

***Sediment Management in Reservoir***  
**(Case study of Gilgel Gibe-I Dam)**



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**October, 2016**



**Addis Abba University**  
**Addis Ababa Institute of Technology**  
**School of Graduate Studies**

***Sediment Management in Reservoir***  
**(Case study of Gilgel Gibe-I Dam)**

**A thesis submitted and presented to the School of Graduate Studies of Addis Ababa University in Partial fulfillment of the Degree of Masters of Science in Civil Engineering Under Hydraulics Engineering**

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I, the undersigned, certify that I have read and hear by recommend for acceptance by Addis Ababa Institute of Technology a thesis entitled “Sediment Management in Reservoir (Case study of Gilgel Gibe-I Dam)” in partial fulfillment of the requirements for the degree of Master of Science in **Civil Engineering Specialization in Hydraulic Engineering**.

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Dr. Bayou Chane

(Advisor)

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Date

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## ***Abstract***

*Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river; it is important to predict sediment inflow at Gilgel Gibe I and evaluate its consequences on the reservoir and sustain the reservoir through long term optimum sediment management program.*

*The overall goal of this study focuses on predicting sediment yield and its sustainability and identification of most appropriate sediment management strategy are under the scope of this study and applying SWAT model interface with GIS in predicting sediment yield in the Omo Basin Gilgel Gibe-I Reservoir is the major.*

*The proposed hydroelectric power project (designated as Gilgel Gibe I Reservoir) is located on Gilgel Gibe River (Omo Basin) approximately at 7.8314 degree N and 37.1918 degree E, and Most components of the project is situated in the Jimma zone of the Oromia regional state, more specifically in Asendabo, Sekoru and Saja Weredas.*

*The main objective of this study is to predict the sediment yield to Gilgel Gibe-I Watershed. The model is calibrated and validated taking the Asendabo station found in the catchment by transferring the gaged data to the outlet of Gilgel Gibe-I watershed.*

*The model is calibrated and validated for both flow and sediment concentration at Asendabos station (2966km<sup>2</sup>) and run at Gilgel Gibe-I dam reservoir outlet (3602km<sup>2</sup>) to estimate the sediment yield.*

*Flow calibration gives coefficient of determination (R<sup>2</sup>) and Nash-Sutcliffe simulation efficiency (ENS) 0.68 and 0.67 respectively. Flow validation gives 0.58 and 0.57 for R<sup>2</sup> and ENS values respectively. Sediment calibration gives R<sup>2</sup> and ENS 0.79 and 0.78 respectively and validation test gives R<sup>2</sup> and ENS 0.76 and 0.48 respectively. This result indicates that the observed values show good agreement with simulated value for both flow and sediment yield.*

*In this study the SWAT model yields average annual sediment of 106.178 ton/km<sup>2</sup>/yr or (10617.8 ton/ha/yr) at Gilgel Gibe-I outlet dam site.*

*Identifying erosion prone areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield.*

*Applying **filter strip** and **terracing** (stone bunds) in low slope areas of the catchment could give potential effect of best management practice.*

### **Key words**

***Arc SWAT, Spatial and Temporal data, sediment Yield, Gilgel Gibe-I Watershed, simulation, calibration, validation, SWAT CUP, Erosion prone area ,strategic management practice.***

## Table of Contents

<i>Acknowledgement</i> .....	<i>I</i>
<i>Abstract</i> .....	<i>II</i>
<b>Table of Contents</b> .....	<b>III</b>
<b>List of Figures</b> .....	<b>V</b>
<b>List of Tables</b> .....	<b>VI</b>
<b>Acronyms/Abbreviations</b> .....	<b>VIII</b>
<b>1. INTRODUCTION</b> .....	<b>1</b>
<b>1.1 Background</b> .....	<b>1</b>
<b>1.2 Statement of the Problem</b> .....	<b>2</b>
<b>1.3 Objective of the Study</b> .....	<b>2</b>
<b>1.3.1 General Objective</b> .....	<b>2</b>
<b>1.3.2 Specific Objective</b> .....	<b>2</b>
<b>2. DESCRIPTION OF THE STUDY AREA</b> .....	<b>3</b>
<b>2.1 Location of the Study area</b> .....	<b>3</b>
<b>2.2 Geology and Topography</b> .....	<b>4</b>
<b>2.3 Soil of the study area</b> .....	<b>5</b>
<b>2.4. Land use and cover</b> .....	<b>6</b>
<b>3. LITERATURE REVIEW</b> .....	<b>8</b>
<b>3.1 Hydrological Models</b> .....	<b>8</b>
<b>3.1.1. Selection of model</b> .....	<b>9</b>
<b>3.2. Overview of SWAT model</b> .....	<b>9</b>
<b>3.2.1. Performance of SWAT Model</b> .....	<b>10</b>
<b>3.3. Sediment Yield estimation of the watershed</b> .....	<b>12</b>
<b>3.3.1 Reservoir sedimentation problems in hydropower plants</b> .....	<b>13</b>
<b>4. METHODOLOGY</b> .....	<b>15</b>
<b>4.1 General</b> .....	<b>15</b>
<b>4.2 Hydrological processes in SWAT</b> .....	<b>16</b>
<b>4.2.1 Land Phase of the Hydrologic Cycle</b> .....	<b>18</b>

4.2.2 Hydrology modeling.....	18
4.3 Sediment modeling .....	23
4.3.1 Introduction .....	23
4.3.2 Sediment routing.....	25
4.3.3 Sediment routing in stream channels .....	25
4.4 Evaluation of Model Performance/ Efficiency criteria .....	27
4.5.1 Coefficient of determination (R <sup>2</sup> ).....	28
4.5.2 Nash-Sutcliffe efficiency coefficient (ENS) .....	29
4.5.3 Percent bias (PBIAS).....	29
5. DATA COLLECTION AND PREPARATION .....	30
5.1 General.....	30
5.2 Digital Elevation Model (DEM) .....	30
5.3 Soil Data .....	31
4.4 Land use/land covers Data.....	32
5.5. Flow Data .....	33
5.6 Climate Data/Weather Data .....	34
5.6.1 Rainfall Data .....	34
5.6.2 Data quality control .....	34
5.6.2.1 Visual inspection .....	35
5.6.2.2 Filling of missing data .....	35
5.6.2.3 Multiple Regression Analyses.....	36
5.6.2.4 Double mass curve.....	38
5.6.2.5 Statistical parameters calculation for precipitation data .....	38
5.6.2.6 Temperature Data .....	42
6. RESULTS AND DISCUSSION .....	45
6.1 Sensitive Parameters .....	45
6.1.1 Parameters sensitive to flow .....	45
6.1.2 Parameters sensitive to sediment.....	46
6.2 Model Calibration and Validation .....	47
6.2.1 Model calibration for flow.....	47
6.2.2 Model Validation for flow .....	50
6.2.6 Sediment concentration.....	56

6.2.7 Comparison with Previous Studies and Estimates from Other Reservoir.....	58
6.3 Land use/land cover and management scenarios .....	60
7. Conclusions and Recommendations .....	63
7.1. Conclusions .....	63
<i>REFERENCES</i> .....	65
<i>Appendices</i> .....	70

### List of Figures

Figure 2. 1 <i>Location of Gilgel gibe-I watershed sub basin from Omo basin.</i> .....	3
Figure 2. 2 <i>Slope classification for watershed</i> .....	4
Figure 2. 3 <i>Soil classification of the study area</i> .....	5
Figure 2. 4 <i>Land use and cover Map in the watershed</i> .....	6
Figure 3. 1 <i>Different Hydrological Models</i> .....	8
Figure 3.2 <i>Mechanism of soil Erosion</i> .....	12
Figure 3. 3 <i>Schematic presentation of sedimentation processes in river-fed storage reservoirs (Sloff, 1997).</i> .....	144
Figure 4. 1 <i>Conceptual framework of methodology</i> .....	16
Figure 4. 2 <i>Schematic representation of the hydrologic cycle</i> .....	17
Figure 4. 3 <i>Prism and wedge storages in a reach segment (Adopted from Neitsch et al., 2011)</i> .....	21
Figure 5. 1 <i>DEM and delineated watershed for Gilgel Gibe-I</i> .....	31
Figure 5. 2 <i>Soil map watershed for Gilgel Gibe-I</i> .....	32
Figure 5. 3 <i>Land use/cover map watershed for Gilgel Gibe-I</i> .....	32
Figure 5. 4 <i>Double mass curves</i> .....	38
Figure 5. 5 <i>Total annual precipitation (1986-2015)</i> .....	40
Figure 5. 6 <i>Daily maximum/minimum air temperature at Jimma station</i> .....	42
Figure 5. 7 <i>Summary of input data for SWAT model</i> .....	44

Figure 6. 1 Comparison of observed and simulated monthly runoff at the outlet of Gilgel Gibe-I watershed for calibration period 1989-2006. ....	48
Figure 6. 2 Goodness-of-fit for observed and simulated runoff during calibration period.....	49
Figure 6. 3 Comparison of observed and simulated monthly runoff at the outlet of Gilgel gibe-I watershed model for validation period 2007-2014. ....	50
Figure 6. 4 Goodness-of-fit for observed and simulated Monthly runoff for validation period 2007-2014. ....	51
Figure 6. 5 Comparison of observed and simulated yearly sediment load from Gilgel gibe –I for calibration period 1990 to 2010 year. ....	52
Figure 6. 6 Goodness-of-fit for observed and simulated yearly sediment load from Gilgel Gibe-I watershed. ....	53
Figure 6. 7 Comparison of observed and simulated yearly sediment load from Gilgel Gibe-I for validation period 2011 to 2014 year. ....	54
Figure 6. 8 Accumulated observed and simulated sediment at Gilgel Gibe-I 1990-2010. ....	56
Figure 6. 9 concentrations by weight and discharge G/Gibe 1990-2014 simulated and observed. ....	57
Figure 6. 10 Goodness-of-fit of simulated sediment concentration by weight and discharge.....	58
Figure 6. 11 Propagation of sediment inflow and outflow from simulated watershed.....	60
Figure 6. 12 Comparison of change of sediment load. ....	62

### List of Tables

Table 2. 1 <i>Slope Classification</i> .....	3
Table 2. 2 Soil Classification of Study Area. ....	5
Table 2. 3 Land Use/Cover Classification.....	6
Table 2. 4 Summary of soil/land use and slope used in the Delineated watershed .....	7
Table 3. 1 Summary of SWAT Application (Previous work). ....	11
Table 5. 1 Mean monthly flows at the outlet of the Gilgel Gibe-I watershed. ....	33
Table 5. 2 Stations used in Arc SWAT. ....	34
Table 5. 3 Arranging stations by missing data. ....	35
Table 5. 4 The sample of 7 <sup>th</sup> multiple regression of 8 stations. ....	37
Table 5. 5 Statistical Analysis of Daily Precipitation Data (1986 - 2015). ....	39
Table 5. 6 Total Monthly Precipitation Data (1986 - 2015). ....	40
Table 5. 7 Average daily precipitation in a month (1986 -2015). ....	41
Table 5. 8 Average yearly observed discharge and sediment concentration @ G/Gibe-I.....	43
Table 5. 9 Types and sources of data for Gilgel Gibe-I watershed and summary.....	44

Table 6. 1 Parameters rank based on P-value and t-stat. ....	45
Table 6. 2 Parameters highly sensitive to sediment. ....	47
Table 6. 3 Summary of stat txt of the model for calibration period. ....	49
Table 6. 4 Summary of stat txt of the model for validation period. ....	50
Table 6. 5 Summary of results for behavioral parameters for sediment calibration. ....	52
Table 6. 6 Summary of results for behavioral parameters for sediment validation. ....	54
Table 6. 7 Summary of simulated and observed sediment load of the watershed 1990 to 2010. ....	55
Table 6. 8 Summary of sediment concentration by weight during 1990-2014. ....	56
Table 6. 9 Time series of sediment concentrations by weight and discharge Gilgel Gibe-I ....	57
Table 6. 10 Propagation of sediment inflow and outflow from simulated watershed. ....	60
Table 6. 11 Land use summary to determine erosive area ....	60
Table 6. 12 Summary of scenario development result. ....	62

## Acronyms/Abbreviations

DBF	Data base file
DEM	Digital Elevation Model
DGPS	Differential Global Positioning System
EMA	Ethiopian Mapping Authority
ET	Evapotranspiration
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GWQ	Ground water flow (mm)
HRU	Hydrologic Response Unit
m.a.s.l	Meter above mean sea Level
mm	Millimeter
MoWIE	Ministry of water, irrigation and Electricity
MUSLE	Modified Universal Soil Loss Equation
NMSA	National Metrological Service Agency
RH	Relative Humidity
SURQ	Surface Runoff
SWAT	Soil and Water Analysis Tool
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UTM	Universal Trans Mercator
USLE	Universal Soil Loss Equation

# 1. INTRODUCTION

## 1.1 Background

Reservoir sedimentation is a gradual accumulation of the incoming sediment load from a river. This accumulation is a serious problem in many parts of the world and has severe consequences on water management, flood control and production of energy. In the present Situation, the worldwide loss of storage capacity in surface water reservoirs due to Sedimentation is higher than the increase in storage volume achieved through construction of new reservoirs (White, 2010). The worldwide loss in reservoir storage capacity is estimated to be between 0.5% and 1% per annum (Mahmood, 1987; White, 2010).

Soil erosion is the detachment and transportation of soil particles from their original place to further downstream by erosion agents such as water and wind. It is one of the normal aspects of landscape development. The severity of erosion increases with the decrease in cover material most likely vegetation. The vegetation cover decreases the soil erosion by decreasing the impact of raindrops that cause the detachment of the soil particles. Therefore, bare soil is more likely to be eroded by different soil erosion agents than soil with vegetation cover.

Soil erosion is a serious problem affecting the quality of soil, land, water resources upon which man depends for his sustenance. Today, soil erosion is universally recognized as a major environmental and agricultural problem. Because, as the top soil is eroded by erosion agents such as water, wind, avalanches, etc. its fertility and nutrient content decreases. This eventually results in the loss of productivity. Loss of the organic matter rich surface soil (topsoil) is known to decrease soil quality, which in turn reduces productivity (Verity and Anderson, 1990).

Reservoirs have to be considered as irreplaceable resources and have to be managed in accordance with the objective of sustainable utilization. Sediment production of a watershed is highly influenced by weathering effects caused by climatic factors like temperature variation, action of rain and chemical action from elements contained in the soil and water (ASCE, 1975).

Since the velocity of water in the reservoir is very low, sediments get deposited in the reservoir unless there exists a facility to avoid the settlement. The sedimentation of reservoirs causes another serious problem by decreasing the capacity of reservoirs. The loss in capacity of reservoirs increases the probability of floods. As more and more sediments get deposited in the reservoirs, its capacity decreases and ultimately will not be able to handle high flood. Sedimentation in irrigation canals will hamper and endanger proper irrigation management. To tackle all the aforementioned problems caused by erosion and sedimentation, identifying erosion prone areas and proper application of management options on those areas is crucial.

The sustainability of water storage reservoirs require a balance to be maintained between the volume of sediment deposited and the volume of sediment removed from the reservoir. In most cases it is difficult to achieve a complete sediment balance as sediment deposit in a reservoir is

influenced by several factors (Morris and Fan, 1998). But it is possible to optimize services of the reservoirs through different sediment management strategies (Palmieri, et al., 2003).

