.** Therefore, the best model might be the one which gives results close to reality with the use of a minimum number of parameters and reduced model complexity.

2.5.1 Hydrological model selection criteria

According to Cunderlik and Simonovic (2007), there are four common criteria to select hydrological models for specific projects. These are: - Does the model predict the variables required by the project? (Required model output is important to the project), is the model capable of simulating single-event or continuous processes? (Hydrological processes that need to be modeled to estimate the desired outputs adequately), Can all the inputs required by the model be provided within the time and cost constraints of the project? (Availability of input data), Does the investment appear to be valuable for the objectives of the project? (Price).Based on the criteria mentioned above, Soil and Water Assessment Tool (SWAT) was used for this study. SWAT model is preferable than the other models due to its advantages like, It is physically based, spatially distributed and belongs to the public domain, computational efficiency, can show the results both spatially and in table form, Simulation of different management practices and etc. The model has been tested in different tropical watersheds in Ethiopia (Andualem and Gebremariam, 2015).

2.5.2 Description of SWAT model

The Soil and Water Assessment Tool (SWAT) model was developed by US Department of Agriculture-Agriculture Research Service (USDA-ARS). SWAT model is physically based, semi-distributed, and can continuously simulate stream flow, sediment yield, nutrient, pesticides and agricultural management in watersheds with varying soils, land use and management conditions over long periods of time (Neitsch, *et al*., 2011). Based on their topographic situation the model spatially divides the entire watershed into smaller sub basins. The sub basins are divided further into hydrologic response units (HRUs), which consists homogeneous soil type, land use and slope with in watershed.

2.5.3 SWAT model setup

Arc SWAT 2012, with an interface in ArcGIS 10.1, was used to setup the model in this study. The model setup includes: watershed delineation, HRU definition, editing weather input tables, editing SWAT input and SWAT simulation. The input data required to SWAT model to build up the process are Digital Elevation Model (DEM), land use map, soil map, weather data, stream flow and sediment data.

2.5.4 Hydrological components of SWAT model

The Simulation of the hydrology of a watershed is separated into two divisions. One is the land phase of the hydrological cycle that controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub basin. The second one is routing phase of the hydrologic cycle that can be defined as the movement of water, sediments, nutrients and organic chemicals through the channel network of the watershed to the outlet. In the SWAT model the water balance is the backbone of the hydrologic simulation in a watershed.

$$SW_t = SW_o + \Sigma (R_{day} - Q_{surf} - E_a - W_{sweep} - Q_{gw}) \text{ ------------------------------------- } 2.1$$

Where; SW_t is the final soil water content (mm H_2O), SW_0 is the initial soil water content on day i (mm H_2O), t is the time (days), R_{day} is the amount of precipitation on day i (mm H_2O), Q_{surf} is the amount of surface runoff on day i (mm H_2O), E_a is the amount of evapotranspiration on day i (mm H_2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H_2O), and Q_{gw} is the amount of return flow on day i (mm H_2O).

2.5.4.1 Surface Runoff

Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT provides two methods for estimating surface runoff: the SCS curve number procedure and the Green & Ampt infiltration method. Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The total amount of runoff leaving a field can be computed using the runoff curve number (CN) method, an empirical approach widely used to compute runoff volume for different soil types and surface conditions, as follows (Neitsch, 2005):

$$Qsuf = \frac{(Rday - Ia)2}{Rday - Ia - S} \quad \text{--}2.2$$

Where, Qsurf is the accumulated runoff or rainfall excess (mm H2O), Rday is the rainfall depth for the day (mm H2O), I_a is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H2O), and S is the retention parameter (mm H2O). The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 * \frac{100}{CN} - 10 \text{--}2.3$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition. Commonly Ia is approximated by 0.2S and the above equation rewritten as follow.

$$Qsurf = \frac{(Rday - 0.2S)2}{Rday + 0.8S} \text{--}2.4$$

Among the factors that influence CN are: hydrologic soil group, land use, soil management, cropping system, conservation practices, and antecedent water content. The values of CN vary from 0 to 100 depending on the soil and surface conditions Values of CN decrease with increase in surface vegetative cover. Bare soils without crop residues have the largest CN values, whereas undisturbed soils covered by dense vegetation have the smallest CN values.

2.5.4.2 Sediment Component of SWAT

Erosion and sediment yield for each HRU are estimated with the modified universal soil loss equation, MUSLE, (Williams and Berndt, 1977). The general equation is:

$Sed=11.8*(Q_{surf}*Q_{peak}*A_{HRU})^{0.56}*KUSLE*C_{USLE}*P_{USLE}*LS_{USLE}*CFRG$ ------------2.5

Where: Sed is the sediment yield on a given day in metric tons, Q_{Surf} is the surface runoff from the watershed in mm/ha, Qpeak is the peak runoff rate in cubic meter per second, A_{HRU} is the area of HRU, K_{USLE} is the USLE soil erodability factor, C_{USLE} is the USLE land cover and management factor, P_{USLE} is the USLE support practice factor, LS_{USLE} is the USLE topographic factor, and CFRG is the coarse fragment factor.

2.6 SWAT calibration and uncertainty programs (SWAT Cup)

According to Vilaysane *et al* (2015), SWAT CUP is a computer based program developed for the calibration, Validation, sensitivity analysis and uncertainty analysis of the SWAT model and also its performance was better than the auto-calibration modulus embedded in SWAT model. There are five calibration approaches widely used by the scientific community in SWATCUP. These are the Sequential uncertainty Fitting (SUFI2), Generalized Likelihood Uncertainty Estimation (GLUE), Parameter Solution (Parasol), Markov Chain Monte Carlo (MCMC) and Particle Swarm Optimization (Pso) (Abbaspour, 2015).

2.6.1 Sensitivity

Sensitivity analysis is a mechanism for the assessment of the input parameters with respect to their impact on model output and useful for model development, for model validation and reduction of uncertainty (Len hart *et al*., 2002).

2.6.2 Calibration

Calibration is a model testing with known input and output to adjust or estimate the factors (SWAT manual). Model calibration aims to ensure that model components such as hydrological processes and parameters to keep their physical meaning; however results are influenced by multiple sources of uncertainty (uncertainty in the data, model parameters and model structure).

2.6.3 Validation

Model validation/verification aims to validate the models strength and ability to describe the catchments hydrological response, and further detect any biases in the calibrated parameters (Pechlivanidis *et al*.,2011).Its importance is to check correlation between observed and simulated data.

2.6.4 Uncertainty

Uncertainty analysis algorithms used to decrease model uncertainty by eliminating some probable source of modeling and calibration errors. According to Abbas (2014), uncertainties can be quantified in SUFI-2 by a measure of p -factor and r – factor and the p-factor is the percentage of measured data bracketed by 95PPU or 95% prediction uncertainty, Whereas, r- factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. It means r-factor measures the strength of uncertainty analysis and calibration. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU).

2.6.5 Previous related studies Using SWAT Model

Different researchers conducted their research on different watersheds in Ethiopia using SWAT model. Fetene(2008), used physically based SWAT model for developing the relationship between rain fall runoff and sediment yield for Blue Nile river basin and concluded that SWAT model was applicable for developing the relationship, by obtaining a reasonable agreement of the regression coefficient (R^2) and Nash Sutcliffe efficiency (NSE) for both Flow and Sediment. Ayisheshum(2015), used SWAT based identification of best management practice option for sediment yield reduction in Gumera watershed and justified that SWAT model gives a good results for identification of best management option for sediment yield reduction and obtained regression coefficient(R^2) and Nash Sutcliffe efficiency (NSE) of acceptable limit for monthly flow and sediment yield. Tesfu (2015) modeled runoff and sediment yields of Kesem Dam watershed by using SAWT model and discussed spatial and temporal variability of runoff and sediment in the watershed and the result showed that good relation between observed and simulated data using performance evaluation criteria of R^2 and NSE. In addition to this, the study also simulated best management options (filter strip and grassed waterway) for that specific watershed by selecting the critically eroding sub basins and the result indicated the proposed reduction options can satisfactorily reduce the sediment yield (filter strip by 59% and grassed waterway by 57.34%) from the existing baseline for affected sub basins, in turn, reduce the sediment yield inflow to the reservoir. (Jemal, 2015) modeled stream flow and sediment yield at Gidabo watershed, rift valley basin, and discussed that the result of R^2 and NSE. The study of Betrie *et al.* (2011) on Blue Nile Basin using SWAT model reports, applying filter strips has reduced the average annual sediment yield at the outlet by 44%. The study conducted by Manawko (2017) showed that application of contouring on proposed middle Awash Dam watershed reduced the average annual sediment yield for critical sub basins by 61.1%.

3 MATERIALS AND METHODS

3.1 Location of the study area

Bilate watershed is the sub-basin of the Rift Valley Lake Basin and located in the southwestern part of Ethiopia. It situated roughly between 6°33'18'' to 8°6'54'' N latitudes and 37°47'14'' to 38°20'14'' E longitudes. Bilate River drains from northern part of the Lake Abaya drainage basin. Drainage area of Bilate watershed was 5756km^2 and perimeter of 474km. It has two tributaries: such as the Gudar and Weira river. Gudar originates from near hosanna and flows east to reach Boyo Swamp and Weira originates from Guragie zone. Both tributaries join at the outlet of Boyo swamp and form river Bilate and flow southwards in to Lake Abaya. The basin usually classified in to three sub basins: the upper, the middle and the lower sub basins. The Upper Bilate Sub-basin: comprises the areas upstream of Boyo Swamp outlet excluding the swamp area. The Middle Bilate Sub-basin: this is part of the basin that stretches from Boyo Swamp outlet up to Alaba Kulito. The Lower Bilate Sub-basin: this is sub-basin which extends from Bilate Tena to LakeAbaya

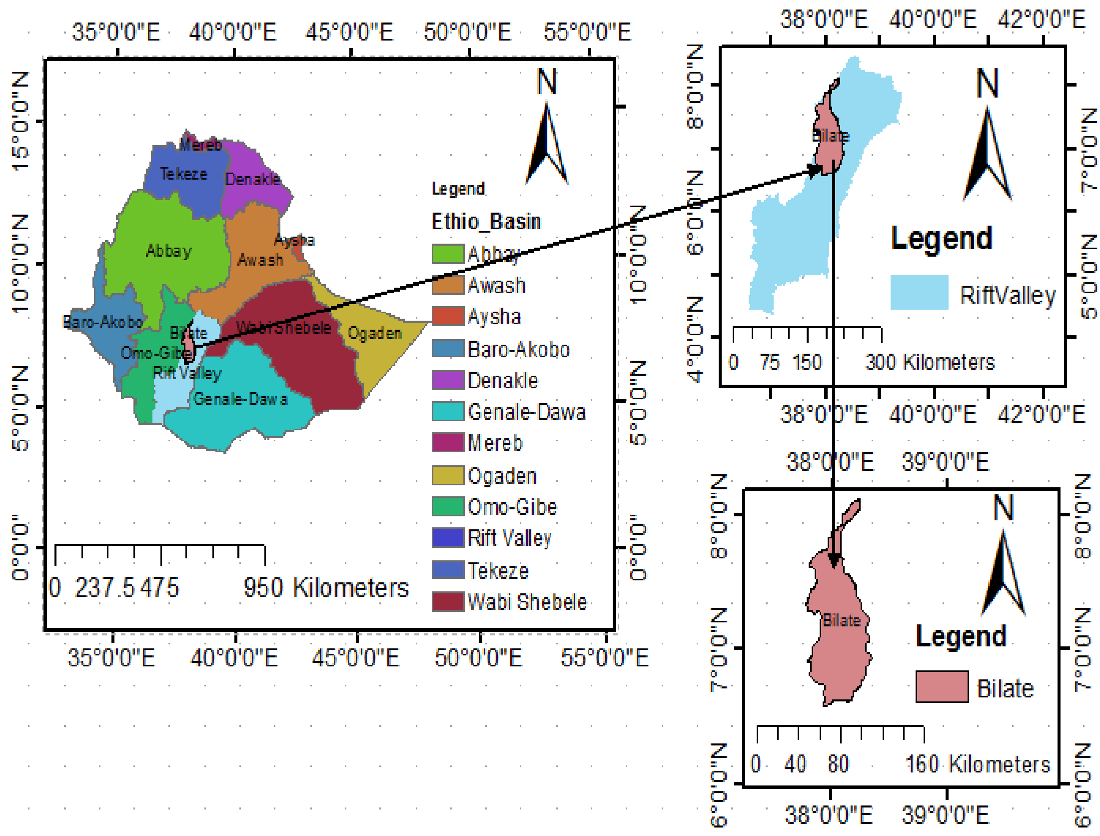

Figure 1 Location of the study area

3.1.1 Topography

The elevation of Bilate water shade ranges between 3315m a.m.s.l in the northern and 1116m a.m.s.l in the south and has maximum length of about 160 km. The slope of Guder and Weira tributaries of upper Bilate is very steep and therefore, the topographical features on these tributaries are not easy for construction of storage reservoirs.

3.1.2 Climate

The climate of Ethiopia is mainly controlled by seasonal migration of inter tropical convergence zone (ITCZ) and it is associated atmospheric circulation but the topography has also an effect on the local climate. The traditional climate classification of country is based on altitude and temperature shows the presence of five climatic zone namely Wurch (cold climate more than 3000m altitude), Dega (temperate like climate-high land with 2500-3000m altitude), WoinaDega (Warm climate with 1500-2500m altitude), Kola (hot and aired type with less than 1500m altitude), and Bereha (hot and hyper-arid type) climate. Based on this classification the study area comprises all of the climatic condition. There is a high spatial and temporal variation in rainfall in the study area. The total mean annual rain fall in the basin was between 876- 1724mm.The temperature condition of Bilate basin was not varying uniformly. The mean monthly minimum and maximum temperature varies from 4.7°C in July to 34.5°C in the month of February respectively as shown below.

