JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

MASTER OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL BASED RUNOFF AND SEDIMENT YIELD PREDICTION OF DURA RIVER SUB BASIN, ABAY BASIN, ETHIOPIA.

MASTER OF SCIENCE THESIS

BY

TADESSE ADUGNA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY FOR PARTIAL FULFILLMENT OF REQUIREMENT FOR MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

OCTOBER, 2016

JIMMA, ETHIOPIA.

JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

MASTER OF SEINCE PROGRAM IN HYDRAULIC ENGINEERING

SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL BASED RUNOFF AND SEDIMENT YEILD PREDICTION OF DURA RIVER SUB BASIN, ABAY BASIN, ETHIOPIA

MASTER OF SCIENCE THESIS

BY

TADESSE ADUGNA

ADVISOR: Dr.ing.TAMENE ADUGNA (PhD).ASS. PROFESSOR

CO-ADVISOR: DAWUD TEMAM (MSc)

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY FOR PARTIAL FULFILLMENT OF REQUIREMENT FOR MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

Approved By Board of Examiners

This Thesis Entitled “SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL BASED RUNOFF AND SEDIMENT YEILD PREDICTION OF DURA RIVER SUB BASIN” has been approved by the advisors and examiners in the partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering

Dr.ing. Tamene Adugna	---------	----------
Advisor	signature	Date
Mr. Dawud Temam (MSc)	------------	---------
Co-Advisor	signature	Date
-------------------------------	----------	----------
Internal examiner	signature	Date
-----------------------------	----------	---------
External examiner	signature	Date
----------------------------	----------	---------
Chair	signature	Date

DECLARATION

I undersigned, declare that this thesis Entitled "SOIL AND WATER ASSESSMENT TOOL (SWAT) MODEL BASED RUNOFF AND SEDIMENT YEILD PREDICTION OF DURA RIVER SUB BASIN, ABAY BASIN, ETHIOPIA" is my original work and has not been presented for a degree in any other university and that all sources of materials used for the thesis have been fully acknowledged.

Tadesse Adugna Signature.………………..Date……........

This final thesis has been submitted for examination with my approval as university supervisor or advisor.

Tamene Adugna (PhD).Asst. Professor

Signature………………….Date………..

This final thesis has been submitted for examination with my approval as university co- advisor.

Dawud Temam (MSc).

Signature…………………..Date………..

ACKNOWLEDGMENT

First and for most I thank my almighty God for never ending help for all path of my life. Without good will of God nothing is always possible.

Next, I would like to forward my sincere gratitude to my major advisor Dr.Ing. Tamene Adugna for his important professional endless support and for his kindness to give clear solutions for problems occurred during my work. I also like thank my second advisor Mr. Dawud Temam for his guidance how to organize data and analysis.

Thirdly I thank my families who are ever with me in every aspects of my life to reach here.

Fourthly, my thank goes to Jimma university, institute of technology and all staff members in affairs of Hydraulic Engineering and my classmate friends. At last, my deepest thank is to ministry of water, irrigation and energy that sponsored me to study here in Jimma University as well as for the supply of hydrological data for my thesis work free of charge. I would also thank National Meteorological Agency that offered Meteorological data.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Long term planning in water resource development requires full information about the water resource and the amount sediment which affects amount and availability of water.

For this the soil and water assessment tool (SWAT) model was applied to simulate runoff, the sediment yield and associated uncertainty with the simulated output from the Dura River sub basin (area 545 km^2), located in North-Western Amhara Regional State, Ethiopia. The SWAT model was calibrated for the period of 1985 to 1994 and validated for the period of 1995-2004 based on nine parameters identified during sensitivity analysis for both flow and sediment for which GW_DELAY for flow and Curve number for sediment were the most sensitive ones with their t-stat and p-values. The uncertainty analysis was done by using SUFI-2 which is package for a SWAT –CUP. The calibration and validation of the model was found satisfactory as performance rating criteria value of coefficient of correlation (R^2) and Nash-Sutcliffe simulation efficiency (NSE) is found to be 0.85 and 0.82 during calibration and 0.83 and 0.81 during validation for flow and 0.8 and 0.73 during calibration and 0.78 and 0.72 during validation for sediment yield prediction respectively. In the same order from the model uncertainties analysis the percentage of the observed data within the uncertainty bound is 88% during calibration and 77% during validation for flow and 80% during calibration and 70% during validation for sediment yield prediction. The water and sediment yield of Dura sub basin was quantified and also the most sediment yielding part of the basin was identified. Accordingly, annual average flow of Dura River was estimated to be 18.8M^3/sec. and annual average sediment yield of the sub basin was estimated to be 10.9 ton per hectare. Substantial sediment contributing sub basins were sub basin 1 (73.36 ton ha^{-1}yr^{-1}), sub basin 6 (78.33 ton ha^{-1}yr^{-1}) and sub basin 9 (96.5ton ha^{-1}yr^{-1}) identified as severe condition of extent. In conclusion, the SWAT model could be effectively used to predict runoff and sediment yield in order to effectively design and plan water related development in absence of gauged information.

***KEY WORDS**: Dura sub basin, SWAT, Sediment, Runoff, Calibration, uncertainty.*

LIST OF ACRONYMS

ARS = Agricultural Research Service

BoA = Bureau of Agriculture

CFSR =Climate Forecast System Reanalysis

DEM = Digital Elevation Model

EHRS = Ethiopian Highland Reclamation Study

GIS = Geographic Information System

GLUE = Generalized Likelihood Uncertainty Estimation

HRUs = Hydrological Response Units

LH = Latin Hyper cube

MCMC = Markov Chain Monte Carlo

MoWR = Ministry of water resource

MUSLE = Modified Universal Soil, Loss Equation

PARASOL = Parameter Solution

SCRP = Soil Conservation Research Project

SCS = Soil Conservation Service

SUFI = Sequential Uncertainty Fitting

SWAT = Soil and Water Assessment Tool

SWAT CUP= Soil and Water Assessment Tool Calibration and Uncertainty program.

USDA = United States Development of Agriculture

USLE = Universal Soil Loss Equation

WXGEN = Weather Generator

CHAPTER ONE

INTRODUCTION

1.1. BACKGROUND

Ethiopia, often referred to as the water tower of East Africa, is dominated by mountainous topography, and the rainfall-runoff processes on the mountainous slopes are the source of the surface water for much Ethiopia(Derbi S.D.*et al*., 2009). And thus, understanding the rainfall-runoff processes is critical to controlling erosion and enhancing agricultural productivity.

Ethiopia has huge potential resources which includes total of 122 billion cubic meters of surface water, 2.6 billion cubic meters of groundwater resources and 3.7 million hectare of potentially irrigable land that can be used to improve agricultural production and productivity(Awulachew S. B.*et al*., 2007).

But, water availability and sediment delivery have become challenging issues for food security ,human health and natural ecosystem(Chaplot V. *et al*., 2004).

Rapid increase in population, deforestation, over cultivation, expansion of cultivation at the expense of lands under communal use right (grazing and woody biomass resource),cultivation of marginal and steep lands, over grazing and other social, economic and political factors are the driving forces to a series of soil erosion(Resource, 1998).

Poor land use practices, improper management system and lack of appropriate soil conservation measures have played a major role for causing land degradation problems for the country. Ethiopia loses about 1.3 billion metric tons of fertile soil every year and the degradation of land through soil erosion is increasing at a high rate. This calls for immediate measures to save the soil and water resources degradation of the country. (Universityof Berne).

The majority of the sedimentation of rivers in the basin occurs during the early period of the rainy season and peaks of sediment are consistently measured before peaks of discharge for a given rainy season(Steenhuis T.S.*et al.*, 2009).

Watershed management strategies are critical to efficiently utilize the natural resources base while maintaining environmental quality. Of the many resources at risk in the Ethiopian Highlands Soil and water are arguably the most critical, as nearly 85% of the population depends on subsistence agriculture. One process that threatens the resource base is soil erosion(Hurni H., 1990).

A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation with land surface. The quantity and quality of water produced by the watershed are an index of amount and intensity the precipitation and nature of watershed management(Sanjay K. *et al*., 2010).

A basin sediment yield refers to the amount of sediment exported by a basin over a period of time which is also the amount which will enter a reservoir or a weir located at the downstream limit of the basin(Moris G. and J., 1998).

Implementation of comprehensive watershed management requires the detailed understanding and evaluation of hydrological and erosion processes at the watershed scale. With the development of computer technology and understanding of hydrological process, Modeling has become one of the most powerful tools for watershed management. Reasonable prediction of runoff and sediment transport is essential for development of watershed plan (Jayakrishnan R.*et al*., 2005).

A hydrologic modeling provides information beneficial to natural resource managers for planning, flood and drought mitigation, erosion control and other watershed and water resource management practices. Hydrologic models provide a cost effective means of evaluating alternative management plans with in a watershed .However, accuracy of results obtained from the models depend heavily on the accuracy of the model inputs, especially rainfall which is the deriving function in the hydrologic cycle(Raneesh K.Y. *et al*., 2010).

Accurate prediction of runoff and sediment yield from distributed models of runoff and sediment yield depends in the part of how well matched the model structure is to input data of spatial representation(chen and Makay, 2004).

Soil loss from a watershed can be estimated based on an understanding the underlying hydrological processes in a watershed, climatic conditions, form and soil factors. Assessing and mitigating soil erosion at the basin level is complex both spatially and temporally. Hence watershed   models are capable of capturing these complex processes in a dynamic manner so that used to provide an enhanced understanding of the relation between hydrologic processes, erosion/sedimentation and management options. The Soil and water Assessment Tool (SWAT) model is a basin scale model where runoff and sediment yield is based on land use and soil type. The ability of the model to sufficiently simulate sediment yield and stream flow for a specific application is evaluated through sensitivity analysis, model calibration and model validation(Kati. L *et al*,2009).

1.2. Significance the study

The research was intended to examine the spatial and temporal variability of the sediment yield and identify the major sensitive and vulnerable areas to erosion within the sub basin such that the remedial measures can be taken. As a result a result of which sediment accumulation rate of the Dams, weir and irrigation canal that can be built downstream of the sub basin can be reduced. In other words, saving soil erosion is enhancing Agricultural productivity in the area in such a way that sustainable development can be brought. Assessing the availability of water resource within the sub basin is also an essential task so that planning of other activities will be integrated. It is also significant to use physically based and spatially distributed SWAT model and verification of its performance for future application with in the study area for similar studies.

1.3. Statement of the problem

Blue Nile is the largest river Basin in Ethiopia which is known to carry so many cubic metric of sediment and runoff every year.

In contrast, demand for irrigation and hydropower is increasing in the basin while experiencing rapid population growth and environmental degradation under a limited water resource. The Grand Renaissance Dam once completed will receive all the sediment generated in the Blue Nile catchment (Dam Speech, 2011).

Deposition of sediment in the weir and irrigation canals not only reduce the conveyance efficiencies of the structures, but also influence the cost in maintenance and removal of sediment accumulated.

Before any planning activity for water resource development works in a certain river basin, it is also very important issue to assess amount of sediment yield and the total available water in the basin to integrate the planning with other activities.

Dura sub basin is among basins draining to Nile river basin. It is one of the agricultural areas of Awi zone in Amhara regional state. From regional soil degradation map reported by (Dr.Armando Molina, 2009), it is characterized by sheet erosion type, strong in severity and frequent in extent

Therefore, assessing the runoff and associated sediment yield and identifying erosion vulnerable areas is critical in the study area to take possible actions so that the problem will be minimized.

1.4. Objectives

1.4.1. General Objective:

To evaluate the performance of the SWAT hydrological model, predict runoff and sediment yield and identify the most vulnerable (hot spot) areas to save erosion and consequent sedimentation.

1.4.1. Specific Objectives:

- To evaluate the performance of the SWAT model and uncertainty analysis.
- To predict the runoff and sediment yield of the sub basin.
- To identify the most erosion vulnerable areas within the sub basin.

CHAPTER TWO

LITRATURE REVIEW

Today, soil erosion is almost universally recognized as a serious threat to man's well-being. A worldwide cost of soil erosion is estimated to be about four hundred billion dollars per year, More than 70 dollars per person per year. Sediment degrades water quality, and carries soil- adsorbed polluting chemicals. Sediment depositions in irrigation canals, stream channels, reservoirs, water conveyance structures, reduce their capacity and would require costly operation for removal(Foster, 2002)**.**

Soil erosion from the upstream of the basin and the subsequent sedimentation in the downstream area is an immense problem threatening the existing and future water resources development in the Nile basin. The benefits gained by the construction of micro-dams in the Upper Nile are threatened by the rapid loss of storage volume due to excessive sedimentation. Both the Nile Basin Initiative and the Ethiopian government are developing ambitious plans of water resources projects in the Upper Blue Nile basin, locally called the Abbay basin. Thus, an insight into the soil erosion/sedimentation mechanisms and the mitigation measures plays an indispensable role for the sustainable water resources development in the region(Betrie *et al*., 2011).

Heavy sedimentation experienced by Ethiopia's existing dams is a very real risk to the lifespan of new dams. The soon to be constructed on Blue Nile "Renaissance Dam", which will be the largest hydroelectric dam in the country, is expected to experience a high sedimentation rate. These sediments are currently being captured in the Egypt and Sudan dams but will soon be trapped by the Renaissance Dam(MEHAMED,2014).

The Bureau of Reclamation of US Department of Interior (1964) identified major hydropower development sites on the Blue Nile. One of them is Grand Renaissance (Millennium) Dam, at present under construction in Ethiopia 30 km upstream of the border with Sudan, will be the largest hydroelectric power plant of Africa, with a storage capacity of 74 billion m^3(Dam speech,2011). Once completed, the reservoir will receive all the sediment generated in the Ethiopian part of the Blue Nile catchment.

Estimating the sediment loads along the Blue Nile River is important for the proposed and existing dams along the Blue Nile, since this is necessary to obtain realistic quantifications of the sedimentation rates inside their reservoirs(Yasir *et al*., 2014).

As a consequence of land degradation, the productive capacity of the soils in Ethiopian highlands is reducing at a rate of 2-3% annually the north and northeastern highland parts of the country have seen the greatest damage to their soil resources due to soil degradation. These are also the most affected parts of the country by famine due to degradation and recurrent drought. In this regard, soil degradation certainly contributes to a higher vulnerability to famine**(**Hurni, 1993).

2.1. Estimation of soil loss

The Ethiopian Highland Reclamation Study (EHRS) has developed a 1:1,000,000 scale soil loss rate map, which shows the types of soil degradation processes, causes, severity and extent. The map is based on the universal soil loss equation (USLE) and soil-erodibility and land use maps.

In the Ethiopian Highlands the estimated soil erosion rates range from as low as 16 t ha^{-1} y^{-1}(A .,1995). to as much as 300 t ha^{-1} (K and B., 1999).

The soil conservation research project (SCRP) has estimated an annual soil loss of about 1.5 billion tons from high lands(SCRP, 1996).

Soil erosion is estimated to cost the country 1.9billion US Dollars between 1985 and 2010.This calls for immediate measure to save the physical quality of the soil and water resource of the country(EHRS, 1984).

2.2. Impact of Soil erosion

Sediment delivery to rivers is probably the most consequence of soil erosion in catchments. The input of sediment by erosion process into rivers, reservoirs, weirs and ponds result in high sediment deposition rates(Verstraeten and Poesen , 1999).

Many canals of irrigation projects suffer from excessive sedimentation which is entering through the head work (weir). Often this is due to the fact that sediment transport in the river was not properly assessed and appear to be much larger than the anticipated(Yehayis, 2010).

Increased sediment loads that shorten the useful life of the reservoir, the lives of other water related structures and increase the cost of maintenance and sediment remediation are impacts of erosion.

To develop effective erosion control plans and to achieve reduction in sedimentation, it is important to quantify the sediment yield and identify areas that are vulnerable to erosion(Mequanint *et al*.,2009). The need for relative estimates of sediment yield are essential throughout water resources analyses, modeling and engineering as sediment is a major transporter of pollutants, and sedimentation rates and amounts determine the performance and life of reservoirs, canals, drainage channels etc. Moreover, as a watershed wide measure of soil erosion, transport and deposition, sediment yield reflects the characteristics of a watershed, its history, development, use, and management.

2.3. Impact of land use on erosion and sediment load

Forests are checkers of soil erosion. Protection is largely because of under storey vegetation and litter, and the stabilizing effect of the root network. On steep slopes, the net stabilizing effect of trees is usually positive. Vegetation cover can prevent the occurrence of shallow landslides(Bruijnzeel, 1990). However, large landslides on steep terrain are not influenced appreciably by vegetation cover. These large slides may contribute the bulk of the sediment, as for example in the middle hills of the Himalayas(Bruijnzeel and Bremmer, 1989).

The degree of change in annual runoff from catchments depends on the intensity and extent of land development. The generalized relationship based on catchments worldwide is that a 10% reduction in coniferous forest (Deciduous forest, shrubs),being converted to grassland causes an average increase of 40mm(25mm for deciduous forest,10mm for shrubs) in annual runoff. Land use activities also affect storm flow response and in turn flood peaks through changes in vegetation cover, Soil infiltration capacity, conveyance system, increased erosion and siltation(Biruk, 2009).

2.4. Hydrology and Water Resource Management

In Ethiopian highlands the summer rainfall accounts for large percent of the total annual precipitation in the area. The intensity of this rain depends on the amount of moisture that enters and recycles in the region, and the degree to which it ascends to form cloud. According to Viste (2012), moisture transported from Red Sea contributes very importantly to the Ethiopian highland summer. However, moisture from south; coming from Atlantic and Indian oceans are also significant to the central Ethiopian rainfall although its transport to the region is affected by SST and pressure anomalies in Indian Ocean and Gulf of Guinea. Once the moisture is transported to the highland area, it recycles there as a result of the altitudinal feature that favors the process. It is this recycling of moisture along with transportation in to the region that gives summer season in Ethiopian highlands.

Runoff is that part of the rainfall, as well as any other flow contributions, which appears in surface streams of either in perennial or intermittent form. This is the flow collected from a drainage basin or watershed, and it appears at an outlet of the basin. According to the source from which the flow is derived, runoff may consist of surface runoff, subsurface runoff and ground water runoff.

For the practical purpose of runoff analysis, total runoff in stream channels is generally classified as base flow and direct flow which consists of all other types of flows. The direct runoff is that part of runoff which enters the stream promptly after the rainfall. It occurs only when the rainfall rate is greater than the infiltration rate. The base flow is defined as the sustained runoff composed of ground water runoff and delayed subsurface runoff(Buras, 1972). Physically based distributed hydrological models, whose parameters have a physical representation for the spatial variability of hydrological processes and are capable of simulating the impact of climate change and human activities on hydrological cycle, are increasingly being used to simulate complex water resource systems including simulation for the impact of land use and climate change on water resources in river basins.

A systematic assessment of water resources availability with high spatial and temporal resolution is essential in Ethiopia for strategic decision-making on water resource related development projects. Although empirical formulas are adopted, this simply simulates rainfall runoff relationship which is developed in other similar agro climatic zone. There is a great uncertainty on the estimations because it does not consider complex interaction that takes place in the watershed.

Impacts of land use practices on surface water can be divided into (i) impacts on the overall water availability or the mean annual runoff, and (ii) impacts on the seasonal distribution of water availability

The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and the nature of watershed management.

Integrated water management of large area should be accomplished with in a spatial unit (watershed) through modeling. Integrated water management can be viewed as a three dimensional process centered on the need for water, the policy to meet the needs and the management to implement the policy. Therefore, Modeling is fundamental to integrated water resource management(Yeheyes, 2010).

In some watersheds the aim may be to harvest maximum total quantity of water throughout the year for irrigation and drinking purpose. In another watershed the objectives may be to reduce the peak rate of runoff for minimizing soil erosion and sediment yield or to increase ground water recharge. Hence, the modeling of runoff, soil erosion and sediment yield are essential for sustainable development.

Therefore, a comprehensive understanding of hydrological process in the watershed is the pre-requisite for successful water management and environmental restoration.(Sanjay *et al.,* 2010)

2.5. Classification of Hydrological models

Several systems of classification of hydrologic models have been used. In one system of classification, the models are classified according to three main criteria.

1. Randomness (deterministic or stochastic)
2. Spatial variation (lumped or distributed)
3. Time variability (time-dependent or time-independent)

In the other system of classification, hydrological models are divided into two main categories: physical models and abstract models. Physical models include scale models such. As hydraulic models of a spillway, and analog models which use another physical system having properties similar to those of the real system. Abstract models represent the system in mathematical form. The system operation is described by a set of equations and logical statements in number of different model(Killingtveit, 1993).

2.6. GIS Applications in Hydrologic Analysis

Geographic Information Systems (GIS) provide a digital representation of watershed characteristics used for hydrologic modeling(Bruce A. D. *et al*., 1993). Recent advances in GIS enabled planners, watershed managers, and hydrologic engineers to expand their capabilities for watershed management(DeBarry, 2004). Several procedures have been developed to incorporate GIS into watershed application (De Barry, 2004). These GIS applications improve efficiency and accuracy and cut costs in the hydrologic parameter calculation methodology required by hydrologic models.