The Gilgel Gibe I reservoir is one of the largest reservoirs planned on the Omo River Basin involving large investment cost. Therefore; it is important to predict sediment inflow at Gilgel Gibe I and evaluate its consequences on the reservoir and sustain the reservoir through long term optimum sediment management program.

Sedimentation and Sustainability of Hydropower Reservoirs: Cases of Gilgel Gibe I Reservoir Sediments are all the basin rock and soil particles which water carries away by sliding, rolling or jumping on the bed and suspended in the flow. Very fine particles move in suspension. {*Feasibility Study Gilgel Gibe I Hydropower Project, The Federal Democratic Republic of Ethiopia Ministry of Water Resources.*}

## **1.2 Statement of the Problem**

The major problem in Reservoir sedimentation is one of the most important factors in the planning of a storage-dam, because uncontrolled soil erosion, Poor land use practices and improper mitigation management systems, land degradation resulting in heavy sediment transport in streams and rivers causes significant reduction of the capacity of reservoirs.

Soil erosion is a crucial problem in Gilgel Gibe River where the land area is mountainous and still tectonically active. Although deforestation, overgrazing and intensive agriculture, due to population pressure, have caused accelerated erosion. Therefore, understanding the impacts of soil erosion and looking for solutions to minimize is essential. It is important to assess the magnitude of the problem so that effective measures can be implemented (Shrestha, 1997).

This study focuses on estimating the sediment yield from Gilgel Gibe-I watershed, identifying erosion prone areas in the watershed and proposing alternative management plan to minimize erosion rate in the watershed.

The highest rate of erosion and sediment transport is during monsoon season when high intensity rainfall causes significant loss of soil. In addition to soil erosion by running water the high intensity rainfall causes severe landslides. (Galay et al., 1995)

## **1.3 Objective of the Study**

### **1.3.1 General Objective**

The overall goal of this study is to model the hydrological processes to estimate the sediment Yield Gilgel Gibe-I watershed and identification of most appropriate sediment management strategy of this watershed by making use of the SWAT (Soil and Water Assessment Tool) model.

### **1.3.2 Specific Objective**

- ✓ To estimate the amount of sediment yield of the Gilgel Gibe-I Watershed by SWAT
- ✓ To estimate the annual specific sediment of Gilgel Gibe-I
- ✓ To recommend appropriate mitigation measure to reduce sediment yield of watershed

## 2. DESCRIPTION OF THE STUDY AREA

### 2.1 Location of the Study area

The Gilgel Gibe-I Dam is a rock-filled embankment dam on the omo river in Ethiopia, it is located about 57km north east of Jimma in Oromia regional state, the primary purpose of the dam is generation of Hydroelectric power production and it diverts water through a 9.2km tunnel to underground power station to Gilgel Gibe-II downstream of Gilgel Gibe-I. The Gilgel Gibe –I watershed is geographically located at Latitude 7.8314 N and Longitudes 37.3216 E

Gilgel Gibe River is one of the major tributaries of Great Gibe River, which originates in mountainous area south – west of Jimma and flows towards the north until it joins Great Gibe River.

The river regulated by the upstream dam (which is currently in operation) here after called Gilgel Gibe-I could be utilized further downstream without constructing substantial structure. This site has a total catchments area of about 3,602km<sup>2</sup> as shown on fig 2.1. {*Feasibility Study Gilgel Gibe I Hydropower Project, The Federal Democratic Republic of Ethiopia Ministry of Water Resources.*}

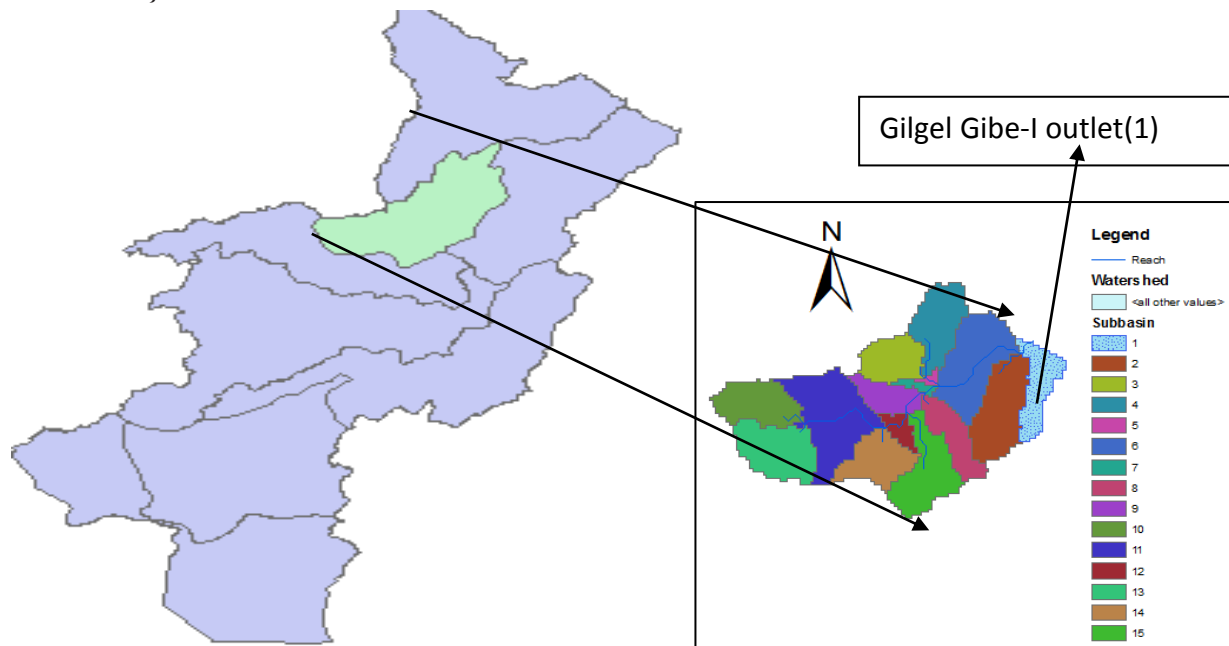


Figure 2.1 Location of Gilgel gibe-I watershed sub basin from Omo basin.

Table 2.1 Slope Classification

ID	Range of Slope	Area (ha)	% Coverage
1	0-2	76856.887	21.34
2	2-4	85724.99	23.80
3	4-6	58077.37	16.12
4	6-9999	139542.199	38.74

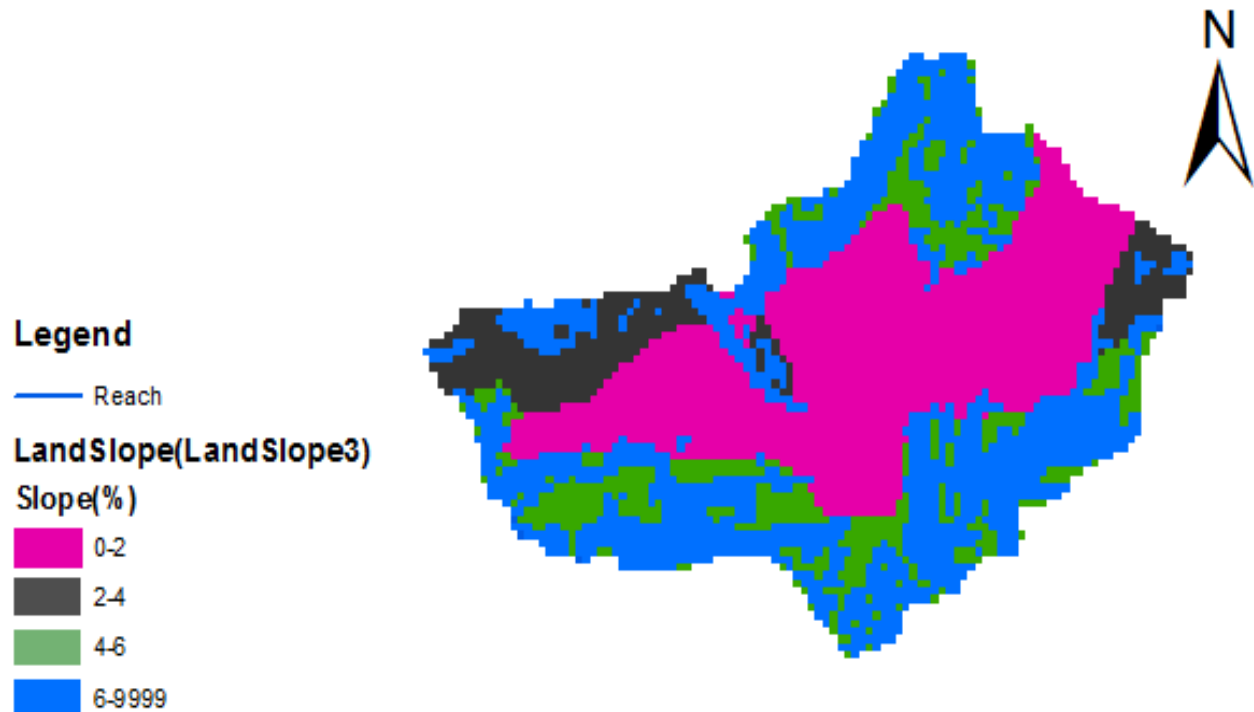


Figure 2. 2 Slope classification for watershed

## 2.2 Geology and Topography

While selecting the diversion weir site, geological characteristics, rock type and thickness of strata, inclination of the bedding planes, existing faults and fissures etc. affect the selection. Also it is better to have foundation with high bearing capacity, resisting to erosion, and resistance to percolation.

The Gilgel Gibe I project area is located in the southwest plateau very near to the Main Ethiopian Rift (MER), and the geology of the project area comprised rocks, which range in ages from Precambrian to Quaternary dominantly Pliocene volcanic.

The most likely occurred rock types in the project area are mainly lower basalt, rhyolites, ignimites and upper basalt etc. The lower basalt is the oldest rock in the site, which is described as dark grayish to black, very strong, with two joint sets vertical and dipping west or southern west.

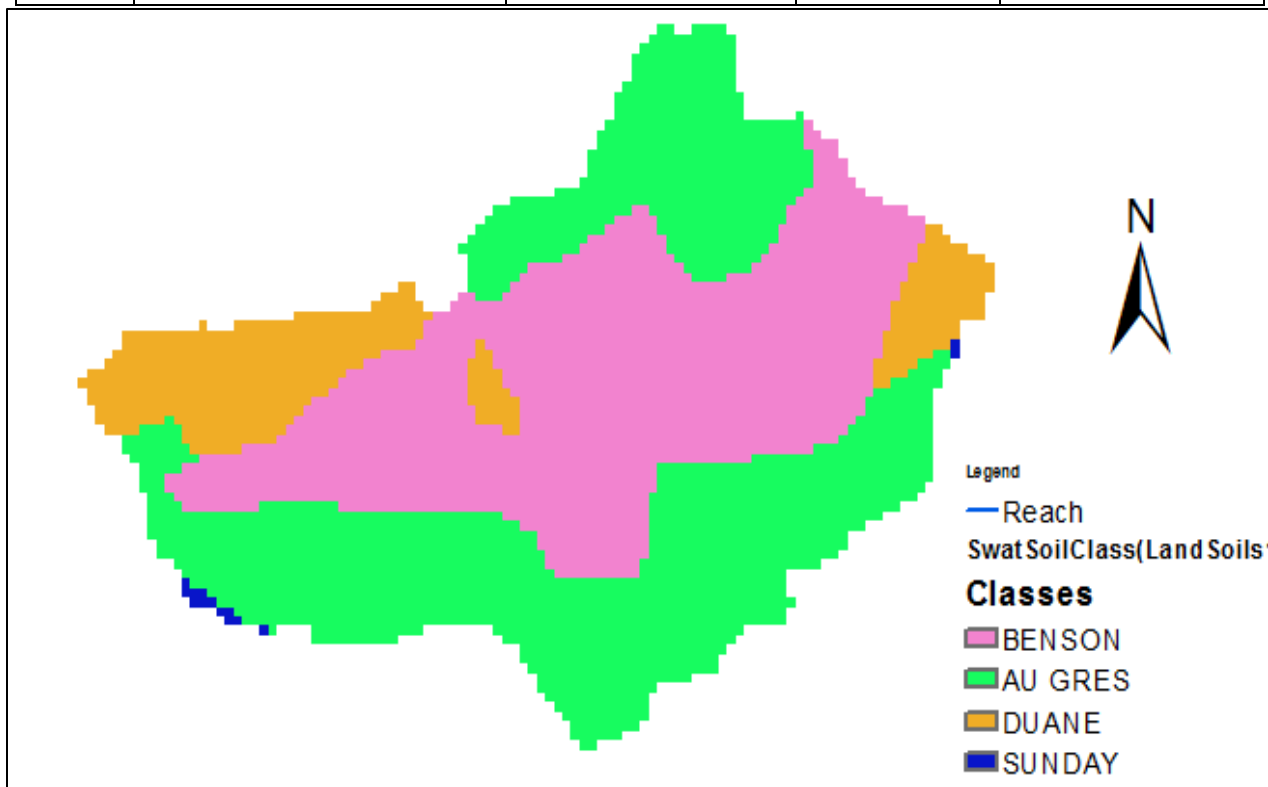
Generally, the river channel at the proposed diversion weir site is concentrated by very big blocks, boulders and cobbles trace sand and gravel deposits, which are alluvial as well as colluvial origin. From close inspection of the site, the bedrock, which is very sound one, are estimated to be found at a shallow depth below the river channel. {Feasibility Study Gilgel Gibe I Hydropower Project, The Federal Democratic Republic of Ethiopia Ministry of Water Resources.}

### 2.3 Soil of the study area

Soils that have predominantly available in the study area are Andosols, Cambisols, Vertisols, Leptosols, Luvisols, Nitisols, (WWDSE and WPCS, 2005). From these soil groups Andosols have a high potential for agricultural activity because of their fertility, ease of cultivation and ease of root penetration. In areas covered by such soils, there is less probability of occurrence of erosion. Erosion is the greatest threat to Leptosols. As a result, severe erosion problems may be observed in Leptosols under high anthropogenic effects. The erosion risk of Nitisols is high on hilly sides, where there are no proper land use management practices. (WWDSE and WPCS, 2005).