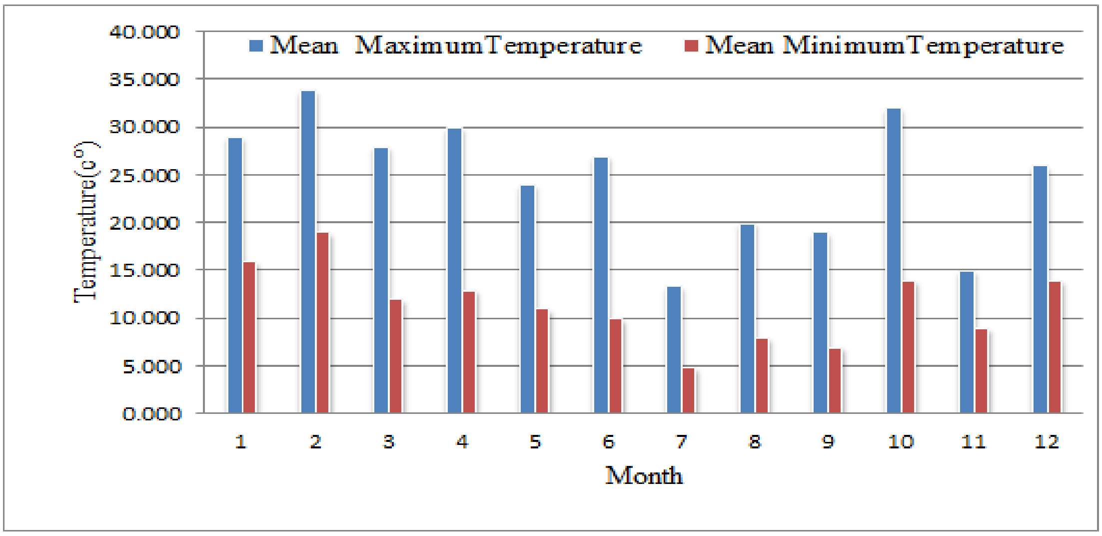

Figure 2 Mean monthly minimum and maximum temperature

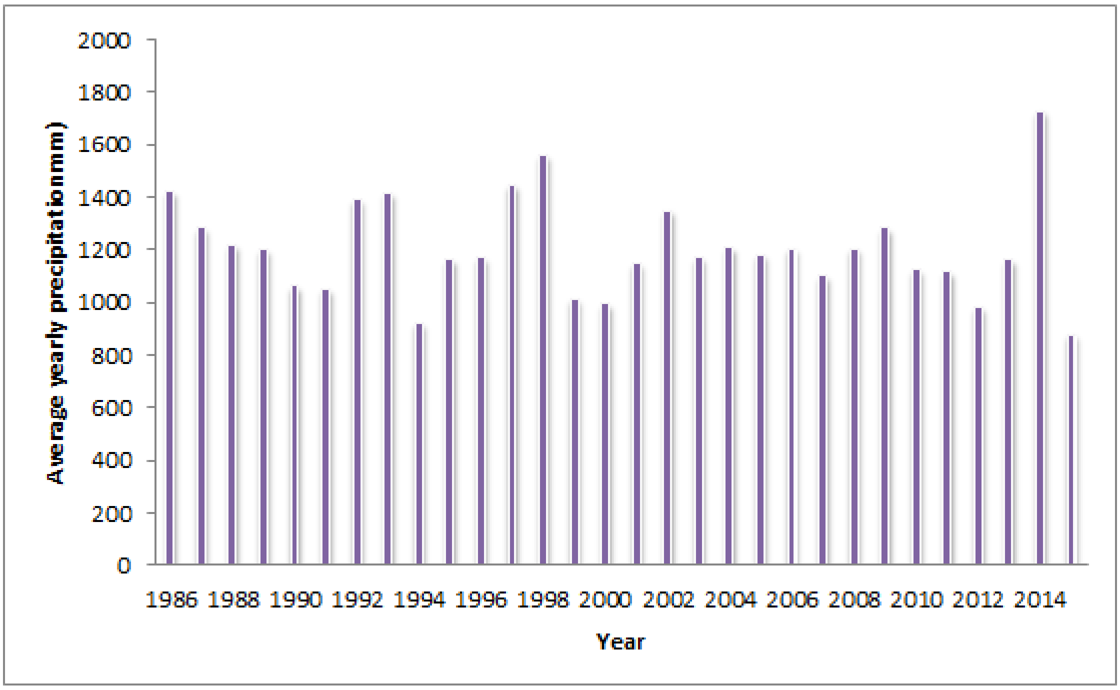

Figure 3 Average yearly precipitations

3.1.3 Land use and land cover

The commonly observed land use and land cover is agricultural, forest-mixed and Range-Grasses, pastoral grazing and scattered seasonal cultivation. Especially in Guragie highlands, there are cultivation of Inset, Banana and Cereals; mixed agriculture in fields, cultivation of cereals and pulses grazing and forest harvesting is also common. In lower basin, large state farms (Abaya, Bilate-Tobacomonopole) were cotton, tobacco, and maize productions are available. Regarding the recent land use, land management and conservation attempt, there are some galley reintegration works practiced near Abaya and few areas of the watershed by plantation and by constructing rain fall controlling strips. These conservation attempts show a better management of the area by producing bushes and small grass variety because of soil and water conservation induced, through the effective control yet has not been achieved and therefore the water shade needs further management and utilization of available water.

3.1.4 Soil and geology

The dominant soils in the basin includes Chromic vertisols from clay to clay loam, lithosols, chromic cambisols from clay to clay loam and sandy clay loams in the upper sub basin; vertic andosols with sandy to sandy loam, deep red to · brownish soil associated with vertisols cover the rolling hilly plains around Alaba to Wolaita Soda in the middle sub-basin and the lower sub-basin consists of vertic andosols of loam to loamy sand, eutric cambisols, vertic cambisols, lithosols with clay loam to sandy clay loam**.** The geology of Bilate River Basin in the northern upland is predominantly volcanic quaternary rhyolites and trachytes and in the southern, Oligocene to Miocene basalts occur whereas the lowlands of the watershed are covered with Holocene alluvial and Eolian deposits of the Rift Valley**.**

3.1.5 Hydrology of Bilate watershed

Bilate River is the main perennial river that flows in the basin. Its main tributaries are the Weira River with its seasonal tributaries (Urulicho and Guracha) flowing south and the Guder River which originates near Hossana and flows east to join Bilate at the outlet of Boyo swamp. Most of the tributaries are seasonal. The maximum stream length is about 160km. River Bilate contributes a large quantity of flow to Lake Abaya. Visual assessment of the river showed high turbidity of the flow which has reddish brown color throughout the year. This indicates that large amount of washed materials from the basin are transported to the lake through the river flow. The most significant water quality problem of Bilate River is associated with high total suspended solid concentration throughout the basin and this results the sedimentation and water quality problem in the watershed. Most of the tributaries are seasonal. The maximum stream length is about 160 km. The recorded mean minimum and maximum annual flows of River Bilate at Alaba kulito was 0.413-283.54cumecs.

3.2 Data collection

Before conducting any research it is required to collect data based on the type of research. Different types of data which were collected from different sources and organization and used as an input for SWAT model in this study includes spatial data (DEM, Land use/Land cover map and Soil map), Meteorological data (precipitation, maximum and minimum temperature, relative humidity, wind speed, Sunshine hour) and hydrological data (daily river flow and sediment data).

3.2.1 Spatial data

3.2.1.1 Elevation Model (DEM)

Digital Elevation Model (DEMs) is a useful GIS layer that can be used for automatic delineation of flow, Stream networks and watershed analysis. It can be used to create terrain attribute maps, data and other stream characteristics entered into the SWAT model. Further, it also plays an important role in fast and slow runoff process. The SWAT model provides three spatial levels: the watershed, the sub basins, and the hydrologic response units (HRUs). Each level is characterized by a parameter set and input data. The largest spatial level of the watershed refers to the larger entire area being represented by the model. The first step in creating the model input is the watershed delineation accomplished using digital elevation model data. DEM is the first input of SWAT model for delineating the watershed to be modeled. Based on threshold specifications and the DEM, the Arc GIS interface was used to delineate the watershed into sub basins. Consequently, sub basins were divided into Hydrologic Response Units (HRU). DEM with a resolution of 30 m by 30m downloaded from United States of Geological Survey (USGS) Earth Explorer was used. The DEM was used to analyze the drainage patterns of the land-surface terrain. Sub basin Parameters such as slope, slope length, and defining of the stream network with its characteristics such as channel slope, length, and width were derived from DEM. All spatial data sets were projected to UTM 37 North and D_WGS_1984 datum.

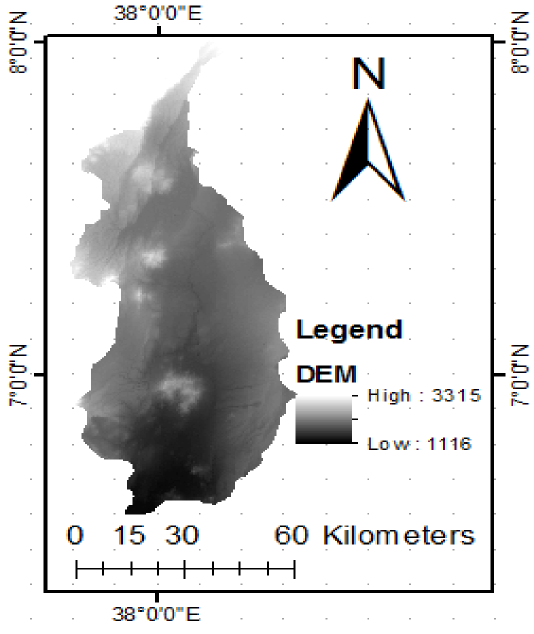

Figure 4 DEM of the study area

3.2.1.2 Land Use/Land Cover Data

Land use/land cover data set is used to understand the hydrological process and governing system and is the important GIS input layer required by SWAT. Land use/land cover affect surface runoff, erosion, evapo- transpiration and other hydrological process in watershed to be modeled. The land use map of the study area was acquired from Ethiopia Ministry of Water; Irrigation and Electricity. SWAT has predefined land use classes in its crop database. The LULC data in the basin had been divided in to eight as shown below in figure. Among these Agricultural Land-Generic (AGRL) covers the area of 69.86% and is the most dominant land use type in the catchment. So it is necessary to prepare a look up table, which refers land use land cover classes found in hand with SWAT land use land cover codes. Since in HRU definition the model refers the land use classes found in the SWAT model. So, well preparation of the look up table of the land use/land cover types in the SWAT compatible way is basic for the loading of the land use/land cover of the study area unless the error may happen when loading lookup table. The name of LULC, SWAT CODE and area coverage are shown in the table-1 in appendix-1.

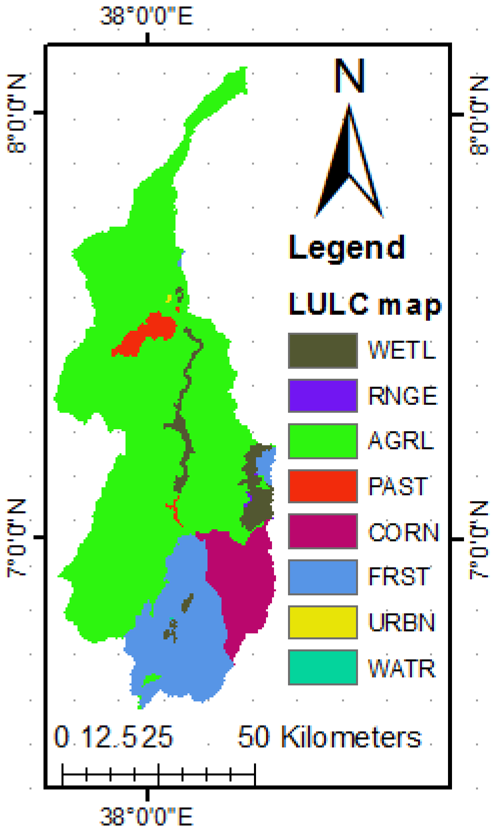

Figure 5 LULC of the study area study area

3.2.1.3 Soil Data

Soil physical and chemical properties are other inputs required by SWAT's soil data base. The soil map of the study area was obtained from Ethiopia Ministry of Water; Irrigation and Electricity. The physical property of the soil in each horizon governs the movement of water, air through the soil profile and has major impact on cycling of water in hydrologic response unit (HRU) and is used to determine water budget for the soil profile, daily runoff and erosion. Soil of study area was classified in to eight major soil groups in the watershed and these are: Eutric Cambisol , Eutric Vertisol , Haplic Luvisol , Cambic arenosol , Vitric Andosol ,Leptosol , Rhodic Nitisol and Calcaric Fluvisol. Among these, Haplic Luvisol is the dominant soil in the catchment and covers about 40% of the catchment and that of Euteric vertisol is the least soil type which covers an area of 3.01%. Soil look up table including the soils in the watershed was prepared in the text form and the grid values in the map were loaded which exists in the SWAT database. The Name of soil,SWAT CODE and area coverege of each type of soil is shown in the table-2 in appendix-1.

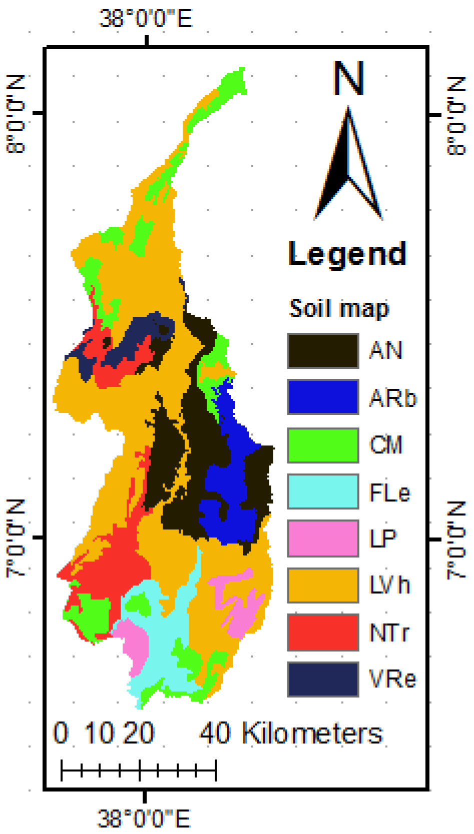

Figure 6 Soil of the study area

3.3 Meteorological and hydrological data collection

3.3.1 Meteorological data

The weather variables required by the SWAT model for driving the hydrological balance are daily rainfall, minimum and maximum temperatures, relative humidity, wind speed and Sunshine hour. These data were collected from National Meteorological Service Agency (NMSA). Among eight stations collected from NMSA, five of them which have better data series were used for this study. The table-

3 below shows the stations which were used in this study and availability of data for each station was shown in appendix-2.

Table 1 Rainfall gauged stations

S.No	Station	Latitude	Longitude	Easting	Northing	Elevation
1	Hossana	7°34'04"	37°51'2"	373805	836605	2307
2	Wolaita	6°8'1"	37°7'3"	360987	754927	1869
3	Alaba Kulito	7°18'38"	38°05'38"	399981	808107	1772
4	Awassa	7°6'5"	38°48'06"	442781	782805	1694
5	Bilate	6°81'67"	38°7'33"	403428	766214	1361

3.3.2 Hydrological data

The stream flow and sediment data of Bilate River used for calibration and validation the model was collected from ministry of Water, Irrigation and Electricity (MoWIE).There are four gauging stations inside the watershed but only two stations such as Bilate near Alaba kulito and Bilate Tena have long record. Gauging station at Bilate near Alaba kulito was selected for calibration and validation of the model because the station has better records than Bilate Tena. Moreover, limited daily sediment discharge measurement data were collected and the gap of daily sediment data was generated using sediment rating curve. Monthly river flow and sediment discharges at the gauging station were used for flow and sediment calibration and Validation.

3.4 Data preparation and analysis

After the collection of data from different sources and organization, the next step should be arranging, preparing, organizing and analyzing it based on model requirement using different tools. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers (Vedula,2005).

Table 2 Collected data types and Sources

Data type	Source	Remark
DEM	Downloaded from USGS	
Land use map	MoWIE	
Ethio soil map	MoWIE	
Stream flow data	MoWIE	Missing data
Weather data	NMSA	Missing data
Sediment data	MoWIE	Missing data

3.4.1 Filling and generating missing meteorological data

To perform hydrological analysis and simulation when using long time series data, filling in missing data is very important. There are numbers of methods and tools have been proposed to estimate missing rainfall data, Such as Arithmetic average method, Normal ratio method, weighting method, and regression method and the XLSTAT. XLSTAT which is a data analysis system and statistical software for Microsoft Excel developed to fill missing data with different options (remove observations with missing value, use a mean imputation method, use a nearest neighbor approach, use the LIPALS algorithm and use an MCMC multiple imputation algorithm).This tool is simple and better to use large quantitative data series and applicable for all types of excel sheet and uses an innovative message system to give information to the user to report problems. For this study MCMC imputation technique using XLSTAT add-ins plugin in Microsoft excel was used because it replaces missing values with mean and standard error equal to the mean and standard error of available data. Some of the average weather data were generated by the weather generator programs developed by Williams(1991), for SWAT weather generating station which has full data. Solar radiation data which was required by Arc SWAT was not available in the National Meteorology Service Agency. But it was calculated from the available measured latitudes, sunshine hour's and average day length data obtained from standard tables. The global solar radiation varies from latitude to latitude. Thus, a solar radiation measurement parameter is obtained and defined as the ratio of the actual number of hours of sunshine received at a site to the day length (Technology *et al.*,2011). Linear interpolation technique was used to calculate the average monthly day length (hours) of the weather generator stations for their given respective north latitudes. Daily solar radiation values of principal weather stations were computed using the following equation.

Rs= (a+b*n/N)*Ra--3.1

Where; Rs is solar radiation in $MJ/m^2/day$, a and b are angstrom constants=0.25, 0.5 respectively, Ra is extraterrestrial radiation in $MJ/m^2/day$, n is daily sunshine hrs, N is day length (hrs) depending on latitude, longitude and months of the year and the clear derivation was shown in appendix-3

3.4.2 Filling and generating missing hydrological data

In some of the hydrological stations, due to several reasons sometimes the records may not be kept properly and results in missing. Missing flow data records for the watershed may be filled by developing correlation station by scatter plot between the station with missing data and any of the adjacent stations with the same hydrological features and common data points and XLSTAT with various alternatives. For this study MCMC imputation technique using XLSTAT add-ins plugin in Microsoft excel was used to fill missing hydrological data since, it estimates missing value iteratively.