Many subroutines have been developed to analyze the terrain and hydrologic processes from the grid cells of the Digital Elevation Models (DEMs). Some of the hydrologic subroutine includes: flow direction, sub-basin or watershed boundary determination, accumulation and stream channel determination. The GIS hydrologic operations are based on the premise that water flows downhill in the direction of steepest descent, and the elevations of the grid cells dictate this direction(Maidment, 2002).

2.7. SWAT Model

Soil and Water Assessment Tool (SWAT) is a distributed river basin or watershed scale model which was developed by Dr. Jeff Arnold at USDA-ARS. The model is used for predicting the impacts of land management on water, sediment and agricultural chemicals yield in complex watershed (Neitsch *et al*., 2005). It is physically based, i.e., it uses physical data like weather data, soil data, vegetation data, land use and etc., from the watershed under consideration. SWAT is computationally efficient model because; it does simulation on a large basin within short period of time with less cost. The input data for SWAT is easily obtainable from local agencies. It combines empirically and physically based equations to simulate long term hydrologic events.

SWAT is the acronym for Soil and Water Assessment Tool, a river basin, or watershed, scale model developed by Dr. Jeff Arnold for the USDA Agricultural Research Service (ARS). SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time(Neitsch *et al*., 2005).

2.8. SWAT model in Abay Basin

In recent years, SWAT model developed by Arnold *et al*. (1998), has gained international acceptance as a robust interdisciplinary watershed modeling. SWAT is currently applied worldwide and considered as a versatile model that can be used to integrate multiple environmental processes, which support more effective watershed management and the development of better informed policy decision (Gassman *et* *al*., 2007) The review of SWAT model applicability to Ethiopian situations (Setegn *et al*., 2010) at relatively larger watersheds and (Ashenafi,*et al.* 2009) indicated that the model is capable of simulating hydrological processes with reasonable accuracy and can be applied to large ungagged watershed. SWAT model can be a potential monitoring tool for watersheds in mountainous catchments of the tropical regions.(Birhanu *et al.,* 2007).

SWAT is a basin-scale, continuous-time model that operates on a daily time step and is designed to predict the impact of management on water, sediment, and agricultural chemical yields in ungagged watersheds. The model is physically based, computationally efficient, and capable of continuous simulation over long time periods. Major model components include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens. In SWAT, watershed is divided into multiple sub watersheds which are further sub divided into Hydrologic response units (HRUs) that consists of homogenous land use, management and soil characteristics. The HRUs represent percentages of the sub basin area and are not identified spatially with in SWAT simulation. Alternatively, a watershed can be sub divided into only sub basins that are characterized by dominant land use, soil and management.

SWAT model requires a watershed divided into sub watersheds. Sub watersheds are connected through stream channels. The assessment work by SWAT is done on units called Hydrologic Response Units (HRU). Hydrologic Response Units are unique combinations of soil and vegetation types in a sub watershed. SWAT then simulates hydrology, vegetation growth, and management practices at the Hydrologic Response Unit level. The results (water, nutrients, sediment, and other pollutants from each Hydrologic Response Units) are summarized for each sub watershed and then routed through the stream network to the watershed outlet.

2.9. Base flow Separation of the watershed

Base flow is one component of hydrological process that contributes for stream flow. Using the time-series record of stream flow to derive the base flow contributions in the study area,

The first step in hydrograph analysis entails separation of stream flow into the two major components: surface runoff and base flow (Arnold *et al.,* 1999). However, the exact separation of each component is difficult. All methods suffer from the lack of real knowledge of how the water moves through the watershed over time for a multitude of storm events and antecedent moisture conditions(Arnold *et al*., 1999). Numerous analytical methods have been developed to separate base flow from total Stream flow. Although most procedures are based on physical reasoning, elements of all separation techniques are subjective. Manual separation of stream flow hydrograph into surface flow and ground water flow is difficult and inexact; often results derived from such manual methods cannot be replicated among investigators (White *et al*., 2005). Attempts to automate the manual methods with the computer remove some of the subjectivity inherent in these methods and substantially reduce the time required analysis of stream flow records(White *et al.,* 2005). And tested Base flow is considered to be the ground-water contribution to stream flow. Estimates of the amount of base flow can be derived from stream flow records. Such estimates are critical in the assessment of low flow characteristics of stream for use in water supply, water management, and pollution assessment. An automated technique was developed to calculate the slope of the base flow recession curve from the stream flow records. This technique is an adaptation of the Master Recession curve procedure (Arnold *et al.,* 1999). The base flow filter can be passed over the stream flow data three times (forward, backward and forward); depending on the user's selected estimates of base flow from pilot studies of stream flow data.

2.10. Overview of SWAT-CUP

It is a computer program which is an interface of SWAT to perform sensitivity, calibration and validation of SWAT model. SWAT-CUP is the deterministic

approach to get the desired variable through adjusting parameters of that are sensitive in the study area. It is an approach of trial and error until the objective function is attained but in highly managed catchment the objective function has easily determined. In calibration process of SWAT-CUP, there is always an uncertainty due to the input data or the error by the modeler (Abbaspour *et al.,* 2015).
The ability of a watershed model to sufficiently predict water quantity and quality for a specific application is evaluated through sensitivity analysis, model calibration, and model validation. It is certainty analysis hydrological parameters of stream flow.

2.11. Sensitivity analysis

Sensitivity is measured as the response of an output variable to a change in an input parameter, with the greater change in output response corresponding to a greater sensitivity. Sensitivity analysis evaluates how different parameters influence a predicted output. Parameters identified in sensitivity analysis that influence predicted outputs are often used to calibrate a model (White & Chaubey, 2005). It is a necessary process to identify key parameters and parameter precision required for calibration(Ma and L., 2000).
Hence, sensitivity analysis was performed to limit the number of optimized parameters to obtain a good fit between the simulated and measured data. Sensitivity analysis helps to determine the relative ranking of which parameters most affect the output variance due to input variability (Van Griensven *et al.,* 2002) which reduces uncertainty and provides parameter estimation guidance for the calibration step of the model.
(Spruill *et al.,* 2000) performed a manual sensitivity analysis of 15 SWAT input parameters for a 5.5 km^2 watershed in Kentucky, which showed that saturated hydraulic conductivity, alpha base flow factor, drainage area, channel length, and channel width were the most sensitive parameters that affected stream flow.

Numerous sensitivity analysis have been reported in the SWAT literature, which provide valuable insights regarding which input parameters have the greatest impact on SWAT output. A two-step sensitivity analysis approach is described by (Francos and A., 2003) which consists of:

(1) A "Morris" screening procedure that is based on the One factor at a time (OAT) design, and

(2) The use of a Fourier amplitude sensitivity test (FAST) method.

The screening procedure is used to determine the qualitative ranking of an entire input parameter set for different model outputs at low computational cost, while the FAST method provides an assessment of the most relevant input parameters for a specific set of model output.(Holvoet *et al*. 2005) Presented the use of a Latin hypercube (LH) OAT sampling method, in which initial LH samples serve as the points for the OAT design. The LH-OAT method has been incorporated as part of the automatic sensitivity/calibration package included in SWAT 2009 (Gassman *et al*., 2007).Therefore, sensitivity analysis as an instrument 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(Hamby and D. M., 1994). The sensitivity analysis method in the SWAT-CUP interface combines the global sensitivity and One- factor-At-a-Time (OAT) sampling (Abbas pour, 2015).

2.12. Model Calibration

Calibration refers to the adjustment or fine-tuning of model parameters to reproduce observations within acceptable levels of agreement. Calibration is the process whereby model parameters are adjusted to make the model output match with observed data. There are three calibration approaches widely used by the scientific community. These are the manual calibration, automatic calibration and a combination of the two. The manual calibration approach requires the user to compare measured and simulated values, and then to use expert judgment to determine which variables to adjust, how much to adjust them, and ultimately assess when reasonable results have been obtained (Gassman *et al*., 2007). (Coffey *et al.,* 2004), Presented nearly 20 different statistical tests that can be used for evaluating

SWAT stream flow output during a manual calibration process. They recommended using the Nash-Sutcliffe simulation efficiency NSE and regression coefficients R^2 for analyzing monthly output, based on comparisons of SWAT stream flow results with measured stream flows for the same watershed studied by (Spruill, *et al*., 2000).

(Eckhartd *et al.,* 2001), Outlined the strategy of imposing the constraints on the parameters to limit the number of interdependently calibrated values of SWAT. Subsequently, an automatic calibration of the version SWAT-G of the SWAT model with a stochastic global optimization algorithm and Shuffled Complex Evolution algorithm is presented for a meso-scale catchment.

Automated techniques involve the use of Monte Carlo or other parameter estimation schemes that determine automatically what the best choice of values are for a suite of parameters, usually on the basis of a large set of simulations, for a calibration process (Gassman *et al.,* 2007). Automatic calibration involves the use of a search algorithm to determine best-fit parameters.

It's desirable as it is less subjective and due to extensive search of parameter possibilities can give results better than if done manually. The manual trial-and-error method of calibration is the most common and especially recommended for the application of more complicated models in which a good graphical representation is a prerequisite.(Refsgaard *et al.,* 1996) However, it is very cumbersome, time consuming, and requires experience.

2.13. Model Validation

Following calibration, a validation test was conducted by applying the calibrated model to a second period of data not used in the calibration. This section of the report presents the process used to calibrate the model for both hydrology and water quality. In order to utilize any predictive watershed model for estimating the effectiveness of future potential management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data. This testing of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set performs reasonably well under an independent data set. Provided the model predictive capability is demonstrated as being reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under somewhat different management scenarios (Alamirew, 2006).

2.14. Uncertainty analysis

Most important issue with calibration of watershed models is that of uncertainty in the Predictions. Watershed models suffer from large model uncertainties. These can be divided into: Conceptual model uncertainty, input uncertainty, and parameter uncertainty.

1. Conceptual model uncertainty (or structural uncertainty)

2. Input uncertainty is as a result of errors in input data such as rainfall, and more importantly, extension of point data to large areas in distributed models.

3. Parameter uncertainty

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

2.15. The SUFI-2 uncertainty analysis

In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty in driving variables (e.g., rainfall), conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). As all the processes and model inputs such as rainfall and temperature distributions are correctly manifested in the model output (Which is measured with some error?)-The degree to which we cannot account for the measurements - the model is in error; hence uncertain in its prediction. Therefore, the percentage of data captured (bracketed) by the prediction uncertainty is a good measure to assess the strength of our uncertainty analysis.

Another measure quantifying the strength of a calibration/uncertainty analysis is the R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data with the smallest possible uncertainty band. The concept behind the uncertainty analysis of the SUFI -2 algorithm is depicted graphically in Figure1. This Figure illustrates that a single parameter value (shown by a point) leads to a single model response (Fig 1a), while propagation of the uncertainty in a parameter (shown by a line) leads to the 95PPU illustrated by the shaded region in Figure 1b. As parameter uncertainty increases, the output uncertainty also increases (not necessarily linearly) (Fig 1c). Hence, SUFI-2 starts by assuming a large parameter uncertainty (within a physically meaningful range), so that the measured data initially falls within the 95PPU, then decreases this uncertainty in steps while monitoring the P-factor and the R-factor. In each step, previous parameter ranges are updated for 95% confidence intervals of the parameters. Parameters are then updated in such a way that the new ranges are always smaller than the previous ranges, and are centered on the best simulation (Abbas pour *et al*., 2009).

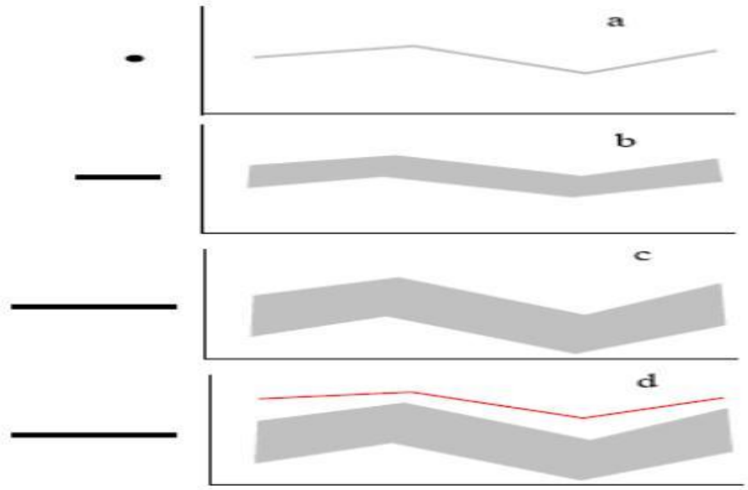


Figure 1 A conceptual illustration of the relationship between parameter uncertainty and prediction uncertainty (Source: SWAT CUP user manual, 2009)

2.16. Performance measuring unit for uncertainty

A) P factor

The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by the 95% prediction uncertainty (95PPU). As all the processes and model inputs such as rainfall and temperature distributions are correctly manifested in the model output (which is measured with some error) - the degree to which we cannot account for the measurements - the model is in error; hence uncertain in its prediction. Therefore, the percentage of data captured (bracketed) by the prediction uncertainty is a good measure to assess the strength of our uncertainty analysis.

B) R factor

R factor is the average thickness of the 95PPU band divided by the standard deviation of the measured data. SUFI-2, hence seeks to bracket most of the measured data with the smallest possible uncertainty band.

Further goodness of fit can be quantified by the R^2 (coefficient of correlation) and/or Nash Sutcliff (NSE) coefficient between the observations and the final “best” simulation. It should be noted that we do not seek the “best simulation” as in such a stochastic procedure the “best solution” is actually the final parameter ranges (Abbas pour *et al*., 2009).

2.17. Weather Generator

Lack of full and realistic long period climatic data is the problem of developing countries. Weather generators solve this problem by generating data having the same statistical properties as the observed ones(Danuso and F, 2002). SWAT requires daily values of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The user may choose to read these input from a file or generate the values using monthly average data summarized over a number of years.

SWAT includes the WXGEN weather generator model(Sharpley *et al*., 2000) to generate climatic data or to fill in gaps in measured records. The occurrence of rain on a given day has a major impact on relative humidity, temperature and solar radiation for the day. The weather generator first independently generates precipitation for the day (Neitsch *et al*., 2005).

Once the total amount of rainfall for the day is generated, the distribution of rainfall within the day is computed if the Green and Ampt method is used for infiltration. Maximum temperature, minimum temperature, solar radiation and relative humidity are then generated based on the presence or absence of rain for the day. Finally, wind speed is generated independently (Neitsch *et al*., 2005).

CHAPTER THREE

MATERIAL AND METHODS

The methodology was mainly focused on the application of physically based model, SWAT, imbedded with Arc GIS 10.1 for Dura river sub basin. The application of the model also involved calibration, sensitivity and uncertainty analysis with SWAT_CUP.

The data were collected from different agencies and organizations such as Regional and Ethiopian Meteorological Agency, Bureau or Ministry of water, Irrigation and Energy, and also Ethiopian Map Authority.

3.1. Description of the study Area

3.1.1. Location of Dura Sub basin

The Dura River is located in Amara region, North West of Go jam. It is one of the tributary of the Blue Nile River. Dura sub-basin drainage area is nearly 545km^2. The main stream reach has the total length of 55kms.The mean elevation of the watershed is 2000m with the maximum of 2400m and minimum of 1600 at the outlet above mean sea level. The average slope of the watershed is about 12% with the lowest point located at the outlet 1600m and the highest point at the maximum ridge 2400m above mean sea level in the watershed. The outlet of the river is located in Guangua woreda of Awi zone near to Chagni town at X=226270, Y=1215526 and Z=1600m in Projected coordinate system. The majority of the area is characterized by a humid tropical climate with heavy rainfall and most of the total annual rainfall is received during one rainy season called kiremt. The minimum and maximum temperature varies between 4.4–11.8^{0}c and 23.5 -31.4^{0}c, respectively. The mean annual rainfall in the study area is equal 1539mm per annum within the catchments. June to October is the major rainy months.

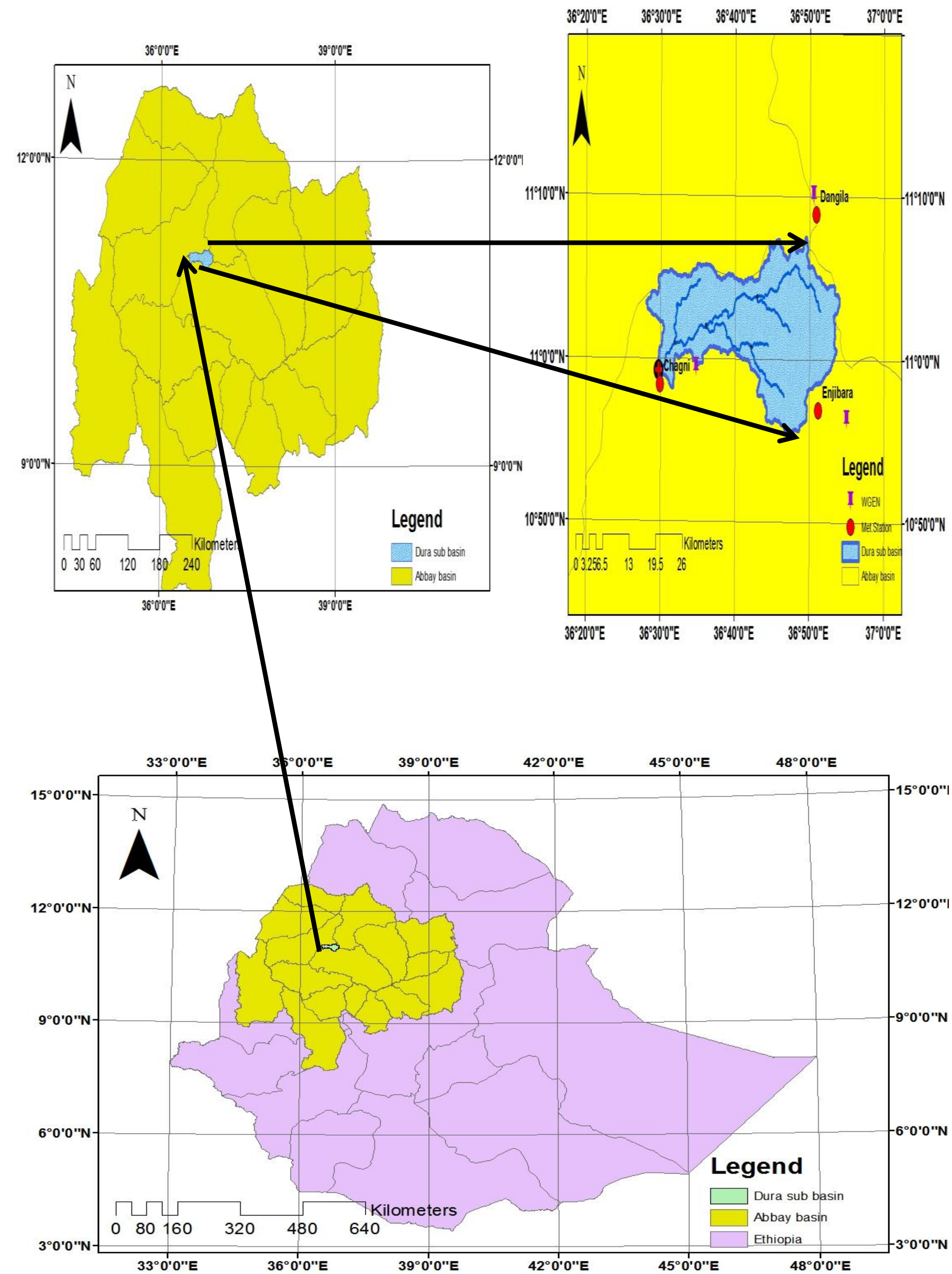


Figure 2 Description of the study area

3.2. Model Description

3.2.1. Theoretical description of SWAT

SWAT model is a watershed scale, continuous, long-term, semi distributed model designed to predict the impact of land management practices on the hydrology, sediment, and contaminant transport in agricultural watersheds(Neitsch *et al*. 2005). SWAT subdivides a watershed into different sub basins connected by a stream network, and further into hydrological response units (HRUs).The SWAT system is embedded within geographic information system (GIS) that can integrate various spatial environmental data including soil, land cover, climate, and topographic features. This study concerns the application of the latest version of the model, SWAT2012. Currently, SWAT is imbedded in an Arc GIS interface called Arc SWAT (Stone Environmental Inc., Montpelier, Vermont in collaboration with Texas A&M Spatial Science Laboratory, College Station, Texas and Black land Research and Extension Center; support for its development was provided by the Texas Agricultural Experiment Station).The Arc SWAT Arc GIS extension is a graphical interface for the SWAT model.

The large scale spatial heterogeneity of the study area is represented by dividing the watershed into sub basins. Each sub basin is further discretized into a series of hydrologic response units (HRUs), which are unique soil-land use combinations. Soil water content, surface runoff, nutrient cycles, sediment yield, crop growth and management practices are simulated for each HRU and then aggregated for the sub basin by a weighted average.