**Table 2. 2** Soil Classification of Study Area.

VALUE	SOIL_USE	AREA USED (hectare)	SWAT_CODE	% COVERAGE
1	ANDOSOLS,LTLEPTOSOLS	164755.4321	AU GRESS	45.74
2	CAMBISOLS,DYVERTISOLS	147714.764	BENSON	41.01
3	RNLEPTOSOLS	46514.66	DUANE	12.91
4	NITISOLS,CHLUVSOLS	1217.19	SUNDAY	0.34



**Figure 2. 3** Soil classification of the study area

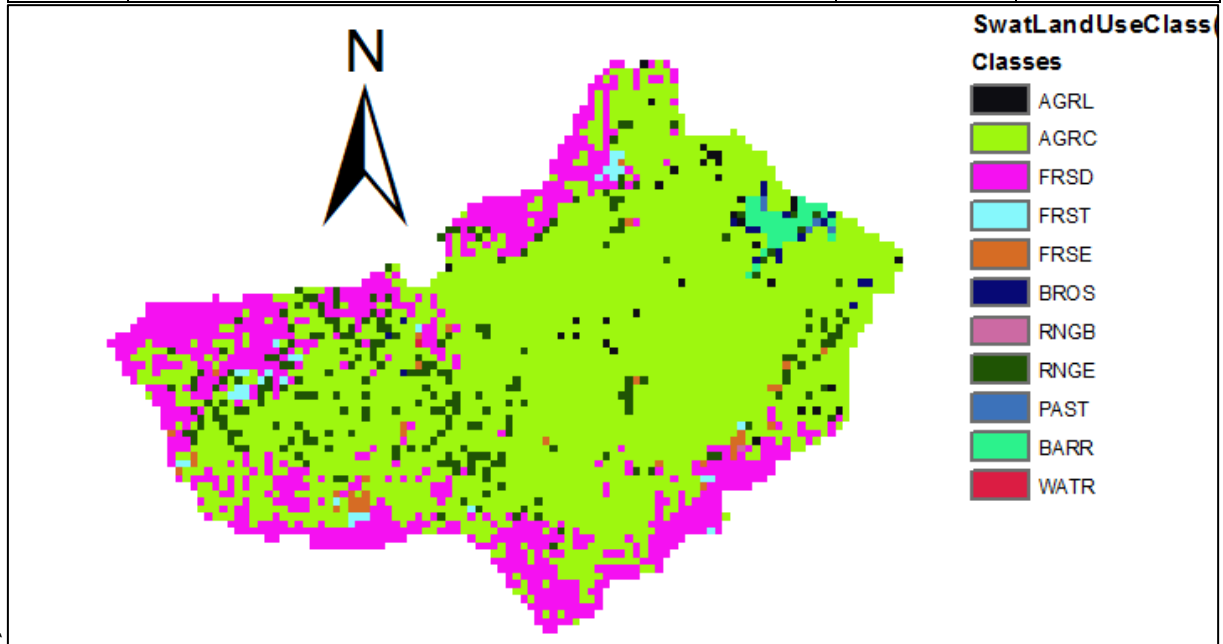
## 2.4. Land use and cover

The main land use types are forest, hill slope cultivation, valley cultivation, and water body (reservoir). Agriculture occupies about 68% of the watershed area. Forest cover is about 30% of the total area of the watershed, about 1.88 range grasses and the reservoir covers about 0.02% of the watershed area. The summary of the land use of Gilgel gibe-I watershed is given in the Table 2.3 below. These percentages are different from those stated on different papers since are based on the total area of the catchment as delineated by ArcSWAT.

Presently, the natural vegetation of the region is highly disturbed by man and livestock and partly cleared and replaced by permanent cultivated fields. Grass, shrub, wood land, wet land, exposed soil and exposed rocks were identified as dominant land use and cover types.

**Table 2.3** Land Use/Cover Classification.

VALUE	LAND USE	SWAT_CODE	% AREA
1	AFRO-ALPINE/FOREST EVER-GREEN	FRSE	0.92
2	AGRICULTURAL LAND GENERIC	AGRL	0.77
3	AGRICULTURAL LAND –CLOSE GROWN/CULTIVATION	AGRC	68.43
4	PLANTATION AND FALLOW/DECIDIOUS FOREST	FRSD	21.41
5	BUSH LAND/SHRUB LAND	RNGB	0.02
6	GRASS LAND/RANGE-GRASS	RNGE	6.03
7	FOREST/WOOD-LAND	FRST	0.82
8	SMOOTH BROME GRASS	BROS	0.43
9	PASTURE	PAST	0.12
10	BARREN LAND	BARR	0.01
11	OPEN WATER/ WATER BODY	WATR	0.02



**Figure 2.4** Land use and cover Map in the watershed

Table 2.4 Summary of soil/land use and slope used in the Delineated watershed

watershed		Area [ha]	Area[acres]	
Number of Subbasins: 15		360201.4538	890075.8025	
LANDUSE:		Area [ha]	Area[acres]	%wat.Area
	Agricultural Land-Generic --> AGRL	2782.1498	6874.8312	0.77
	Agricultural Land-Close-grown --> AGRC	246481.0817	609067.0770	68.43
	Forest-Deciduous --> FRSD	77117.7141	190561.7274	21.41
	Forest-Mixed --> FRST	2956.0341	7304.5082	0.82
	Forest-Evergreen --> FRSE	3303.8029	8163.8621	0.92
	Smooth Bromegrass --> BROS	1564.9592	3867.0926	0.43
	Range-Brush --> RNGB	86.9422	214.8385	0.02
	Range-Grasses --> RNGE	21735.5451	53709.6188	6.03
	Pasture --> PAST	434.7109	1074.1924	0.12
	Barren --> BARR	3651.5716	9023.2160	1.01
	Water --> WATR	86.9422	214.8385	0.02
SOILS:				
	AU GRES	164755.4321	407118.9104	45.74
	BENSON	147714.7647	365010.5693	41.01
	DUANE	46514.0666	114938.5842	12.91
	SUNDAY	1217.1905	3007.7387	0.34
SLOPE:				
	0-2	76856.8876	189917.2120	21.34
	2-4	85724.9900	211830.7365	23.80
	4-6	58077.3766	143512.1014	16.12
	6-9999	139542.1997	344815.7526	38.74

### 3. LITERATURE REVIEW

#### 3.1 Hydrological Models

Modeling is defined by Wight (1988) as the process of organizing, synthesizing, and integrating component parts into a realistic representation of the prototype. USDA (1980) lists the following benefits of modeling: Models help sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiments instead of conducting the experiments on the watershed itself. Hydrological Models can be categorized into three classes: Black-box models, Conceptual models, and Deterministic models (Beven, 1985).

**Empirical models or black box models:** contain non physically-based transfer functions to transform input data to output data mathematically. These models are often referred to as cause and effect models where the physical processes taking place are not simulated. Black box models are divided generally as linear and non-linear and in particular artificial neural network (ANN) method is used commonly in the modeling of non-linear system behavior (Cigizoglu and kisi, 2006).

**Deterministic model:** have a complex physical theory and need to have large amount of data

**Conceptual models:** can be defined as semi-physical models since they simulate physical processes using major simplifications. Each physical component of the system or process is modeled in a simplified manner.

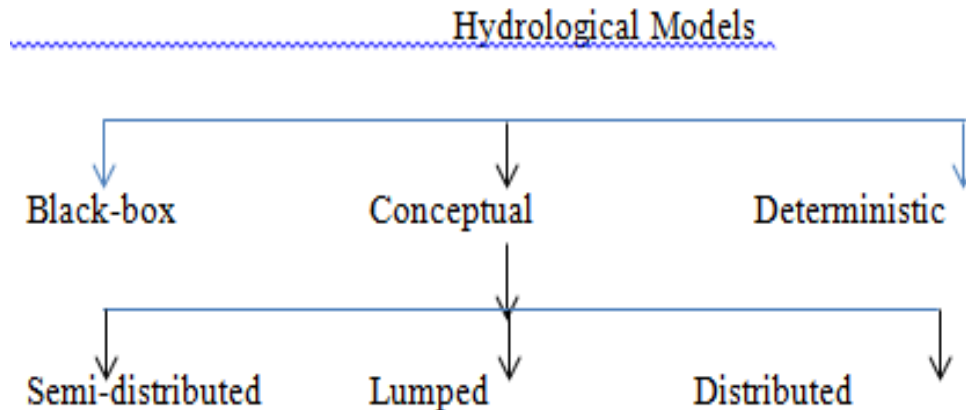


Figure 3. 1 Different Hydrological Models

**Physically-based models (Semi-Distributed):** this type of models tries to simulate the internal mechanisms of the system using a theoretical approach without using major simplifications. These models use physical parameters that can be either measured or determined using

appropriate equations. Hydrological assessment models further divided into lumped and distributed models.

**Lumped models:** provide a unique output for the whole watershed. They do not provide any information regarding the spatial behavior of the outputs. The whole catchment is assumed to be homogeneous and all the potential variations are lumped (averaged) together. Thus, the degree of accuracy of the model is expected to vary with the degree of non homogeneity of the catchment (Huggins and Monke, 1966).

**Distributed models:** this type of models takes into account the spatial variability of watershed characteristics. It divides the watershed into units which are assumed homogeneous. All the hydrologic, climatic and management parameters are assumed homogeneous within each cell, but may vary from cell to cell. The dynamics of the simulated processes are then described at each point within the watershed, and the outputs from each cell are routed to the watershed outlet (Beven, 1985).

### 3.1.1. Selection of model

Even though, estimates of sediment yield are required in a wide spectrum of practical studies for the planning, design, operation and maintenance of water resources structures, the measurement and sampling of sediment transportation is very lengthy and costly. So that it requires other options to challenge such problems of sediment estimation in water resources development.

Reason for the selection of SWAT model was: It is physically based, spatially distributed, identify vulnerable (erosion prone areas) and adopt best management practice for the watershed and belongs to the public domain and the model has been tested in different tropical watersheds(Tadele and Forch 2007)

### 3.2. Overview of SWAT model

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model 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 (Arnold *et al.*, 1998, 2000; Neitschet *al.*, 2001). The SWAT (Soil and Water Assessment Tool) (Arnold *et al.*, 1998) model developed in the early 1990's by the U.S. Department of Agriculture, Agricultural Research Service (USDA-ARS) to overcome all limitations of previous model.

In the SWAT model, the modeling or estimation of flow, sediment or nutrient transport of the watershed is done by dividing the watershed into sub basins and the land areas in the sub basins are also sub-divided again into one or more land units, possessing similar land use, soil type and applied management strategies. These similar land units in land use, management and soil attributes are called Hydrologic Response Units (HRUs). The HRUs are helpful for a better estimation of the loadings (flow, sediment, pollutants) from the sub basins. The Arc SWAT

extension of Arc GIS is a graphical user interface for the SWAT model (Arnold *et al.*, 1998). To create a SWAT dataset, the interface will need to access Arc GIS compatible raster (GRIDs) and vector datasets (shape files or feature classes) and database files which provide certain types of information about the watershed. In the SWAT model the water balance is the backbone of the hydrologic simulation in a watershed; and the hydrology of a watershed can be separated into two major divisions, land phase and routing phase (Neitschet *et al.*, 2002).

### **3.2.1. Performance of SWAT Model**

The applicability of Soil and Water Assessment Tool (SWAT) model in estimating daily discharge and sediment delivery from mountainous forested watersheds and the assessment of the impact of forest cover types on stream discharge pattern and sediment load was carried out by Tyagi *et al.*, (2014) to two small watersheds located in lower Himalaya, India: Arnigad (304.4 ha). The model was calibrated and validated for daily discharge and sediment concentration using the observed data. The model calibration result for Arnigad watershed showed very good agreement between observed and simulated daily values with R<sup>2</sup> Value of 0.91 and ENS value of 0.84 in discharge simulation; and R<sup>2</sup> value of 0.89 and ENS value of 0.83 for sediment simulation. The result of the study was a clear evidence of the capability of the SWAT model in estimating the discharge and sediment yield from Himalayan forested watersheds and can be used to assess the hydrology and sediment yield response of the watersheds in the region.

The performance of the SWAT model to some extent can be affected by the resolution of the time series dataset used in calibration and validation of the model.

In general, the model is known to perform well with monthly data compared to daily data. This was shown by Jain *et al.*, (2010). Jain *et al.*, (2010) applied SWAT model to part of Satlug River basin lying between Suni and Kasol in western Himalayan region to simulate the runoff and sediment yield from the watershed. The model was calibrated for the years 1993-1994 and validated with the observed runoff and sediment yield for the years 1995-1997. The R<sup>2</sup> value for daily and monthly sediment yield during calibration was found as 0.33 and 0.38 respectively and the c value for daily and monthly sediment yield during validation period was calculated as 0.26 and 0.47 respectively. For the same statistical parameter used as model performance evaluation, SWAT's daily flow predictions were not as good as monthly predictions. The simulation result showed that the R<sup>2</sup> value for daily simulation is lower than that of monthly values because of monthly totals tend to smooth the data which in turn increases the value of R<sup>2</sup>. Ayana *et al.*, (2012) applied SWAT model to Fincha watershed (3,251 km<sup>2</sup>), located in western Oromiya Regional State, Ethiopia. The model was calibrated using a time series dataset of 22 years from 1985 to 2006 estimated monthly sediment yield with R<sup>2</sup> value of 0.82 and ENS value of 0.80 during calibration and R<sup>2</sup> value of 0.80 and ENS value of 0.78 during the validation period. The result of the study showed that the model adequately predicted the sediment yield from the study watershed with high performance and can be applied to other watersheds in the region with some catchment specific parameter modifications.

Betrie *et al.* (2011), applied the SWAT model to simulate daily sediment yield From the Upper

Blue Nile basin under different Best Management Practice (BMP) scenarios on sediment reductions. The scenarios applied were maintaining existing conditions (baseline), introducing] filter strips, applying stone bunds (parallel terraces) and reforestation. The results of the study showed that there is good agreement between the observed and simulated daily sediment concentrations as the value of Nash-Sutcliffe efficiency was 0.83. Applying the other management practices such as filter strips, terraces and reforestation scenarios reduced the sediment yield at both basin and sub basin level. For instance, applying stone bunds or parallel terraces reduce soil erosion and sediment transport by reducing the slope length. This because the slope length factor is directly involved in sediment yield calculation from the watershed by using MUSLE equation. The slope length will be affected by the terrace interval.

Setegn et al, (2008) applied SWAT model to the Lake Tana Basin for modelling of the hydrological water balance. The objective of this study was to test the applicability of SWAT model for prediction of stream flow in the basin. The model was successfully applied to the basin in simulating the daily and monthly stream flows and found out that the flow was more sensitive to the HRU definition thresholds than sub basin discretization effect.

The application of SWAT model in catchment parameterization was also carried out successfully by Mulungu and Munishi, (2007). The result of the study showed that surface water model parameters were the most sensitive and have more physical meaning for instance, CN2 (curve number) and SOL\_K (saturated hydraulic conductivity of soil layers). The model efficiency (R2) value as low as 0.14 obtained in this study showed that other factors than the spatial land data were greatly important for improvement of flow estimation by SWAT in the catchment.

The result of the study revealed that the number and size of sub-watersheds do not significantly affect surface runoff but had noticeable effect on other components of the water balance: evapotranspiration, percolation and soil water content. Therefore, it is possible to conclude that the watershed subdivision has an effect of the water balance in general. The number and size of sub-watersheds for a given catchment depends on the resolution of spatial data used in the model. High resolution data results in higher number of sub-watersheds and thereby enhance the water balance prediction of the model.

Easton et al. (2010) applied SWAT model to a Blue Nile Basin, Ethiopia and found out that the SWAT model is incapable of realistically model gully erosion. The study showed that SWAT model under predicted the sediment from a basin where gully erosion is high

**Table 3. 1 Summary of SWAT Application (Previous work).**

Basin name	Sensitivity analysis to flow				Sensitivity analysis to sediment				Authors	Model Performance
	Flow calibration		Flow validation		Sediment calibration		Sediment validation			
	R2	ENS	R2	ENS	R2	ENS	R2	ENS		
Lower Himalaya	0.91	0.84			0.89	0.83			Tyagi et al.(2014)	high
Satlug River					0.38		0.47		Jain et al ..(2010)	Low
Fincha					0.82	0.8	0.8	0.78	Ayana et al.(2012)	high

### 3.3 Soil Erosion Models

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water (Foster and Meyer, 1977; Wischmeier and Smith, 1978; Julien, 1998). The major forces originate from raindrop impact and flowing water. Figure 3.2 shows the mechanisms of soil erosion, in which water from sheet flow areas runs together under certain conditions and forms small rills. The rills make small channels. When the flow is concentrated, it can cause some erosion and much material can be transported within these small channels. A few soils are very susceptible to rill erosion. Rills gradually join together to form progressively larger channels, with the flow eventually proceeding to some established streambed. Some of this flow becomes great enough to create gullies. Soil erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems.