3.4.3 Sediment rating curve preparation

The sediment data of Alaba kulito station collected from ministry of water, irrigation and electricity (MoWIE), was not in continuous time step. Therefore, it is necessary to generate the continuous sediment load by relating the stream flow with sediment load using sediment rating curve. The sediment rating curve is a relationship between the discharge and sediment load**.** It is widely used to estimate the sediment load being transported by a river. According to (Porterfield, 1977) the available instantaneous suspended sediment discharge (Qs) in Tons/day is computed as follows:

Qs= K* Qi * C=0.0864*Qi*C ---3.2

Where, K=Concentration factor, Qi=instantaneous discharge (m^3/sec), C=Sediment concentration (ppm or mg/lit). According to Morris& Fan (1998), general relationship used to generate sediment load from recorded discharge at the gauging station using a mathematical curve fitting method is as follows:

$Qs=aQw^n$ Where, Qs is sediment load in ton/day, Qw is the discharge in m^3/s and a and n are regression constants. The regression analysis for sediment rating formulated in this case is given by: $Qs = 63.71 * Q^{1.43}$

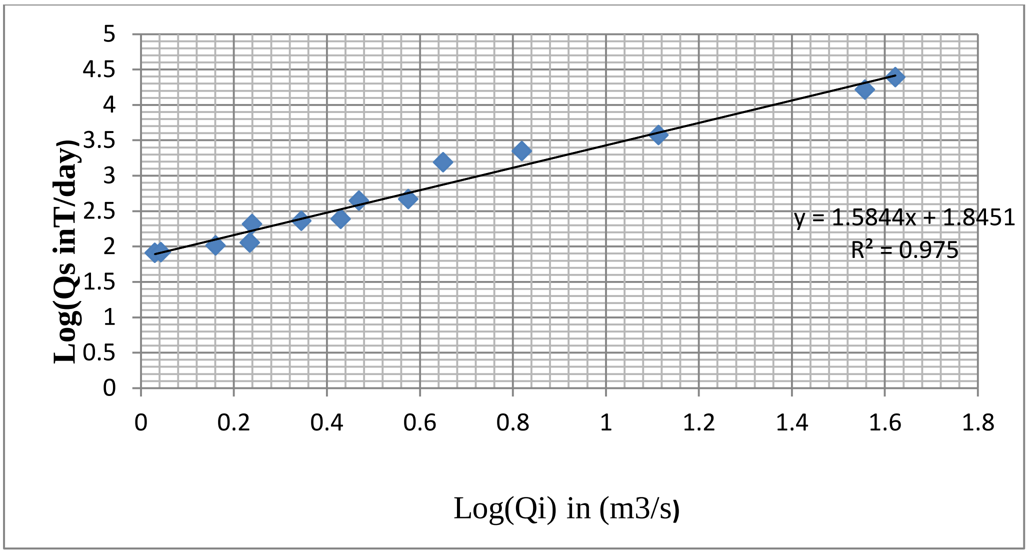

Figure 7 Sediment rating curve of Alaba kulito

3.5 Data consistence and homogeneity

3.5.1 Checking consistency of meteorological data

Inconsistency of data could be happened during record because of changes in time of record, instrumentation, gauging location, problem in observation and etc. Before using any weather data, it is essential to check whether it is consistent or not. There are different types of data consistence checking techniques .For this study double mass curve consistency checking techniques was selected, because it has the following advantages: Shows clearly the consistency of individual station cumulative data with cumulative average in one graph. It is a graphical method which identifies or adjusts inconsistencies in a station record by comparing its time trend with those of other stations nearby. To identify and analyze historical sediment trends in the river via breaks in slope and used to identify sources or sinks of sediment (Albert, 2004).

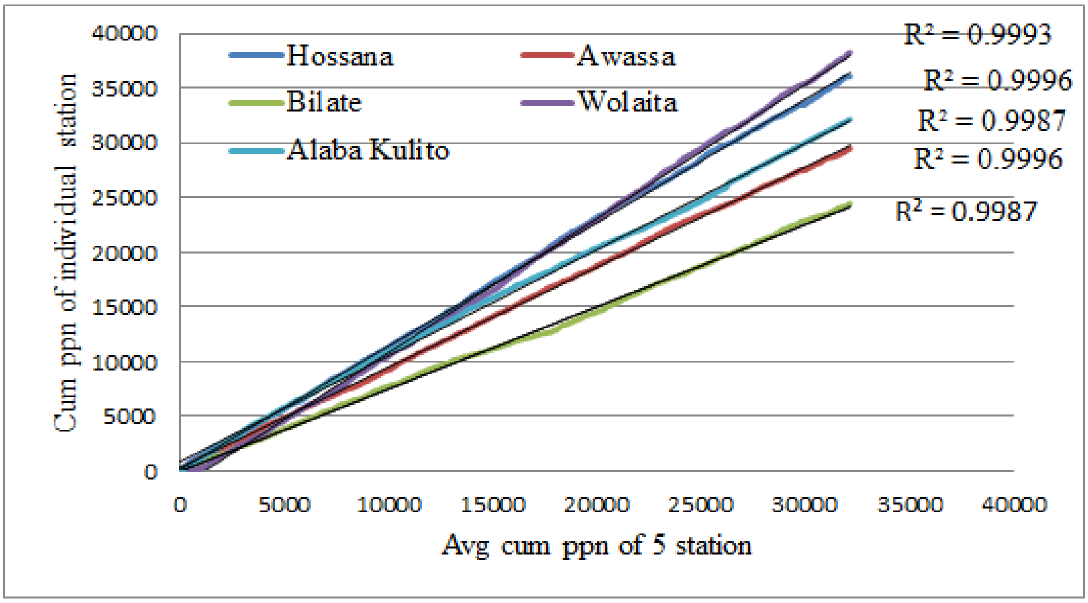

Figure 8 Double mass curve of 5 stations of study area

3.5.2 Homogeneity test

Data quality assurance would be ensured during data collection, coding, entry and analysis. The appropriate Measures should be taken on time for completeness before data entry, and the data collectors should be well informed about the respondents to keep the secret of their response to avoid bias of the information obtained. The purpose of homogeneity test is to check quality of data collected from different sources and to identify a change in the statistical properties of the time series data which is caused by either natural or man-made factors before using it to avoid convolution in results. RAINBOW is a software package developed by the Institute for Land and Water Management of the K.U. Leuven in order to test the homogeneity of hydrological and meteorological records and to execute a frequency analysis of rainfall and evaporation data based on the adjusted partial sums or cumulative deviations from the mean. For this study RAINBOW software which was based on the cumulative deviation from the mean was used to check the homogeneity of data because it is easy to install and use and if the range of cumulative deviation and maximum cumulative deviation shows No, it shows the data was homogenous.

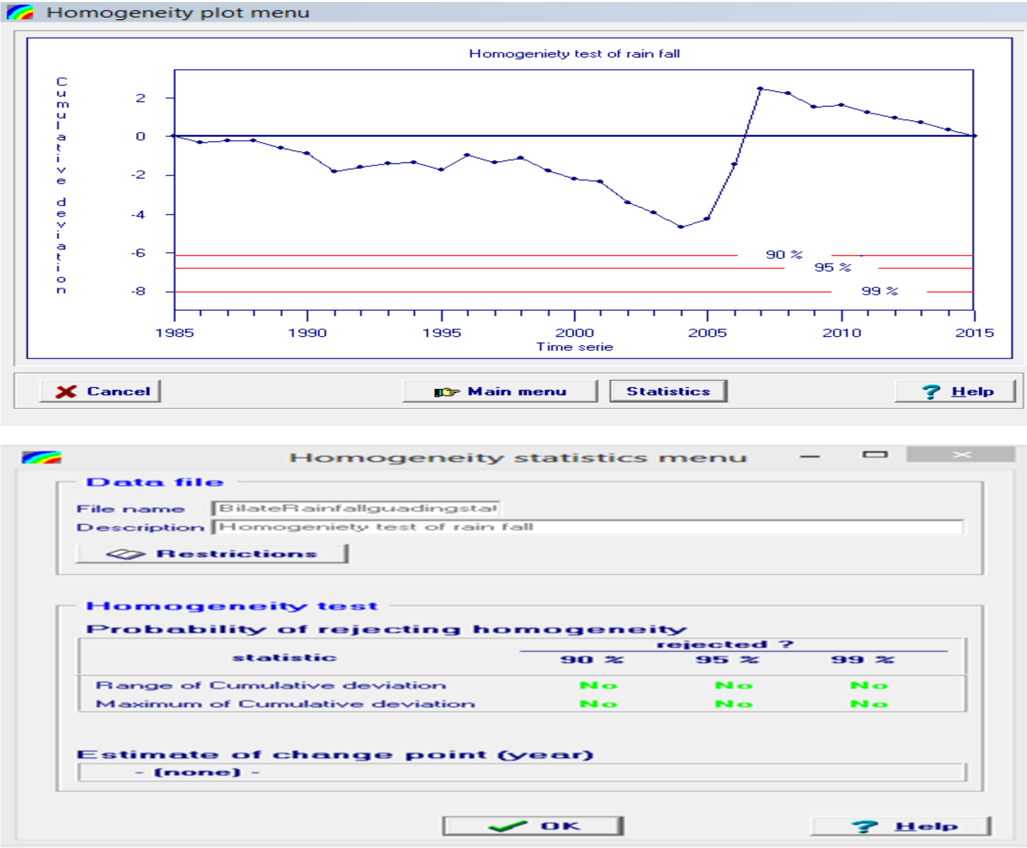

Figure 9 Homogeneity test of data using RAINBOW

3.6 Materials used

To achieve the objectives of this study, different tools were used for data processing and analyzing. The materials listed below are used in this research.

Arc-GIS-10.1 version: was used for capturing, storing, analyzing and displaying geographically referenced information.

Arc SWAT of 2012 version was used to predict the impact of land management practices on water, runoff and sediment yields in the watersheds with varying soils, land use and to evaluate best management practices in the watershed.

SWAT-Calibration and Uncertainty Programs (SWAT_CUP) - is a computer program used for the calibration, Validation, sensitivity analysis and uncertainty analysis of the SWAT model. In this study SWAT_CUP of version 5.2 with SUFI-2 algorithm was used.

PCPSTAT: Used to calculate the daily statical parameters of daily precipitation data used by weather generator of SWAT model.

Dew02: Used to calculate the average daily dew point temperature per month using daily air temperature and humidity data.

Rainbow: was used to test the homogeneity of hydrological and meteorological data.

3.7 Preparation of SWAT model input data

The SWAT model build up process involves the preparation of the input data. This input data is classified mainly as spatial data (DEM, land use land cover, soil map), weather data (rainfall, maximum and minimum temperature, relative humidity, solar radiation and wind speed) and hydrological data (stream flow and sediment concentration). Spatial data is usually prepared in a GIS environment, which allows a relatively comfortable unification of all relevant maps of the watershed. The maps of the study area such as DEM, soil and land use land cover map was processed using Arc GIS; all layers have the same coordinates and projection systems. A user lookup table was created that identifies the SWAT code for different categories of Land use/Land cover and soil type on the map as per the required format. The meteorological station in the study area which has full data has been selected to be principal station for the weather generator. This principal station was Hossana station. The statistical variables of meteorological data generation system (weather generator data) have been calculated using Excel, PCPSTAT and dew 02. The missing Values which are common in the existing data sets were filled with no dataset indicator (-99) and generated by the Program inserted in the model. The geographical coordinate names of the weather stations of the study area were introduced into Arc SWAT database. The prepared weather generator parameters have been loaded into a WGEN-user of SWAT database. Solar radiation is converted from sun shine hour based on the latitude of the location, monthly average daily bright sunshine duration and the monthly average maximum possible daily bright sunshine duration. Finally, stream flow and sediment load observations, which is vital for calibration and validation target, were prepared consequently.

3.8 Model setup

Arc SWAT 2012, with an interface in ArcGIS 10.1, were used to setup the model in this work. The model setup includes: watershed delineation, HRU definition, editing weather input tables, editing SWAT input and SWAT simulation carried out step by step.

3.8.1 Watershed delineation

The first step in creating SWAT model input is delineation of the watershed from DEM. Inputs entered into the SWAT model were organized to have spatial characteristics. Before going to process with spatial input data (soil map, land use land cover map and the DEM) have to be projected into the same projection called UTM Zone 37N, which is projection parameter for Ethiopia. A watershed was divided into 29 sub-basins, for modeling purposes. The watershed delineation process include five major steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition and calculation of sub-basin parameters. For the stream definition of this study, the threshold area of 10000ha was used. As thresh hold area decreases, the number of HRUs and sub basins decrease. Based on the above information and the selected outlet point the model automatically delineated a watershed area with in the 29 sub-basins.

3.8.2 Hydrological Response Units (HRUs)

After watershed delineation, HRU definition is going to be prepared before passing to the next steps. The Hydrologic Response Unit in the Arc SWAT requires the land use, soil maps to be loaded to the project and classification of the slope of the sub basins. The land use, soil and slope map was reclassified in order to correspond with the parameters in the SWAT database. After reclassifying the land use, soil and slope in SWAT database, all these physical properties were made to be overlaid for HRU definition. 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. Land uses, soils or slopes which cover less than the threshold level are eliminated. For this specific study a 5% threshold value for land use, 5% for soil and 10% for slope were used.

3.8.3 Importing input data

The weather variables required by SWAT are daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate text format and these input variables imported together with their weather location.

3.8.4 SWAT Simulation

SWAT simulation run was carried out for 30 years which is from 1986-2015 weather data. Three year data was kept as warm up period. The warm-up period is important to make sure that there are no effects from the initial conditions in the model. It enables the establishment of the basic flow conditions for the simulations to occur and brings the hydrologic processes to an equilibrium condition. The run output data imported to database and the simulation results were saved in the files of SWAT output. From the generated output of SWAT, sensitivity analysis, calibration and validation were monitored using SWAT-CUP to evaluate the model performance.

3.8.5 Sensitivity analysis

When SWAT model simulation took place, there was a variation between measured data and simulated results. So, to minimize this variation, it was required to identify parameters that mostly affect the results and the level of variation. Hence, Sensitivity analysis as a mechanism for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty. In this study, sensitivity analysis of stream flow and sediment yield was performed by SWAT_CUP using SUFI-2 algorithm. Global sensitivity analysis used t-test and p-values to determine the sensitivity of each parameter for both stream flow and sediment yield. The t-test provides a measure of the sensitivity (larger in absolute values are more sensitive) and the p-values determine the significance of the sensitivity.

3.9 Calibration

Calibration is an integral part of the modeling process, as it is in practice impossible to measure all hydrological properties of a system. In general, model calibration aims to ensure that model components such as hydrological processes and parameters to keep their physical meaning; however results are influenced by multiple sources of uncertainty (uncertainty in the data, model parameters and model structure). It is therefore important to develop models that can better exploit the information content of the available data. For this study Sequential uncertainty Fitting (SUFI2) was used to get the best model parameters. Before selection of sensitive parameters the mean and standard deviation of observed and simulated data was checked to know how much they are approximate to each other. After sensitive parameters have been identified, calibration process was applied. Stream flow calibration was carried out for a period of 18years, which included both the calibration period from 1989 to 2003, and the warm up period from 1986 to 1988 for stream flow and 1993 to 2003 and the warm up period from 1990 to 1992 for sediment. Calibration took place until the minimum recommended model evaluation parameters of R^2, NSE, RSR and PBIAS were attained.

3.10 Validation

Validation takes place after calibration to test if the model performs well on a portion of data, which was not used in calibration. Model verification aims to validate the model's strength and ability to describe the catchment's hydrological response, and further detect any biases in the calibrated parameters. In this study, stream flow and sediment yield validation was performed without any further adjustment of calibrated parameters. The statistical criteria of R^2, NSE, RSR and PBIAS were used in the validation procedure to make sure that the validated result is within the given bounds.