Physical characteristics, such as slope, reach dimensions, and climatic data are considered for each sub basin. For climate, SWAT uses the data from the station nearest to the centric of each sub basin. Calculated flow, sediment yield, and nutrient loading obtained for each sub basins are then routed through the river system. Channel routing is simulated using the variable storage or Muskingum method.

The water in each HRU in SWAT is stored in four storage volumes: snow, soil profile (0–2 m), shallow aquifer (typically 2–20 m), and deep aquifer. Surface runoff from daily rainfall is estimated using a modified SCS curve number method, which estimates the amount of runoff based on local land use, soil type, and antecedent moisture condition. Peak runoff predictions are based on a modification of the Rational Formula(Chow *et al*. 1988). The watershed concentration time is estimated using Manning's formula, considering both overland and channel flow.

Daily average soil temperature is simulated as a function of the maximum and minimum air temperature. If the temperature in a particular layer reaches less than or equal to 0^0C, no percolation is allowed from that layer. Lateral sub-surface flow in the soil profile is calculated simultaneously with percolation. Groundwater flow contribution to total stream flow is simulated by routing a shallow aquifer storage component to the stream(Arnold and M. 1996).

The model computes evaporation from soils and plants separately. Potential evapotranspiration can be modeled with the Penman–Monteith.(Monteith, 1965), Priestley–Taylor (Priestley and Taylor, 1972), or Hargreaves methods (Hargreaves, Hargreaves *et al.* 1985), depending on data availability. Potential soil water evaporation is estimated as a function of potential ET and leaf area index (area of plant leaves relative to the soil surface area). Actual soil evaporation is estimated by using exponential functions of soil depth and water content. Plant water evaporation is simulated as a linear function of potential ET, leaf area index, and root depth, and can be limited by soil water content.

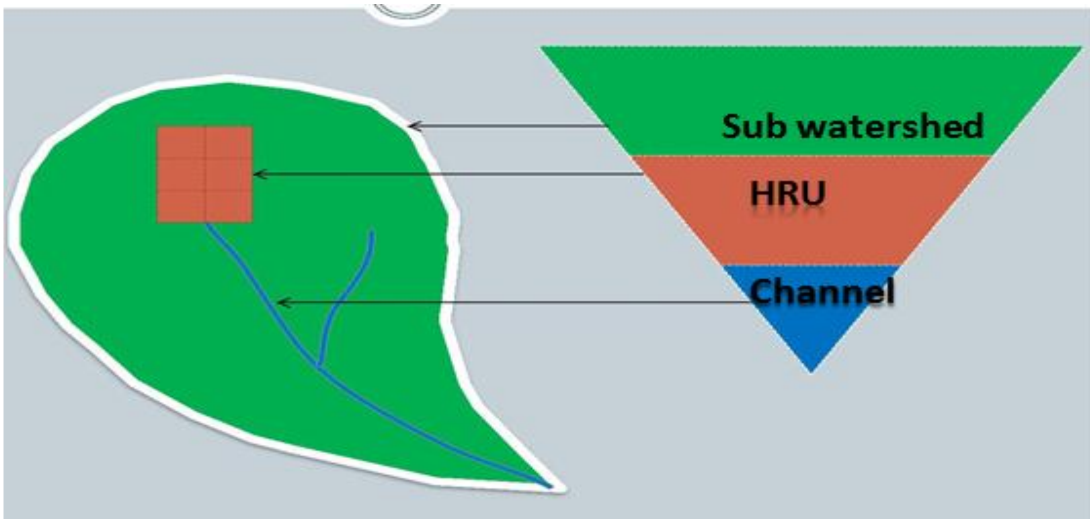


Figure 3 Conceptual representation of sub watershed, HRU and channel (source: KYLE FLYNN P.H, 2005)

3.2.2. Hydrological component of SWAT

Simulation of hydrology of a watershed is done in two separate components. One is the land phase of the hydrologic cycle that controls the water movement in the land and determines the water, sediment, nutrient and pesticide amount that will be loaded into the main stream. Hydrological components simulated in land phase of the Hydrological cycle are canopy storage, infiltration, redistribution, and evapotranspiration, lateral subsurface flow, surface runoff, ponds and tributary channels return flow. The second component is routing phase of the hydrological cycle in which the water is routed in the channels network of the watershed, carrying the sediment, nutrients and pesticides to the outlet. In the land phase of the hydrologic cycle, SWAT simulates the hydrological cycle based on the water balance equation.

$$SWt = SW0 + \Sigma\,(Rday - Qsurf - Ea - Wseep - Qgw) \qquad 3.1$$

Where SWt is the final soil water content (mm), SW0 is the initial soil water content for day i (mm), t is the days (days), Rday is the day precipitation (mm), Qsurf is the surface runoff (mm), Ea is the evapotranspiration (mm), Wseep is the seepage from the bottom soil layer (mm) and Qgw is the groundwater flow on day i (mm).

More detailed descriptions of the different model components are listed in Arnold *et al*., (1998),(Neitsch, Arnold *et al*. 2005).Surface runoff occurs whenever the rate of precipitation exceeds the rate of infiltration. SWAT offers two methods for estimating surface runoff: the SCS curve number procedure((SCS) 1972) and the Green & Ampt infiltration method (Green and and Ampt, 1911).Using daily or sub daily rainfall, SWAT simulates surface runoff volumes and peak runoff rates for each HRU. The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \qquad 3.2$$

In which, Qsurf is the accumulated runoff or rainfall excess (mm), Rday is the rainfall depth for the day (mm), S is the retention parameter (mm).

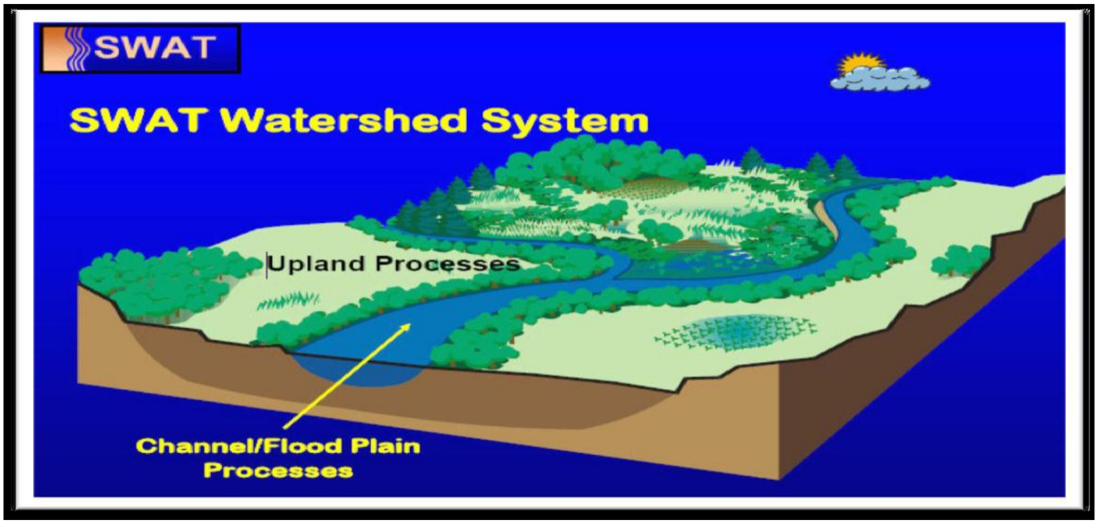


Figure 4 Upland and channel processes in SWAT (Source: KYLE FLYNNP.H, 2005)

3.2.3. Sediment Components of SWAT

SWAT can be used to simulate a single watershed or a system of multiple hydrologically connected watersheds. Each watershed is first divided into sub basins and then into HRUs. SWAT calculates the surface erosion within each HRU with the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975, Equation1).

$$Sed = 11.8 * (Qsurf) * qpeak) * areahru)^{0.56} * KUSLE * CUSLE * PUSLE * LSUSLE * CFRG \quad 3.3$$

where sed is the sediment yield on a given day (metric tons), Qsurf is the surface runoff volume (mm⁄ha), qpeak is the peak runoff rate (m^3/s), areahru is the area of the HRU (ha), KUSLE is the soil erodibility factor [0.013 metric ton m^2 h⁄(m^3-metric ton cm)], CUSLE is the cover and management factor, PUSLE is the support practice factor, LSUSLE is the topographic factor, and CFRG is the coarse fragment factor.

The sediment routing model(Arnold and M, 1996), Consists of two components operating simultaneously: deposition and degradation. The deposition in the channel and flood plain from the sub watershed to the watershed outlet is based on the sediment particle settling velocity. The settling velocity is determined using Stoke's Law(Chow *et al*. 1988) and is calculated as a function of particle diameter squared. The depth of fall through a routing reach is the product of settling velocity and reaches travel time. The delivery ratio is estimated for each particle size as a linear function of fall velocity, travel time, and flow depth. Degradation in the channel is based on Bagnold's stream power concept(Bagnold, 1977);(Williams, 1980). Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach is determined by

$$Sedch = Sedch, i - Seddep + Seddeg \quad 3.4$$

Where Sedch is the amount of suspended sediment in the reach (t), Sedch, i is the amount of suspended sediment in the reach at the beginning of the time period (t), Seddep is the amount of sediment deposited in the reach segment (t), and Seddeg is the amount of sediment retrained in the reach segment (t). Finally, the amount of sediment transported out of the reach is calculated by:-

$$Sedout=sedch*vout/vch \quad 3.5$$

Where Sedout is the amount of sediment transported out of the reach, Vout is the volume of outflow during the time step (m^3), and Vch is the volume of water in the reach segment (m^3). The volume of water in the segment (Vch) is the product of the length of the segment (m), the cross-sectional area (m^2), and the flow at a given depth (m).

The maximum amount of sediment that can be transported from a reach segment during channel sediment routing is determined by the modified Bagnold's equation(Bagnold, 1977).

$$CONCsed, ch, mx=SPCON*VC*SPEXP \quad 3.6$$

Where CONCsed, ch, mx is the maximum concentration of sediment that can be transported (ton/m^3 or kg/L), SPCON is the coefficient in this equation defined by the user, VC is the peak flow velocity (m/s) in the channel, and SPEXP is an exponent parameter in the equation. The coefficient (SPCON) should be between 0.0001 and 0.01. The exponent (SPEXP) normally ranges from 1.0 to 2.0.

3.2.4. SWAT strength and limitation

3.2.4.1. Strength

Key features that make the model applicable for a wide range of studies are:

- ❖ Modeling based on physical processes associated with soil and water interaction
- ❖ Flexibility on input data requirement
- ❖ Capability of modeling the changes in land use and management practices
- ❖ Computational efficiency
- ❖ Capability of long-term simulations
- ❖ Capability of modeling catchments areas varying between few hectares to thousands of sq.km.
- ❖ The model is freely available and can be easily downloaded from the internet.

3.2.4.2 Limitation

Following are some of the limitations using SWAT for hydrological modeling:

1. Due to the heterogeneity of the catchments, a number of meteorological observation stations are required to present the spatial variation in the hydro-meteorological characteristics in the area. The lack of adequate number of observation stations affects the model output.

2. In order to calibrate the model for the historic land use scenarios, the corresponding land use maps are needed. In order to get the real time picture of the land use pattern, this information can be extracted from the remote sensing satellite imageries by using digital image processing technique. However, acquisition of satellite imageries is expensive and also the expertise required for the image interpretation is another major limitation.

3. Though SWAT is a free software tool, in order to represent the spatial variation in the catchments characteristics, GIS software is the pre-requisite to run the model.

3.3. SWAT Input Data

Input for SWAT is defined at several levels of details: watershed, sub basin and HRUs.The watershed level inputs used to model the processes throughout the watershed. Generally the following input data were used to assess the runoff and the sediment yield of Dura River Sub basin.

3.3.1. Digital Elevation Model (DEM)

The 90 by 90 meter resolution DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain of the topography of the catchments. The DEM describes the elevation of any point in a given area at a specific spatial resolution .Before the DEM data was loaded in to Arc SWAT interface it was projected in to projected coordinate system. It was obtained from Ministry of water resource, Irrigation and Electricity.

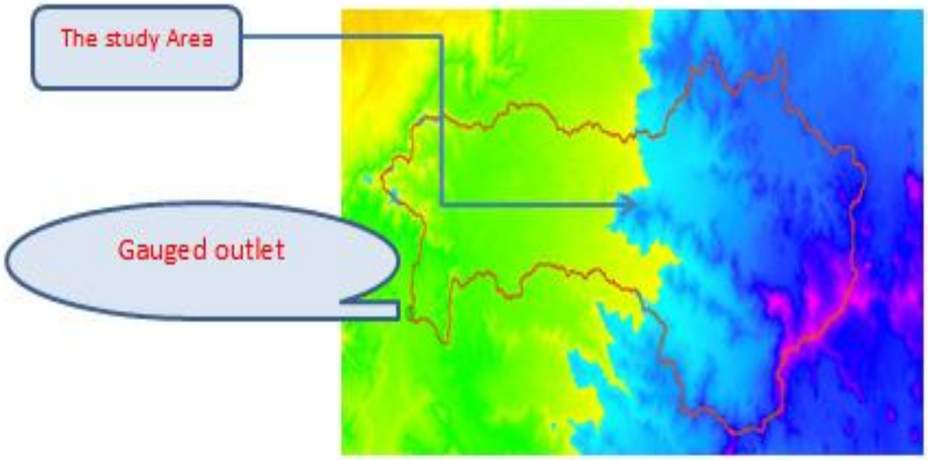


Figure 5 Digital Elevation Model (DEM) for the study Area

3.3.2. Land use and land cover

Land use is one of the most important factors that affect runoff, evapo-transpiration and surface erosion in a watershed. Different soil texture and other properties such as texture, moisture content, hydraulic conductivity, and organic carbon content, for different layer of each soil type is required for SWAT model. 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 hydrologic response unit (HRU) and is used to determine water budget for the soil profile daily runoff and sediment erosion. It is collected from Ministry of Water resource, Irrigation and Electricity.

The land use of the study area is categorized mainly as 41.97% dominantly cultivated, 51.32% moderately cultivated, 1.68% Forest, 0.03% Urban and 5%Wooden open. The terms land use and land/cover is often

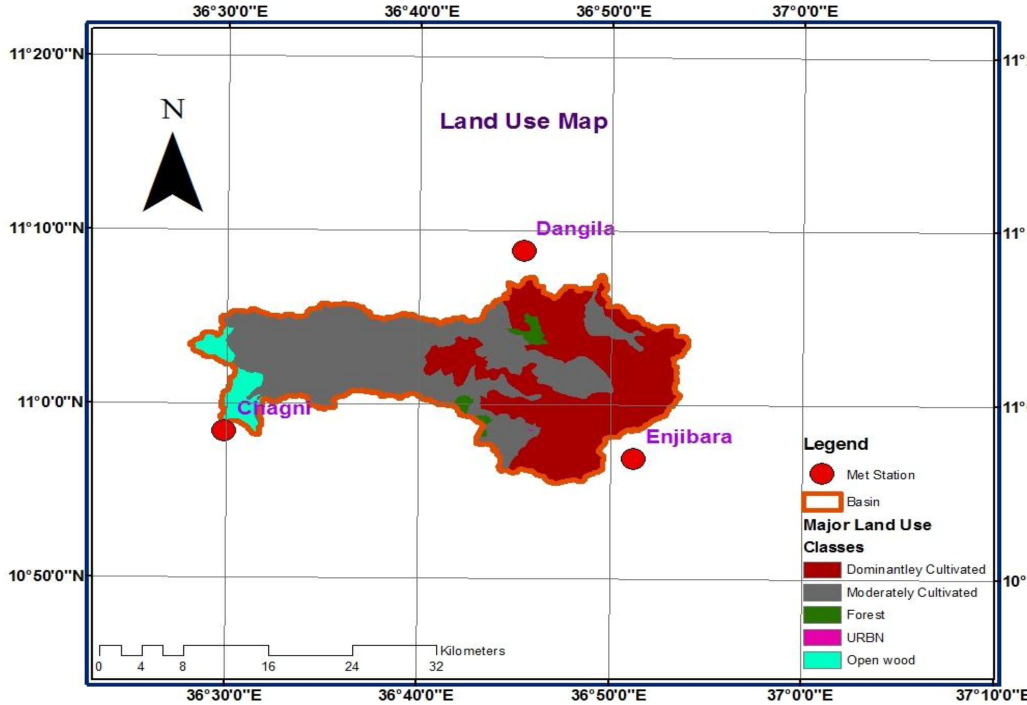


Figure 6 Land use map of Dura River sub basin.

3.3.3. Soil

The SWAT model requires different soil textural and physical-chemical properties such as soil texture, available water content, hydraulic conductivity, bulk density and organic carbon content for different layers of soil. The soil types in the study area was classified as 64.45% haplic alisols, 17.15% Eutric Leptosols, 8.57% Chromic Luvisols 5.03%Haplic Luvisols 4.075 %Eutric Vertisols and 0.73% Rhodic Nitisols. It was collected from Ministry of Water resource, Irrigation and Electricity.

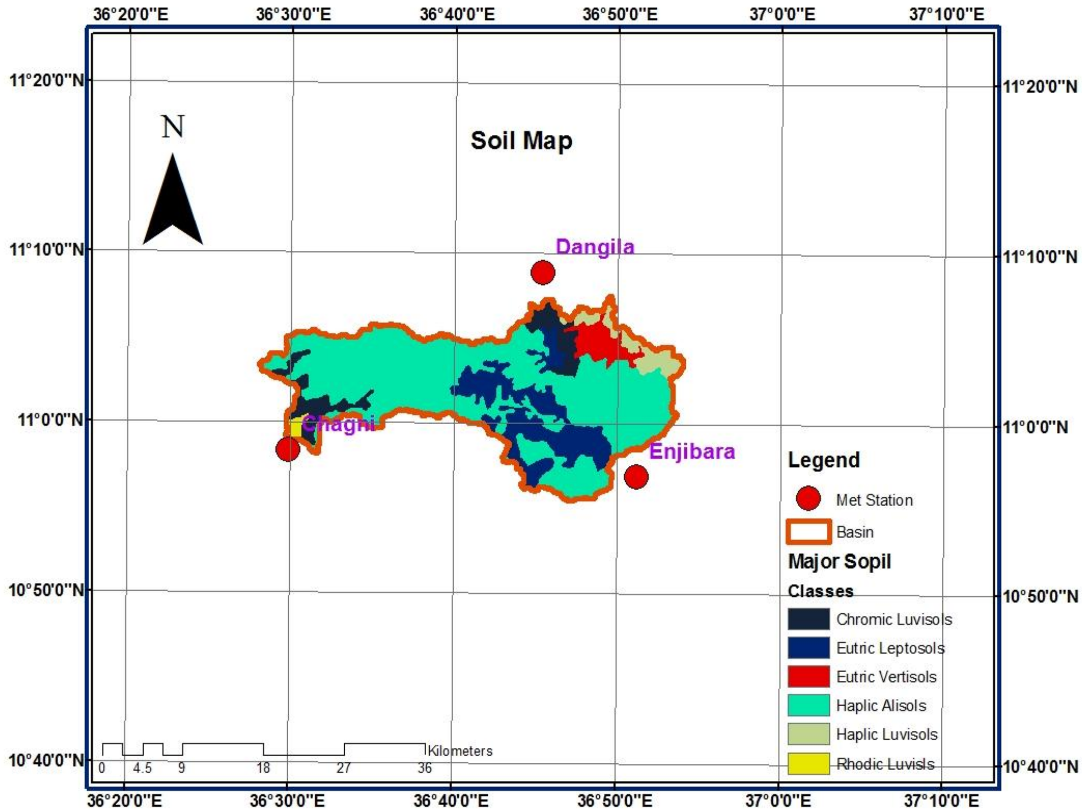


Figure 7 Soil map of Dura River sub basin

3.3.4. Slope Distribution

Slope is predominant topographic factor which can greatly affect the runoff and sediment detachment process in the given watershed. Delineation of watershed, sub basins and stream network characteristics are derived with respect to slope difference within the watershed. In general the slope of the study area is 62.72% between 0-10%, 20.29% between 10-20% and 16.99% lies above 20%.