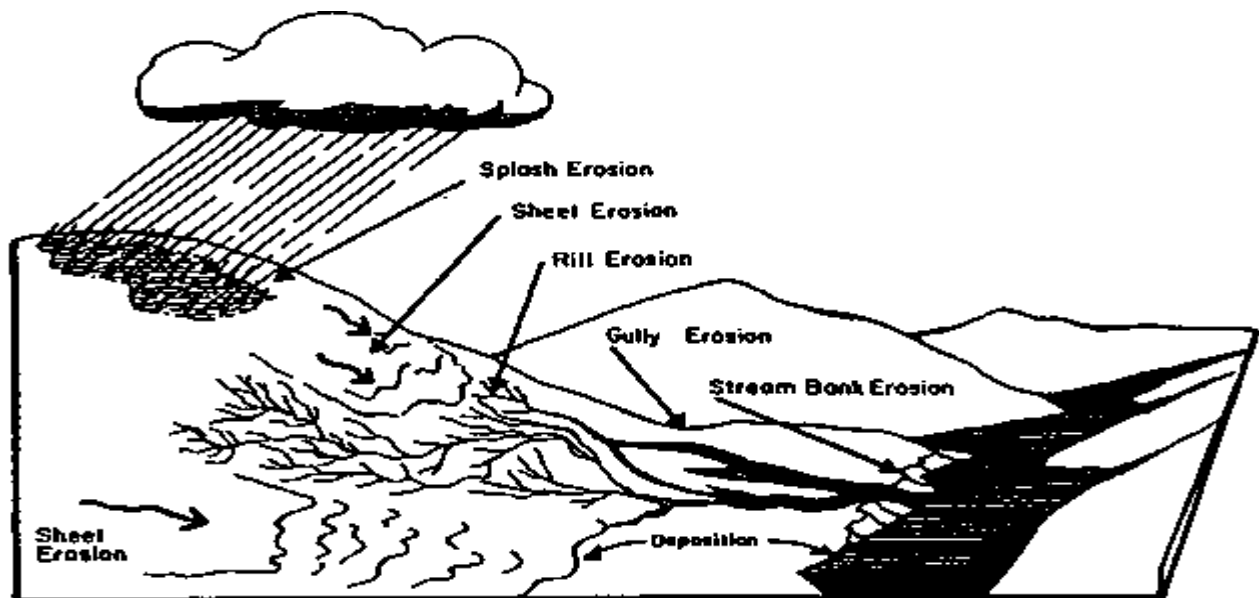


Figure 3.2 The mechanisms of soil erosion (USACE, 1985)

The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall by Wischmeier and Smith (1965) in order to calculate the amount of soil erosion in agricultural areas. The equation was modified in 1978. It is the most widely used and accepted empirical soil erosion model developed for sheet and rill erosion based on a large set of experimental data from agricultural plots. The USLE has been enhanced during the past 30 years by a number of researchers. Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), Revised Universal Soil Loss Equation RUSLE (Renard et al., 1997), Areal Nonpoint Source Watershed Environmental Resources Simulation (ANSWERS) (Beasley, 1989) and Unit Stream Power based Erosion Deposition (USPED) (Mitasova et al., 1996) are based on the USLE and represent an improvement of the former.

### **3.4. Sediment Yield estimation of the watershed**

*Sediment yield* refers to the amount of eroded sediment discharged by a stream at any given point over a period of time, which is also the amount which will enter a reservoir located at the downstream limit of its tributary watershed (Vanoni, 2006). The most common unit for sediment yield is tones/year. The *specific sediment yield* is the yield per unit of land area which is most commonly given in tones/km<sup>2</sup>/year. Long-term sediment yield estimates have been used for sizing storage reservoirs and estimating reservoir life (Morris and Fan, 1998).

Accurate estimation of sediment yield is very important in order to plan a reservoir and efficiently manage its sediment so that the reservoir can meet its requirements. Sediment yield is affected by geology, slope, climate, drainage density and patterns of human disturbance and therefore, no single parameter or simple combination of parameters explains the wide variability in sediment yields (Morris and Fan, 1998; Vanoni, 2006; Lustig, 1965).

Sediment yield from drier areas tends to be limited because of low runoff and yield in wetter areas is limited by the protective soil cover and reduced erodibility of humid zone soils (Vanoni, 2006).

The process of soil erosion involves detachment, transport and subsequent deposition (Meyer & Wishmeier, 1969). Sediment is detached from soil surface both by the raindrop impact and the shearing force of flowing water. The detached sediment is transported down slope primarily by flowing water, although there is a small amount of down slope transport by raindrop splash also (Walling, 1988). Once runoff starts over the surface areas and in the streams, the quantity and size of material transported depends on transport capacity of runoff water. However, if transport capacity is less than the amount of eroded soil material available, then the amount of sediment exceeding the transport capacity gets deposited and estimation of sediment load is required in practical studies for the planning, design, operation and maintenance of water resources structures. (Meyer & Wishmeier, 1969; Haan et al., 1994).

#### **3.4.1 Reservoir sedimentation problems in hydropower plants**

Dealing with reservoir-sedimentation problems, engineers are challenged by the difficult questions emerging. How to incorporate reservoir problems in feasibility studies (cost benefit analyses) including environmental and technical effects, limitations on benefit and possible measures? or what is the impact of silting and desilting of the reservoir?

By focusing on sediment impacts in hydropower plant the following impacts may be notified:

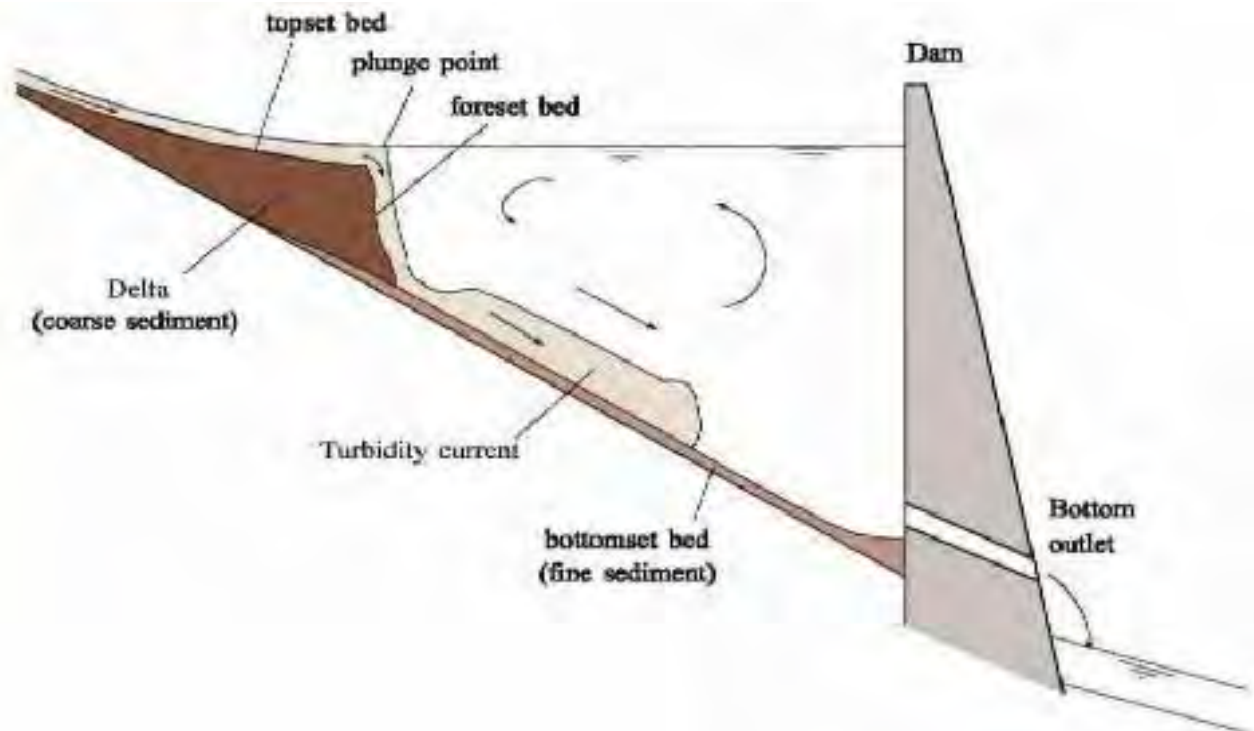
1. The effect of reservoir sedimentation on regulating water resources and its impact on power generation.
2. The effect of sediment inflow to power intakes and its impacts on turbine system and other components of the hydropower plant.

For Run-of-river projects are constructed to utilize the available water throughout the year without having any storage.

The most important distribution principles of these sediments in the reservoir can be subdivided into the following groups:

**Coarse sediment deltaic deposits:** mainly the coarse sediment fractions are deposited in the head of the reservoir by backwater effects during high discharges, forming delta. The delta proceeds into the reservoir while the forest slope can be considered as an area of instability and slumping.

**Fine sediments in homogeneous flow:** A large part of the fine sediments transported in suspension or as wash load are transported beyond the delta after which they settle out to form the bottom set bed. They are more evenly spread than coarse sediment, but the distribution is highly dependent on reservoir circulation and stratification, for instance generated by river inflow and wind shear, or precluded by an ice cover.



**Figure 3.3** Schematic presentation of sedimentation processes in river-fed storage reservoirs (Sloff, 1997).

### 3.4.2 Sediment management measures for reservoirs

Sediment management practices for reservoirs are often as different as their physical and technical conditions and social-economic and environmental aspects. Based on literatures and existence experiences, a tentative long-list of alternatives for sediment control of dam reservoirs can be found. The list is sub-divided into four general categories as follows:

- i. watershed rehabilitation (Structural and non- Structural Measures)
- ii. Sediment flushing
- iii. Sediment routing
- iv. Sediment removal and disposal

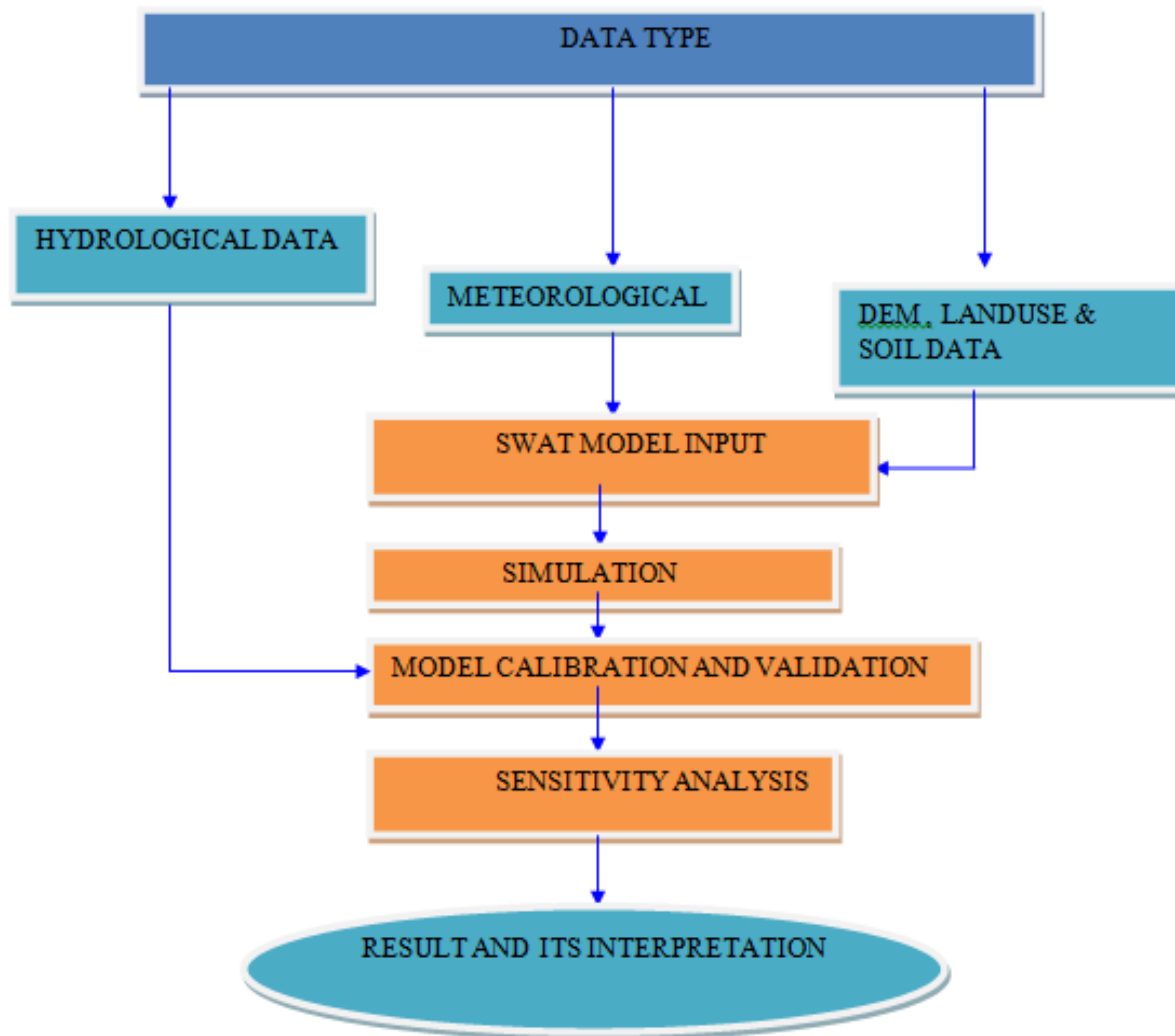
Based on the above general categories some of the measures commonly used to reduce reservoir sedimentation are summarized in the following sections.(Case Study – Dez Dam Project,2011)

## 4. METHODOLOGY

### 4.1 General

The general methodology of this study is depending on the data which are collected from different organization and also field observation. In this methodology the first part is the prediction of sediment yield in the watershed by using SWAT model for determination of sediment yield at the Reservoir site and to characterize the sub basins in terms of sediment yield. The conceptual framework followed to accomplish this work can be described as follows. This is the driving force and the target to be accomplished during the course of the project work. For this specific project the SWAT (Soil and Water Assessment) model was selected. The reason for the selection of the SWAT model was that SWAT model is physically distributed and continuous time developed to predict the impact of land management practices on water, sediment and agricultural chemical yields from a watershed. After the objective is set and the suitable model is selected, the necessary data required to run the model was collected and prepared as to the requirement of the SWAT model format. The geospatial data including the digital elevation map, land use/land cover map, soil map and the hydro-meteorological data including the daily stream flow data (1989-2014), daily rainfall data (1986-2015), maximum and minimum daily air temperature data and sediment load/concentration data are all collected and processed as per the input requirement format of the model. The conceptual framework of the steps followed during the course of this project is shown below.