3.11 Evaluation of SWAT model

It was difficult to specify ranges of values of the goodness-of-fit indicators that determine whether a model simulation is acceptable, good, or very good. Calibration and validation of stream flow and sediment yield can be compared both graphically and statistically. A graphical display of simulated and observed flow or sediment data is a key way of model performance testing than evaluating model performance by statistical measures with limitations. Statistical indices are not effective on explaining qualitative information, such as, types of errors and distribution patterns or trends. So, the result not depend on a single statistical measure of model performance alone, which is sometimes confusing because of the high possibility of compensation of errors from season to season or over years in a long term calibration but graphical representation gives hint to identify the degree of variation between observed and simulated data. On both calibration and validation processes the simulated and observed hydrographs have been compared graphically. Evaluation using statistically is used to determine the quality and reliability of predictions when compared to observed values. Coefficients of a determination (R^2), Nash-Sutcliffe simulation efficiency (NSE), Percent bias (PBIAS) and Root mean Square Error Standard Deviation Ratio (RSR) were used as measure of the goodness of fit to evaluate model prediction. The regression coefficient (R^2): is the square of the Pearson product moment correlation coefficient and implies the proportion of the total variance in the observed data that can be explained by the model. The R^2 value is an indicator of strength of relationship between the observed and simulated values. The closer the value of R^2 to 1 implies the higher the agreement between the simulated and measured data.

$$R^2 = \frac{\sum(Xi-Xav)(Yi-Yav)}{\sqrt{\sum(Xi-Xav)2}\sqrt{\sum(Yi-Yav)2}} ------------------------3.3$$

Where: Xi is measured value, Yi is simulated value and Xav is average of measured value. The Nash-Sutcliffe simulation efficiency (NSE): indicates how well the plot of observed versus simulated value fits the 1:1 line. If the measured value is the same as all predictions, NSE is 1. If the value of NSE is negative, predictions are very poor, and the average value of output is a better estimated than the model prediction. NSE is between 0 and 1; it indicates deviations between measured and predicted value and computed as follows (Nash and Sutcliffe, 1970).

$$NSE = 1 - \frac{\sum(Xi-Yi)2}{\sum(Xi-Xav)2} -------------------------3.4$$

Where: Xi is measured value, Yi is simulated value.

Percent bias (PBIAS): evaluates the average tendency of the simulated output data to be larger or smaller their observed data equivalents, being the optimum value zero, while, low magnitude values indicating accurate model simulation. Positive values imply model underestimation bias, and a negative value indicates model overestimation bias and computed as follows (Gupta *et al.*, 2005).

$$\frac{PBIAS = 100(\sum Yi - \sum Xi)}{\sum Xi} ------------------------3.5$$

Where: Xi is measured value, Yi is simulated value

Root mean Square Error Standard Deviation Ratio (RSR):-is calculated as the ratio of Root Mean Square Error (RSR) and standard deviation of measured data. RSR is an error index indicator. RSR ranges from 0 to 1, with the lower value closer to zero indicating the higher accuracy of the model performance. Values approaching 1 indicate a poor model performance.

$$RSR = \frac{RMSE}{STDEVobs} = \frac{\sqrt{\sum_{i=1}^{m}(Yi-Xi)2}}{\sqrt{\sum_{i=1}^{m}(Xi-Xm)2}} ----------------------3.6$$

Where, *Xi* – measured value, *Yi* – simulated value and Xm is average measured value

According to Moriasi *et al*. (2007), the model performance evaluation criteria are listed in the table below.

Table 3 Model performance evaluation criteria

Rating	R^2	RSR	NSE	PBIAS	
				Flow	Sediment
Very good	0.75-1	0-0.5	0.75-1	<10%	<15%
Good	0.65-0.76	0.5-0.6	0.65-0.76	10%-15%	15%-30%
Satisfactory	0.5-0.65	0.61-0.7	0.5-0.66	16-25%	31%-55%
Unsatisfactory	<0.6	>0.7	<0.5	>25%	>55%

3.12 Uncertainty analysis

Uncertainty of the model estimation rise from model parameters, model itself and input data. Uncertainty analysis algorithms used to decrease model uncertainty by eliminating some probable source of modeling and calibration errors. Uncertainties can be quantified in SUFI-2 by a measure of p - factor and r - factor. The p-factor is the percentage of measured data bracketed by 95PPU or 95% prediction uncertainty. Whereas, r- factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The larger absolute values are more sensitive than the lower ones. It means r-factor measures the strength of uncertainty analysis in the calibration. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the p-factor. A p-factor of 1 and r-factor of zero is a simulation that highly corresponds to measured data. Theoretically, the value for p-factor ranges between 0 and 100%, while that of r-factor ranges between 0 and infinity. A larger p-factor can be achieved at the expense of a larger r- factor. Hence, often a balance must be reached between the two and values of r-factor and p-factor are reached, then the parameter uncertainties are in the desired parameter ranges.

3.13 Best management practices

Catchment management practices involved to introduce best management practices (BMPs) to reduce soil erosion and sediment transport. These BMPs were represented in the SWAT model under edit option by modifying SWAT parameters to reflect the effect, the practice has on the processes simulated within SWAT. Implementation of watershed management plan provides the necessary measures for protecting the catchments from sedimentation. Each of the BMPs has a different effect on flow and sediment with distinct representation of parameters. However, selection of BMPs and their parameters values is site specific and should reflect the study area reality. For this study, three management practices were selected based on their ability to reduce sediment yield stated in different literature are described as follows. Grassed water ways: are natural or constructed channels of dense and deep-rooted grass species established along the bottom perimeters of upland agricultural fields to drain and retard surface runoff while preventing formation of gullies and runoff erosion along the waterways. Differences in land availability and ownership, land topography, climate, vegetation, and tillage and cropping systems influence the capacity of grass waterways. Simulation of sediment yield in SWAT model with application of grassed waterway requires adjustment of grassed waterway parameters like length (GWAT_L), average slope (GWAT_S), depth (GWAT_D), manning's roughness coefficient (GWAT_N), average width (GWAT_W) and linear factor for the channel sediment routing (GWAT_SPCON). Waterways are designed using the continuity equation and open channel flow theory.

$Q=A*V$--3.7

Where, Q is rate of runoff (m^3/ s), A is area of the waterway (m^2), and V is velocity of runoff (m/ s) which is computed using the Manning's equation and velocity is given by:

$V=R^{2/3}S^{1/2}$ --3.8

Where, R is waterway hydraulic radius (m), S is waterway slope (m/m m), and n is vegetation roughness.

Filter strips: Dense vegetation is installed along the perimeter of the field to intercept and filter surface runoff, Sediment and nutrient loads are trapped in the strip vegetation. In SWAT model filter strip parameters such as flag for filter strips (VFSI), ratio of field area to filter strip area (FILTER_RATIO), fraction of HRU which drains to most concentrated ten percent of the filter strip area (FILTER_CON) and fraction of flow within the most concentrated ten percent of filter strip which is fully channelized (FILTER_CH) were adjusted. The SWAT calculates trapping efficiency (trapef) for sediment and the parameter FILTERW, which indicates the width of the vegetation strip and the amount of sediment trapped respectively as follows:

$trapef = 0.367*FILTERW^{0.2967}$---3.9

$$Y = 2.23 \exp(-0.26X) \quad \text{------} 3.10$$

Where, Y is amount of sediment trapped and X is width of grass strip.

Contouring: Contour planting practices entail tilling and planting crops, delineating the contour of the field to increase soil infiltration capacity, intercept surface runoff and reduce sediment and nutrient losses. In the present study, contour planting was simulated by activating the contouring option in the scheduled management operations tool (.ops) for the non-woody agricultural land uses in the SWAT. The main parameters for simulating contour planting in the SWAT model are curve number (CONT_CN) and USLE Practice factor (CONT_P).

3.14 Conceptual frame works of the study

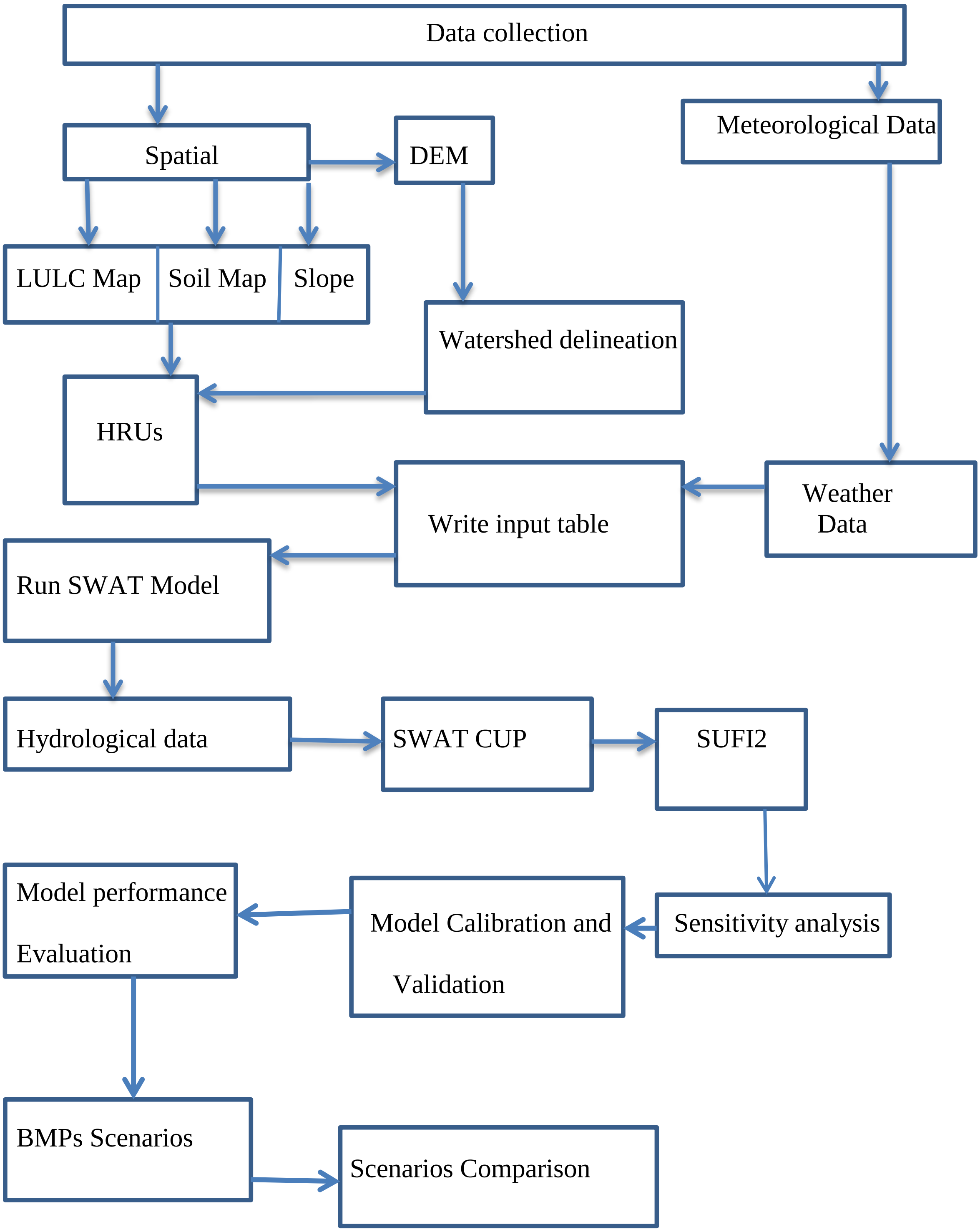

Figure 10 Conceptual frame work of the study

4 RESULTS AND DISCUSSION

SWAT model was used to estimate the amount of runoff and sediment yield in the catchment. To estimate the results of runoff and sediment, 30 years meteorological data (1986 to 2015), DEM, LULC, and Soil of the study area was used as input to the model. Based on this in put the model divided the watershed into 29 Sub basins and 478 HRUs and calculated the average annual runoff and sediment yield. Calibration and validation was carried out for both stream flow and sediment yield using SWAT CUP with SUFI2- algorithms to check/correlate how much simulate data agree with observed data.

4.1 Stream flow modeling

4.1.1 Sensitivity Analysis

Sensitivity analysis was carried out to identify which model parameter is most important or sensitive to change stream flow. Flow sensitivity analysis was carried out for a period of 18 years, which includes both the calibration period (1989 to 2003) and three year of warm-up period (1986 to 1988).During sensitivity analysis 20 parameters like (CN2, GWQMN, ALPHA_BF and etc) were tested for flow. From the tested sensitivity results about eleven parameters which have more effect on the simulated values were considered for calibration and shown in the table below.

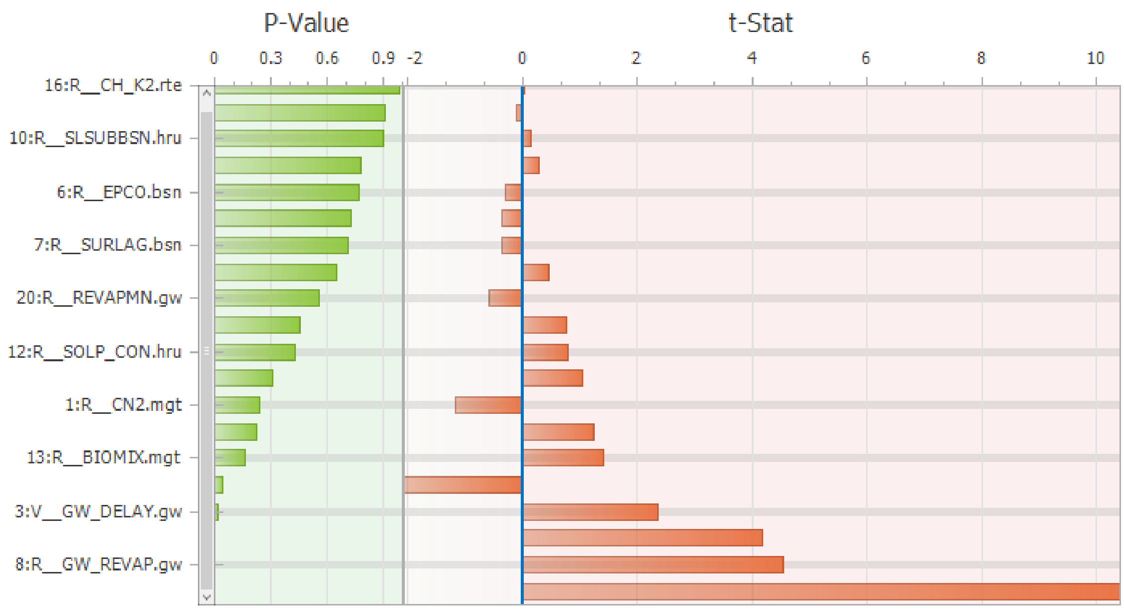

Figure 11 Graphical view of flow sensitive parameters

4.1.2 Stream Flow Calibration

Even if there exists a number of flow gauging stations in Bilate watershed, considering the availability of reliable data, Alaba kulito station was selected and used for calibration. The flow calibration was carried out 18 years (1989 to 2003) including 3 years warm up periods (1986 to 1988).using selected most sensitive parameters, it was carried out up to observed and simulated values falls under their range using four performance evaluation criteria's and the result showed that, correlation coefficient (R^2) of 0.82, Nash–Sutcliffe simulation efficiency (NSE) of 0.7, Root mean Square Error Standard Deviation Ratio (RSR) of 0.6 and PBIAS of -15.4% and this shows there was a good agreement between measured and simulated monthly flows. The calibration result demonstrates the SWAT's ability to predict realistic flow. The uncertainty of parameters quantified in SUFI-2 by measuring p and r-factor showed the result of p-factor of 0.76(the percentage of observed data being bracketed by 95PPU during calibration was 76%) and r-factor of 0.41. As shown below in the figure, the model slightly over estimated the flow in large part and under estimated the flow in small areas and this indicates that was uncertainty, and this might be due to many reasons but most likely it is due to Curve Number (CN2) method that is used to predict the surface runoff and also which might be resulted from the quality of weather or flow data used as an input to the model, the model itself and the others.