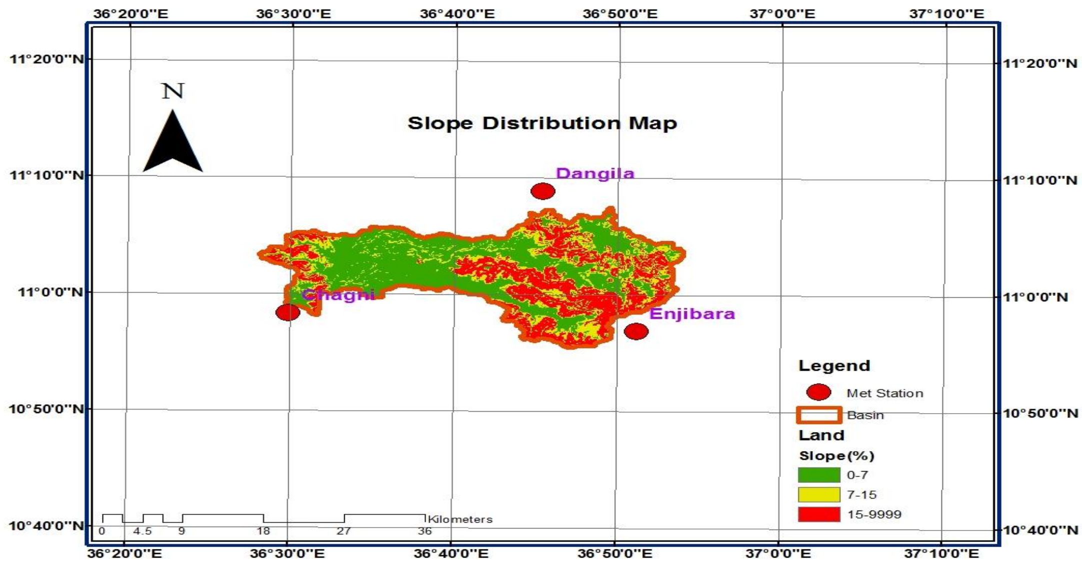


Figure 8 Slope Distribution of the study Area

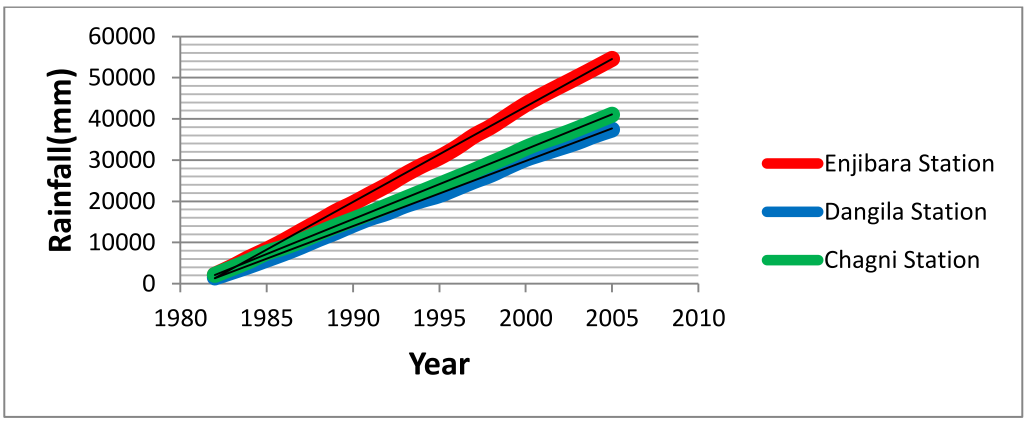
3.3.5. Meteorological Data

Meteorological data is needed by the SWAT model to simulate the hydrological conditions of the basin.The daily metrological data (precipitation, temperature (maximum and minimum), wind speed, relative humidity and solar radiation of the meteorological station with in and around the watershed were collected from the National Meteorological Agency and 24 years daily data were used.

Table 1 Location of meteorological stations

No	Station Name	Location			Nearest User_WGEN		
		Lat	Long	Elevation	Lat	Long	Elevation(m)
1	Chagni	10.97^0	36.5^0	1622	11.4^0	36.56^0	1645
2	Dangila	11.43^0	36.85^0	2028	11.4^0	36.87^0	2063
3	Enjibara	10.9^0	36.9^0	2322	11.08^0	36.87	2281

The missing meteorological data from the weather station was filled by a weather generator model imbedded in SWAT. SWAT integrates weather generator in order to generate and fill missing data using the monthly weather generator parameters. Therefore, the missing weather data for the stations were estimated using user weather generator (User_WGEN) developed by Ministry of Water, Irrigation and Electricity using 32 years of data from Climate Forecast System Reanalysis (CFSR) for SWAT users. Chagni for Main Beles Basin, Dangila and Enjibara stations for Gilgel Abay Basin were used to evaluate applicability of CFSR in the upper Blue Nile Basin by (Tilahun *et al*, 2015) and concluded that CFSR can be used to complement station data scarcity. Utilizing CFSR weather data provides stream simulations that are as good as or better than using land based weather stations (Daniel, 2013).



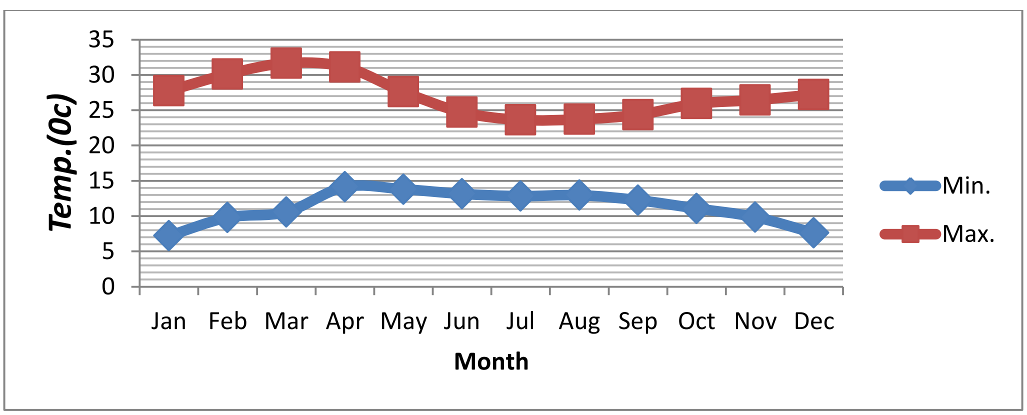


Figure 9 Annual Cumulative Rainfall and average Max.and Min. temperature of the study area above and below respectively

3.3.6. Hydrological Data

The hydrological data was required for performing sensitivity analysis, calibration and Uncertainty analysis and validation of the model. Daily discharge measured data and the suspended sediment data of Dura River were collected from Ministry of Water, Irrigation and Electricity. The suspended sediment sample data were collected only during the rainy season and were not sufficient to carry out calibration and validation. For this sediment rating curve for the linear relationship between sediment (Q_{s}) in ton/day and flow (Q) in M^3/sec developed by (Yasir *et al* 2014*)* was used for additional samples. Average monthly flow for Dura River is presented in the figure bellow.

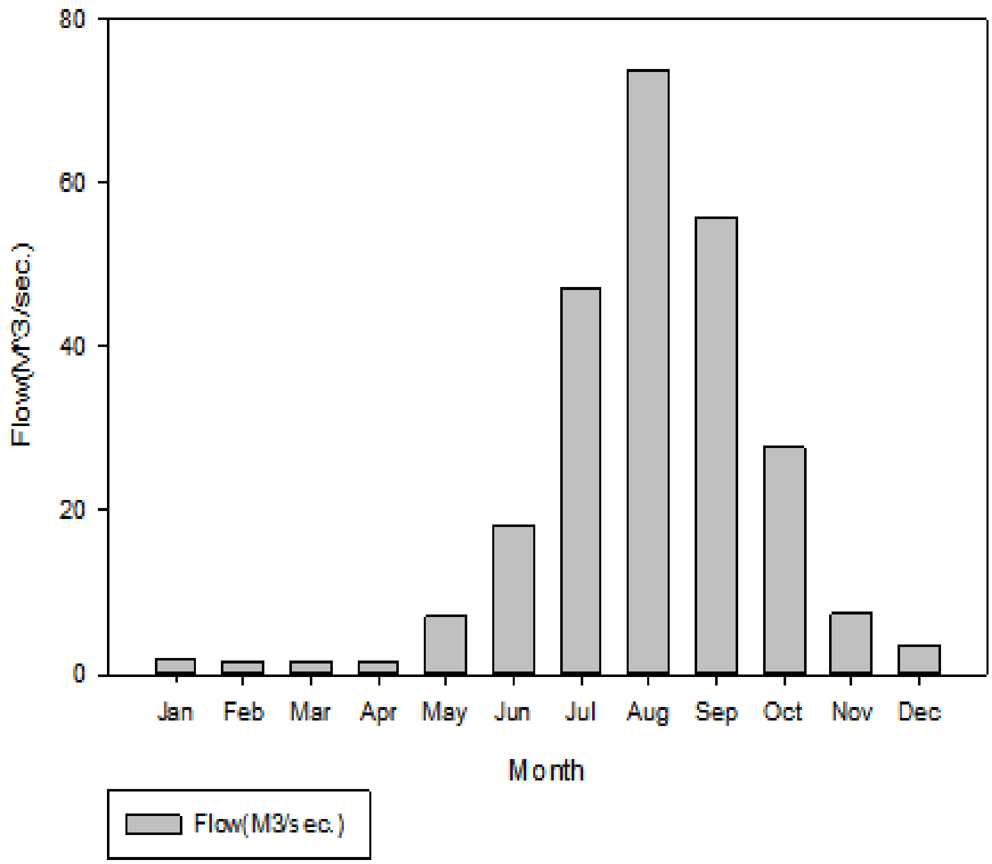


Figure 10 Average Monthly Flow Graph Dura River

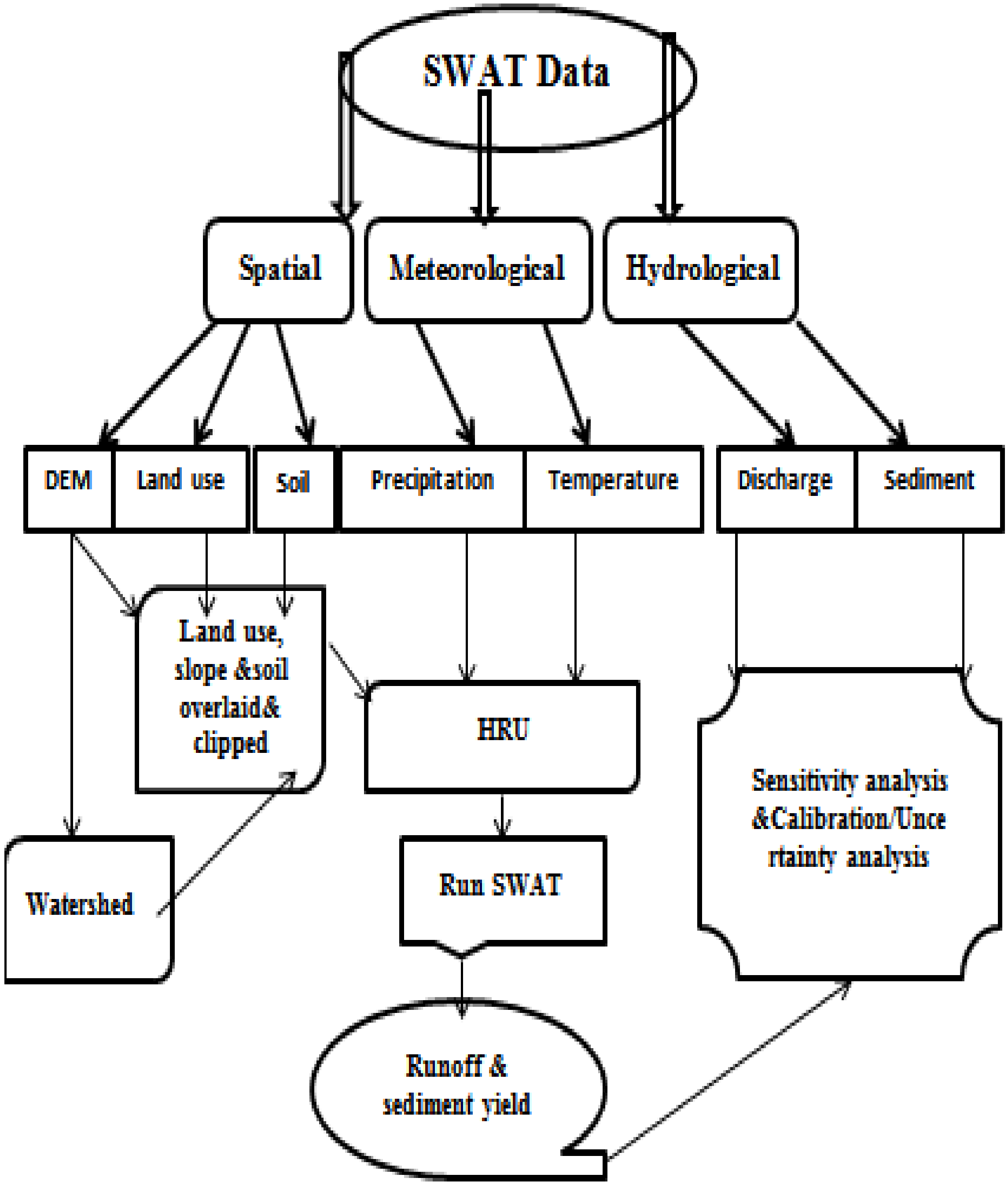


Figure 11 Schematic Diagram of Methodology

3.4. SWAT Model Setup

Geographic information systems data for the SWAT model were preprocessed by two separate Functions watershed delineation and determination of hydrologic response units (HRUs).

3.4.1. Watershed delineation

Arc SWAT uses Digital Elevation Model (DEM) data to automatically delineate the watershed into several hydrologically connected sub-watersheds. The watershed delineation operation uses and expands ArcGIS and Spatial Analyst extension functions to perform watershed delineation.

The first step in the watershed delineation was loading the properly projected DEM. To reduce the processing time of the GIS functions, a mask was created over the DEM around the study area.

The initial stream network and sub-basin outlets were defined based on drainage area threshold approach. The threshold area defines the minimum drainage area required to form the origin of a stream. The interface lists a minimum, maximum and suggested threshold area. The smaller the threshold area, the more detailed the drainage network delineated by the interface but the slower the processing time and the larger memory space required. In this study, defining of the threshold drainage area was done using the threshold value of 2250ha. Besides those sub-basin outlets created by the interface, outlets were also manually added at the gauging stations where sensitivity analysis, calibration and validation tasks were later performed. Sub basin distribution of the study area is represented in the figure 12 below.

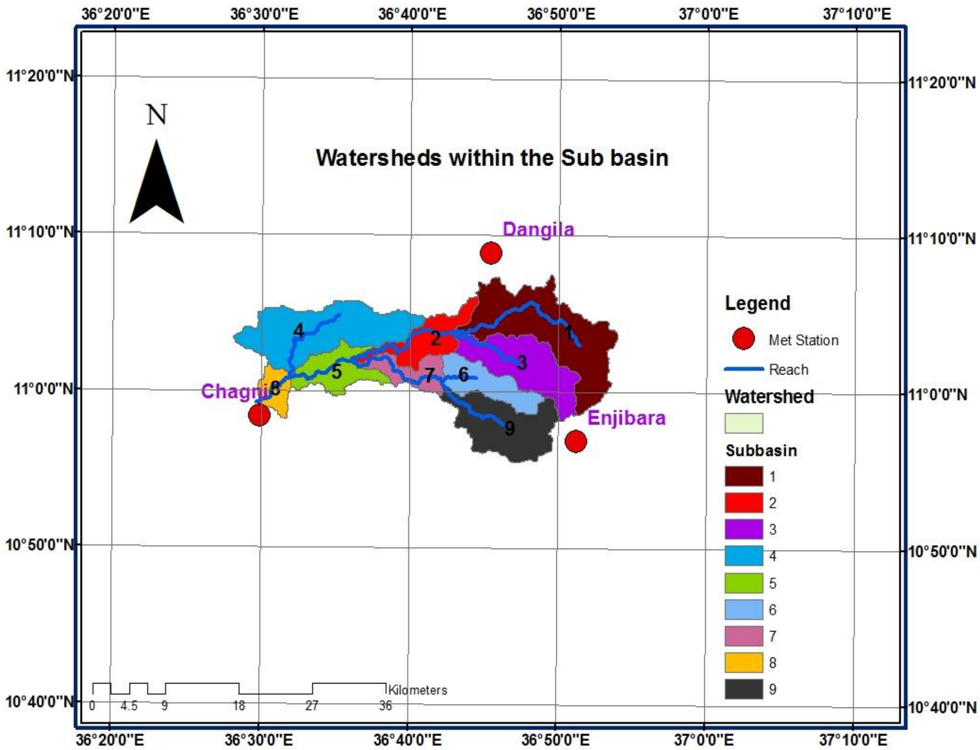


Figure 12 Watershed Distribution within Dura Sub basin

3.4.2. Hydrologic response unit (HRU) analysis

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that are comprised of unique land cover, soil, slope and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land cover classes were defined using the look up table. A look-up table that identifies the 4-letter SWAT code for the different categories of land cover/land use was prepared so as to relate the grid values to SWAT land cover/land use classes.

After the land use SWAT code assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As of the land use, the soil layer in the map was linked to the user soil database information by loading the soil look-up table and reclassification applied. The land slope classes were also integrated in defining the hydrologic response units. The DEM data used during the watershed delineation was also used for slope classification. The multiple lope discretization operation was preferred over the single slope discretization as the sub-basins have a wide range of slopes between them.

The last step in the HRU analysis was the HRU definition. The HRU distribution in this study was determined by assigning multiple HRU to each sub-watershed. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils or slope classes in each sub basin.

Land uses, soils or slope classes which cover less than the threshold level were eliminated and the area of the remaining land use, soil, or slope class was reapportioned so that 100% of the land area in the sub-basin was modeled. The threshold levels set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that it is better to use a larger number of sub-basins than larger number of HRUs in a sub-basin; a maximum of 10 HRUs in a sub-basin is recommended. Hence, taking the recommendations in to consideration, 5%, 10%, and10% threshold levels for the land use, soil and slope classes were applied, respectively so as to encompass most of spatial details. Percentage areas of sub basins and the respective HRUs distribution are represented in the table 2.

Table 2 Areal Watershed percentage and HRUs Distribution

Sub basin No	Area(km2)	Areal percentage (%)	No of HRUs
1	124.8	22.9	13
2	42.2253	7.75	7
3	72.3492	13.28	8
4	107.4384	19.71	7
5	38.2725	7.02	2
6	40.2975	7.39	10

7	27.2241	5	3
8	17.9982	3.3	9
9	74.3904	13.65	11
∑	**545**	**100**	**70**

3.4.3. Importing climate data

The climate of a watershed provides the moisture and energy inputs that control the water balance and determine the relative importance of the different components of the water cycle.

The climatic variables required by SWAT daily precipitation, maximum and minimum temperature, solar radiation, wind speed and relative humidity were prepared in the appropriate dbase format. Due to data availability and quality, daily precipitation, and maximum and minimum temperature in dbase format were the climatic input variables imported together with their weather location. And due to lack of complete weather data we used the Hargreaves method which uses Temperature to determine the potential evapotranspiration.

3.4.4. Sensitivity analysis

A model sensitivity analysis can be helpful in understanding which model input are the most important or sensitive and to understand potential limitation of the model. Sensitivity analysis is a method of identifying the most sensitive parameters that significantly affects the model calibration or model prediction. Sensitivity analysis is the process of determining the rate of change in model output with respect to changes in model inputs (parameters). It is necessary to identify key parameters and the parameter precision required for calibration. Sensitivity analysis describes how model output varies over a range of a given input variable (Dilesaw, 2006).

When a SWAT simulation is taken place there will be discrepancy between measured data and simulated results. So, to minimize this discrepancy, it is necessary to determine the parameters which are affecting the results and the extent of variation. Hence, to check this, sensitivity analysis is one of SWAT model tool to show the rank and the mean relative sensitivity of parameters identification and this step was ordered to analysis. This appreciably eases the overall calibration and validation process as well as reduces the time required for it.

3.4.5. Calibration and validation

Calibration and validation are typically performed by splitting the available observed data into two datasets: one for calibration, and another for validation. Data are most frequently split by time periods, carefully ensuring that the climate data used for both calibration and validation are not substantially different, i.e., wet, moderate, and dry years occur in both periods(Gan *et al*., 2008).Calibration is the process whereby model parameters are adjusted to make the model output match with the observed data. In order to the watershed model for estimating the effectiveness of future potential management practices, the model must be first calibrated to measured data and then should tested without further parameter adjustment against an independent set of measured data. For the verification purpose SWAT CUP is power full. SWAT CUP was used for the model verification. SWAT-CUP (SWAT Calibration and Uncertainty Procedures) is a program designed to integrate various calibration analysis programs like SUFI_2, PARASOL, GLUE and MCMC for SWAT (Soil & Water Assessment Tool) using the same interface. But the sequential uncertainty Fitting version 2(SUFI_2) was used for this research as it accounts for all sources of uncertainties such as uncertainties in driving variables like rainfall. The program guides the input files necessary for running a calibration program. Each SWAT method and allows running the procedure many times until convergence is reached. It allows saving calibration iterations in the iteration history for later use.