- ❖ Set objective
  - Clearly specify the aim of the research
  - List all tasks to be done to reach the aim of the research
- ❖ Data collection and preparation
  - Collect all necessary data required for the model to run
  - Prepare the collected data as per the requirement of the model (model input)
- ❖ Import prepared data in to the model
- ❖ Model set up and run
  - Delineate the watershed
  - Create HRUs
  - Model Setup
  - Run the Model
    - ❖ Sensitivity analysis
      - Identify Sensitive parameters prior to calibration to save time during calibration
    - ❖ Calibration and validation
      - Calibrate the model for better prediction of the observed value
      - Validate the model outside the calibration period to see if the model is applicable

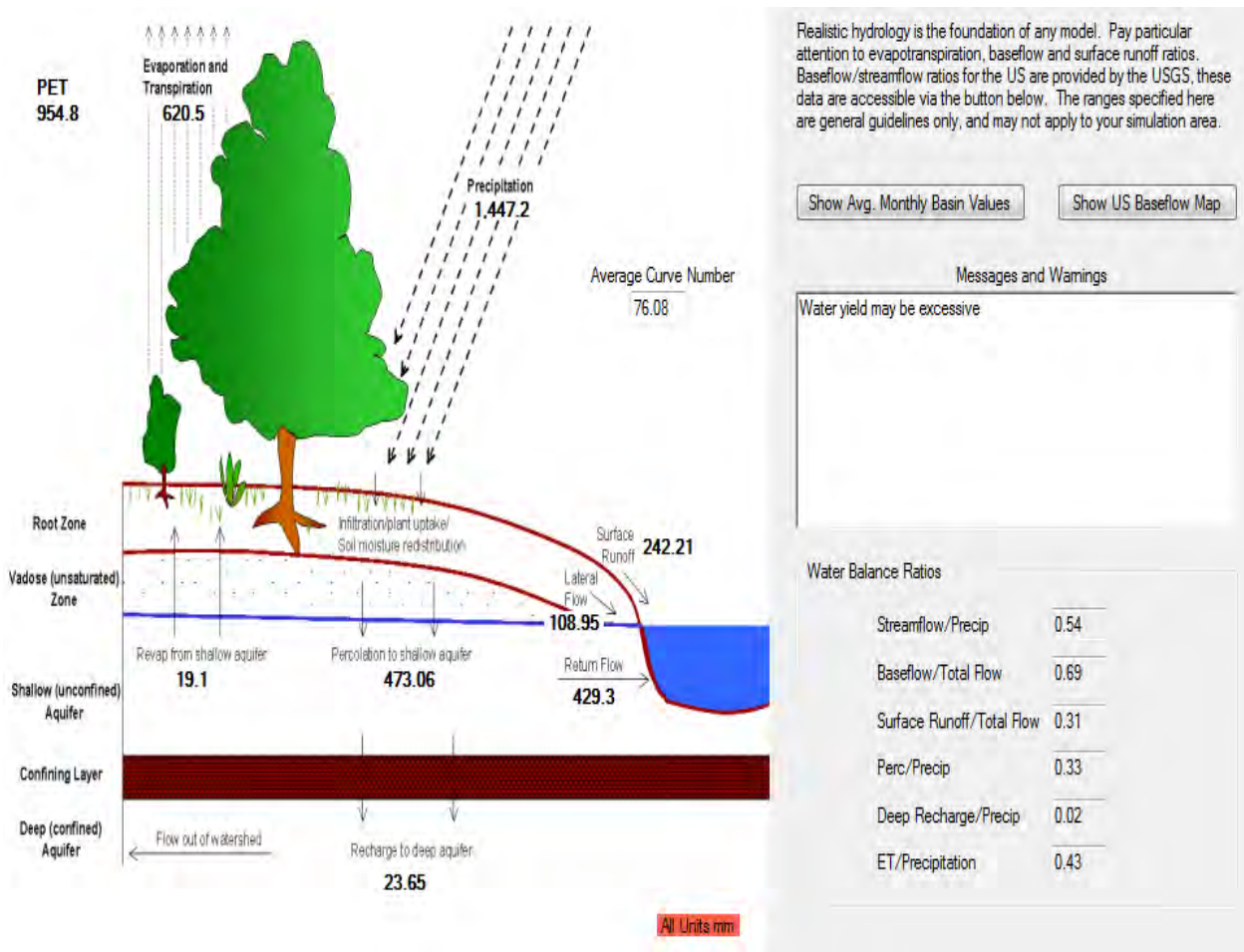


**Figure 4.1 Conceptual framework of methodology**

## 4.2 Hydrological processes in SWAT

SWAT allows a number of different physical processes to be simulated in a watershed (Neitsch et al., 2011). The simulated processes include surface runoff, sediment, infiltration, evapotranspiration (ET), lateral flow, percolation to shallow and deep aquifers and channel routing (Arnold et al., 1998). All these hydrological processes are simulated in surface, soil, and intermediate (vadose) zone, shallow and deep aquifers. Among the hydrological processes, surface runoff, subsurface or lateral flow and return flow or base flow contributed to stream flow in the main channel. As it was described earlier the water that enters the deep aquifer is assumed to be lost out of the system of the watershed under study. In SWAT, the local water balance is represented through four storage volumes. These storage volumes are: snow, soil profile (0-2 m), shallow aquifer (2-20 m) and deep aquifer storage (>20 m) (Abbaspour et al., 2009). Since there was no significant snow fall in the catchment no process related to snow was considered in this study.

SWAT first delineates a basin or a watershed and then, a basin is delineated into sub-basins, which are then further subdivided into hydrologic response units (HRUs). Hydrologic Response Units (HRUs) are lumped land areas within the sub basin that are comprised of unique land cover, soil and management combinations (Neitsch et al., 2011) and based on two options in SWAT, they may either represent different parts of the sub-basin area or sub-basin area with a dominant land use or soil type (also, management characteristics). Therefore, each HRU is assumed to be spatially uniform in terms of slope, land use, soil type and climate. With this semi-distributed (sub-basins) set-up, SWAT is attractive for its computational efficiency as it offers some compromise between the constraints imposed by the other model types such as lumped, conceptual or fully distributed, physically based models. A full model description and operation is presented in (Neitsch et al., 2011).



**Figure 4.2 Schematic representation of the hydrologic cycle**

To accurately predict the movement of pesticides, sediments or nutrients, the hydrologic cycle as simulated by the model must conform to what is happening in the watershed. Simulation of the hydrology of a watershed can be divided in to two major divisions. (1) The land phase of the hydrologic cycle and (2) the water or routing phase of the hydrologic cycle. The first division

controls the amount of water, sediment, nutrient and pesticide loadings to the main channel in each sub-basin. And, the second division is with the movement of water, sediments, nutrient and pesticide through the channel network of the watershed to the outlet (Neitsch et al., 2011).

#### 4.2.1 Land Phase of the Hydrologic Cycle

The hydrologic cycle simulated by SWAT is based on the water balance equation.

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

Where:  $SW_t$  -is the final soil water content (mm H<sub>2</sub>O),

$SW_0$  -is the initial soil water content on day  $i$  (mm H<sub>2</sub>O),

$t$  -is the time (days),

$R_{day}$  -is the amount of precipitation on day  $I$  (mm H<sub>2</sub>O),

$Q_{surf}$  -is the amount of surface runoff on day  $i$  (mm H<sub>2</sub>O),

$E_a$  -is the amount of evapotranspiration on day  $I$  (mm H<sub>2</sub>O),

$W_{seep}$  -is the amount of water entering the vadose zone from the soil profile on day  $I$  (mm H<sub>2</sub>O), and

$Q_{gw}$  -is the amount of return flow on day  $I$  (mm H<sub>2</sub>O).

The subdivision of the watershed into sub-watersheds and further into HRUs enables the model to reflect the differences in evapotranspiration for various crops or land covers and soils. Runoff is predicted separately for each HRU and routed to obtain the total runoff for the watershed. This increases the accuracy and gives much better physical description of the water balance.

#### 4.2.2 Hydrology modeling

As the rain descends, it may be intercepted and held in the vegetation canopy or fall to the soil surface. Water on the soil surface will infiltrate into the soil profile or flow overland as surface runoff. Runoff moves relatively quickly toward a stream channel and contributes to short term stream response. Infiltrated water may be held in the soil profile and later evapo-transpired or it make its way to the surface water system through underground paths (Neitsch et al., 2011).

##### 4.2.2.1 Surface Runoff/overland Flow

Surface runoff occurs whenever the rate of water application to the ground surface exceeds the rate of infiltration (Neitsch et al., 2011). When water is initially applied to a dry soil, the infiltration rate is usually very high. However, it will decrease as the soil becomes wetter. When

the rate of application is higher than the infiltration rate, surface depressions begin to fill. If the application rate continues to be higher than the infiltration rate once the all surface depressions have filled, surface runoff will commence (Neitsch et al., 2011). SWAT provides two methods for estimating the surface runoff: the SCS curve number procedure (SCS, 1972) and the Green and Ampt infiltration method (Green and Ampt, 1911).

The SCS curve number is a function of the soil’s permeability, land use and antecedent moisture conditions (SCS, 1972) whereas the Green and Ampt infiltration method calculates infiltration as a function of the wetting front metric potential and effective hydraulic conductivity (Green and Ampt, 1911). SWAT uses the daily and hourly time steps to calculate surface runoff. For daily time steps, SWAT uses an empirical SCS curve number (CN) method and for daily time steps SWAT uses the Green and Ampt equation. For this project the SCS curve number was adopted for the simulation of surface runoff in SWAT since it requires the readily available daily data that can be obtained from easily from government ministries and/or offices. The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \text{-----5.1}$$

Where  $Q_{surf}$  is the accumulated runoff or rainfall excess (mm H<sub>2</sub>O),  $R_{day}$  is the rainfall depth for the day (mm H<sub>2</sub>O),  $I_a$  is the initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm H<sub>2</sub>O), and  $S$  is the retention parameter (mm H<sub>2</sub>O). The retention parameter varies spatially due to changes in soil water content. The retention parameter is defined as:

$$S = 25.4 \left( \frac{1000}{CN} - 10 \right) \text{-----5.2}$$

Where  $CN$  is the curve number for the day. The SCS curve number is a function of the soil’s permeability, land use and antecedent moisture conditions: 1 – dry (wilting point), 2 – average moisture, and 3 – wet (field capacity).

The moisture condition 1 curve number is the lowest value that the daily curve number can assume in dry conditions. The curve numbers 2 and 3 are calculated from equations 4.3 and 4.4 below.

$$CN_1 = CN_2 - \frac{20*(100 - CN_2)}{(100 - CN_2 + \exp[2.533 - 0.0636*(100 - CN_2)])}$$

$$CN_3 = CN_2 * \exp[0.00673*(100 - CN_2)]$$

Where,  $CN_1$  is the moisture condition 1 curve number,  $CN_2$  is moisture condition 2 curve number, and  $CN_3$  is the moisture condition 3 curve number (Neitsch et al., 2011).

The initial abstractions,  $I_a$ , is commonly approximated as  $0.2S$  and the above equation above becomes

$$q_{peak} = \frac{\alpha_{tc} Q_{surf} Area}{3.6 t_{conc}}$$

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

#### 4.2.2.2 Routing Phase of the Hydrologic Cycle

Once SWAT determines the loadings of water, sediment, nutrients and pesticides to the main channel, the loadings are routed through the stream network of the watershed using a command structure similar to that of HYMO (Williams and Hann, 1972). In addition to keeping track of mass flow in the channel, SWAT models the transmission of chemicals in the stream and streambed.

SWAT routes water, sediment, nutrients and organic chemicals in the main channel. In this study attention had been given on the first two: water and sediment processes in the main channel. SWAT provides two methods routing (Neitsch et al., 2011):

- a) Variable storage method, and
- b) The Muskingum River routing method

Both Variable Storage and Muskingum routing methods are variations of the kinematic wave model. A detailed discussion of the kinematic wave flood routing model can be found in Chow et al. (1988). Since there is no reservoir considered in this study, Muskingum River routing method

was adopted to model the storage volume in channel length as a combination of wedge and Prism storages.

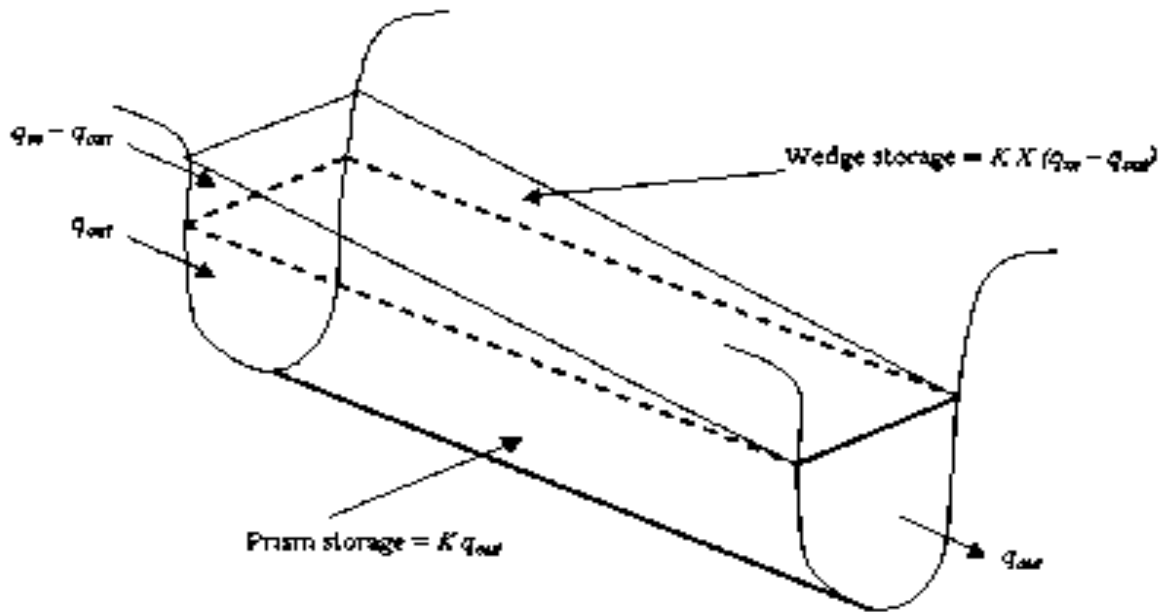


Figure 4.3 Prism and wedge storages in a reach segment (Adopted from Neitsch et al., 2011)

SWAT assumes the main channels, or reaches, have a trapezoidal shape. Therefore, Manning's equation for uniform flow in a trapezoidal channel was used to calculate the rate and velocity of flow in a reach segment for a given time step.

$$q_{ch} = \frac{A_{ch} * R_{ch}^{2/3} * slp_{ch}^{1/2}}{n}$$

$$v_c = \frac{R_{ch}^{2/3} * slp_{ch}^{1/2}}{n}$$

Where,  $q_{ch}$  is the rate of flow in the channel ( $m^3/s$ ),  $A_{ch}$  is the cross-sectional area of the channel ( $m^2$ ),  $R_{ch}$  is the hydraulic radius for a given depth of flow ( $m$ ),  $slp_{ch}$  is the slope along the channel length ( $m/m$ )  $n$  is manning's coefficient for the channel, and  $v_c$  is the flow velocity ( $m/s$ ).

SWAT routes water as a volume.

Manning's equation shows that there is a direct relationship between the cross-sectional area of flow and the discharge for a given reach segment. This assumption is used to express the volume of prism storage (Figure 5.3) as a function of the discharge,

$$V_{prism} = K * q_{out}$$

Where, K is the ratio of storage to discharge and has the dimension of time. Similarly, the volume of wedge storage (Figure 5.3) can be expressed as,

$$V_{wdg} = KX(q_{in} - q_{out})$$

Where, X is a weighting factor that controls the relative importance of inflow and outflow in determining the storage in a reach. The total storage in a reach segment will be the sum of prism storage and wedge storage and expressed by equation,

$$V_{stored} = V_{prism} + V_{wdg} = K * q_{out} + KX(q_{in} - q_{out})$$

Where,  $V_{stored}$  is the storage volume ( $m^3$ ),  $q_{in}$  is the inflow rate ( $m^3/s$ ),  $q_{out}$  is the discharge

Or outflow rate ( $m^3/s$ ) K and X as expressed above

$$V_{stored} = K * (X * q_{in} + (1 - X) * q_{out})$$

The weighting factor, X varies from 0.0 – 0.5 and it is a function of the wedge storage. The value of X depends on the type of storage.

$$q_{out,2} = C_1 * q_{in,2} + C_2 * q_{in,1} + C_3 * q_{out,1}$$

For instance, reservoir-type storage does not have wedge and the value of  $X$  is 0.0 and for a full wedge,  $X = 0.5$ . For rivers, the value of  $X$  falls between 0.0 and 0.3.