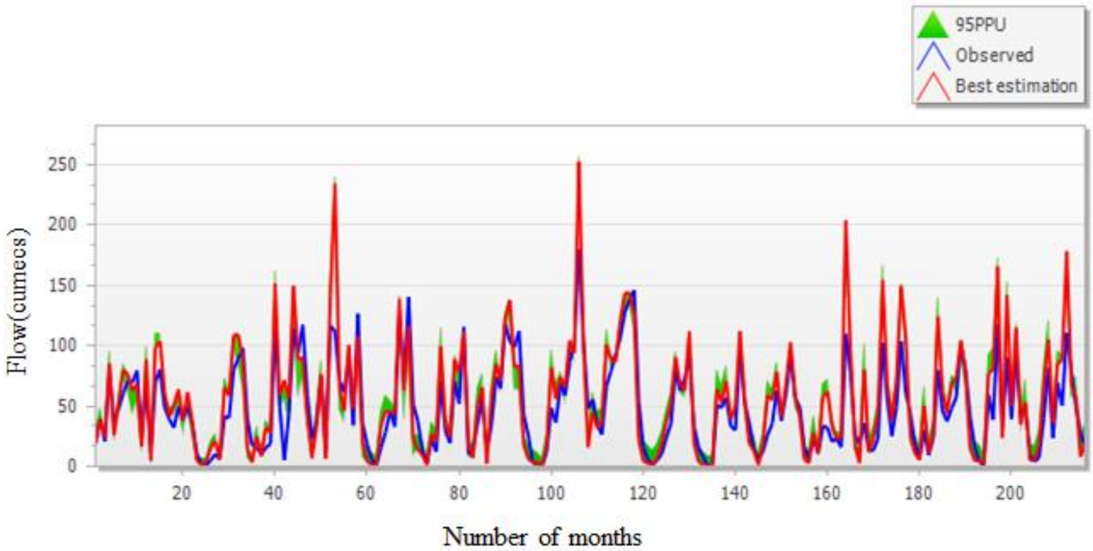

Figure 12 Monthly calibrated hydrograph of flow (1989-2003)

4.1.3 Stream Flow Validation

After calibration, the model with calibrated parameters was validated by using an independent set of measured flow data which were not used during model calibration. Flow validation was carried out from 2004 to 2015 without further adjustment of the parameters of flows used in calibration. Accordingly, good relationship between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient (R^2) of 0.77, Nash - Sutcliffe simulation efficiency (ENS) of 0.65, Root mean Square Error Standard Deviation Ratio (RSR) of 0.54 and a Percent bias of monthly flow was found to be -14.1%.The uncertainty of parameters measured by using p-factor and r-factor showed that the p-factor of 0.71 and r-factor of 0.45 during validation. This shows that the percentage of observed data being bracketed by 95PPU during validation was 71%. The hydrograph for the validation period of the observed and simulated flow in a monthly base estimation, the model slightly over estimated and under estimated similarly during validation. This might be resulted from lack of quality of weather or flow data used as an input to the model because, Some of the stations have many missing weather data which were left to be estimated and filled by the model's weather generator and inaccuracy in measurement of flow and weather data may be another reason for the slight variation between measured and simulated flows.

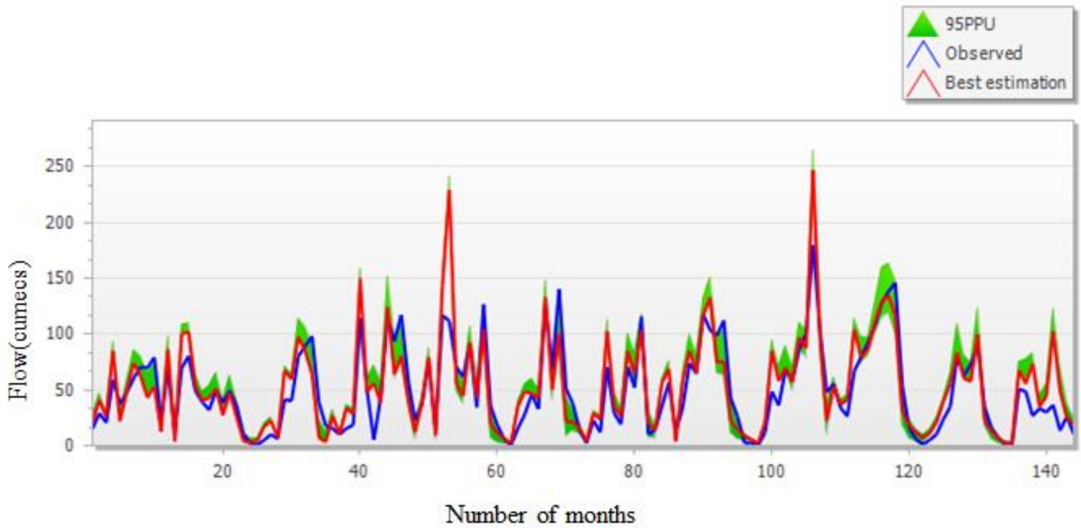

Figure 13 Monthly validated hydrograph of flow (2004-2015)

4.2 Sediment yield modeling

4.2.1 Sensitivity Analysis

Sensitivity analysis was carried out for sediment to identify parameters that mostly affect sediment yield. Sediment sensitivity analysis was carried out for a period of 9 years, which includes the calibration period of (1993 to 1998) and 3 years warm up period (1990 to 1992). From Sensitive parameters used in simulation twelve were used for calibration of sediment yield in the watershed from global sensitivity of SWATCUP and are shown below in table-7.

Table 4 Sensitive parameters used in sediment calibration

Rank	Parameters	Description	Range value	Fitted value
1	CANMX	Maximum canopy storage	0-10	0.41
2	CN2	SCS runoff curve umber	35-98	49
3	SPCON	Linear factor for channel sediment routing	0.0001-0.01	0.0032
4	SPEXP	Exponent factor for channel sediment routing	0-1	0.706
5	CH_COV1	Channel erodibility factor	0-1	0.415
6	PHOSKD	Phosphorus partitioning coefficient	100-200	139.64
7	USLE_P	USLE support practice factor	0-1	0.076
8	TIMP	Snow pack temperature lag factor	0-1	0.038
9	GW_REVAP	Groundwater revap coefficient	0.02-0.2	0.085
10	CH_COV2	Channel cover factor	0-1	0.292
11	SMTMP	Snow melt base temperature	0-5	2.187
12	SOLP_CON	Soluble phosphorus concentration	0-1	0.534

4.2.2 Sediment Yield Calibration

After identification of the most sensitive parameters of sediment, the next step was calibrating sediment yield of the watershed. Like Flow, sediment calibration for the Bilate watershed by comparing monthly model simulated sediment load against monthly sediment load generated by using sediment rating curve from Alaba kulito gauging station for the period 1990 to 1998. The calibration of sediment yield of the watershed was done based on sediment sensitivity analysis which was identified as the most sensitive parameters for sediment yield of the watershed shown above in the table. By varying the iteration within the allowable ranges of the parameters, for each run and sediment parameter change, the corresponding goodness of fit statistics were checked. Moreover, the fit between simulated and observed sediment was checked graphically. The process of calibration was continued until the value of model performance criteria are in the tolerable ranges. After adjustment of all the above parameters, the monthly calibration was resulted Coefficient of determination (R^2) of 0.74, Nash– Sutcliffe Coefficients (NSE) of 0.71, Root mean Square Error Standard Deviation Ratio (RSR) of 0.6 and percent of bias (PBIAS) of -34.8%. The uncertainty measure of SUFI-2 algorithm showed that the p-factor of 0.72 and r-factor of 0.53.The observed and calibrated sediment yield in monthly basis were plotted for visual comparison to explore the similarity within the peak values resulting from the procedures of SUFI-2 algorithm and it is shown that the model highly over predicted the sediment during simulation. Due to scarcity of observed sediment data in the watershed sediment rating curve was developed and this made high uncertainty in the result as shown below in the figure.

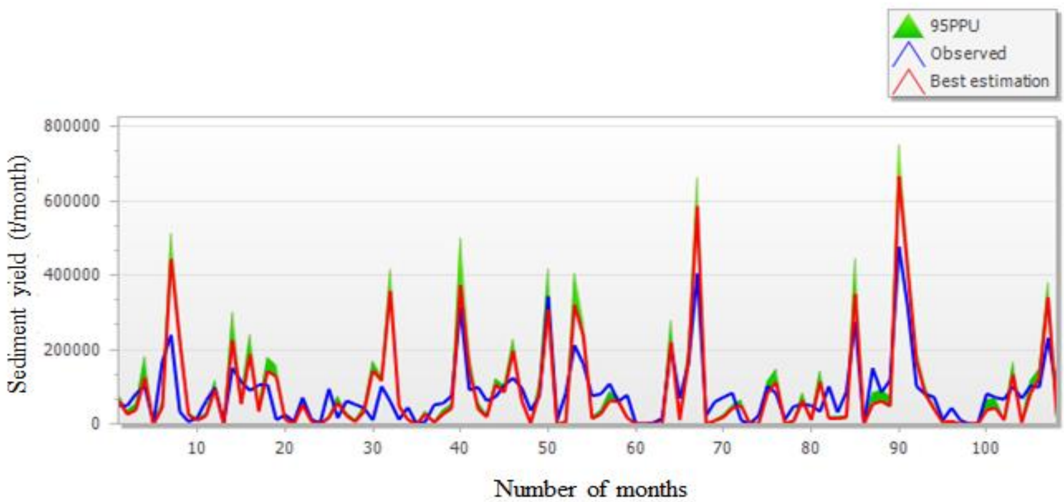

Figure 14 Monthly hydrograph of sediment yield (1990-1998)

4.2.3 Sediment Yield Validation

Validation of sediment yield in the watershed was carried out for the years of 1999 to 2004. An independent sediment measurement data that was not used in sediment calibration was used to validate sediment yield with those parameters adjusted during calibration. In the validation period, good approximation between simulated and measured sediment was demonstrated by correlation coefficient (R^2) of 0.72, Nash-Sutcliffe model efficiency (NSE) of 0.68, Root mean Square Error Standard Deviation Ratio (RSR) of 0.57 and Percent bias (PBIAS) of -31.3%. The uncertainty measure of SUFI-2 indicated that the p-factor of 0.63 and r-factor of 0.57.The validation statistics indicate that calibrated SWAT model can simulate sediment yield satisfactorily outside the calibration period. The observed and simulated sediment yield in monthly time step of the validation period shows that model highly overestimated the sediment yields in some months and in other months it under predicted slightly and these was result of scarcity of observed data, variation due to rainfall intensity, duration, land use land cover etc. The average annual runoff and sediment yield from Bilate watershed was 292mm/ha/y and 53.4t/ha/y respectively.

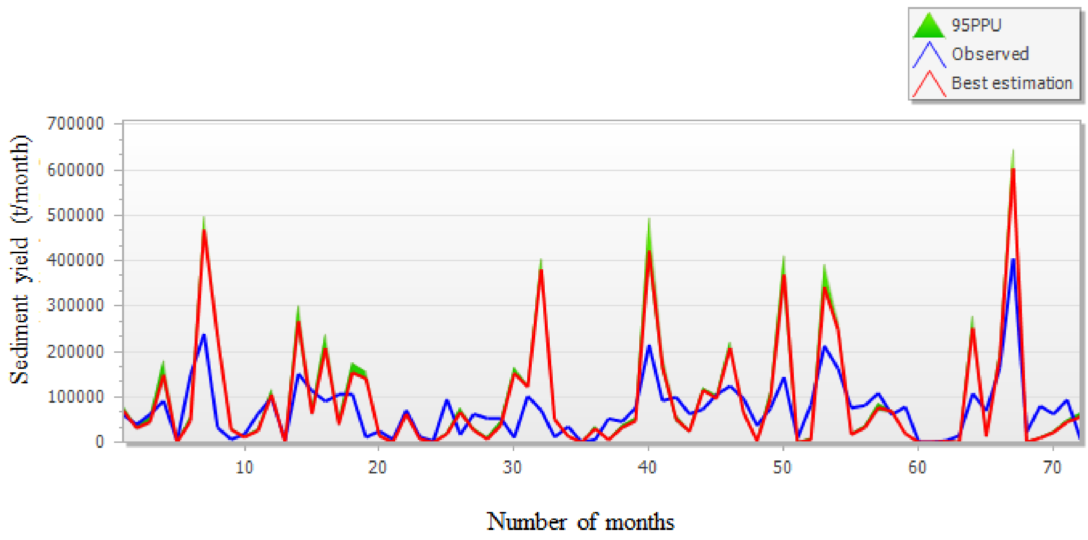

Figure 15 Monthly hydrograph of sediment yield (1999-2004)

4.2.4 Comparing observed and simulated daily sediment data

Developing sediment rating curve from stream flow might increase Uncertainty between observed and simulated data. In order to understand the relationship between observed and simulated data and to minimize uncertainty the graph of daily measured available data and simulated daily data for the same corresponding day using excel sheet was carried out. The visual observation from the graph below shows that the correlation between observed and simulated data is higher than that of sediment yield calibrated and validated.

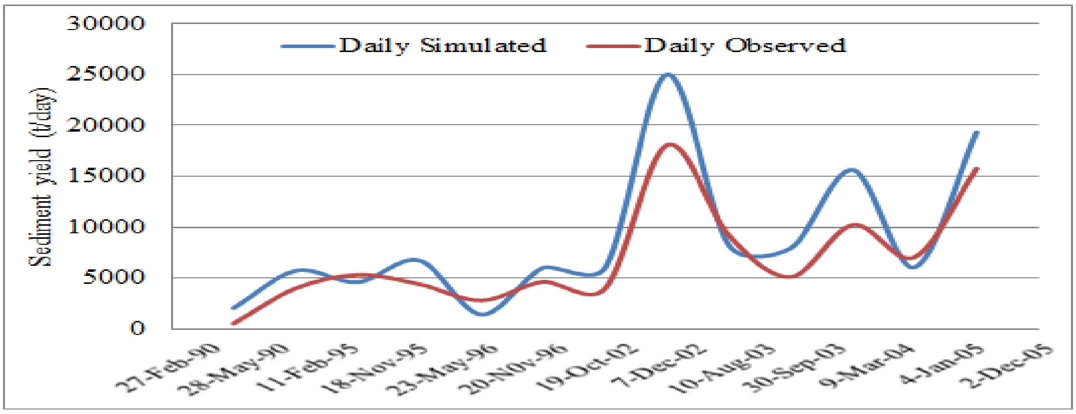

Figure 16 Graph of observed and simulated sediment data for recorded period

4.3 Spatial and temporal variability of runoff and sediment yield

4.3.1 Spatial Variability of runoff

Spatial variability of runoff took place due to rainfall intensity, rainfall amount, , Direction of storm movement, land use, vegetation, soil type, drainage area, basin shape, elevation, slope, topography and etc. Based on this and other factors runoff varies from place to place in this watershed. As shown in the figure below, the average yearly maximum runoff generated from Sub basin 14 was 426mm and this might be due to poor LULC, less infiltration capacity of the soil, poor management systems, steep slope and etc in that Sub basin and the minimum average yearly runoff was generated from Sub basin 20 was 49mm and this is existing soil condition, land use land cover and management practices have high ability to retard runoff.

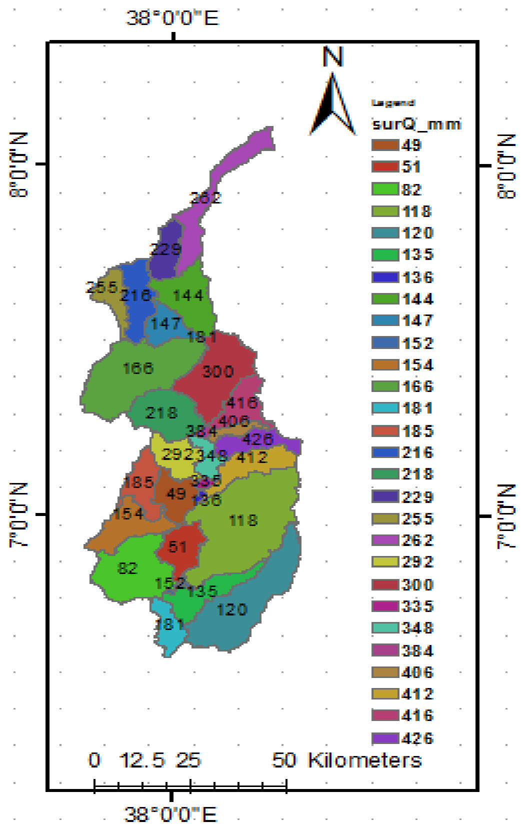

Figure 17 Spatial variability of runoff

4.3.2 Spatial Variability of sediment yield

The spatial variation of sediment yield in the catchment was due to topographic condition, slope variation LULC variation and other related factors. The figure below shows the spatial variation of sediment yield. The Sub basin 23 has small amount of sediment yield which was 4t/ha/y and that of 9 has high sediment yield (83t/ha/y). Most of the time if the Sub basin has low elevation it has tendency to take high amount of sediment yield. The result showed the range of sediment yield in Sub basins was between 4.076 to 83.286 tons/ha/year with average sediment yield of 53.4 ton/ha/y. Spatial variability of sediment yield map shown below was generated using average annual sediment yield based on sediment yield potential.