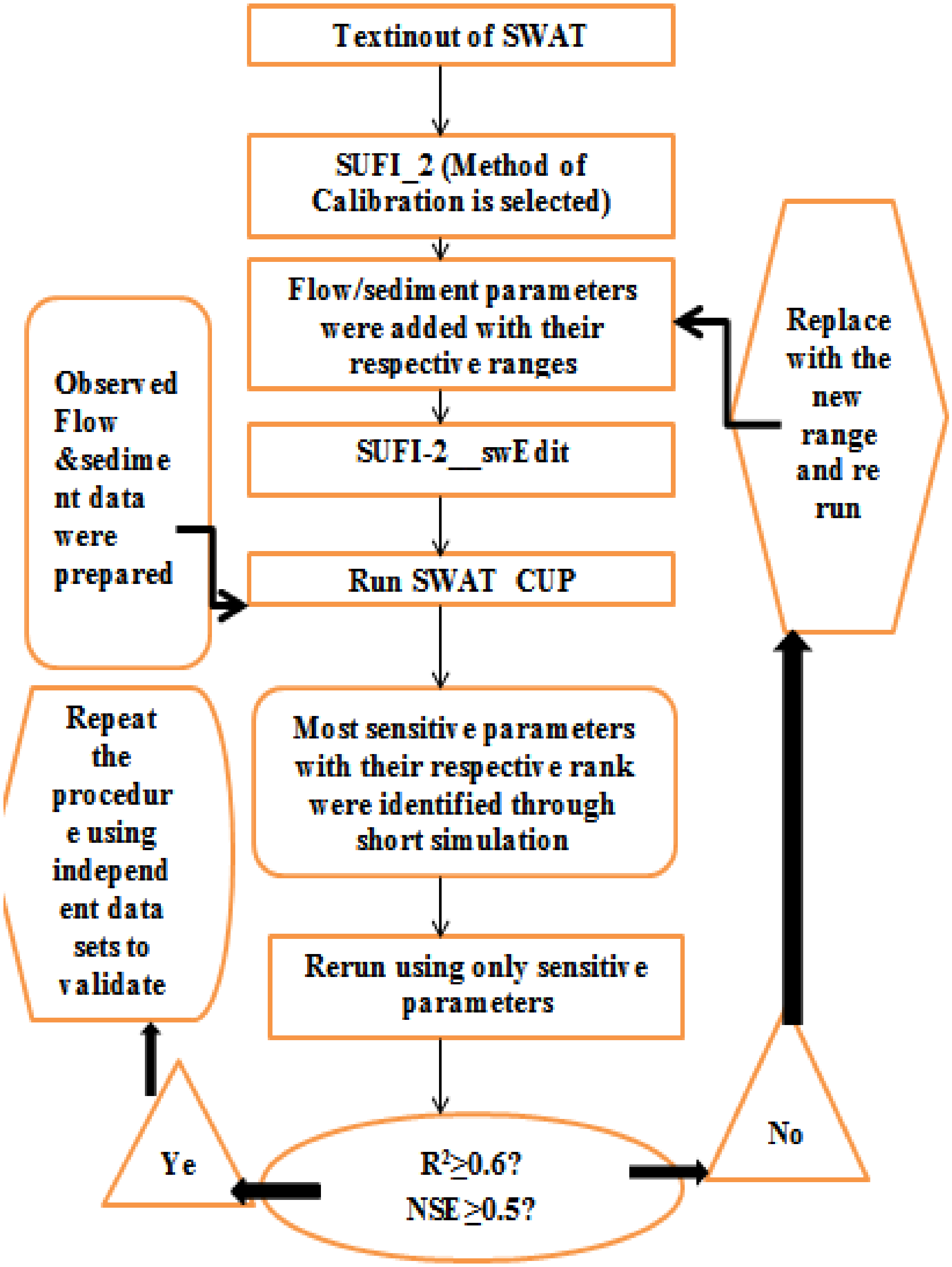


Figure 13 schematic diagram of calibration by SWAT_CUP

3.4.6. Uncertainty Analysis

Model calibration does not guarantee reliability of model predictions. The parameter values obtained during calibration and the subsequent predictions made using the calibrated model are only as realistic as the validity of the model assumptions for the study watershed and the quality and quantity of actual watershed data used for calibration and simulation.

This study used SUFI-2 for overall uncertainty analysis to investigate uncertainties involved with predicting stream flow and sediment yield for the study sub basin.

The goodness of fit and the degree to which the calibrated model accounts for the uncertainties are assessed by the p-factor and R- factor measures. Theoretically, the value for P factor ranges between 0 and 100%, while that of R-factor ranges between 0 and infinity. A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data. The degree to which we are away from these numbers can be used to judge the strength of our calibration. 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. When acceptable values of R factor and P-factor are reached, then the parameter uncertainties are the desired parameter ranges.

3.4.7. Model Evaluation

The performance of SWAT was evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination (R^2) and Nash-Sutcliffe simulation efficiency (NSE) were the goodness of fit measures used to evaluate model prediction. The R^2 value is an indicator of strength of relationship between the observed and simulated values. 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 NSE is between 0 and 1, it indicates deviations between measured and predicted values. If NSE is negative, predictions are very poor, and the average value of output is a better estimate than the model prediction (Nash and Sutcliffe, 1970). The R^2, NSE, RSR and D% values are explained in equations 3.7, 3.8, 3.9 and 3.10 respectively

$$R^2 = \frac{\left(\sum_{i=1}^{n}(O_i - O_{av})(P_i - P_{av})\right)^2}{\sum_{i=1}^{n}(O_i - O_{av})^2 \sum_{i=1}^{n}(P_i - O_{av})^2} \qquad \textbf{.......................................3.7}$$

$$E_{NS} = \frac{\sum_{i=1}^{n}(O_i - O_{av})^2 - \sum_{i=1}^{n}(P_i - O_{av})^2}{\sum_{i=1}^{n}(O_i - O_{av})^2} \qquad \textbf{....................................3.8}$$

Where n is the number of observations during the simulation period Oi and Pi are the observed and predicted values at each comparison point i, Oav and Pav are the arithmetic means of the observed and predicted values.

$$\boldsymbol{RSR} = \frac{[\sum_{i=1}^{n}(\boldsymbol{obs} - \boldsymbol{sim})^2]^{1/2}}{[\sum_{i=1}^{n}(obs - av_{obs})^2]^{1/2}} \qquad \textbf{.......................................3.9}$$

Where: obs is the observed value

Sim = the simulated value

$$\mathbf{D\% = 100.} \frac{[\sum \mathbf{obs} - \sum \mathbf{sim}]}{\sum \mathbf{obs}} \qquad \textbf{.......................................3.10}$$

Where: obs is observed value and
sim is simulated value.

Note: $ENS = 1 - [RSR]^2$

Table 3 General Performance ratings for recommended statistics for a monthly time step. (D. N Moriasi, *et al*. 2007) and Santhi *et.al*, (2001) for R^2

Performance Rating	Recommended statistical ranges				
	R^2	NSE	RSR	%D(Flow)	%D(Sediment)
Very good		0.75<NSE<=1	0.0<=RSR<=0.5	D <=±10	D <=±15
Good		0.65<NSE<=0.75	0.5<RSR<=0.6	±10<=D ±15	±15<=D ±30
Satisfactory	>0.6	0.5<NSE<=0.65	0.6<RSR<=0.7	±15<=D<±25	±30<=D<±55
Unsatisfactory	<0.6	NSE<=0.5	RSR>=0.7	D >= ± 25	D >= ± 55

CHAPTER FOUR

RESULT AND DISCUSSION

4.1. Sensitivity Analysis

The global sensitivity analysis of SUFI_2_SWAT_CUP program was carried out for ten years of calibration period (from January 1st, 1985 to December 31, 1994) for both flow and sediment yield. The Sensitivity scale of hydrologic parameters was expressed in t -stat and p-values.

In sensitivity analysis the larger, in the absolute value, the value of t -stat and the smaller the p value the more sensitive the parameter.

4.1.1. Flow Sensitive parameters in the sub basin

The most sensitive parameters controlling the surface runoff in the sub basin Were found to be base flow alpha factor (Alpha_Bf), curve number (CN2), effective hydraulic conductivity in main canal (CH_K2), Ground water delay (GW_DLAY), Threshold water depth in the shallow aquifer (REVAPMN), available water capacity (SOL_AWC), Groundwater "revap" coefficient(Gw_Revapmn), Threshold depth of water to occur return (GWQMN) and Soil evaporation compensation factor(ESCO).

Table 4 SWAT_CUP_SUFI_2 Output result of t-stat and p-value for flow sensitivity analysis

Parameter Name	t-Stat	P-Value
2:R__ESCO.hru	-0.08	0.94
8:R__GW_REVAP.gw	-0.43	0.67
3:R__REVAPMN.gw	-0.54	0.59
1:R__SOL_AWC(.).sol	0.71	0.48
7:V__ALPHA_BF.gw	0.79	0.43
6:R__CN2.mgt	-1.40	0.16
9:V__CH_K2.rte	2.04	0.04
5:V__GWQMN.gw	-3.84	0.00
4:V__GW_DELAY.gw	-5.09	0.00

Table 5 Flow sensitive parameters Description and Sensitivity Rank

No	Parameters	Parameter Description	Sensitivity Rank
1	GW_DELAY.gw	Ground water delay	1
2	GWQMN.gw	Threshold depth of water to occur return	2
3	CH_K2.rte	Effective hydraulic conductivity in main canal	3
4	CN2.mgt	Initial SCS CN II value	4
5	ALPHA_BF.gw	Bas flow Alpha factor	5
6	SOL_AWC (...).sol	Available water capacity	6
7	REVAPMN.gw	Threshold water depth in the shallow aquifer	7
8	GW_REVAP.gw	Groundwater "revap" coefficient	8
9	ESCO.hru	Soil evaporation compensation factor	9

4.1.1. Sediment Sensitive parameters in the sub basin

The most sensitive parameters controlling the sediment yield in the sub basin Were found to be curve number (CN2), effective hydraulic conductivity in main canal (CH_K2), Channel erodibility factor (CH_EROD), Linear re-entrainment parameter for channel sediment routing (SPCON), Channel cover factor (CH_COV), USLE management support (USLE_P), Bas flow Alpha factor (ALPHA_BF), Exponential re-entrainment parameter for channel sediment routing (SPEXP) and Minimum USLE cover factor for the basin (C_FACTOR).

Table 6 SWAT_CUP_SUFI_2 Output result of t-stat and p-value for Sediment sensitivity analysis

Parameter Name	t-Stat	P-Value
5:R__SPEXP.bsn	0.02	0.99
8:R__SPCON.bsn	0.44	0.66
1:R__CH_ERODMO(.).rte.	0.50	0.61
3:R__USLE_P.mgt	-1.19	0.23
4:R__C_FACTOR.bsn	1.23	0.22
2:R__CH_COV1.rte	1.30	0.20
7:V__ALPHA_BF.gw	4.18	0.00
9:V__CH_K2.rte	-13.14	0.00
6:R__CN2.mgt	35.23	0.00

Table 7 Sediment sensitive parameters Description and Sensitivity Rank

No	Parameters	Parameter Description	Sensitivity Rank
1	CN2.mgt	Initial SCS CN II value	1
2	CH_K2.rte	Effective hydraulic conductivity in main canal	2
3	ALPHA_BF.gw	Bas flow Alpha factor	3
4	CH_COV.rte	Channel cover factor	4
5	C_FACTOR.bsn	Minimum USLE cover factor for the basin	5
6	USLE_P.mgt	USLE management support	6
7	CH_ERODM (.).rte.	Channel erodibility factor	7

8	SPCON.bsn	Linear re-entrainment parameter for channel sediment routing	8
9	SPEXP.bsn	Exponential re-entrainment parameter for channel sediment routing	9

4.2. Model Calibration and Validation

After the sensitive parameters identification, A SWAT model was calibrated and validated on a monthly basis to predict the flow and daily sediment yields from the Dura sub basin using a time series dataset of 24 years from 1982 to 2005. The first 3 years of the modeling period were used for 'model warm-up'. Data for the period 1985 to 1994 were used for calibration and the remaining part of the data set was reserved for validation. The calibration and validation of the model was executed using sequential Uncertainty Fitting in SWAT_CUP (SUFI_2_SWAT_CUP).The watershed was subdivided into 9 sub basins based on a chosen threshold area of 2250 ha. The overlay of land use, soil and slope maps resulted in the definition of 70 HRUs. The simulated flow and sediment yields at the outlet of the watershed gauging station were compared with the observed flow and sediment yields.

4.2.1. Flow Calibration

During the calibration period (1985 to 1994), the simulated monthly flows matched well with the measured monthly flows (R^2= 0.85 and NSE = 0.82) as shown in Figures 14 and 15. The trends of seasonal variability and monthly average discharge were generally well captured. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes (as for example in August 1986,August 1988 and August 1994). However, the model underestimated the peak monthly flow during 1985 and 1989 and overestimated the peak flows during 1990.

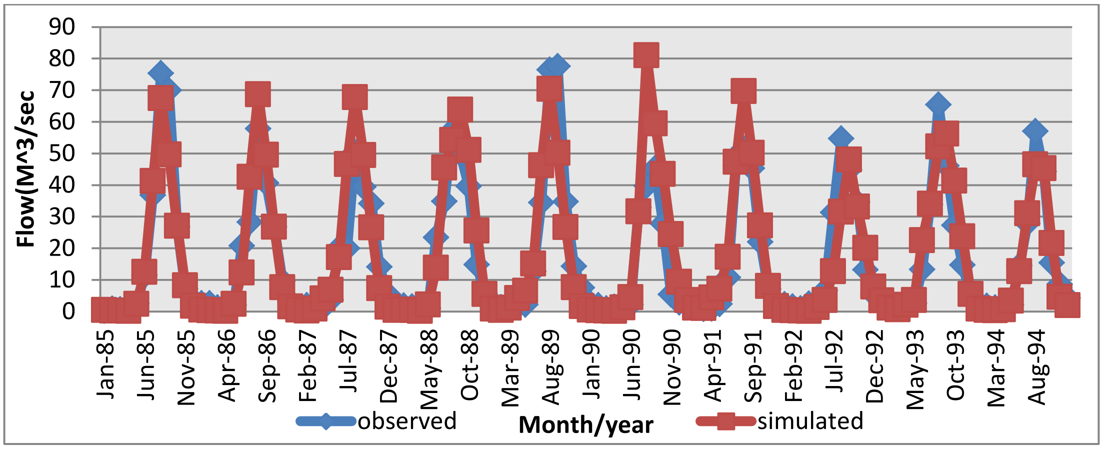


Figure 14 Graphical plot of Flow during Calibration period (1985-1994)

Table 8 Flow parameter range and the fitted value

Parameter Name	Fitted Value	Min_value	Max_value
1:R__SOL_AWC (.).sol	0.390625	0.0	1.0
2:R__ESCO.hru	0.653	0.0	1.0
3:R__REVAPMN.gw	321.562500	0.0	500.00
4:V__GW_DELAY.gw	11.5625	0.0	500.00
5:V__GWQMN.gw	1434.375	0.0	5000.00
6:R__CN2.mgt	-0.005750	-0.200000	0.200
7:V__ALPHA_BF.gw	0.138125	0.000000	1.000
8:R__GW_REVAP.gw	0.022363	0.02000	0.2000
9:V__CH_K2.rte	368.4345	-0.010000	500.00

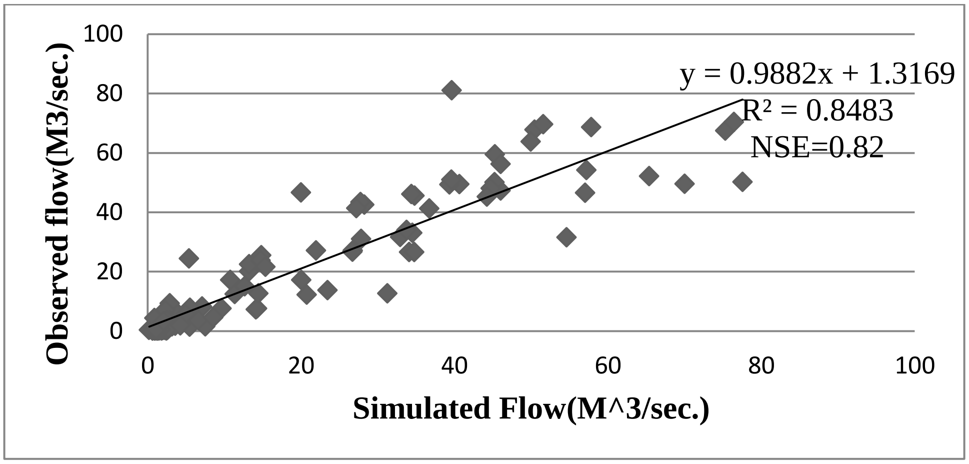


Figure 15 Scatter plot between Observed and Simulated flow during Calibration period (1985-1994)

4.2.2. Sediment Calibration

The model also adequately predicted the sediment yields in the study area during calibration with R^2 and NSE values of 0.80 and 0.73 respectively.

Note that during Calibration of sediment only peak flow months of the year (July, August and September) were considered throughout the calibration period as it is important to capture more sediment yielding periods to evaluate the model performance. During this period, the simulated daily sediment yields matched well with the measured daily sediment yields (Figures 16 and 17). adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high sediment yield. However, the daily sediment yield values were over-predicted by the model during 1986 and 1987. On the other hand, during the wet season from 1988 to 1989, daily sediment yields were under-predicted by the model which could have been due to deposition in the stream channel.

Table 10 presents the monthly statistical results during the calibration period for both flow and sediment yield at Dura sub basin gauging station.

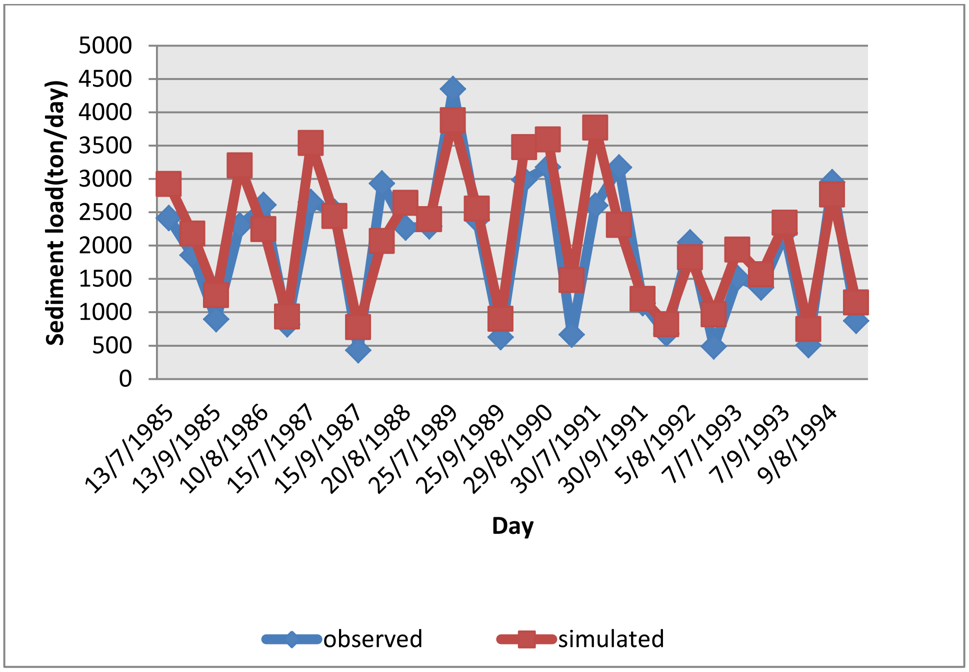


Figure 16 Graphical plot of Sediment during Calibration period (1985-1994)

Table 9 Sediment parameter range and the fitted value

Parameter Name	Fitted Value	Min_value	Max_value
1:R__CH_ERODMO (...) .rte.	0.4895000	0.000000	1.000000
2:R__CH_COV1.rte	1.799000	1.000000	2.000000
3:R__USLE_P.mgt	0.935000	0.000000	1.000000
4:R__C_FACTOR.bsn	0.403065	0.003000	0.450000
5:R__SPEXP.bsn	1.1635000	1.000000	2.000000
6:R__CN2.mgt	0.074075	-0.200000	0.2000000
7:V__ALPHA_BF.gw	0.313391	0.000000	1.0000000
8:R__SPCON.bsn	0.009851	0.000100	0.010000
9:V__CH_K2.rte	60.49010	-0.010000	500.0000

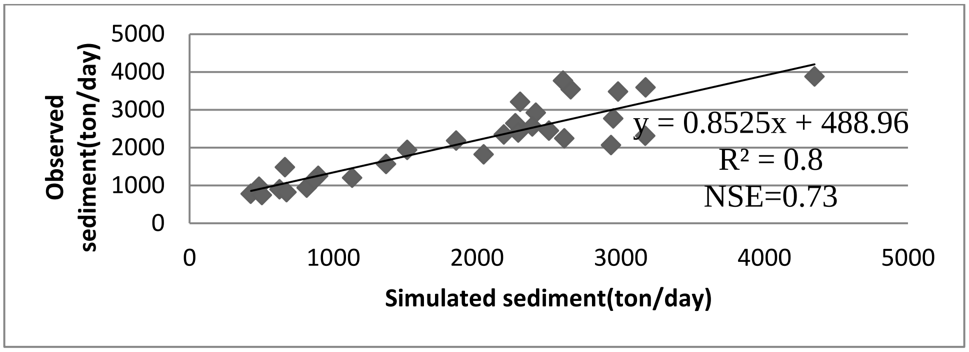


Figure 17 Scatter plot between Observed and Simulated sediment during Calibration period (1985-1994)

4.2.3. Flow Validation

The SWAT model also successfully validated the flow from 1995 to 2004 (Table 10) Monthly flow rates were well predicted, and the measured and simulated monthly flows matched well (R^2 = 0.83 and NSE = 0.81) as shown in Figures 18 and 19. The trends of seasonal variability and monthly average discharge were generally well captured during validation as well. The adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high runoff volumes. The model only slightly under-predicted the flow during the year 1998 and over predicted during 2000 and 2004.