Considering a time step of  $\Delta t$ , the following simplified continuity equation known as Muskingum equation can be obtained.

Where,  $q_{in,1}$  is the inflow rate at the beginning of the time step ( $m^3/s$ ),  $q_{in,2}$  is the inflow rate at the end of the time step ( $m^3/s$ ),  $q_{out,1}$  is the outflow rate at the beginning of the time step ( $m^3/s$ ),  $q_{out,2}$  is the outflow rate at the end of the time step ( $m^3/s$ ), and

$$C_1 = \frac{\Delta t - 2KX}{2K(1-X) + \Delta t}$$

$$C_2 = \frac{\Delta t + 2KX}{2K(1-X) + \Delta t}$$

$$C_3 = \frac{2K(1-X) - \Delta t}{2K(1-X) + \Delta t}$$

Where,  $C_1 + C_2 + C_3 = 1$ . To maintain numerical stability and avoid the computation of negative outflows, the following condition must be met:

$$2KX < \Delta t < 2K(1-X)$$

## 4.3 Sediment modeling

### 4.3.1 Introduction

For a watershed in which erosion and sedimentation process is significant, it is important to identify the source erosion and what causes it. Identifying the source of erosion helps to apply different management practices to reduce the erosion rate. In addition to this, it is also very crucial to identify which erosion type is significant in the watershed of interest so that the correct and suitable erosion model can be applied. In this study since there was a time limitation to conduct field investigation to the watershed of study, it aimed at applying SWAT (Soil and Water Assessment Tool) model to simulate the sediment yield from Gilgel Gibe-I watershed. Therefore, a semi-distributed, physics-based watershed model, Soil and Water Assessment Tool (SWAT) model was used for this study to quantify the sediment yield from the watershed of study.

SWAT uses a Modified Universal Soil Loss Equation (MUSLE) developed by Williams (1975) to simulate sediment yield from the upland watersheds. MUSLE is a modified version of Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1965, 1978) (Neitsch et al., 2011).

$$Sed = 1.292EI_{USLE}K_{USLE}C_{USLE}P_{USLE}LS_{USLE}CFRG$$

Where,  $Sed$  is the sediment yield on a given day (metric tons/ha),  $EI_{USLE}$  is the rainfall erosion index (0.017 m-metric ton cm/(m<sup>2</sup> hr)),  $K_{USLE}$  is the USLE soil erodibility factor (0.013 metric ton m<sup>2</sup> hr/(m<sup>3</sup>-metric ton cm)),  $C_{USLE}$  is the USLE cover and management factor,  $P_{USLE}$  is the USLE support practice factor,  $LS_{USLE}$  is the USLE topographic factor and  $CFRG$  is the coarse fragment factor. The value of  $EI_{USLE}$  for a given rainstorm is the product, total storm energy ( $E_{storm}$ ) times the maximum 30 minutes intensity ( $I_{30}$ ). The storm energy indicates the volume of rainfall and runoff, while the 30 minutes intensity indicates the prolonged peak rates of detachment and runoff (Neitsch et al., 2011).

$$Sed = 11.8(Q_{surf}q_{peak}Area_{hru})^{0.56}K_{USLE}C_{USLE}P_{USLE}LS_{USLE}CFRG$$

Where,  $Q_{surf}$  is the surface runoff volume (mm),  $q_{peak}$  is the peak runoff rate (m<sup>3</sup>/s),  $Area_{hru}$  is the area of the HRU (ha), and the other variables in the equation carries the same meaning as described in USLE equation. The equation for surface runoff and peak rate was discussed under hydrologic modelling topic earlier.

Sediment yield estimation is improved because runoff is a function of antecedent moisture condition as well as rainfall energy (Neitsch et al., 2011). Delivery ratios (the sediment yield at any point along the channel divided by the source erosion above that point) are required by the USLE because the rainfall factor used by USLE represents energy used in detachment only.

Delivery ratios are not needed with MUSLE because the runoff factor represents energy used in detaching and transporting sediment (Neitsch et al., 2011). The detail of equations used to calculate  $K_{USLE}$ ,  $C_{USLE}$ ,  $P_{USLE}$ ,  $LS_{USLE}$ , and  $CFRG$  can be found in Neitsch et al (2011).

### 4.3.2 Sediment routing

Sediment transport in the channel network is a function of two processes, deposition and degradation, operating simultaneously in the reach (Neitsch et al., 2011). There are two options in SWAT to compute deposition and degradation in the reach. The first and traditional way is to keep the channel dimensions constant so that SWAT will compute deposition and degradation using the same channel dimensions throughout the simulation and the second is to activate channel degradation and allow channel dimensions to change and updated as a result of down cutting and widening (Neitsch et al., 2011). When channel down cutting and widening is simulated, channel dimensions are allowed to change during simulation period. Three channel dimensions are allowed to vary in channel down cutting and widening simulations: bankfull depth, channel width and channel slope. Channel dimensions are updated when the volume of water in the reach exceeds  $1.4 * 10^6 m^3$  (Neitsch et al., 2011). In this study the former option was adopted in channel routing since the latter option is still in the testing phase.

### 4.3.3 Sediment routing in stream channels

Sediment routing is the function of peak flow rate and mean daily flow. When the watershed was delineated into smaller sub-basin, each sub-basins has at least one main routing reach. Therefore, the sediment from upland sub-basins is routed through these reaches and then added to downstream reaches. To do this, SWAT uses the simplified version of Bagnold equation (Bagnold, 1977) and the maximum amount of sediment that can be transported from a reach segment is a function of the peak channel velocity (Neitsch et al., 2011).

$$conc_{sed, ch, mx} = Csp * v_{ch, pk}^{sp exp}$$

Where,  $conc_{sed, ch, mx}$  is the maximum concentration of sediment that can be transported by water ( $ton/m^3$  or  $kg/L$ ),  $Csp$  and  $sp exp$  are coefficient and exponent of the equation defined by the user, and  $v_{ch, pk}$  is the peak channel velocity ( $m/s$ ). The exponent  $sp exp$  normally varies from between 1.0 and 2.0 and was set at 1.5 in the original Bagnold stream power equation (Arnold et al., 1995). But, in SWAT2012 the value of this exponent varies between 1.0 and 1.5.

$$v_{ch, pk} = \frac{q_{ch, pk}}{A_{ch}}$$

Where,  $q_{ch,pk}$  is the peak flow rate ( $m^3/s$ ) and  $A_{ch}$  is the cross-sectional area of flow in the channel ( $m^2$ ).

$$q_{ch,pk} = prf * q_{ch}$$

Where,  $prf$  is the peak rate adjustment factor, and  $q_{ch}$  is the average rate of flow ( $m^3/s$ ).

The routing in the river reach starts off by comparing the maximum concentration of sediment calculated with equation (4.19) above to the concentration of sediment in the reach at the beginning of the time step,  $conc_{sed,ch,i}$ . If  $conc_{sed,ch,i} > conc_{sed,ch,mx}$ , deposition is the dominant process in the reach segment and the net amount of sediment deposited is calculated as in

Equation below

$$sed_{dep} = (conc_{sed,ch,i} - conc_{sed,ch,mx}) * V_{ch}$$

Where,  $sed_{dep}$  is the amount of sediment re-entrained in the reach segment (metric tons),  $V_{ch}$  is the volume of water in the reach segment ( $m^3$ ). On the other hand, if  $conc_{sed,ch,i} < conc_{sed,ch,mx}$ , degradation is the dominant process in the reach segment and the net amount of sediment re-

$$sed_{deg} = (conc_{sed,ch,mx} - conc_{sed,ch,i}) V_{ch} * K_{CH} * C_{CH}$$

Where,  $sed_{deg}$  is the amount of sediment re-entrained in the reach segment (metric tons),  $K_{CH}$  is the channel erodibility factor ( $cm/hr/psf$ ), and  $C_{CH}$  is the channel cover factor.

The channel erodibility factor is conceptually similar to the soil erodibility factor used in the USLE equation (Neitsch et al., 2011). Channel erodibility is a function of properties of the bed or bank materials (Neitsch et al., 2011). The detail discussion of factors are found in Neitsch et al., (2011). In general, values for channel erodibility are an order of magnitude smaller than values for soil erodibility (Neitsch et al., 2011). The channel cover factor can be defined as the ratio of degradation from a channel with a specified vegetation cover to the corresponding degradation from a channel with no vegetation cover (Neitsch et al., 2011). The vegetation affects degradation by reducing the stream velocity, and consequently its erosive power, near the bed surface (Neitsch et al., 2011).

Once the amount of deposition and degradation has been calculated, the final amount of sediment in the reach is determined.

$$sed_{ch} = sed_{ch,i} - sed_{dep} + sed_{deg}$$

Where,  $sed_{ch}$  is the amount of suspended sediment in the reach (metric tons),  $sed_{ch,i}$  is the amount of suspended sediment in the reach at the beginning of the time period (metric tons),  $sed_{dep}$  is the amount of sediment deposited in the reach segment (metric tons), and  $sed_{deg}$  is the amount of sediment re-entrained in the reach segment (metric tons).

$$sed_{out} = sed_{ch} \cdot \frac{V_{out}}{V_{ch}}$$

Where,  $sed_{out}$  is the amount of sediment transported out of the reach (metric tons),  $V_{out}$  is the volume of outflow during the time step ( $m^3$ ), and  $V_{ch}$  is the volume of water in the reach segment ( $m^3$ ).

SWAT incorporates a simple mass balance model to simulate the transport of sediment into and out of water bodies (ponds, wetlands, reservoirs and potholes) (Neitsch et al., 2011). In this study no wetlands and potholes are identified. But, in Gilgel Gibe-I watershed, the Gilgel Gibe-I reservoir is located at the outlet of the catchment. This reservoir was not considered in the study as the area of interest for which the sediment yield is calculated located upstream of the reservoir.

#### 4.4 Evaluation of Model Performance/ Efficiency criteria

There are a large number of performance criteria used by different researchers to quantitatively measure the accuracy, efficiency and reliability of their models. It is difficult to select one criterion as a benchmark standard and some criteria are only applied to certain specific problems. Generally, they are grouped in to graphical and numerical performance indicators (Wang, 2001). For this study both the graphical and some of numerical performance measures are selected for both SWAT and ANN model. From the numerical indicator Coefficient of determination ( $R^2$ ), Coefficient of efficiency or Nash Sutcliffe efficiency (NSE) and Percent bias (PBIAS) were selected performance measures for this study.

The systematic and dynamic behavior of the model can be visualized by plotting simulated flow and observed flow on the same coordinate system. By looking at the graph a modeler can understand whether the model over predicted or under predicted and also the timing of the rising

and falling limb of the hydrograph and give subjective decision on the performance of the model. But, to quantitatively evaluate the model, we need mathematical measures of model performance.

Reasons to evaluate model performance (Krause et al., 2005),

- 1) To provide a quantitative estimate of the model's ability to reproduce historic and future watershed behavior;
- 2) To provide a means for evaluating improvements to the modeling approach through adjustment of model parameter values, model structural modifications, the inclusion of additional observational information, and representation of important spatial and temporal characteristics of the watershed;
- 3) To compare current modeling efforts with previous study results. To assess the goodness-of-fit of the model, two methods were used during the calibration and validation periods. These are: coefficient of determination ( $R^2$ ) and the Nash-Sutcliffe efficiency coefficient (NS). These two statistical parameters are used to measure the model performance.

#### 4.5.1 Coefficient of determination ( $R^2$ )

The coefficient of determination ( $R^2$ ) measures the fraction of the variation in the measured data that is replicated in the simulated model results. The coefficient of determination  $R^2$  is defined as (Krause et al., 2005) the squared value of the coefficient of correlation is given by:

$$R^2 = \frac{\left[ \sum_i (Q_{m,i} - \bar{Q}_m)(Q_{s,i} - \bar{Q}_s) \right]^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2 \sum_i (Q_{s,i} - \bar{Q}_s)^2}$$

Where,  $Q_m$  is the observed (measured) stream flow on day  $i$  ( $m^3/s$ ),  $Q_s$  is the simulated stream flow on day  $i$  ( $m^3/s$ ), and bars indicate averages.

The value of  $R^2$  ranges from (0-1) where a value close to 1.0 indicates good performance (good correlation) of the model and the value close to 0.0 indicates poor performance (poor correlation) of the model. The main drawbacks of  $R^2$  is that it only quantifies dispersion. A model which systematically over-or under-predicts all the time will still result in good  $R^2$  values close to 1.0 even if all predictions were wrong (Krause et al., 2005). To avoid this ambiguity, it is advisable to use additional information which can cope with that problem.

#### 4.5.2 Nash-Sutcliffe efficiency coefficient (ENS)

The Nash-Sutcliffe efficiency coefficient (Nash and Sutcliffe, 1970) is used to assess the predictive power of the hydrological models. The value of NS varies from 1.0 (perfect fit) to -infinity. An efficiency of lower than zero indicates that the mean value of the observed time series would have been a better predictor than the model (Krause et al., 2005). The NS value of 0.0 indicates that the model predictions are as accurate as the mean of the observed data. According to Krause et al, (2005) the major disadvantage of the Nash -Sutcliffe efficiency is the fact that the differences between the observed and simulated values are calculated as squared values. This leads to an over estimation of the model performance during peak flows and an under estimation during low flows.

$$NS = 1 - \frac{\sum_i (Q_m - Q_s)_i^2}{\sum_i (Q_{m,i} - \bar{Q}_m)^2}$$

This method is highly affected by a few extreme errors and it can be biased if a wide range of events is experienced.

#### 4.5.3 Percent bias (PBIAS)

Measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 1999). The optimal value of PBIAS is zero, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999) and calculated by equation below.

$$PBIAS = \frac{\sum_{i=0}^n (S_{ob} - S_{sim})}{\sum_{i=0}^n (S_{ob})} * 100$$

Where: Sobs= is the Observed sediment data; Ssim is the simulated sediment data with the respected time.