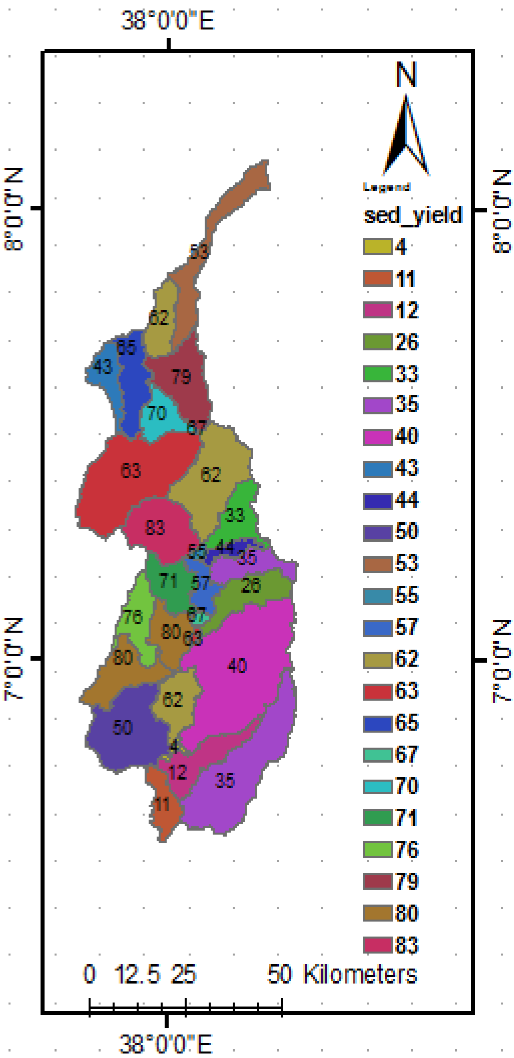

Figure 18 Spatial variability of sediment yield

Referring different researches, I tried to classify the amount of sediment generated in the watershed into different classes. Based on this from the total twenty nine sub basins twenty five sub basins producing sediment yield from medium to sever (40.405-83.286 ton/ha/year) and identified as sediment prone areas. Out of these critical sub basins, fifteen were sever (61.66-83.286 ton/ha/year), four were high (50.41-56.545 ton/ha/year) and six were medium (33.02-43.96 ton/ha/year) as shown below in the figure.

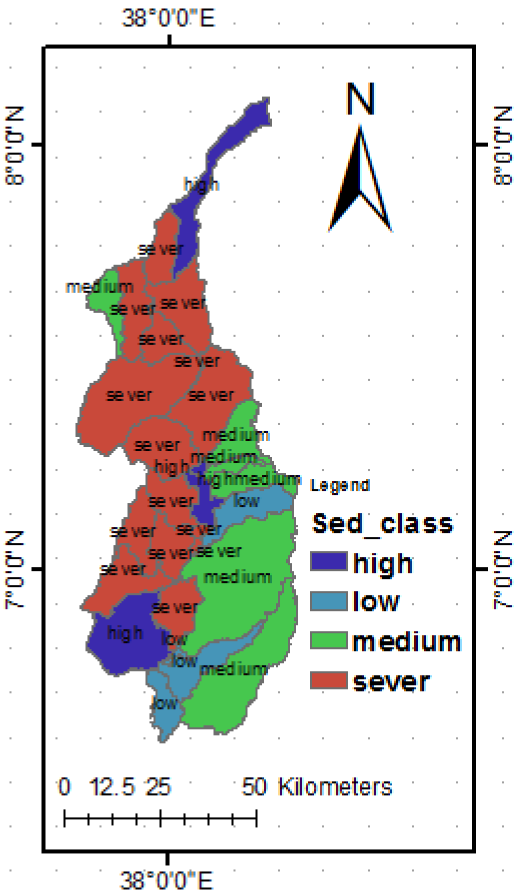

Figure 19 Severity of sediment yield

4.3.3 Temporal Variability of runoff

Runoff varies from season to season based on the amount of rainfall, soil type, land use land cover, topography and other factors directly or indirectly affecting it. The figure shows that runoff varies randomly in the catchment and the maximum runoff took place in the month of August and the minimum runoff took place in the month of January and this match's with our countries rainfall distribution condition. This shows that in the month of August, soil moisture content is high and infiltration capacity is low. In the month of January, soil is dry and requires large amount of precipitation to rich moisture condition.

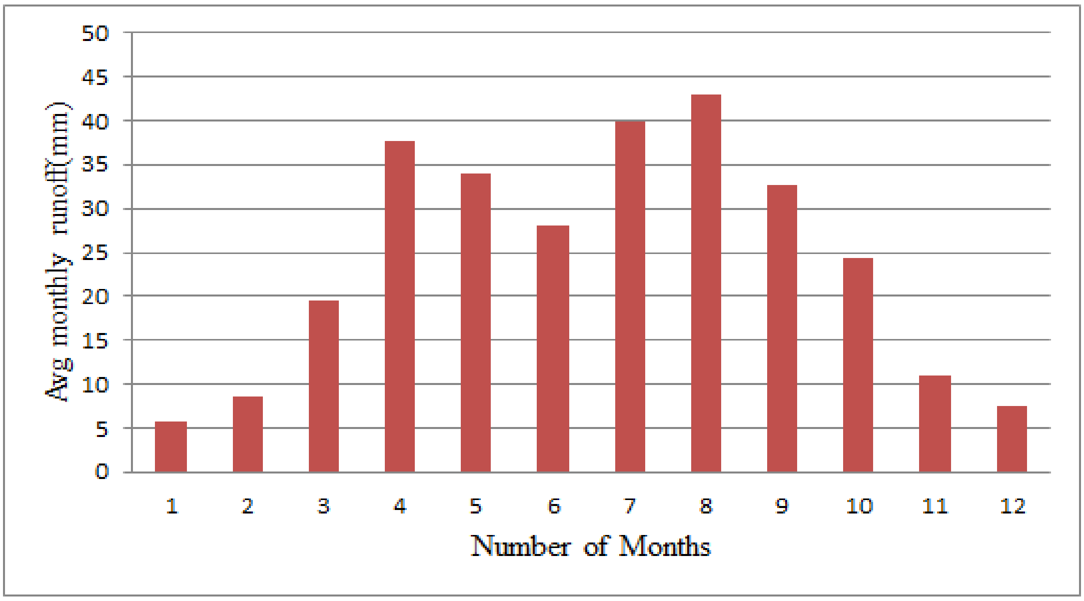

Figure 20 Temporal variability of runoff

4.3.4 Temporal Variability of sediment

Temporal variability of sediment yield highly correlated with precipitation and surface runoff. Due to weather condition variation, the amount of rainfall in the watershed and existing condition of LULC and soil density varies from season to season and these variation results in alteration of sediment yield from time to time. It was witnessed that the highest sediment yield was observed during the months of August and whereas the lowest sediment yield was observed during the month of December as shown below in the figure.

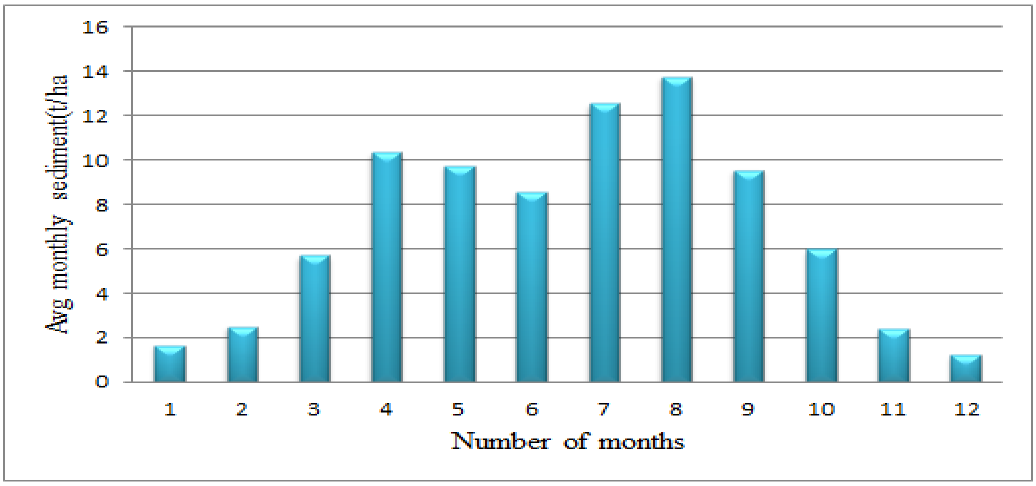

Figure 21 Temporal variability of sediment yield

4.4 Effects of Best management Practices

Once the sediment prone area is identified, the next step is evolving sediment reduction methods for affected sub basins in order to reduce sediment yields. The scenarios developed for the selected mitigation measures were discussed below.

4.4.1 Baseline Scenario

Baseline scenario assumed to reflect the current land management practices without conservation measures. Each scenario runs for the same simulation period (1986-2015) to provide reliable basis for comparison of scenario results. The histogram below shows the non-uniform distribution of sediment yield in Sub basins.

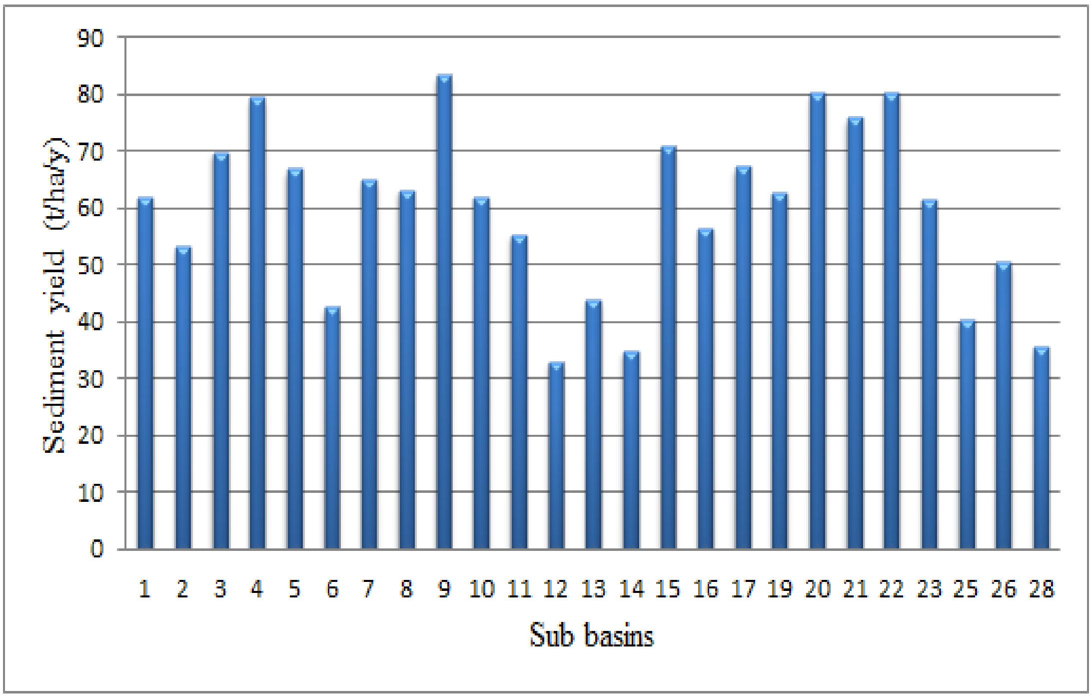

Figure 22 Critical sub basins mean sediment yield for baseline scenarios

4.4.2 Scenario I: Grassed Waterway

Simulation of sediment yield in SWAT model with application of grassed waterway requires adjustment of grassed waterway parameters like length (GWAT_L), average slope (GWAT_S), depth (GWAT_D), manning's roughness coefficient (GWAT_N), average width (GWAT_W) and linear factor for the channel sediment routing (GWAT_SPCON). Application of grassed waterways for the critical sediment prone sub basins with width of 5m was reduced average annual sediment yield from 59.8ton/ha/year to 16ton/ha/year (73.2%) and at entire watershed it reduced the sediment yield from 53.4 ton/ha/year to 14ton/ha/year. In this scenario, all sediment prone sub basins changed from the category of sever high and medium to the low and very low sediment yielding as shown below in the table.

Table 5 Grassed waterway scenarios for selected prone sub basins

Selected critical sub basin	Base line condition	Grassed water way(5m)	Sediment yield reduction in Percent (%)
9	83.286	22.214	73.3
22	80.436	21.286	73.5
20	80.278	20.996	73.8
4	79.37	20.478	74.2
21	75.865	19.729	74.0
15	70.826	18.946	73.2
3	69.76	18.711	73.2
17	67.244	18.343	72.7
5	66.862	17.617	73.7
7	64.854	17.575	72.9
8	63.148	17.487	72.3
19	62.659	16.979	72.9
10	61.945	16.809	72.9
1	61.822	16.55	73.2
23	61.659	15.874	74.3
16	56.545	15.367	72.8
11	55.247	15.186	72.5
2	53.184	14.367	73.0
26	50.408	13.047	74.1
13	43.965	12.053	72.6
6	42.532	11.507	72.9
25	40.405	10.785	73.3
28	35.394	9.642	72.8
14	34.813	9.453	72.8
12	33.02	8.965	72.8
Average	59.8	16	73.2

4.4.3 Scenario II: Filter Strip

In SWAT model filter strip parameters such as flag for filter strips (VFSI), ratio of field area to filter strip area (FILTER_RATIO), fraction of HRU which drains to most concentrated ten percent of the filter strip area (FILTER_CON) and fraction of flow within the most concentrated ten percent of filter strip which is fully channelized (FILTER_CH) were adjusted. Applying filter strips with 10m width for the twenty five sediment prone sub basins brought average sediment reduction of 82.3% (59.8ton/ha/year to 10.56ton/ha/year). At entire watershed level the reduction was from53.4 ton/ha/year to 9.5ton/ha/year. In this case, all sediment critical sub basins changed from the category of sever, high and medium to the low and very low sediment yielding.

Table 6 Filter strip scenarios for selected prone sub basins

Selected critical sub basin	Base line condition	Filter strip(10m)	Sediment yield reduction in Percent (%)
9	83.286	14.663	82.4
22	80.436	14.05	82.5
20	80.278	13.858	82.7
4	79.37	13.516	83.0
21	75.865	13.022	82.8
15	70.826	12.505	82.3
3	69.76	12.35	82.3
17	67.244	12.107	82.0
5	66.862	11.628	82.6
7	64.854	11.6	82.1
8	63.148	11.543	81.7
19	62.659	11.207	82.1
10	61.945	11.095	82.1
1	61.822	10.924	82.3
23	61.659	10.478	83.0
16	56.545	10.143	82.1
11	55.247	10.024	81.9
2	53.184	9.483	82.2

26	50.408	8.612	82.9
13	43.965	7.956	81.9
6	42.532	7.595	82.1
25	40.405	7.119	82.4
28	35.394	6.364	82.0
14	34.813	6.24	82.1
12	33.02	5.918	82.1
Average	59.8	10.56	82.3

4.4.4 Scenario III: Contouring

The main parameters for simulating contour planting in the SWAT model are curve number (CONT_CN) and USLE Practice factor (CONT_P). Simulation of contouring for sediment prone sub basins with alteration of curve number from default value of 89 to 69 reduced average sediment yield by 89.9% (59.8ton/ha/year to 6.04 ton/ha/year) at treated sub basins. At entire watershed level, sediment yield reduced from 53.4ton/year to 6.4ton/ha/year. In this scenario, all sediment prone sub basins changed from the category of sever, high and medium to the low and very low sediment yielding.

Table 7 Contouring scenarios for selected prone sub basins.