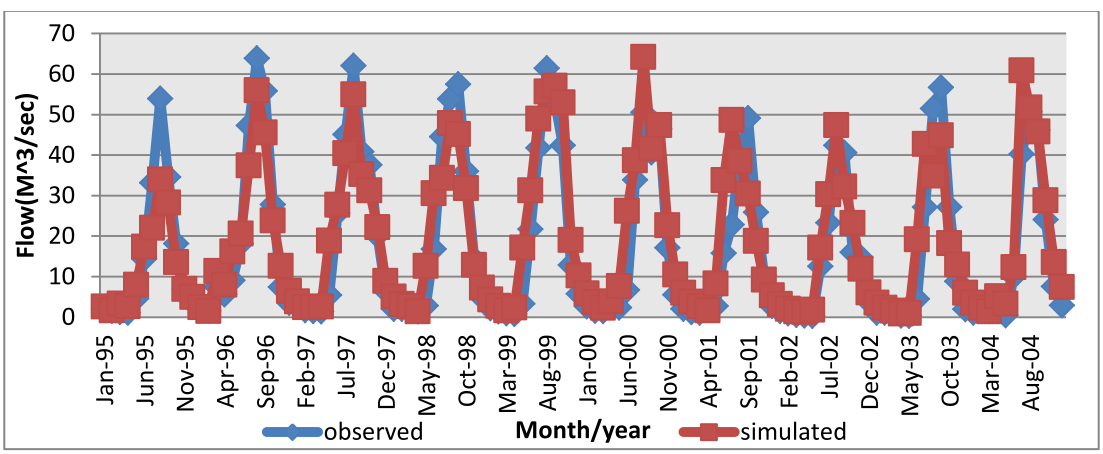


Figure 18 Graphical plot of Flow during Validation period (1995-2004)

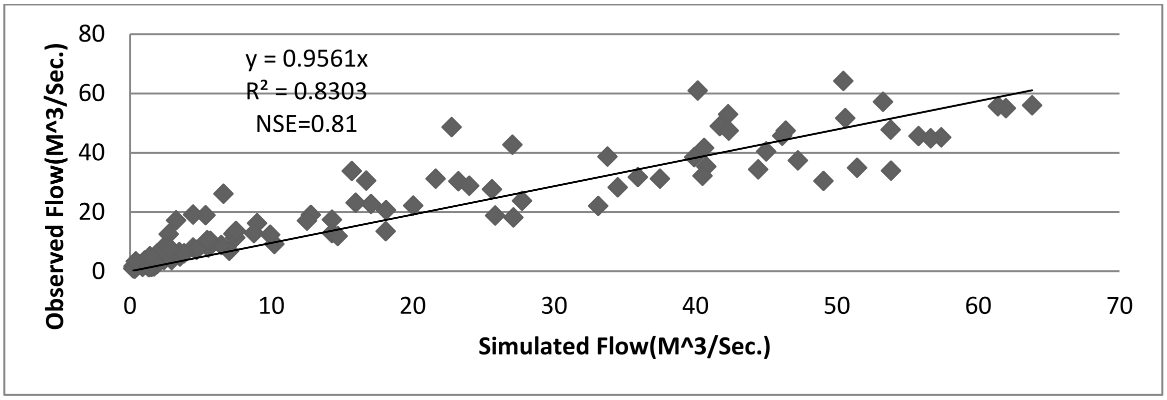


Figure 19 Scatter plot between Observed and Simulated Flow during Validation period (1995-2004)

4.2.4. Sediment Validation

The model also adequately predicted the sediment yields in the study area during validation with R^2 and NSE values of 0.78 and 0.72 respectively.

Note that during validation of sediment only peak flow months of the year (July, August and September) were also considered throughout the validation period as it is important to capture more sediment yielding periods to evaluate the model performance. During this period, the simulated daily sediment yields matched well with the measured daily sediment yields (Figures 20 and 21). Adequacy of the model is further indicated by its clear response to extreme rainfall events resulting in high sediment yield. However, the daily sediment yield values were over-predicted by the model during 2000 and under predicted the first month (July) of this year.

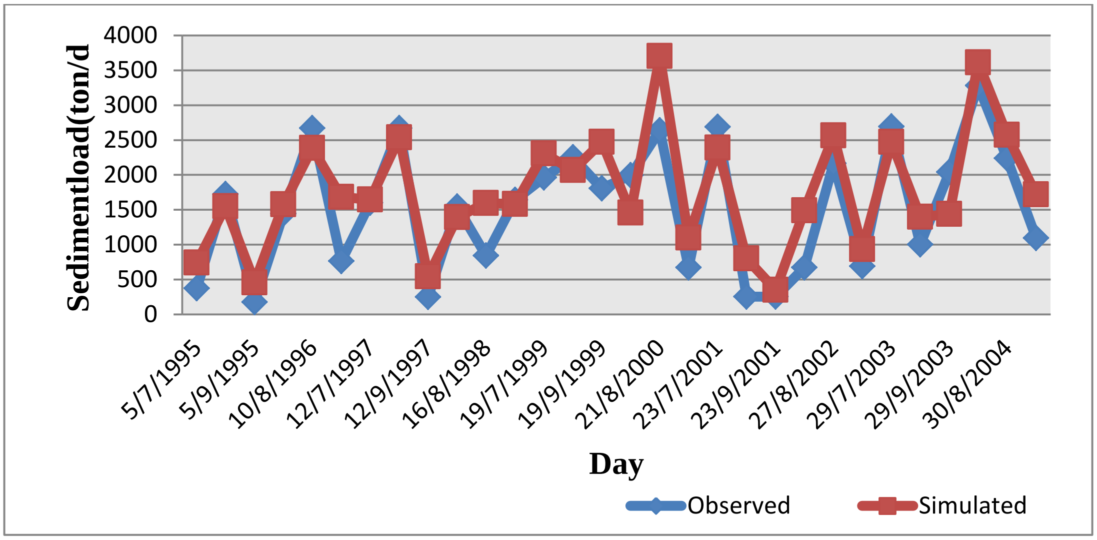


Figure 20 Graphical plot of Sediment during Validation period (1995-2004)

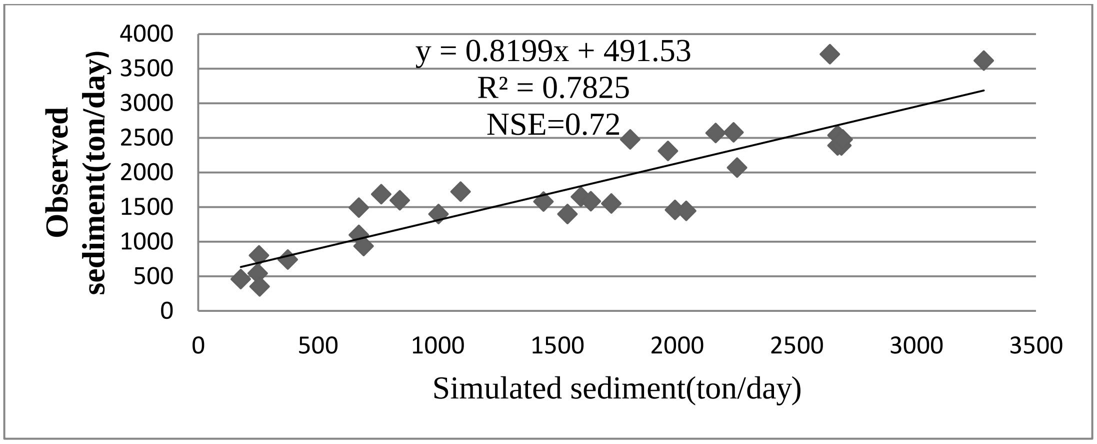


Figure 21 Scatter plot between Observed and Simulated Sediment during Validation period (1995-2004)

Table 10 Statistical performance Results of SWAT Model during Calibration and validation period for Flow and Sediment yield

Variable Description	Mean					
	Observed	Simulated	R^2	NSE	RSR	D%
Flow (M^3/sec.)						
Calibration	17.34	18.45	0.85	0.82	0.42	-6.4
Validation	17.48	18.78	0.83	0.81	0.44	-7.4

Sediment(Ton/day)						
Calibration	1922.3	2127.6	0.8	0.73	0.52	-10.6
Validation	1537	1751.7	0.78	0.72	0.53	-14.0

As recommended by (Moriasi, *et al.* 2007) and Santhi *et.al*, (2001), the statistical result in the table10 showed that the R^2 value during calibration and validation for both sediment yield and runoff fall under a very good range of performance. But NSE value for runoff is still in a very good range of performance and for the sediment yield it is in a good range of performance during both calibration and validation periods. The RSR Value for the runoff simulation is still in a very good range of performance while for sediment yield simulation is under a good performance range during both calibration and validation periods. The D% value for runoff and sediment yield prediction is in a very good range of performance. The value of D% for both runoff and sediment yield prediction is negative during calibration and validation periods. This shows that the SWAT model over predicted both the runoff of and the sediment yield.

This model performance result is comparable to the recent SWAT model performance results reported by different researchers in the Blue Nile basin. Yasir *et al*., (2014) calibrate and validate SWAT model in the gauged stations: Kessie Bridge, Birr, Jemma and Eldein in order to simulate stream flow and sediment budgets in the Blue Nile river Basin. The performance criteria showed a satisfactory result. The performance of SWAT model in "Sediment management modeling in the Blue Nile basin" by Betrie *et al.*, (2011) showed that NSE=0.82, RSR=0.42, D=10 and NSE=0.79, RSR=0.46, D=-8 for calibration and validation of flow respectively. And NSE=0.92, RSR=0.29, D=-21 and NSE=0.88, RSR=0.34, D=-11 for calibration and validation of sediment respectively.

Shimelis G.Setegn *et al.,* (2010) used SWAT for "modeling of sediment yield from ANJENI watershed in Blue Nile Basin and came up with the following statistical performance results R^2=0.85, NSE=0.81, RSR=0.23, D=28% and R^2=0.8, NSE=0.79, RSR=0.23, D=30% during calibration and validation periods respectively. Multi basin SWAT model analysis of runoff and sedimentation in the Blue Nile was conducted by Esaston *et al*., (2010) and calibrated the model in Anjeni(0.76,0.84),Gumara(0.83,0.81),Ribb(0.74,0.77),N.Merawi(0.78,0.75),Jemma(0.91,0.92),Angar(0.87,0.79) and Kessie(0.73,0.53) sub basins with respective values of R^2 and NSE.

4.3. Uncertainty Analysis

SWAT was calibrated based on the daily sediment yield and average value of monthly measured flows at Dura River outlet using SUFI_2 Program in SWAT_CUP. It should be noted that a watershed model can never be fully calibrated and validated because of the possible uncertainties that may exist from inputs such as rain fall and temperature. Rainfall and temperature data are measured at local stations and regionalization of these data may introduce large errors. In SWAT, climate data for every sub basin is furnished by the station nearest to the centroid of the sub basin. Therefore, carrying out uncertainty analysis for the prediction of the hydrological model is crucial to decide the calibrated parameters to transfer to be used for further predictions. In SUFI-2, parameter uncertainty accounts for all sources of uncertainty, e.g., input uncertainty, conceptual model uncertainty, and parameter uncertainty. The statistical and graphical results of un certainty analysis using Sequential Un certainty Fitting (SUFI_2) is presented in the table 11 and figure 22 for flow and table 12 and figure 23 for sediment yield.

Table 11 Uncertainty Analysis Result for Flow during Calibration and Validation periods

	P Factor	R Factor	R^2	NSE
Calibration period(1985-1994)	0.88	0.81	0.85	0.82
Validation period(1995-2004)	0.77	0.93	0.83	0.81

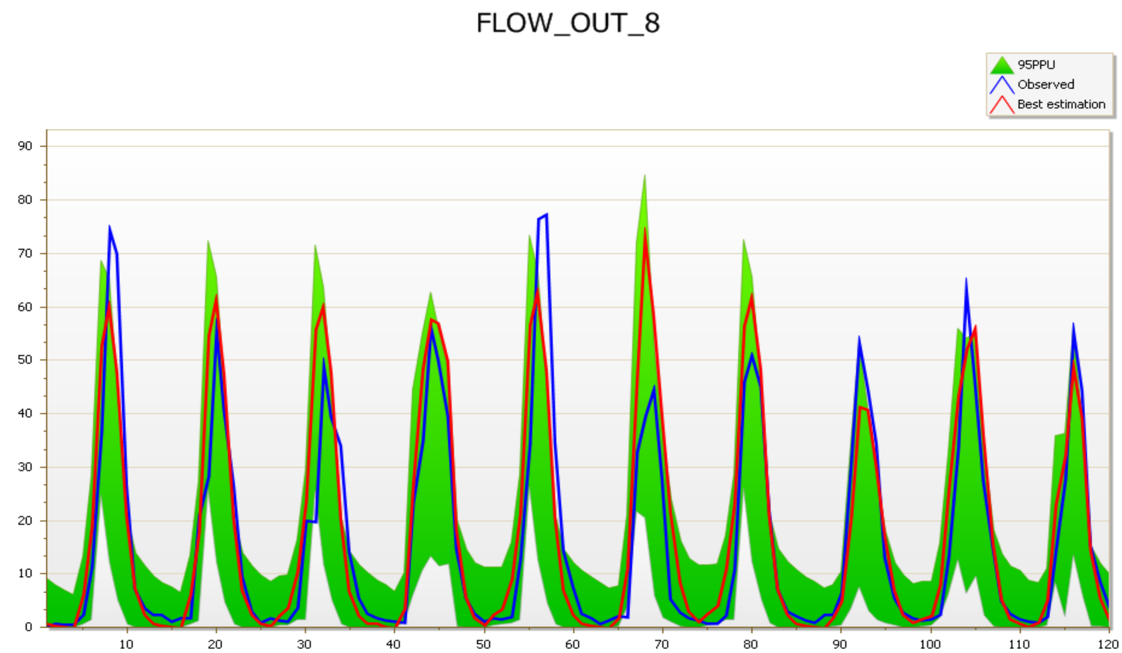


Figure 22 The 95% prediction uncertainty (95PPU) for Dura River flow for calibration

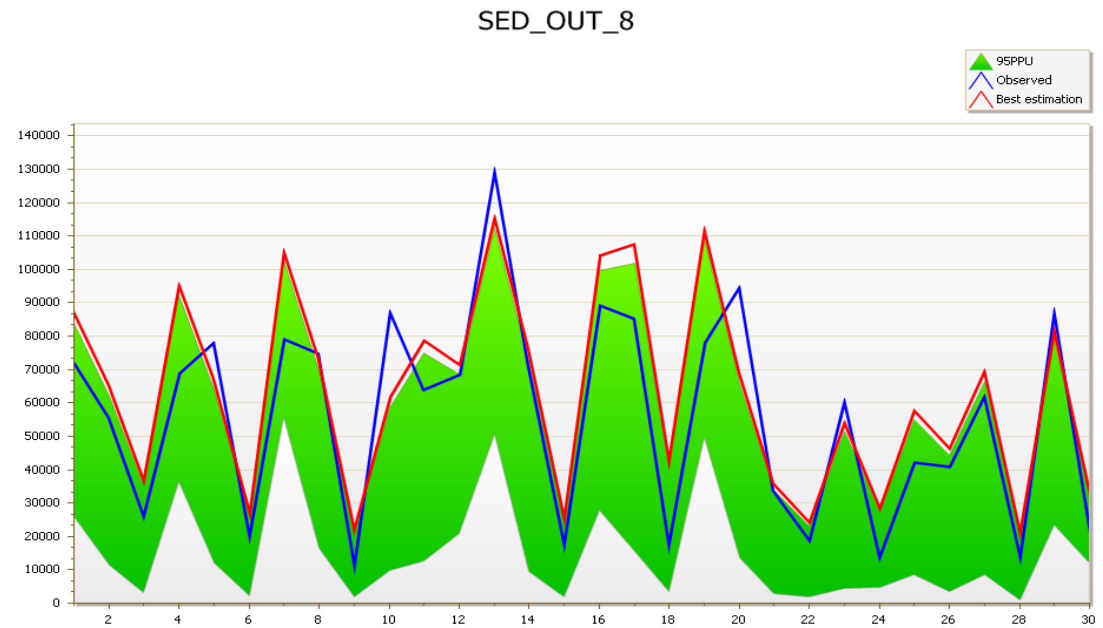


Figure 23 The 95% prediction uncertainty (95PPU) for Dura River Sediment yield for calibration

Table 12 Uncertainty Analysis Result for sediment during Calibration and Validation periods

	P Factor	R Factor	R^2	NSE
Calibration period(1985-1994)	0.8	1.5	0.80	0.73
Validation period(1995-2004)	0.7	1.59	0.78	0.72

P-factor shows the percentage of observations covered by the 95PPU and as a result the value of p factor in the above table 11 showed that 88% and 77% of the observation data were considered (captured) during flow calibration and validation respectively. The R value of 0.81 and 0.93 showed that there is a reasonable thickness of 95PPU probability band to fit the parameter value in flow calibration and validation.

Uncertainty analysis for sediment yield prediction showed that the P value of 80% during calibration and 70% during validation. This indicates that the majority of the observed data is captured during both periods. The value of R 1.5 during calibration and 1.59 during validation showed that there is a relative uncertainty in sediment yield prediction than runoff prediction.

4.4. The Water yield

After calibration of flow sensitive parameters, the simulated monthly water yield for Dura river sub basin is summarized from 1985 _2005 is shown in the table13.As SWAT model performs in the monthly prediction than the daily and yearly basis, the result of simulation is reported for each month through simulation years in M^3/sec.

Table 13 Average Monthly and annual yield of water for Dura River through Simulation years in M^3/sec.

	Month											
YEAR	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEP	OCT	NOV	DEC
1985	0.9	0.4	0.15	0.05	6.1	19	53	61.2	48	21	7.3	2.6
1986	0.8	0.4	0.14	0.04	6.2	18	55	62.3	47	20	6.9	2.4
1987	0.8	0.4	2.34	3.61	10	24	56	60.8	48	20	6.8	2.2
1988	0.8	0.8	0.13	0.05	3.5	27	48	57.9	57	50	19	5.8
1989	1.8	0.7	2.44	3.51	9.1	21	57	63.6	48	20	6.9	2.4
1990	0.9	0.4	0.17	0.05	1.9	11	47	75	58	40	22	8.4
1991	3	1.2	2.75	4.05	11	23	56	62.7	48	21	7.2	2.4
1992	0.8	0.4	0.17	0.1	1.9	4.9	21	41.5	41	30	17	7
1993	2.4	0.9	1.63	2.29	8	26	43	52.1	57	36	16	5.3
1994	1.7	0.8	0.27	0.94	5	23	32	50	39	15	5.6	1.9
1995	2.5	1.6	3.25	2.62	7.9	17	22	33.9	28	14	6.9	4.9
1996	2.4	1.4	11.3	7.92	16	21	37	55.9	46	24	13	6.4
1997	3.8	2.4	2.4	2.54	19	28	40	54.9	35	31	22	8.8
1998	5	3.2	2.61	1.39	13	31	34	47.8	45	32	13	7.2
1999	4.2	2.7	1.58	2.34	17	31	49	55.6	57	53	19	10
2000	5.7	3.7	2.19	3.77	7.6	26	39	64.1	42	47	23	10
2001	5.9	3.7	2.61	1.59	8.2	34	49	38.5	30	19	9.2	5.3
2002	3.2	2	1.37	1.18	1.7	17	30	47.4	32	23	12	6
2003	3.5	2.2	1.5	0.82	1	19	43	34.8	45	18	13	6
2004	3.5	2.2	1.35	5.05	3.3	12	61	51.7	46	29	14	7.4
2005	2.9	1.5	2.07	2.14	9.7	24	40	51.8	45	25	14	6.3
Aver	**2.7**	**1.6**	**2.02**	**2.19**	**8**	**22**	**43**	**53.5**	**45**	**28**	**13**	**5.7**

As indicated in the table 13, the first four months (January, February, March and April) can be considered as low flow months below $5M^3$/Sec. May, June, November and December as intermediate flow months and the rest July, August, September and October can be considered as high flow (flood) month. But average annual flow at Dura river out let is $18.88M^3$/sec as shown which is a very important index to determine the average annual yield (budget) of water so that any planning and integration activities within the sub basin is possible.