## **5. DATA COLLECTION AND PREPARATION**

### **5.1 General**

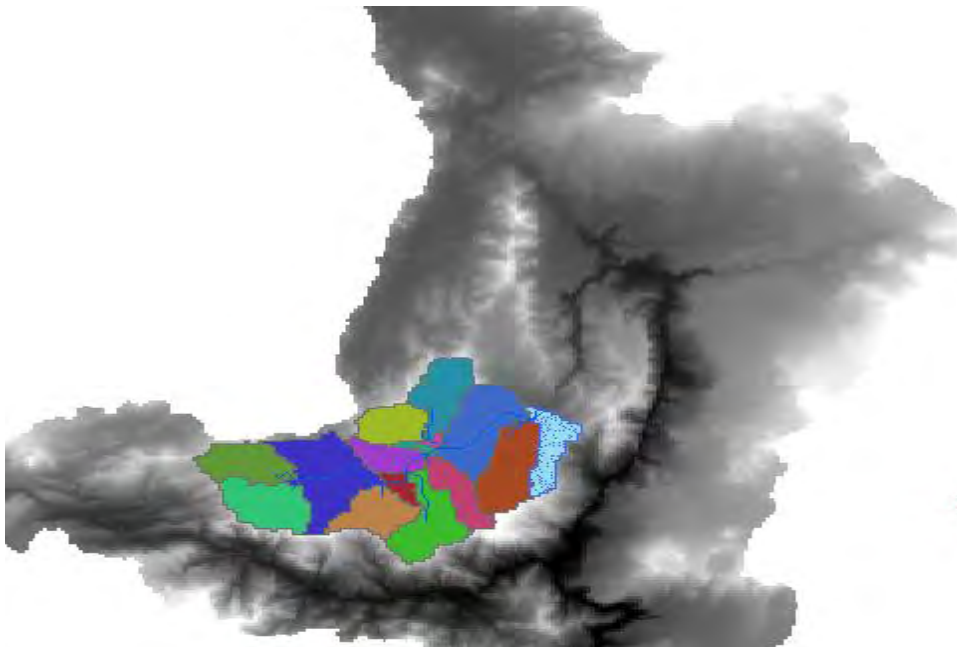
To get a better result, it is critical to use all relevant and good quality data required. The outcome/result depends on the quality and quantity of data used. The spatial and temporal resolution of data used in modeling will greatly influence the model performance. The SWAT (Soil and Water Assessment Tool) needs good quality of Digital Elevation Model (DEM), Soil and Land use/land cover data above all other necessary data to simulate the discharge and sediment from a given watershed. The length of period of weather and climatic data also affect the SWAT model performance. The output from the SWAT model can be affected by the DEM data resolution, mesh size, soil data resolution and soil map scale, watershed subdivision which on the other hand is affected by DEM data resolution etc. Bosch et al., (2004) found that SWAT stream flow estimates were more accurate when using high-resolution topographic data, land use/land cover data, and soil data. The required DEM data, soil data, land use/land cover data, flow data, climatic and sediment data was collected from different sources. The quality and quantity of data used in the development of SWAT project in this study will be discussed in the upcoming sections.

### **5.2 Digital Elevation Model (DEM)**

Digital Elevation model (DEM) is one of the main inputs of the SWAT (Soil and Water Assessment Tool) model. DEM is used in the SWAT model along with soil and land use/land cover data to delineate the watershed and to further divide the watershed into sub-watersheds and hydrologic response units (HRUs). The resolution of the Digital Elevation Model (DEM) is the most critical input parameter when developing a SWAT model (Gassman et al., 2007).

DEM resolution affects the watershed delineation, stream network and sub basin classification in the SWAT model. It affects the number of sub-basins and HRUs. The number of sub watersheds in the sub basin affects the predicted sediment yield for a watershed (Bingner et al., 1997). Jha et al., (2004) found that SWAT sediment predictions were sensitive to HRUs and sub-watershed configurations. According to (Chaubey et al., 2005) a decrease in DEM resolution resulted in decreased stream flow and watershed area. Since the runoff volume and total sediment load depends on the watershed area, the decrease in the DEM resolution resulted in large error in the predicted output. Input DEM data resolution affected SWAT model predictions by affecting total area of the delineated watershed, predicted stream network and sub basin classification (Chaubey et al., 2005). In general, the quality of the DEM data strongly affect the final output of the hydrological model (Defourny et al., 1999). Therefore, it is wise to use the finest available DEM data for model application.

For this project a digital elevation model (DEM) was taken from ministry of water resources, irrigation and energy bureau with a spatial resolution of 30 m x 30 m. The edited DEM was projected to WGS1984 UTM Zone 37N using the raster projection in Arc Map toolbox before it was imported to Arc SWAT. The projected map was used in the watershed delineation in ArcSWAT which is the interface in the Arc Map to use it in SWAT model. The processed DEM map of the Gilgel Gibe-I watershed is shown in Figure 5.1



**Figure 5.1** DEM and delineated watershed for Gilgel Gibe-I.

### **5.3 Soil Data**

Like the Digital Elevation Model (DEM), soil data resolution has also a significant impact on the modeling of stream flow, sediment load and nutrient content. Geza and McCray (2008), evaluated the dependency of the prediction accuracy of the Soil and Water Assessment Tool (SWAT) on how well the model input spatial parameters describe the characteristics of the watershed. They used the same number of watersheds to analyze the effect of soil data resolution. Then the SWAT model predictions were compared for the two US Department of Agriculture soil databases with different resolution, namely the State Soil Geographic Database (STATSGO) and the Soil Survey Geographic database (SSURGO). This on the other hand affected the runoff and sediment prediction. If the low resolution soil data is used to generate the HRUs it assigns same soil type for larger area of the watershed that actually may have different soil types. Different soils have different soil erodibility factor, hydraulic conductivity, infiltration capacity etc. which affects the water balance and sediment yield from the watershed. Therefore, using high spatial resolution soil map will increase the prediction accuracy of the model.

The soil map obtained from MoWIE was projected to WGS1984 UTM Zone 37N using the raster projection in Arc Map before it was imported to Arc SWAT. The soil map of watershed used is in Figure 5.2

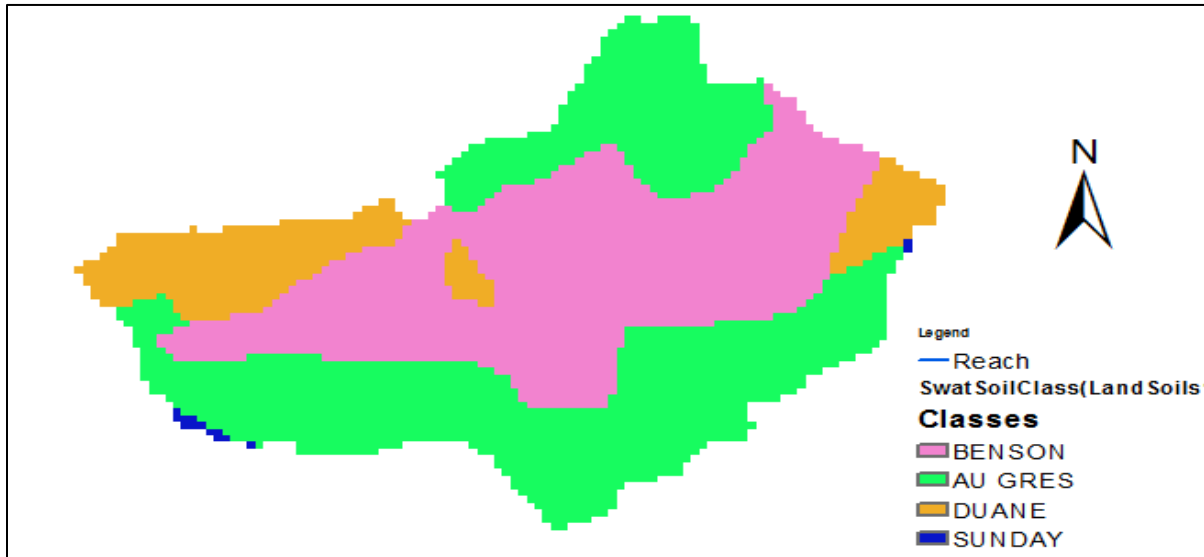


Figure 5. 2 Soil map watershed for Gilgel Gibe--I

#### 4.4 Land use/land covers Data

Land use/land cover data has also a significant effect on the hydrological modeling. Therefore, a detail analysis and mapping of the land use/land cover is crucial for proper hydrological modeling. Land use/land cover affects the runoff and sediment transport in the watershed. The land cover data was available in the form of Binary and ESRI Grid. The ESRI Grid format with a 1 km spatial resolution was used in this study. The land use for this watershed was projected to WGS1984 UTM Zone 37N using the raster projection in Arc Map before it was imported to Arc SWAT. The land use map of the watershed is shown in Figure 5.3

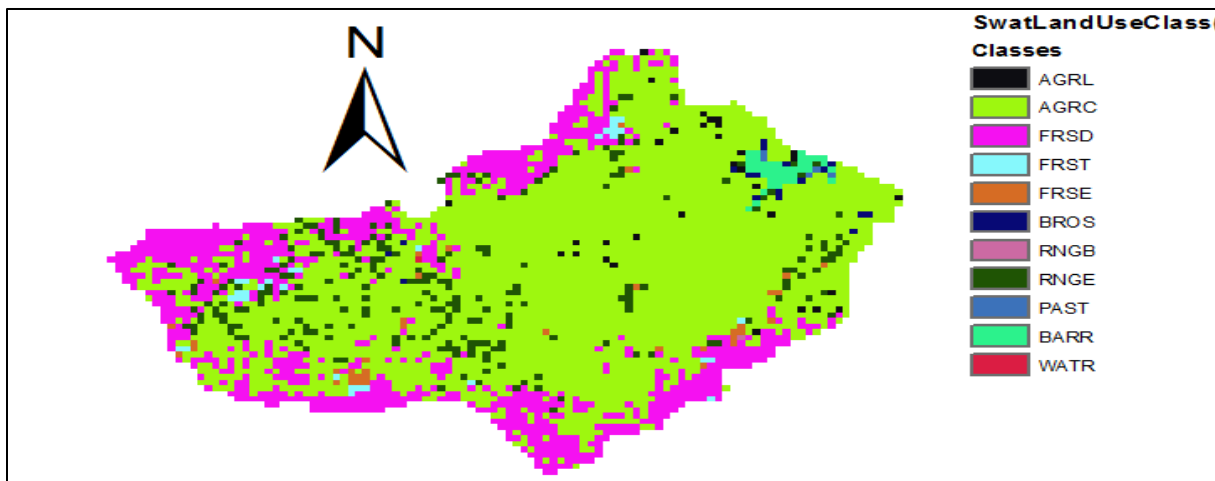


Figure 5. 3 Land use/cover map watershed for Gilgel Gibe--I

## 5.5. Flow Data

Observed flow data was required for the Soil and Water Assessment Tool (SWAT) calibration and validation. The observed stream flow data shown on Table 5.1 was available from 1989-2014 is taken from Ministry of water resources, Irrigation and energy, Hydrology bureau. This flow data was formatted as to the requirement of the SWAT model and used for model calibration and validation. The stream flow data from 1989-2006 was used for model calibration and from 2007-2014 flow data was used for model validation. Here, it should be noted that the efficiency of the model during calibration and validation depends on the accuracy of the calculation. Any error during calculation may cause significant problem in model calibration and validation.

**Table 5.1 Mean monthly flows at the outlet of the Gilgel Gibe-I watershed.**

Years	Months											
	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	FLOWS m3/sec											
1988	4.857489	5.105574	2.039053	1.783355	4.24926	13.18832	70.4857	192.7601	150.76	116.6149	25.20004	9.019735
1989	5.849428	6.154856	4.267875	25.78344	13.98706	33.47798	64.14803	94.43768	95.82238	51.08423	18.36299	20.73599
1990	10.04764	7.940152	11.86143	10.94198	20.01272	59.66288	113.4899	93.62213	148.6077	220.9368	114.6804	11.67607
1991	7.681395	6.469311	9.130401	5.662752	12.92783	42.4965	84.06485	139.2152	104.0518	24.8771	4.139907	3.194314
1992	0.77777	1.734335	0.166327	1.577907	14.59171	51.83203	109.4509	231.1698	146.1754	91.88489	24.44551	9.428475
1993	8.966685	13.01714	5.482365	24.84807	65.54804	95.71677	155.4026	146.6384	103.6992	74.27754	40.77045	12.3906
1994	7.22055	3.914544	5.220705	6.125905	26.55086	86.50264	157.8976	207.45	153.6359	33.48062	13.87632	7.110908
1995	3.977279	3.749888	3.089906	9.908393	14.51131	18.62208	57.13547	79.57666	96.48927	23.01369	9.770248	7.573878
1996	7.932715	6.481145	5.678903	15.97387	68.99313	111.2723	104.563	152.5458	110.8028	56.81135	21.16761	10.95454
1997	8.927055	15.40132	2.988646	20.9936	32.03224	86.41943	88.10631	128.9891	88.32426	165.3539	170.8472	65.30601
1998	33.66157	19.82029	20.013	14.38563	25.49033	36.9279	106.8716	212.0879	122.407	104.388	41.88886	18.21035
1999	12.25659	7.16384	8.901159	7.382464	20.01469	43.37238	94.03827	132.5382	72.6619	88.50856	31.72634	13.29107
2000	7.761286	4.51501	2.905056	8.874402	24.20452	36.35368	79.22235	100.6557	107.1352	91.65514	44.54793	18.62901
2001	27.96035	28.76516	30.08618	29.24946	44.46365	82.53609	141.3976	129.6332	94.5476	60.76926	36.32831	59.70208
2002	11.93254	7.177609	8.838388	11.8782	8.683566	36.22363	70.82954	93.36876	74.71386	26.7971	14.92503	15.14984
2003	12.95935	6.440249	11.02479	12.21419	7.007247	29.64893	97.71677	103.9684	115.3995	37.54947	15.54374	12.12841
2004	7.866481	5.824827	5.00566	8.176196	16.35741	39.7683	80.94779	120.9097	116.6795	94.79467	24.94957	15.96209
2005	11.16276	5.906456	12.53837	10.7236	49.56573	42.34449	82.2158	157.9148	153.3952	63.30855	24.03481	12.16159
2006	9.38365	11.26439	11.97316	14.78896	17.57449	43.83541	143.4731	206.2676	132.843	63.47388	36.0122	28.32136
2007	18.58701	18.70439	11.38177	18.6645	25.60996	70.48766	120.5069	140.2494	168.7296	80.21665	20.52443	11.32333
2008	8.892305	7.027032	4.621045	8.295919	19.07376	55.31114	98.25849	138.689	113.1502	38.90741	67.80069	17.60055
2009	12.30527	10.53535	7.814887	11.88585	10.72911	18.28686	46.01616	132.1743	96.43112	69.19419	19.38348	17.12557
2010	11.55903	9.538309	10.31392	13.06177	38.61548	87.22626	124.5133	147.9086	214.9927	51.26046	20.47347	14.05102
2011	10.56713	7.28462	7.157937	8.072699	17.71475	61.20142	90.80232	122.4349	167.1028	40.19196	28.90371	13.61307
2012	7.898123	4.838057	4.400461	8.652077	9.598173	38.10581	93.92241	122.5634	156.6957	49.22196	18.40516	12.50941
2013	8.473175	5.773127	8.259125	9.346176	22.83352	48.02144	112.1897	160.7732	160.0855	94.62588	29.33396	16.32942
2014	11.6072	8.884476	10.30833	27.3014	71.82164	57.26713	114.3454	210.1809	129.2929	102.3119	21.99717	14.82776

## 5.6 Climate Data/Weather Data

Climate data is among the most important data required for the SWAT model. Obtaining representative meteorological data for watershed-scale hydrological modeling can be difficult and time consuming. Land-based weather stations do not always adequately represent the weather occurring over a watershed, since they can be far from the watershed of interest and can have a missing data series, or recent data are not available (Fuka et al., 2014). It is beneficial to have a meteorological station within the watershed of interest. Rain gauge data are point measurements which may not represent the whole watershed. This problem can be reduced only when there are multiple rain gauges within the watershed. Otherwise, the problem exists specially for large watersheds which may have large hydro-climatic gradients. The problems related to each weather data are stated under the following sections.