Selected critical sub basin	Base line condition	Contouring	Sediment yield reduction in Percent (%)
9	83.286	13.043	84.3
22	80.436	11.616	85.6
20	80.278	10.379	87.1
4	79.37	9.758	87.7
21	75.865	9.26	87.8
15	70.826	8.904	87.4
3	69.76	8.764	87.4
17	67.244	8.665	87.1
5	66.862	8.15	87.8
7	64.854	7.175	88.9
8	63.148	6.863	89.1

19	62.659	6.753	89.2
10	61.945	6.249	89.9
1	61.822	6.073	90.2
23	61.659	5.939	90.4
16	56.545	5.685	89.9
11	55.247	4.112	92.6
2	53.184	3.55	93.3
26	50.408	3.442	93.2
13	43.965	3.422	92.2
6	42.532	2.934	93.1
25	40.405	2.718	93.3
28	35.394	2.527	92.9
14	34.813	2.301	93.4
12	33.02	2.059	93.8
Average	59.8	6.4	89.9

4.5 Comparison of Scenarios Result

After all scenarios results analyzed individually, it was expected to compare and select best sediment reduction practice for affected sub basins. The amount of sediment yield reduced after application of filter strip, grassed waterway and contouring was relatively consistent in all sub basins. From the figure shown below it was observed that comparing the three best management practices introduced in the watershed, contouring has better ability to reduce the amount of sediment yield entering in to the watershed and it was selected as the best management option to reduce the amount of sediment yield in the watershed compared with others. This shows that large amount of sediment was taken by erosion due to in appropriate agricultural system.

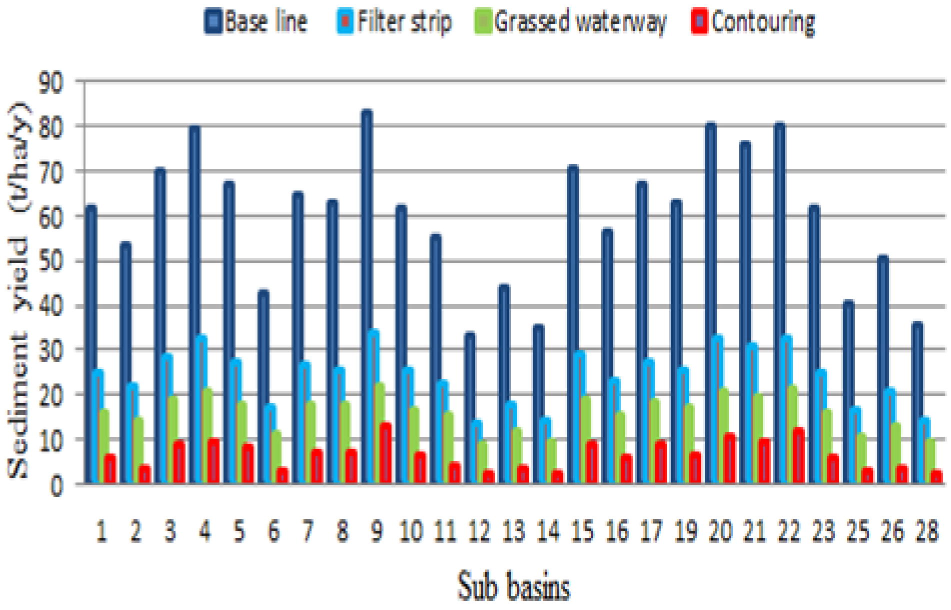

Figure 23 Scenarios comparison of sediment yield reduction in critical sub basins

5 CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Appropriate assessment of runoff and sediment yield amount is vital for the design, planning, and management of river basin projects that deals with conservation and utilization of water for the various purposes. Runoff and sedimentation has been a very serious problem for water resource schemes in Ethiopia and Bilate was one of Sub basins of Ethiopian Rift valley basin and highly affected in runoff and sediment and this is mainly in proper land management and lack of modern technology to predict weather condition. The objective of this study was very important since it addresses the magnitude, the spatial and temporal variability of runoff and sediment yield and provides mitigation measures to reduce sediment entering to watershed. The weather data of 30 years (1986-2015) was used for simulation. Spatial and temporal variability of sediment yield, identification of sediment prone areas, best management scenarios and their result comparison was carried out using SWAT model. The calibration and validation was carried out from 1989 - 2003) and 2004 - 2015) respectively including warm up period on monthly basis of flow and sediment data of (1990-1998) for calibration and (1999-2004) for validation using Sequential Uncertainty Fitting (SUFI-2) in SWAT- CUP. During calibration of both stream flow and sediment yield the sensitive parameters which was highly influenced the result were identified based on ranked in SWAT CUP. The results obtained from this study were revealed that a proper calibration of SWAT model is appropriate for hydrology and sediment yield modeling at the watershed in order to minimize manual measurement took place in catchment.. Model performance evaluation was checked by using correlation coefficient (R^2) of 0.82, Nash–Sutcliffe simulation efficiency (ENS) of 0.7, Root mean Square Error Standard Deviation Ratio (RSR) of 0.6 and PBIAS of -15.4% for calibration and correlation coefficient (R^2) of 0.77, Nash - Sutcliffe simulation efficiency (NSE) of 0.65, Root mean Square Error Standard Deviation Ratio (RSR) of 0.54 and a Percent bias of -14.1% for validation and similarly for sediment yield Nash-Sutcliffe model efficiency (NSE) of 0.71,coefficient of determination (R^2) 0.74, percent bias (PBIAS) of -34.8% and Root mean Square Error Standard Deviation Ratio (RSR) of 0.6 for calibration and R^2= 0.72, NSE=0.68, RSR=0.57 and -31.3% for validation respectively. The average annual runoff and sediment in the watershed was 292mm/ha/y and 53.4t/ha/y. The model also applied with three Best Management Practices (BMPs) scenarios in order to analyze sediment reductions from critical sub watersheds in the Bilate River. The study showed that the three of BMPs applied in the catchment have their own impact on sediment yield reduction but the effectiveness of each BMPs depends upon the percentage of land available, soil and local topographical conditions in the basin. After comparing the scenarios developed using SWAT model, the result showed that contouring has high strength to reduce the amount of sediment yield entering in to the catchment. The land use land coverage of the watershed is dominated by agricultural land.

5.2 RECOMMENDATION

It is recommended that detail investigation and information of data and management practices for study area and is required to obtain more reliable results that can be used for long period of sustainable planning and for the governmental development decision on watershed. For Bilate watershed most stations have missing data both in hydrological and meteorological stations, especially for the sediment no series of long term data and this leads to develop weather Generator and different methods used to fill missing data and this might increase uncertainty of the results and became more challenging in this watershed. In order to minimize this problem and to obtain better results it is recommended that additional gauging stations with better recording capacity in both hydrological and meteorological data are needed, unless for timely varying weather condition it is difficult to develop best watershed management policy related to runoff and sediment yield. In addition to this the zone and Woreda government who directly or indirectly benefit or burden from the Bilate river have to communicate and come up with the solution in order to reduce the amount runoff that washes huge amount of fertile soil from upstream to downstream from agricultural land and causes reservoir sedimentation and decreases the life of Hydraulic structures constructed for different purpose. The result of this research shows great attention should be given for this watershed regarding to runoff and sediment for future time. The agricultural land is the dominant type of land use in the area and this indicates that modern agricultural system is very important to reduce the amount of sediment yield washed by runoff. Finally, I recommend that the study should fatherly extend to evaluate the effect of climate change Flood frequency analysis and other researches which solve the problem of the community in different way.

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APPENDIX

APPENDIX-1 List of Tables

Table-1 Name and SWAT CODE of LULC and area coverage

Grid value	Land Cover	SWAT CODE	Area(KM^2)	% of covering
10	Agricultural Land-Generic	AGRL	3535.213	69.86
20	Corn	CORN	415.7234	8.21
30	Forest-Mixed	FRST	797.7703	15.76
40	Pasture	PAST	97.85663	1.93
50	Range-Grasses	RNGE	3.435707	0.07
60	Residential	URBN	1.683534	0.03
70	Water	WATR	0.607255	0.01
80	Wetlands-Mixed	WETL	208.2912	4.12

Table-2 Name and SWAT CODE of soil type, and area coverage

Grid value	Soil name	SWAT CODE	Area(KM^2)	% of covering
10	Vitric Andosol	AN	862.331	15.34
20	Cambic arenosol	ARb	357.2728	6.35
30	Eutric Cambisol	CM	642.4282	11.43
40	Calcaric Fluvisol	FLe	381.0112	6.78
50	Leptosol	LP	215.4795	3.83
60	Haplic Luvisol	LVh	2435.736	43.32
70	Rhodie Nitisol	NTr	559.513	9.95
80	Eutric Vertisol	VRe	169.096	3.01

Table-3 Sensitive parameters used in flow and their rang and fitted value

Rank	Parameters	Description	Range value	Fitted value
1	CN2	SCS runoff curve umber	35-98	0.0029
2	ALPHA_BF	Alpha base flow recession constant	0-1	0.31
3	GW_DELAY	Groundwater delay	0-500	41.29
4	GWQMN	Threshold depth of water in the shallow aquifer for return flow to occur	0-5000	1491
5	ESCO	Soil evaporation compensation factor	0-1	0.41
6	EPCO	Plant uptake compensation factor	0-1	0.73
7	RCHRG_DP	Deep aquifer percolation fraction	0-1	0.79
8	GW_REVAP	Groundwater revap coefficient	0.02-0.2	0.16
9	BIOMIX	Biological mixing efficie	0-1	0.14
10	SOL_Z	Depth from soil surface to bottom of layer	0-3500	1023
11	SOL_K	Saturated hydraulic conductivity	0-2000	0.39
12	SOL_AWC	Available water capacity of the soil layer	0-1	0.043875
13	CANMX	Maximum canopy storage	0-2000	57.26
14	SOL_ALB		0-0.25	0.01475
15	CH_K2	Effective hydraulic conductive of main channel	0.01-500	0.1125
16	CH_N2	Manning’s “n” value for the main channel	0.01-0.3	0.002
17	SLSUBBSN	Average slope length	10-150	7.325
18	SURLAG	Surface runoff lag time	0.05-24	0.73
19	REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to	0-500	16.875

		occur		
20	SLSOIL	Slope length for lateral subsurface flow	0-150	0.33625

Table-4 The HRUs LULC, Soils and Slopes of sub basins with maximum and

Sub basin 9(maximum sediment yield)				Sub basin 24(minimum sediment yield)			
HRU	Land use	Soil type	Slope class	HRU	Land use	Soil type	Slope class
94	AGRL	AN	>20	324	FRST	FLe	0-5
95	AGRL	AN	15-20	325	FRST	FLe	10-15
96	AGRL	AN	5-10	326	FRST	FLe	5-10
97	AGRL	AN	10-15	327	FRST	FLe	15-20
98	AGRL	AN	0-5	328	FRST	LP	0-5
99	AGRL	LVh	5-10	329	FRST	LP	10-15
100	AGRL	LVh	15-20	330	FRST	LP	5-10
101	AGRL	LVh	10-15				
102	AGRL	LVh	>20				

Table-5 Meteorological stations used.

Station	PPn	Tmax	Tmin	Sunshine	Rh	wind	Flow	Sediment
Awassa	yes	yes	yes	no	yes	ye	no	no

Hosana	yes	yes	yes	yes	yes	yes	no	no
Bilate	yes	yes	yes	yes	yes	no	no	no
Wolaita	yes	yes	yes	yes	no	yes	no	no
Alaba kulito	yes	yes	yes	no	no	no	yes	Yes(small)

Key: yes=available, no=not available

Table-6 Dew02 outputs in weather Generator

Average Daily Dew Point Temperature for Period (1986 - 2015)

Month	tmp_max	tmp_min	hmd	dewpt
Jan	24.55	9.88	85.22	16.00
Feb	25.21	11.14	86.48	17.08
Mar	25.16	11.89	87.68	17.54
Apr	24.33	12.11	89.41	17.36
May	23.39	11.55	89.20	16.49
Jun	21.50	11.30	86.18	14.65
Jul	20.08	11.44	86.36	13.88
Aug	20.43	11.36	87.96	14.38
Sep	21.88	11.07	90.31	15.58
Oct	23.03	10.69	90.74	16.26
Nov	23.87	10.36	88.12	16.23
Dec	23.99	9.55	85.59	15.61

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

Table-7 PCP STAT outputs in weather Generator

Statistical Analysis of Daily Precipitation Data (1986 - 2015)
Input Filename = Rhose.txt

Number of Years = 30
Number of Leap Years = 7
Number of Records = 10955
Number of NoData values = 0

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	25.22	3.3950	5.9076	0.0793	0.4553	4.10
Feb.	49.43	5.2762	4.4729	0.1120	0.6029	6.80
Mar.	102.50	7.3974	3.4622	0.2289	0.6133	12.07
Apr.	135.51	8.5684	2.8492	0.2892	0.6801	14.90
May.	152.66	9.0802	4.2633	0.3155	0.6954	16.63
Jun.	125.09	6.9721	3.2312	0.4704	0.6679	18.17
Jul.	160.82	7.5419	2.2699	0.6312	0.6960	21.60
Aug.	174.26	8.0664	2.9057	0.6092	0.7572	23.07
Sep.	153.37	7.7049	2.6810	0.5417	0.7092	20.40
Oct.	71.54	6.8046	5.6027	0.0971	0.6760	8.33
Nov.	22.31	3.3012	7.0608	0.0438	0.6337	3.37
Dec.	29.93	4.3028	8.5744	0.0485	0.6667	4.20

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

Tabie-8 Conversion of FAO-90 soil unit names to default IPPIC soil classes

VALUE	SYMBOL [10]	IPCC soilclass 11
Haplic chemozms	CHh	HAC
Calcic chemozems	CHk	HAC
Luvic chemozems	CHl	HAC
Calossic chemozems	CHw	HAC
CALCISOLS	CL	HAC
Haplic calcisols	CLh	HAC
Luvic calcisols	CLl	HAC
Petric calcisols	CLp	HAC
CAMBISOLS	CM	HAC
Calcaric Cambisols	CMc	HAC
Dystric Cambisols	CMd	HAC
Eutric Cambisols	CMe	HAC
Gleyic Cambisols	CMg	HAC
Gelic Cambisols	CMi	HAC
Ferralic Cambisols	CMo	LAC
Humic Cambisols	CMu	HAC
Vertic Cambisols	CMv	HAC
Chromic Cambisols	CMx	HAC
Dunes & Shiftsands	DS	SAN
FLUVISOLS	FL	HAC
Calcaric Fluvisols	FLc	HAC
Dystric Fluvisols	FLd	HAC
Euteric Fluvisols	FLe	HAC
Mollic Fluvisols	FLm	HAC
Salic Fluvisols	FLs	HAC
Thionic Fluvisols	FLt	HAC
Umbric Fluvisols	FLu	HAC
Fish pond	FP	WR
FERRAL SOLS	FR	LAC
Geric Ferralsols	FRg	LAC
Haplic Ferralsols	FRh	LAC
Plinthic Ferralsols	FRp	LAC
Rhodic Ferralsols	FRr	LAC
Humic Ferralsols	FRu	LAC
Xanthic Ferralsols	FRx	LAC