4.5. The sediment Yield

In this study the SWAT model was calibrated and validated at the gauging station to estimate the monthly sediment yield of the sub basin.

Table 14 Average Monthly and Annual Sediment yield (ton/ha) of Dura River Sub basin

	Month												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1985	0	0	0	0	0.842	1.257	3.34	2.93	2.52	1.48	0.07	0	12.5
1986	0	0	0	0	0.652	1.59	2.65	1.97	1.62	0.92	0.07	0	9.511
1987	0	0	0.1	0.42	0.722	1.753	3.53	2.9	1.83	0.94	0.09	0	12.28
1988	0	0	0	0	0.751	1.927	3.2	2.82	1.62	1.27	0.09	0	11.74
1989	0	0	0.1	0.34	0.605	0.862	2.73	2.97	1.91	1.37	0.11	0	11.01
1990	0	0	0	0	0.77	0.905	2.68	1.98	1.55	1.27	0.16	0	9.413
1991	0	0	0.1	0	0.862	0.887	2.37	2.6	1.58	1.57	0.18	0	10.17
1992	0	0	0	0	0.769	0.849	2.88	2.84	1.63	1.36	0.12	0	10.56
1993	0	0	0	0.25	0.83	1.049	3.53	2.15	1.69	1.52	0.07	0	11.17
1994	0	0	0	0.09	0.665	1.061	2.89	2.72	2.55	1.24	0.06	0	11.32
1995	0	0	0	0.18	0.653	1.058	3.07	2.68	1.93	0.89	0.09	0	10.63
1996	0	0	0	0.11	0.41	1.721	2.97	2.76	1.65	0.74	0.06	0	10.5
1997	0	0	0	0.22	0.669	1.612	3.2	2.81	1.61	0.92	0.24	0	11.36
1998	0	0	0	0	0.767	0.965	3.01	2.75	1.56	1.27	0.13	0	10.52
1999	0	0	0	0.32	0.673	1.177	2.3	2.04	2.42	0.76	0.11	0	10.56
2000	0	0	0	0.12	0.641	0.897	2.23	2.86	1.67	1.26	0.19	0	10.95
2001	0	0	0	0	0.653	0.976	3.1	2.97	1.57	0.67	0.06	0	10.06
2002	0	0	0	0	0.765	1.071	3.11	2.96	1.63	1.59	0.06	0	11.24
2003	0	0	0	0.3	0.053	0.864	3.31	2.89	1.74	1.39	0.1	0	10.69
2004	0	0	0	0.18	0.59	1.073	1.99	2.75	1.71	1.58	0.06	0	10.99
2005	0	0	0	0	0.73	0.905	2.09	2.85	2.5	1.47	0.04	0	11.64
Aver	**0**	**0**	**0**	**0.12**	**0.67**	**1.165**	**3.04**	**2.68**	**1.83**	**1.21**	**0.1**	**0**	**10.9**

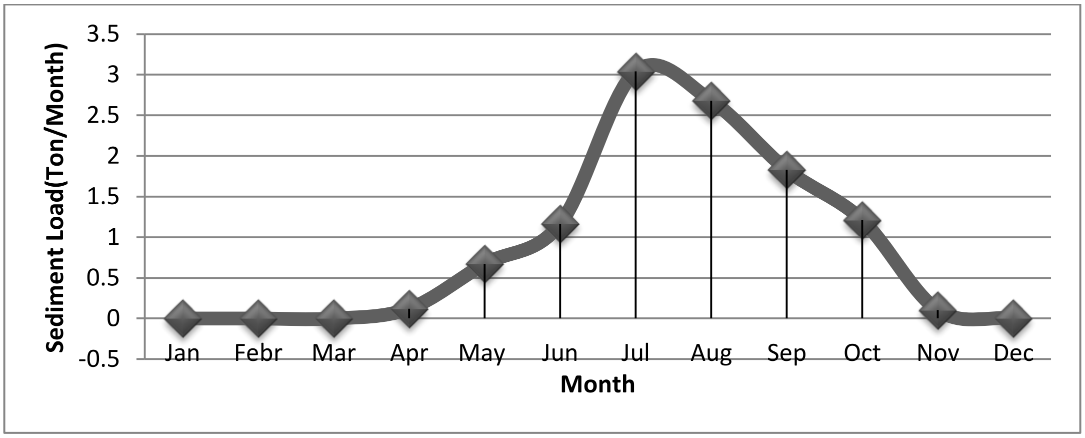


Figure 24 Plot of Monthly Sediment yield Distribution for Dura River Sub basin

After calibration of sediment sensitive parameters, the simulated monthly sediment yield from Dura river outlet is summarized from 1985 _2005 is shown in the table 14. As SWAT model performs better in the monthly prediction than the daily and yearly basis, the result of simulation is reported for each month through simulation years in ton/ha. As indicated in the table14, average annual sediment load for Dura River sub basin is 10.9 ton per hectare per year. This is comparable with 9.89ton/hectare/year measured to the study area and reported by Dr. Armando (2009) in the report on Soil erosion processes in the Nile Basin even the SWAT model over predicted the yield to some extent.

Figure 24 showed the average sediment load (ton/h) for each month in a year. Sediment concentration in the Blue Nile has its maximum in one month earlier than the peak discharge (Gismalla,2013) sited in sediment Balances in the Blue Nile River Basin by(Yasir *et al*., 2014), Similar trend is shown by this study. This may be due to the reason that there is high disturbance of soil mass in the sub basin during this month as it is highly agricultural area. The sediment yield trend of the sub basin through a year shows relatively sudden rising to the peak yield from the dry months. Whereas the recession part of the graph shows gradual fall of the sediment yield. This result clearly showed sediment free and sediment full months in a year. That is January, February, March and December are sediment free months and April to November are sediment full months with the respective magnitudes.

This result is an insight to any planner and designer to take in to account the amount (budget) of sediment in the plan or design with in the sub basin.

4.6. The sediment distribution

The spatial variability of sedimentation rate was identified and shown in table 15 and based on which the potential area of intervention can be identified. The average annual yield of sedimentation for each sub basin was used to generate sediment source map shown in Figure 25.

The output of model showed that Sub basin 1, sub basin 6, and sub basin 9 of Dura River sub basin at the existing condition generate a maximum annual average sediment yield of 73.36 ton/ha, 87.33ton/ha and 96.51 ton/ha respectively. This was attributed due to the topographic slope and land use of these sub basins. That is; 83.47% of sub basin 1 is dominantly cultivated with greater than 12% of which has a slope > 20%, 71.59% of sub basin 6 is dominantly cultivated with its 50.85 % of slope > 20%, and 70.57% of sub basin 9 is dominantly cultivated and whose 35.36% of slope > 20%. And the minimum yield of 3 tons/ha was obtained for sub basin 5, it has 100% of slope < 10% and 100% of it was moderately cultivated.

Table 15 Average Annual Sediment yield of Watersheds within Dura River Sub basin

YEAR	SUBBASIN								
	1	2	3	4	5	6	7	8	9
1985	53.31	27.56	42.178	8.273	3.272	89.61	10.408	19.175	99.1
1986	52.58	26.44	39.891	6.51	3.187	70.22	10.986	18.438	81.3
1987	98.35	52.37	84.513	7.358	3.779	79.32	18.674	45.744	87.0
1988	70.79	42.27	65.193	8.504	2.932	93.47	17.221	32.044	98.7
1989	61.53	34.20	54.493	8.347	2.96	80.32	13.13	29.544	81.5
1990	52.6	32.21	47.151	5.833	2.512	85.07	15.351	21.467	90.7
1991	70.67	41.51	64.062	4.605	2.907	79.80	16.335	31.507	91.2

1992	61.19	16.23	24.433	1.439	2.824	102.1	7.074	11.877	89.4
1993	57.45	30.42	47.698	3.206	2.524	91.53	12.519	24.518	92.1
1994	46.99	26.56	40.941	2.235	3.183	97.57	10.644	20.075	102
1995	57.03	21.23	35.692	2.852	2.355	88.26	6.7	20.256	91.6
1996	128.4	67.44	105.90	11.64	4.84	105.6	20.907	65.379	134
1997	83.49	39.59	62.354	3.566	3.332	89.31	16.971	30.198	99.2
1998	77.82	27.91	43.661	3.184	2.417	85.66	12.462	22.162	90.9
1999	124.6	61.3	97.49	7.039	3.926	102.9	25.629	49.58	125
2000	91.49	37.79	58.613	3.111	2.707	75.89	16.932	28.569	93.5
2001	68.39	18.83	30.037	6.793	2.991	84.83	9.878	16.342	105
2002	76.89	23.23	33.487	8.675	2.174	80.36	20.974	15.454	94.7
2003	66.76	22.01	31.196	9.595	2.956	78.12	20.54	13.553	83.3
2004	77.11	35.17	54.222	9.549	3.706	86.29	16.728	25.014	88.3
2005	63.18	26.70	39.6	7.328	2.165	87.68	21.473	16.831	106
Aver.	**73.36**	33.85	52.51	6.173	3.03	**87.33**	15.31	26.56	**96.5**

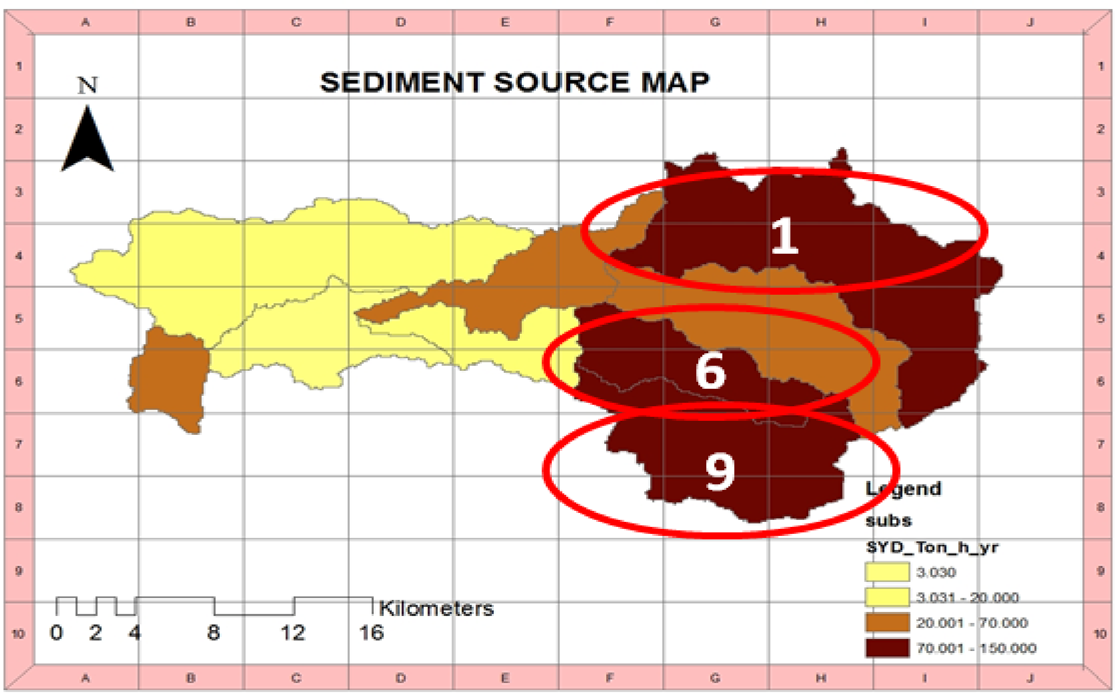


Figure 25 Sediment Source Map for Dura River Sub basin

Table 16.General soil erosion extent classes in the Blue Nile Basin Betrie *et al*., (2011)

No	Class Range(ton.ha^{-1}.yr^{-1})	Description of the extent
1	0-20	Low
2	20-70	Moderate
3	70-150	Severe
4	≥150	Extreme

The low class represents the erosion extent less than the soil formation rates, which is 22 t ha $^{-1}$yr $^{-1}$in the Ethiopian highlands (Hurni, 1983). The moderate class represents erosion level less than the average soil loss from cultivated land, which is 72 ton ha^{-1}yr^{-1}(Hurni, 1985). The severe class represents one fold higher than the average soil loss and the extreme class represents two folds higher than average soil loss. Severe erosion was dominant in sub basins 1, 6 and 9. Moderate erosion was dominant in sub basins 2, 3 and 8.and low erosion was dominant in sub basins 4, 5 and 7.These results show that the erosion level variations within a sub basin and the basin that is very helpful to prioritize BMPs implementation area.

CHAPTER FIVE

CONCLUSSION AND RECOMMENDATION

5.1. Conclusion

Given the complexities of the river basin and the large number of interactive processes taking place simultaneously and consecutively at different times and places within the study area, calibration and validation results of the SWAT model showed that the simulated monthly runoffs as well as daily sediment yields were in reasonable agreement with measured values. It showed that the SWAT model could be used successfully to accurately simulate runoff and sediment yield. Therefore, On the basis of the results obtained in this study, SWAT may be deemed to be a reasonable selection for the simulation of both runoff and sediment yields in the Dura River Sub basin. Furthermore, from this study, the following conclusions are drawn:

(1) The SWAT model simulations compare closely with measurements and produce a set of model parameters within physically realistic ranges and acceptable approximations of runoff and sediment yield from the Dura River Sub Basin.

(2) Sensitivity analysis of the SWAT parameters indicates that runoff is most sensitive to ground water delay (GW_Delay.gw) and threshold depth of water to occur (GWQMN.GW), whereas sediment yield is more sensitive to curve number (CN2) and Effective hydraulic conductivity in main canal (CH_K2.rte). This will help reduce the calibration time for future applications of the model under similar studies.

(3) Although the model slightly over/under estimates monthly runoff and sediment yield, the modeling efficiency for prediction is within the acceptable limits of accuracy.

(4) The simulation for runoff is better than for sediment yield.

However, it should be noted a care full calibration and uncertainty analysis and proper utilization of the model result should be exercised.

In this study runoff and sediment contribution of Dura River sub basin was estimated using semi-distributed SWAT model. For this Arc SWAT, GIS interface for the model can be taken as a basic tool to account geographic factors.

The model was successfully applied to quantify flow amount from the River in order to study the resource potential, manage, optimize and integrate the available water resource at sub basin level.

Accordingly, the mean flow of $18.8M^3$/sec. and mean sediment load of 10.9ton/ha/year was estimated at the outlet. The sediment load rate is an insight to consider the annual sediment yield contribution of Dura River sub basin to impact on the completed and planned water resource projects like Dams and weirs downstream of the sub basin. Hence, estimation of runoff and sediment yield has become important issues for future development in the sub basin.

The SWAT model prediction verified that about 44%($239.5Km^2$) of Dura Rive sub basin is erosion potential area contributing high sediment exceeding the tolerable limit or soil formation rate in the Blue Nile basin. That is sub basins 1, 6 and 9 are grouped under severe conditions of extent in the sub basin. Sub basin 5 with 100% moderately cultivated and 100% slope < 10% resulted in the lowest sediment yield (3.03ton.$ha^{-1}yr^{-1}$). This indicated that the combined effect of land use and slope is dominant in sediment yield in the study area.

Spatially identification of the sediment potential areas will help to prioritize Best management practices to respond to immediate calls and save those hot spot areas timely and economically.

A good performance of the model in the validation period indicates that the fitted parameter values during calibration period can be taken as a representative set of parameters for Dura sub basin and further simulation and evaluation of alternative best management scenarios can be possible.

5.2. Recommendation

SWAT model was calibrated and validated using observed flow and sediment data at the gauging station with some sort of uncertainties. For improved model performance weather stations should have improved quality of data input for SWAT model. Therefore, it is better to recommend that both hydrometric and meteorological stations should have full and realistic data. This is because better description of the climate data decreases model uncertainty. Hence, the reliability of water resource (flow) and sediment yield prediction decreases as uncertainty increases.

This study was only aimed at estimation of flow and sediment yield contribution of Dura River sub basin. However, subsurface condition of the sub basin was not considered. Therefore, it should be recommended that the interaction between surface and subsurface conditions should be studied to assess and incorporate ground water contribution and potential of the sub basin.

The meteorological stations existing around the study area are not sufficient to spatially present the topographic variation. Therefore, ether of the stations used in this study should be first order meteorological station with all measured meteorological parameters.

Some parts of sediment and flow hydrographs over predicted and under predicted. This should be due to uncertainties from discharge and sediment measurements. Therefore, it is recommended that there should be improved data collecting system and approach.

To improve water resource and sediment management practices, better understanding of the sources, magnitude and extent of uncertainty should be always given great emphasis within the sub basin.

In this study erosion hot spot areas are identified. Therefore, it is highly recommended to conduct a research on different alternative scenarios to implement practical and economical best management practices to save soil erosion from the sub basin and decrease subsequent impacts.

CHAPTER SIX

REFERENCE

A, G. (1995). "Soil erosion assesment:Aproaches,magnitude of problem and essues on policy and strategy development."

Abbaspour, J., *et al.* (2015). "*SWAT calibrations and uncertainty programs*:." Swiss Federal institute of Aquatic Science and Technology..
.

Alamirew, D. (2006). " Modeling of hydrology and soil erosion of Upper Awash River Basin, .. *PhD Dissertation. University of Bonn, Germany*." 236.

Arnold, J., *et al*. (1999). " Automated methods for estimating baseflow and ground water recharge from streamflow records." *Journal of American Water Resources Association 35(2).*

Arnold, J. G. and A. P. M. (1996). " Estimating hydrologic budgets for three Illinois watersheds." J. Hydrol. **176**: 57-77.

Ashenafi, T., Binyam, *et al.* (2009). " Impact assessment of land use / land cover changes on Shaya river flow using SWAT (case study of Shaya watershed, in Bale).. *M.Sc. Thesis. Arbaminch university.*.".

A.W.Worqlul, A.S. Collick, S.A. Tilahun, S. Langan, T.H.M. Rientjes and T.S. Steenhuis (2015). "Comparing CFSR and ground based rain fall estimates as input for for hydrological models in upper Blue Nile Basin Ethiopia. International water management Institute Addis Ababa,Ethiopia.

Awulachew S. B, Yilma A.D, *et al.* (2007). Journal of Hydrological process.

Bagnold, R. A. (1977). "Bed load transport in natural rivers. Water Resour. Res." **13 (2)**: 303-312.

Birhanu, Z., *et al.* (2007). " Application of SWAT model for mountainous catchment. Catchment and Lake Research.." *LARS 2007: .Brooks, K. N., P. F.* : 182-187.

Biruk, B. (2009). "SWAT to Identify watershed management options: (Anjeni Watershed Blue Nile Basin, Ethiopia)... *MSc. Thesis Presented to the Graduate School of Cornell University,* ." 25-34.

Bruce, A. D., *et al.* (1993). "Review of GIS application in hydrologic modeling.".*Journal of Water Resources Planning and Management* ***119(2)***: 24.

Bruijnzeel, L. A. (1990). "UNESCO International Hydrological Programme." Hydrology of moist tropical forests and effects of conversion: A state-of-knowledge review. Paris.

Bruijnzeel, L. A. and C. N. Bremmer (1989). "Highland-lowland interactions in the Ganges-Brahniaputra river basin." A review of published literature. ICIMOD Occasional Paper **11**.

Buras, N. (1972). " *Scientific allocation of water resources*.".

Chaplot V., S. A., *et al.* (2004). "Predicting water,sediment and NO3-N Load under scenarios of land use and management practices in flat watershed ." water air and soil pollution **154**(1-4): 271-293.

chen., E. and D. S. Makay (2004). Journal of Hydrology **295**: 211-224.

Chow, V. T., D. R. Maidment, *et al.* (1988). " Applied Hydrology. McGraw-Hill, New York."

Coffey, M. E., *et al.* (2004). " Statistical procedures for evaluating daily and monthly hydrologic model predictions." *Transactions of the ASAE* ***47(1)***: 59-68.

damspeech, T. (2011). "The speech made by P. M. Meles Zenawi of Ethiopia at the official commencement of the Renaissance
" Dam, Grand Millennium Dam, Retrieved 26 April 2011, <http://grandmillenniumdam.net/the-dam-speech/>.
Daniel Richard Fuka (2015). Simplifying Watershed modeling.

Danuso and F. (2002). "Stochastic model for weather data generation.. ." *Italian Journal of Agronomy* *6(1)*: 57-71.

DeBarry (2004). "Watersheds Processes, Assessment, and Management." 700.

Derbi S.D, A. T, *et al.* (2009). "Impacts of microbasin water harvesting structures in improving vegetative cover degraded hill slopes areas of North-East Ethiopia range land." J **31**: 259-265.
Dr.Armando (2009)."Report on soil erosion processes in the Nile basin

Eckhartd, K., *et al.* (2001). "Automatic calibration of a distributed catchment model. ." *J. Hydrol.* ***251***: 103-109

EHRS (1984). "Ethiopian high land reclamation study." Annual Research report(1983-1984).