Figure-1 map of sub basin

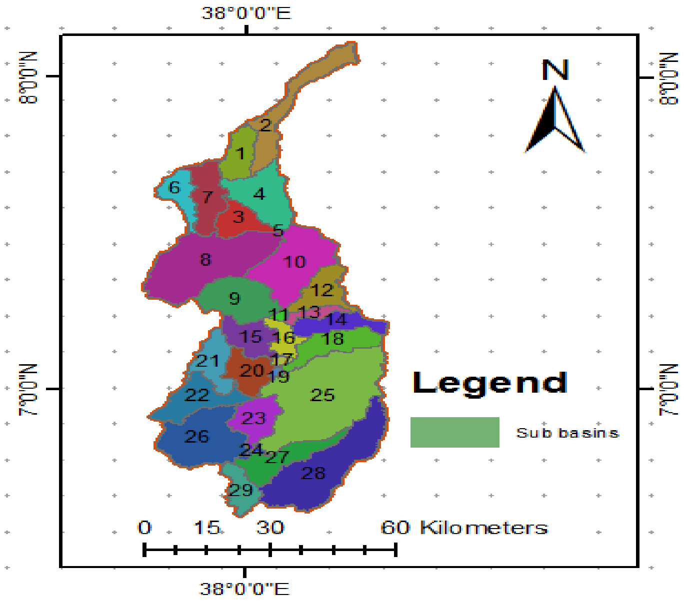


Figure-2 hydrological results of SWAT model

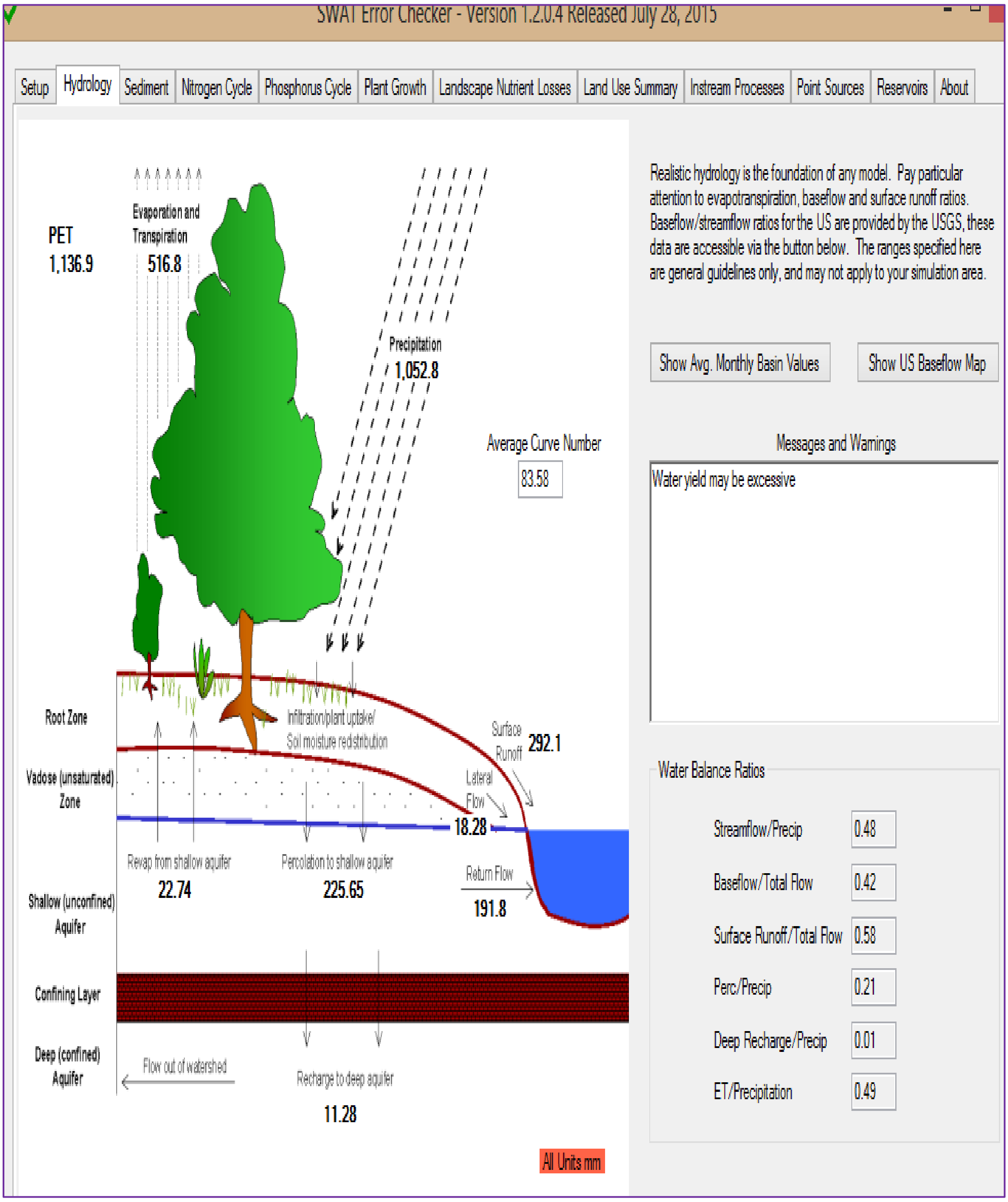
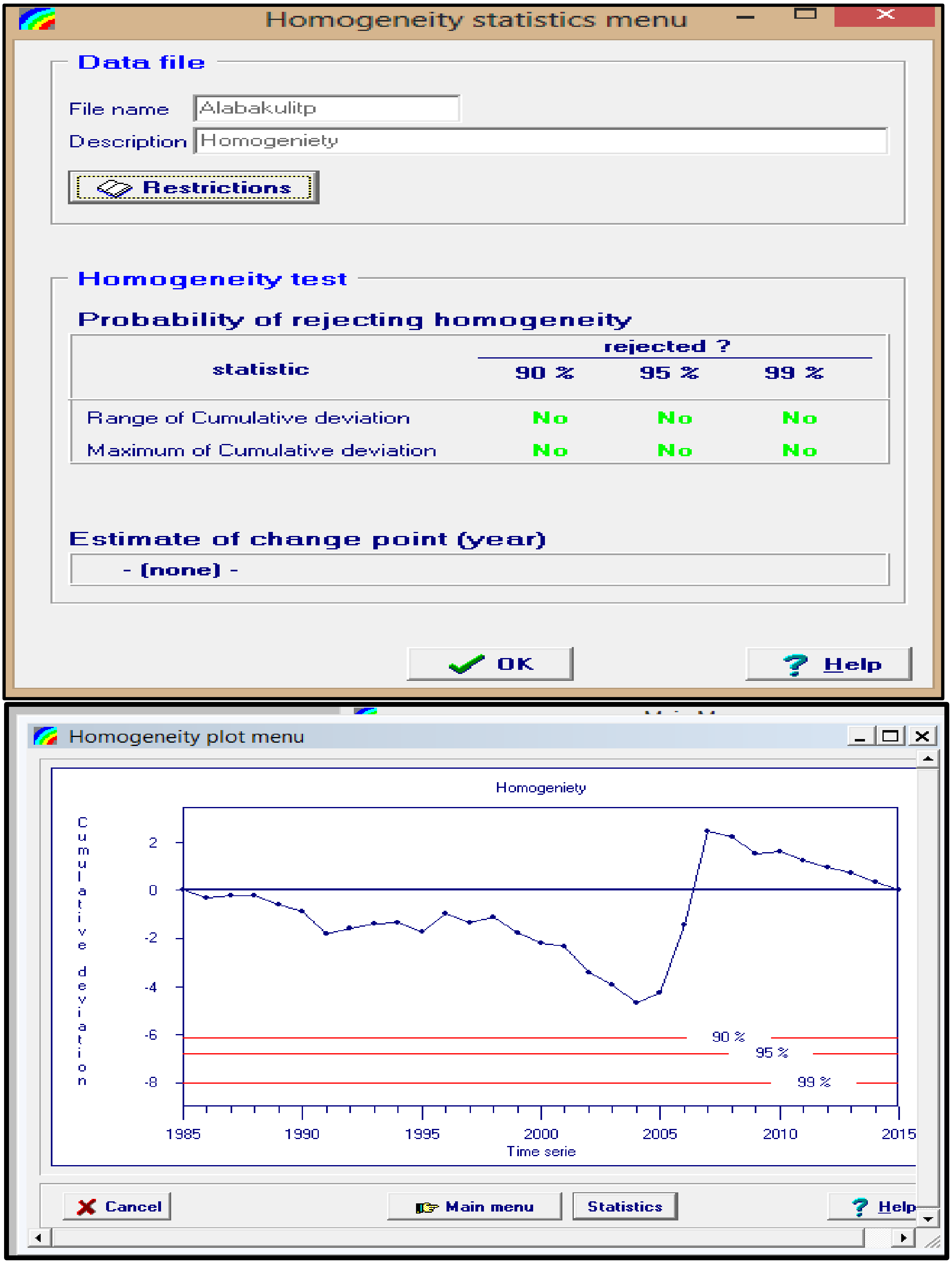
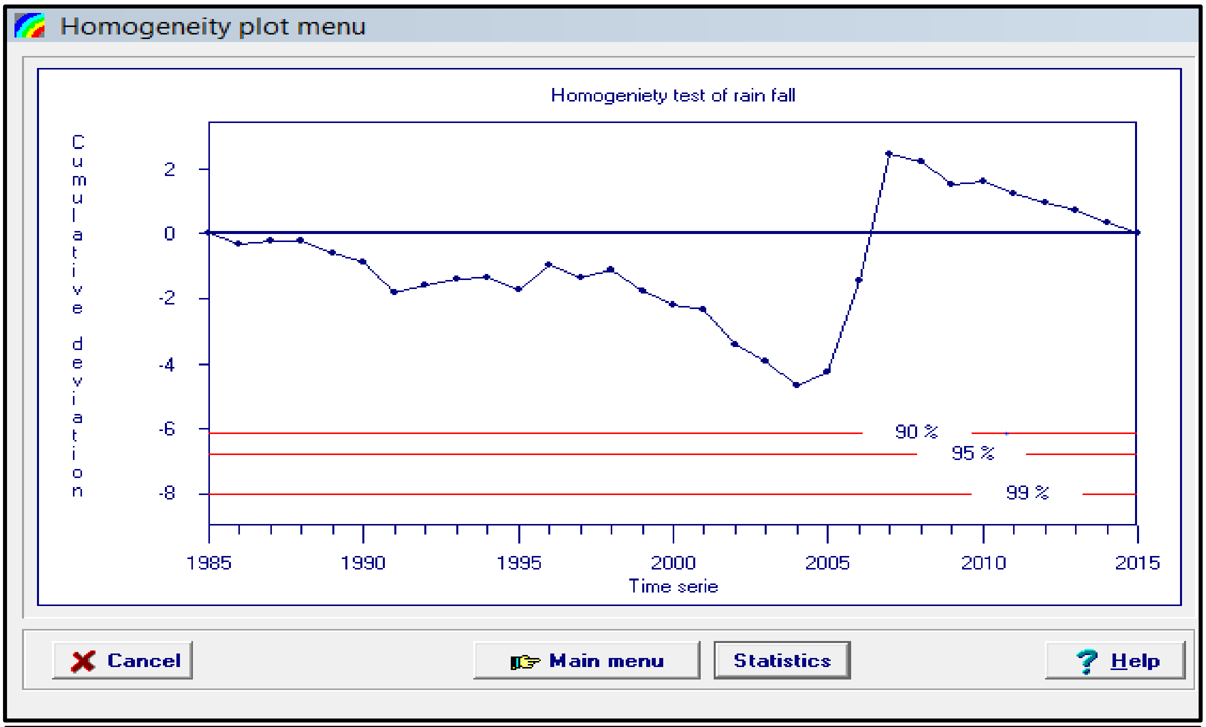
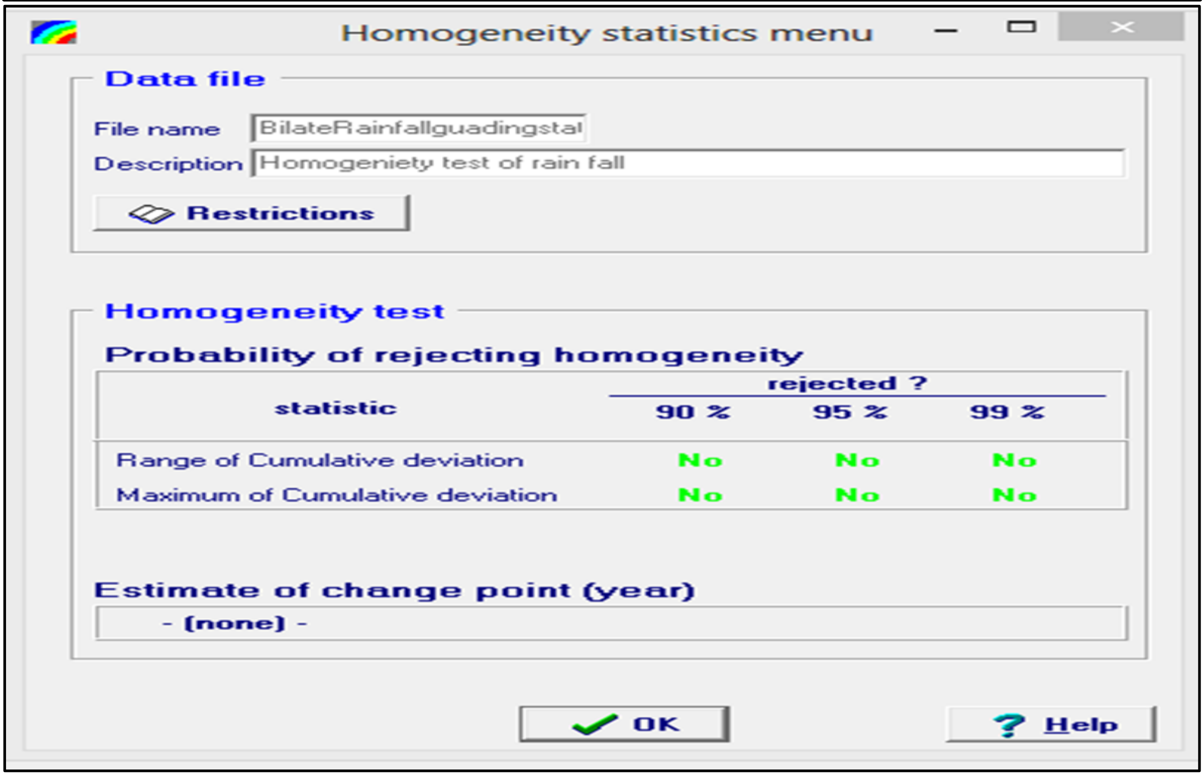


Figure-3 Homogeneity test using RAINBOW




Homogeneity plot menu
Homogeniety test of rain fall
Cumulative deviation
2
0
-2
-4
-6
-8
90 %
95 %
99 %
1985
1990
1995
2000
2005
2010
2015
Time serie
Cancel
Main menu
Statistics
Help


Homogeneity statistics menu
Data file
File name
BilateRainfallguadingstal
Description
Homogeniety test of rain fall
Restrictions
Homogeneity test
Probability of rejecting homogeneity
rejected ?
statistic
90 %
95 %
99 %
Range of Cumulative deviation
No
No
No
Maximum of Cumulative deviation
No
No
No
Estimate of change point (year)
- (none) -
OK
Help

APPENDIX-3 Empirical equations used to derive solar radiation

$$\frac{H}{H_o} = a + b\left(\frac{n}{N}\right)$$

Where *H* is the monthly average daily global radiation, *Ho* is the monthly average daily extraterrestrial radiation, *n* is the day length, *N* is the maximum possible sunshine duration, and *a* and *b* are empirical coefficients. The values of the monthly average daily extraterrestrial radiation (*Ho*) are calculated for days giving average of each month. *Ho* was calculated from the following equation

$$H_o = \frac{24 * I_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]x \left[\cos\varphi\cos\delta\sin w_s + \left(\frac{2\pi . w_s}{360}\right)\sin\varphi\sin\delta\right]$$

Where *Isc* is the solar constant (=1367 W/m^2), φ is the latitude of the site, δ is the sun declination and *ws* is the mean sunrise hour angle for the given month. δ, *ws* and *N* can be computed by the following equations

$$\delta = 23.45\sin[360(n + 284)/365]$$

Where n is the day number of the year starting 1st of January.

Model No.	Regression equation	Model type	Source
1	$H/H_o=a+b(n/N)$	Linear	Angstrom, (1924) and Prescott (1940)
2	$H/H_o=a+b(S/S_o)+c(n/N)^2$	Quadratic	Akinoglu and Ecevit (1990)
3	$H/H_o=a+b(S/S_o)+c(n/N)^2+d(n/N)^3$	Cubic	Samuel (1991)
4	$H/H_o=a+b(n/N)+c\ log(n/N)$	Linear logarithmic	Newland (1988)]
5	$H/H_o=a+b\ log(n/N)$	Logarithmic	Ampratwum and Dorvlo (1999)
6	$H/H_o=a+b(n/N)+c\ exp(n/N)$	Linear exponential	Kadir Bakirci (2009)
7	$H/H_o=a+b\ exp(n/N)$	Exponential	Almorox et. al. (2005)
8	$H/H_o=a(n/N)^b$	Exponent	Kadir Bakirci (2009)
9	$H/H_o=0.18+0.62(n/N)$	Linear, known constants	Rietveld (1978)
10	$H/H_o= 0.29\cos(\varphi)+0.52(n/N)$	Linear, latitude related	Glover and McCulloch (1958)