Eyob Yeheyes (2010). "Predicting Run off and Sediment yield Using SAWT Model For Ija Galma Waqo Spate Irrigation Project."

Foster, G. R. (*2002*). "*Modeling the Erosion Process* " *Hydrologic Modeling of Small Watersheds:American Society of Agricultural Engineers*: *297-380*.

Francos and A. (2003). " Sensitivity analysis of distributed environmental simulation models.. *Understanding the model behaviour in hydrological studies at the catchment scale*." *Real. Eng. Syst. Safe.* 79(2)

G. D. Betrie1, Y. A. Mohamed1, 3,, *et al.* (2011). "Sediment management modelling in the Blue Nile Basin using SWAT model
" Journal of Hydrology and Earth system science **4**: 1234.

Gassman, W. P., *et al.* (2007). "The Soil and Water Assessment Tool: Historical development, Applications, and future Research Direction.." *Transactions of the ASABE 50(4)*: 1211-1250

Green, W. H. and G. A. and Ampt (1911). " Studies on soil physics, 1. The flow of air and water through soils." Journal of Agricultural Sciences **4**: 11-24.

Hamby and D. M. (1994). "A review of techniques for parameter sensitivity analysis of environmental models." *Environmental Monitoring and Assessment .* Volume 32: 135-154.

Hargreaves, G. L., G. H. Hargreaves, *et al.* (1985). "Agricultural benefits for Senegal River basin. ." J. Irrig. And Drain. Engr 111(2): 113-124.

Holvoet, K., *et al.* (2005). " Sensitivity analysis for hydrology and pesticide supply towards the river in SWAT." *Phys. Chem. Earth 30(8-10)*: 518-526.

Hurni H (1990). "Degradation and conservation of soil resource in Ethiopian High Lands." 123-130.

Hurni.H. (*1993*). "*Soil and Water Conservation on Steep Lands.Sn. Jav, Pvetro Rico,* ." *Options of Steep Land Conservation in Subsistence Agriculture*.

Jayakrishnan R., Srinivasan R., *et al.* (2005). "Advances in the application of SWAT model for water resource management." Journal of Hydrological process **19**(3): 683-692.

K, H. and S. H. B. (1999). "The variability of soil erosion in High lands of Ethiopia and Eritrea " Research report 42 center for development and environment:University of Bene.

Kati. L, W. E.D, *et al(2009).* "Sensitivity analysis,calibration and validation for a multi site and multi variable SWAT model." Journal of American water resource association

Killingtveit, A. (1993). "*Hydropower development hydrology*."

Ma and L. (2000). "Root zone water quality model sensitivity analysis using Monte Carlo simulation." *Transactions of the ASAE* ***43(4)***: 883-895.
.

Maidment, D. R. (2002). " *Arc Hydro-GIS for Water Resources*." Redlands: Redlands, CA: ESRI Press.

MEHAMED, S. Z. (2014). "RIVER SEDIMENT TRANSPORT MNITORING TO IMPROVE THE LIFE SPSAN OF DAMS
".

Mequanint, Seleshi Bekele, *et al*. "SWAT Based run off and sediment yeild modeling Gumara watershed,Lke Tana sub basin.
." Journal of International water management institute:Minstry of water resource Addis Ababa.

Monteith, J. L. (1965). " Evaporation and the Environment. In: The State and Movement of Water in Living Organisms. XIXth Symposium, Soc. for Exp. Biol., Swansea, Cambridge University Press, ." 205-234.

Moris G. and F. J. (1998). Design and management of dams,reservoirs and watershed for sustainable use. Reservoir sedimentation Hand Book.

Neitsch, S. I., J. G. Arnold, *et al.* (2005). " *Soil and Water Assessment Tool, Theoretical Documentation: Version 2005. Temple, TX.* .. Texas: USDA Agricultural Research Service A and M Black land Research Center.
."

Neitsch, S. I., J. O. Arnold, *et al.* (2005). " Soil and Water Assessment Tool, Theoretical Documentation: Version 2005. Temple, TX. USDA Agricultural Research Service anti Texas A&5I Black land Research Center."

Priestley, C. H. B. and R. J. Taylor (1972). " On the assessment of surface heat flux and evaporation using large- scale parameters. Mon Weather. Rev. ." **100**: 81-92.

Raneesh K.Y., Sura T.V., *et al.* (2010). International journal of earth science and engineering **03**(05): 654-661.

Refsgaard, J. C., *et al.* (1996). " Construction, calibration and validation of hydrological models, Distributed Hydrological Modelling." *Academic Publishers*: 41-54

Resource, M. o. w. (1998). "Abay River Basin Integrated Development Master plan." xiii.

Sanjay K. Jain¹, Jaivir Tyagi¹, *et al.* (2010). "*Journal of Water Resource and Protection*." 2: 267-281.

Sanjay K.Jain, Jaivir Tayagi, *et al.* (2010). Journal of water resource and protection **2**: 267-281.

SCRP (1996). "Soil conservation Research Project data base." report 1982-1993.

Setegn, S., *et al.* (2010). "Modeling hydrological and hydrodynamic processes in Lake Tana Basin,. *Ethiopia, KTH. TRITA-LWR PhD Thesis 1057.*.".
(SCS), U. S. C. S. (1972). Section 4 Hydrology. National Engineering Handbook

Sharpley, A. N., *et al. (*2000). "EPIC-Erosion Productivity Impact Calculator, 1.Model documentation. U.S. Department of Agriculture. ,." *Agricultural Research Service, Tech.Bull.* : 1768.
.

Spruill, C. A., *et al.* (2000). "Simulation of daily and monthly stream from small watersheds using SWAT model." *Transactions of ASAE* ***43(6)***: 1431-1339.
.

Steenhuis T.S, C. A.S, *et al.* (2009). "predicting discharge and erosion for the abay(Blue Nile) with simple model." Journal of Hydrological process **23**: 3728-3737.

University of Berne, B. "Environmental Research for Development Cooperation." Uni Press 62: 42-46.

Van Griensven, A., *et al.* (2002). "Sensitivity analysis and auto calibration of an integral dynamic model for river water quality." *Water Sci. Technol.* ***45***: 325-332.
.

Verstraeten G and Poesen J (1999). "The nature of small scale flooding,mudy floods and retention pond sedimentation in central Belgium."

White, K.& Chaubey, *et al*. (2005). "Sensitivity analysis, calibration, and validations for a multisite and multivariable SWAT model." Journal of *Water Resource. Association* ***41(5)***: 1077-1089.

Williams, J. R. (1980). "SPNM, a model for predicting sediment, phosphorous, and nitrogen from agricultural basins. Water Resour. Bull." 16 (5): 843-848.

Yasir S. A. ALI1, Alessandra CROSATO1, *et al.* (2014). "Sediment Balance in the Blue Nile River." International Journal of Sediment Research: 316-328.

Yehayis, E. (2010). "predicting run off sediment yeild for IJA GALMA WAQO Spite irrigation project.".

CHAPTER SEVEN

Appendices

Appendix 1 Annual cumulative rainfall for weather stations

Year	Enjibara Station	Dangila Station	Chagni Station
1982	2181.4	1510.4	2147.788889
1983	4122.3	2911.9	3808.002026
1984	6312.8	4313.4	5539.378154
1985	8263.4	5838.1	7516.600237
1986	10409.6	7362.8	8828.600237
1987	12787.1	9021.7	10410.12159
1988	15084.1	10823.2	12234.17493
1989	17480.1	12482.1	13964.07493
1990	19504.1	14294	15553.67493
1991	21757	15944.1	17195.20017
1992	23951.4	17274	18888.34832
1993	26459.1	18988	20592.14414
1994	28690.7	20305.9	22296.06627
1995	30641.3	21498.7	23998.4534
1996	33044.3	23182.2	25701.92906
1997	35872.9	24904.4	27406.85119
1998	38127.6	26478.4	29230.56747
1999	40843.3	28438.6	31004.68747
2000	43539.4	30271	32955.18747
2001	45841.6	31662.5	34586.08747
2002	47998	33002.7	35994.38747
2003	50132.6	34372.2	37587.28747
2004	52325.2	35999.3	39301.08747
2005	54562.6	37400.8	41017.18747

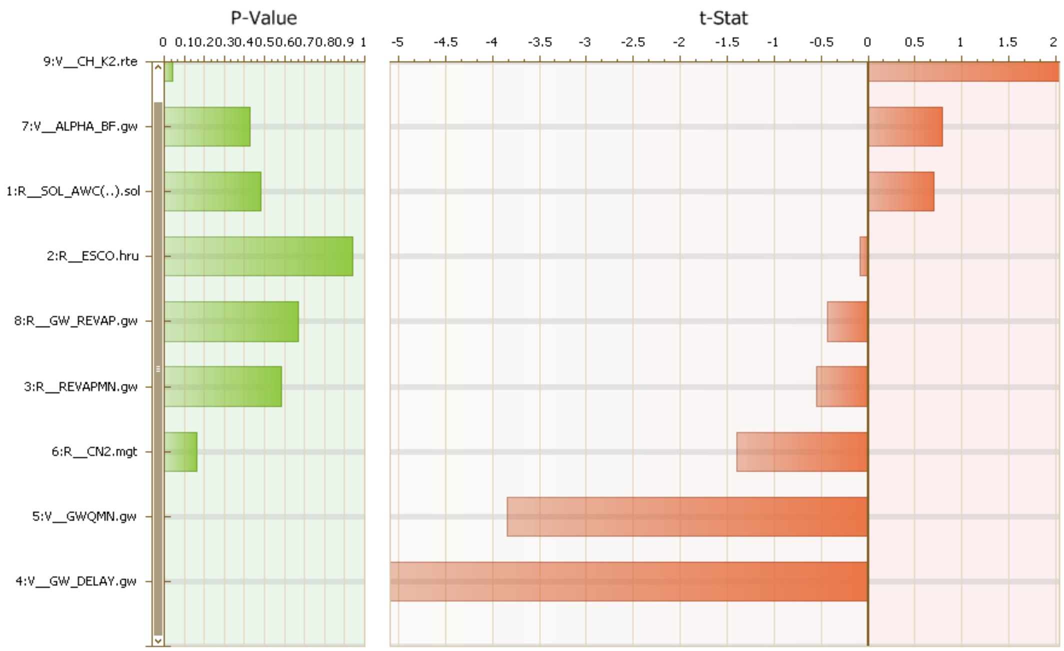
Appendix 2 Average Monthly maximum and minimum temperature for weather stations

Enjibara	Month	Temperature		Dangila	Temperature		Chagni	Temperature	
		Max	Min		Max	Min		Max	Min
	Jan	29.3	8.9		24.7	8.93		29.3	8.926
	Feb	32.4	13		25.5	13.2		32.4	13.2
	Mar	34.6	13		25.7	12.6		34.6	12.62
	Apr	33.7	15		26	15.3		33.7	15.3
	May	29.2	15		24.4	15.1		29.2	15.05
	Jun	25	13		22.7	13.1		26.5	13.14
	Jul	24.1	15		21.9	14.8		25	14.78
	Aug	24.5	15		22.2	14.5		24.5	14.5
	Sep	25.1	13		22.9	13.4		25.1	13.36
	Oct	27.2	13		23.3	12.8		27.2	12.78
	Nov	27.4	12		24.6	11.5		27.4	12.5
	Dec	28.8	11		24.1	10.0		28.8	11.02

Appendix 3 Average maximum and minimum temperature for the study area

Month	Min.	Max.
Jan	7.204301	27.74731
Feb	9.793889	30.10431
Mar	10.57312	31.6648
Apr	14.13914	31.12425
May	13.80323	27.60108
Jun	13.14308	24.71556
Jul	12.82796	23.62097
Aug	12.95914	23.7172
Sep	12.25556	24.34667
Oct	11.07527	25.9129
Nov	9.86	26.43889
Dec	7.606452	27.22366

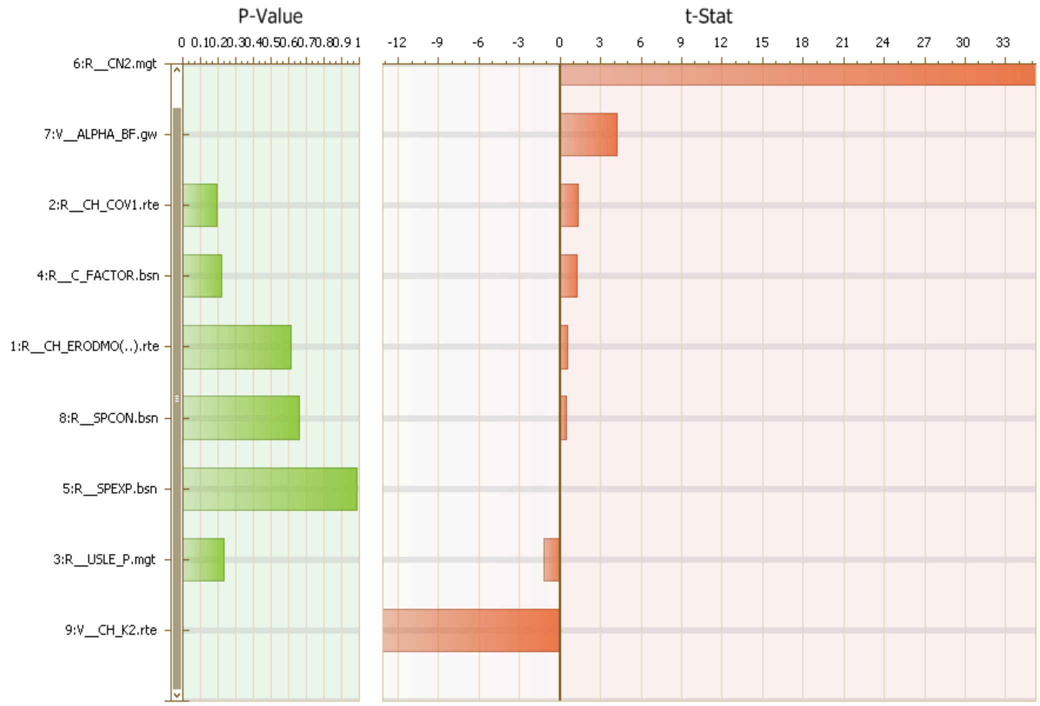
Appendix 4 Graph view for flow sensitive parameters from global sensitivity



Appendix 5 New flow parameter range and fitted value result

par_no	par_name	new_min	new_max	Fitted value
1	r__SOL_AWC().sol	0.085889	0.695361	0.390625
2	r__ESCO.hru	0.326514	0.979736	0.653000
3	r__REVAPMN.gw	160.75694	482.36807	321.5625
4	V__GW_DELAY.gw	2.681412	255.80641	11.5625
5	V__GWQMN.gw	348.6872	3217.4373	1434375
6	r__CN2.mgt	-0.108644	0.097144	-0.005750
7	V__ALPHA_BF.gw	0.092896	0.569146	0.138125
8	r__GW_REVAP.gw	0.02	0.11119	0.022363
9	V__CH_K2.rte	184.18852	452.68127	368.4345

Appendix 6 Graph view for sediment sensitive parameters from global sensitivity



Appendix 7 New Sediment parameter range and fitted value result.

par_no	par_name	new_min	new_max	Fitted value
1	r__CH_ERODMO().rte	0.233403	0.744597	0.489500
2	r__CH_COV1.rte	1.399402	2.198598	1.799000
3	r__USLE_P.mgt	0.4344	1.3036	0.935000
4	r__C_FACTOR.bsn	0.162759	0.482451	0.403065
5	r__SPEXP.bsn	0.995199	1.3318	1.163500
6	r__CN2.mgt	-0.06313	0.210824	0.074075

7	V__ALPHA_BF.gw	0.402846	1.095284	0.313391
8	r__SPCON.bsn	0.004738	0.014014	0.009851
9	V__CH_K2.rte	9.31572	280.298157	60.49010

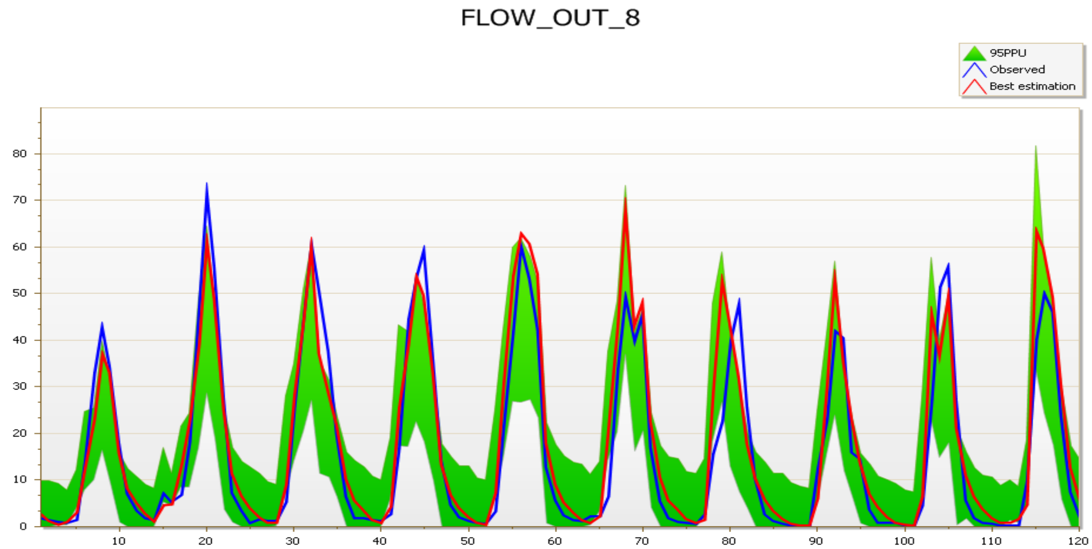
Appendix 8 Average flow during calibration and validation periods

Calibration period		Validation period	
Simulated	Observed	Simulated	Observed
18.24808333	18.80373333	12.06166667	14.5547
18.27138333	16.41960833	20.10916667	20.756992
19.54935	16.05340833	20.8585	20.860733
22.47551667	19.46378333	19.52425	19.745433
19.73555833	22.16965833	25.24191667	20.613267
22.01274167	13.84035	22.81233333	17.563117
20.2205	16.256475	17.2105	14.575908
13.82885	16.66556667	14.7725	13.049117
20.84560833	18.14106667	15.61206667	15.088242
14.59734167	14.88120833	19.62766667	15.619167
18.97849333	17.26948583	18.78305667	17.242668

Appendix 9 Average daily sediment yield for peak flow months (ton).

Calibration period			Validation period		
Date	observed	simulated	Date	Observed	Simulated
13/7/1985	2412.171	2921	5/7/1995	374.3161	741.6667
13/8/1985	1856.261	2178.6667	5/8/1995	1726.225	1551.333
13/9/1985	896.0926	1254.6667	5/9/1995	177.6215	458
10/7/1986	2301.557	3201.6667	10/7/1996	1442.718	1578.333
10/8/1986	2610.449	2243	10/8/1996	2672.363	2386
10/9/1986	816.7715	934	10/9/1996	765.835	1684
15/7/1987	2654.369	3536.6667	12/7/1997	1600.04	1645
15/8/1987	2502.694	2443.3333	12/8/1997	2671.376	2536.333
15/9/1987	427.2819	774.33333	12/9/1997	249.098	543
20/7/1988	2933.601	2064.6667	16/7/1998	1543.898	1395
20/8/1988	2268.165	2637.3333	16/8/1998	842.3624	1595.667
20/9/1988	2288.03	2395.6667	16/9/1998	1640.763	1582.667
25/7/1989	4350.52	3876.6667	19/7/1999	1963.118	2309.333
25/8/1989	2387.401	2553.6667	19/8/1999	2252.675	2066.667
25/9/1989	627.2136	897	19/9/1999	1805.048	2474.333
29/7/1990	2983.541	3476.6667	21/7/2000	1993.07	1455.667
29/8/1990	3176.063	3590	21/8/2000	2639.444	3703.333
29/9/1990	664.8019	1479.6667	21/9/2000	671.1724	1098
30/7/1991	2600.796	3766.6667	23/7/2001	2687.567	2388
30/8/1991	3173.729	2305	23/8/2001	254.523	800.3333
30/9/1991	1132.084	1197.6667	23/9/2001	256.8425	351
5/7/1992	675.9191	817	27/7/2002	672.1307	1491
5/8/1992	2049.12	1821.6667	27/8/2002	2163.022	2565
5/9/1992	485.775	965	27/9/2002	691.8836	933
7/7/1993	1514.838	1936.6667	29/7/2003	2693.895	2472
7/8/1993	1368.96	1565	29/8/2003	1004.519	1398.333
7/9/1993	2187.874	2342.6667	29/9/2003	2038.982	1440.667
9/7/1994	504.8193	746.33333	30/7/2004	3282.606	3613.333
9/8/1994	2950.093	2761.6667	30/8/2004	2237.245	2575.333
9/9/1994	868.8805	1146	30/9/2004	1096.962	1719

Appendix 10 The 95% prediction uncertainty (95PPU) for flow validation



Appendix 11 The 95% prediction uncertainty (95PPU) for sediment validation