### 5.6.1 Rainfall Data

The rainfall data was obtained from the National Metrological Service Agency (NMSA). The daily rainfall data for eight (8) Stations are further analyzed below. The rainfall data for station was available from 1986 to 2015.

The type and coordinates of the climate and meteorological stations are given in Table 5.2

**Table 5. 2 Stations used in Arc SWAT.**

Id.	Name of Station	Type of Station	Geographical Location		Elevation
			Latitude (degree)	Longitude(degree)	
1	Asendabo	Precipitation	7.751	37.216	1764
2	Babu	Precipitation	7.883	36.783	1707
3	Cekorsa	Precipitation	7.616	36.733	1770
4	Cheka	Precipitation	7.816	37.411	1934
5	Jimma	Precipitation	7.666	36.816	1718
6	Kumbi	Precipitation	8.116	37.483	1930
7	Limugenet	Precipitation	8.066	36.951	1766
8	Sekoru	Precipitation	7.916	37.416	1928

### 5.6.2 Data quality control

The precipitation data must be checked for continuity and consistency before it is used for further analysis. The quality control can be done by visual inspection, filling of missing data if there is any, accumulated plot and double mass curve. This will help identify if there are any gaps or unphysical peaks (spikes and negatives) in data series and correct them before the data is used or input to the model. Otherwise, using the inaccurate data as input to the model will give erroneous output from the model.

### 5.6.2.1 Visual inspection

After the rainfall data is obtained from any source it must be checked for its quality. The first step in data quality control is by visual inspection. This can be done by checking if date and time record is complete, unphysical values (spikes and negatives), flat regions (sensor or transfer system fall out) and unphysical variation patterns (sensor malfunctioning). The visual inspection was done by plotting the time series data against time. The percentage of missing data points for all three precipitation stations from 1986 to 2015 is shown in Table 5.3 see the station which has higher missing data compared to other station of data points. The smallest missing data can be filled by average method while other filled by multiple regression analysis.

**Table 5.3 Arranging stations by missing data.**

Id.No	Stations name	No. of Missing Data	% of Missing Data	Rank	
1	Asendabo	576	5.44	3	
2	Babu	1382	13.04	4	
3	Cheka	1863	17.58	5	
4	Cekorsa	2133	20.13	6	
5	Jimma	277	2.62	1	By Avg
6	Kumbi	2583	24.38	7	
7	Sekoru	290	2.74	2	
8	Limugenet	2585	24.40	8	

### 5.6.2.2 Filling of missing data

Some precipitation stations may have short breaks in the records because of absence of the observer or because of instrumental failures. It is often necessary to estimate or fill in this missing record. The missing precipitation of a station was estimated from the observations of precipitation at some other stations as close to and as evenly spaced around the station with the missing record as possible. Here, the station whose data was missing is called interpolation station and gauging stations whose data are used to calculate the missing station data are called index stations.

There are methods to fill in missing data. These are: arithmetic mean method, normal ratio method and inverse distance weighing method. Arithmetic mean method can be used to fill in missing data when normal annual precipitation is within 10% of the gauge/station for which data are being reconstructed. The normal ratio method is used when the normal annual precipitation at any of the index station differs from that of the precipitation station by more than 10%. In the absence of normal annual rainfall for the stations inverse distance weighing method can be used to fill the missing data.

A) Arithmetic mean method

$$P_x = \frac{1}{n} \sum_{i=1}^{i=n} P_i$$

Where,  $n$  is the number of nearby stations,  $P_i$  is precipitation at  $i^{th}$  station and  $P_x$  missing precipitation.

B) Normal ratio method

$$P_x = \frac{1}{n} \sum_{i=1}^{i=n} \frac{N_x}{N_i} P_i$$

Where,  $P_x$  is the missing precipitation for any storm at the interpolation station  $x$ ,  $P_i$  is the precipitation for the same period for the same storm at the  $i^{th}$  station of a group of index stations,  $N_x$  is the normal annual precipitation for station  $x$ , and  $N_i$  is the normal annual precipitation value for the  $i^{th}$  station.

C) Inverse distance weighing method

$$D = \sum_{i=1}^{i=n} d_i^{-b}$$

$$P_x = \frac{1}{D} \sum_{i=1}^{i=n} d_i^{-b} * P_i$$

Where,  $D$  is distance from gauge  $i$  to missing data point,  $b=2$  and the other symbols carry the same meaning as defined above.

Inverse distance weighing method has been used in this study to fill in the missing data. But, the data filled by this method was not used as input to the SWAT (Soil and Water Assessment Tool) model since the model itself has a built in function to fill in the missing data.

### 5.6.2.3 Multiple Regression Analyses.

Multiple regression analysis is a statistical tool for estimating the relationship between dependent and independent variables (Table 5.4). The model computes the conditional expectations of controlling variables against sediment yield in this study, contributes to better understanding of which controlling factors dominantly affect sedimentation processes, and allows one to explore the form of this relationship in a watershed. Although numerous techniques can be used to carry

out regression analysis. In general, multiple regression equation of Y on X1,X2.....XK is given by:

$$Y=b_0+b_1X_1+b_2X_2.....b_kX_k$$

Where: Y=Dependent variable

X=Independent variable

b<sub>0</sub>= intercept

b<sub>1</sub>, b<sub>2</sub>,b<sub>k</sub>= multiple regression coefficients.

**Table 5.4 The sample of 7<sup>th</sup> multiple regression of 8 stations.**

SUMMARY OUTPUT						
<i>Regression Statistics</i>						
Multiple R	0.499231					
R Square	0.249232					
Adjusted R	0.248744					
Standard Error	7.932927					
Observations	10771					
<i>ANOVA</i>						
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>	
Regression	7	224852.9	32121.84	510.4269	0	
Residual	10763	677329.9	62.93133			
Total	10770	902182.7				
<i>Coefficients</i>						
	<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>	<i>Lower 95%</i>	<i>Upper 95%</i>
Intercept	1.430508	0.108781	13.15033	3.4E-39	1.217277	1.64374
X Variable	0.169388	0.011482	14.75298	8.81E-49	0.146882	0.191895
X Variable	0.235427	0.01321	17.822	4.82E-70	0.209533	0.261321
X Variable	0.082142	0.012251	6.704735	2.12E-11	0.058127	0.106156
X Variable	0.248096	0.010812	22.94615	8.4E-114	0.226902	0.26929
X Variable	0.082577	0.012107	6.820713	9.55E-12	0.058846	0.106309
X Variable	0.08012	0.011178	7.167536	8.14E-13	0.058209	0.102031
X Variable	0.009564	0.010718	0.892332	0.372235	-0.01144	0.030572
Y=1.4305+0.1694X <sub>1</sub> +0.2354X <sub>2</sub> +0.0821X <sub>3</sub> +0.2481X <sub>4</sub> +0.0826X <sub>5</sub> +0.0801X <sub>6</sub> +0.0096X <sub>7</sub>						

#### 5.6.2.4 Double mass curve

To check for consistency of the recorded data, the cumulative of JIMMA station which has very few missing data compared to the other 7 stations was plotted against cumulative of 7 other stations.

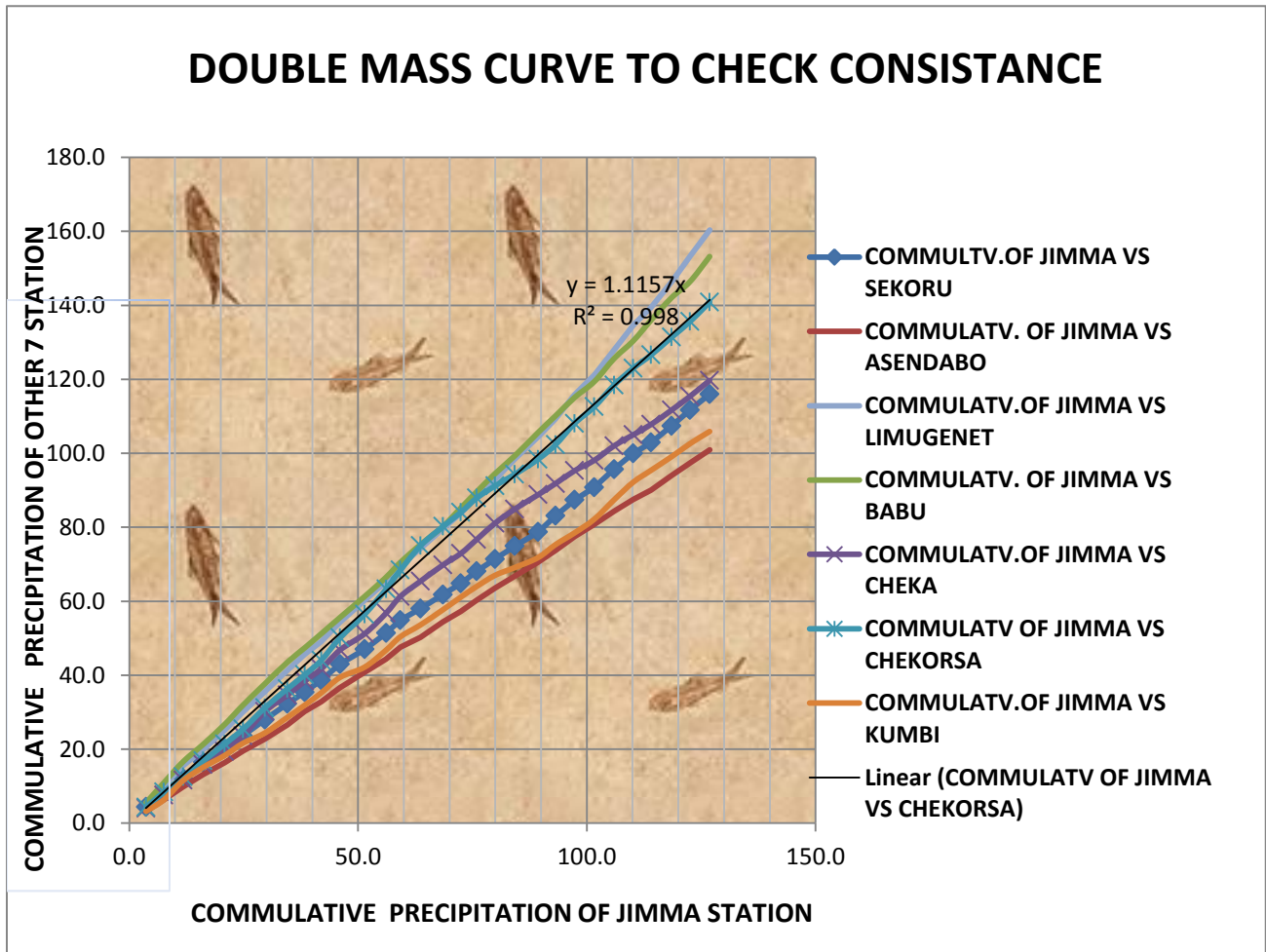


Figure 5.4 Double mass curves.

Therefore, the precipitation recorded at stations Jimma is somewhat consistent with the other stations as we can see from the double mass curve.

#### 5.6.2.5 Statistical parameters calculation for precipitation data

After the precipitation data was checked for quality and the appropriate station selected, the statistical parameters of precipitation data must be calculated before model set up. The statistical parameters for precipitation were calculated using the programmed pcpSTAT.exe. This programmed calculates the statistical parameters of daily precipitation data used by the weather generator of the SWAT model (userwgn.dbf) (Liersch, 2003).

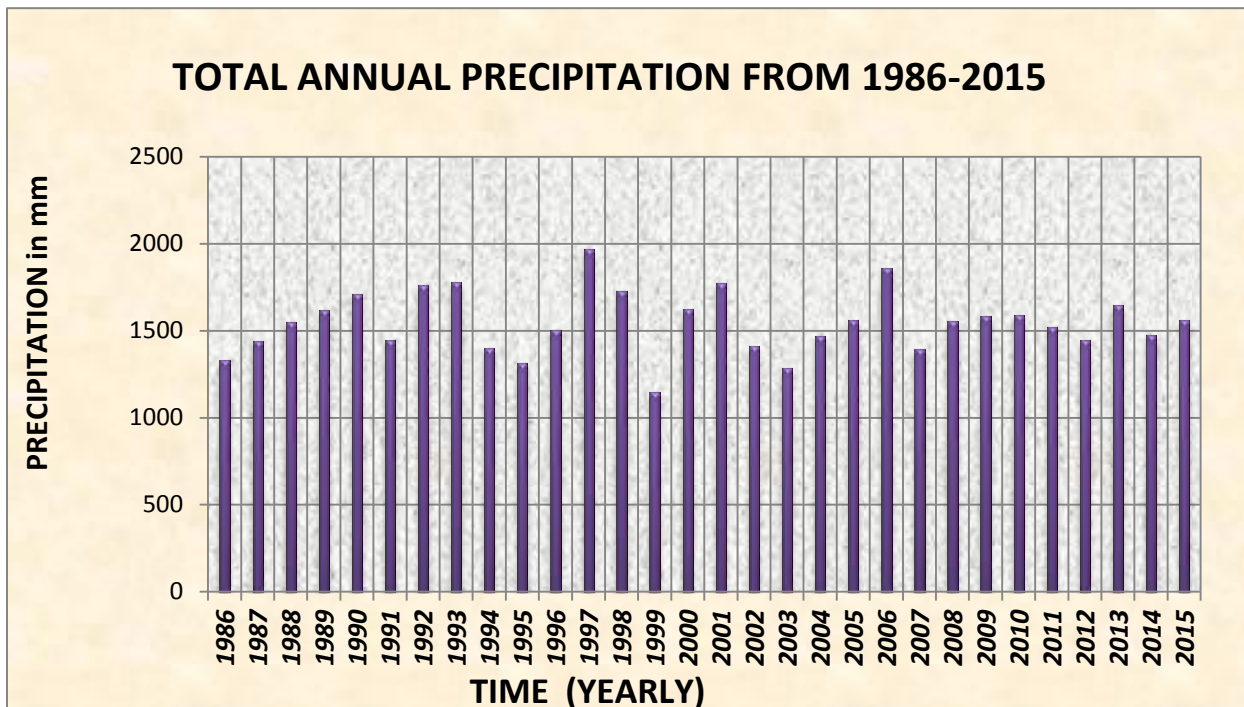
**Table 5.5** Statistical Analysis of Daily Precipitation Data (1986 - 2015).

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	35.56	4.0905	7.2774	0.1451	0.5136	7.33
Feb.	34.67	3.6404	5.3627	0.1861	0.5391	8.53
Mar.	91.52	6.0779	3.5023	0.3033	0.6357	14.73
Apr.	133.03	7.9902	2.9675	0.379	0.7102	17.6
May.	183.65	9.4714	2.6108	0.4214	0.7451	20.4
Jun.	220.76	9.6323	1.9913	0.6825	0.782	23.7
Jul.	212.43	9.1494	2.1645	0.7751	0.8042	25.37
Aug.	216.64	8.8843	1.8717	0.7259	0.844	26.5
Sep.	196.61	9.0278	2.1346	0.6748	0.7608	23.13
Oct.	114.4	7.6464	3.1701	0.2068	0.7176	14.4
Nov.	64.28	6.4158	4.3852	0.1405	0.584	7.93
Dec.	43.27	4.2899	4.831	0.108	0.6129	7.23

PCP_MM	=	average	monthly	precipitat	[mm]					
PCPSTD	=	standard	deviation							
PCPSKW	=	skew	coefficient							
PR_W1	=	probabilit	of	a	wet	day	following	a	dry	day
PR_W2	=	probabilit	of	a	wet	day	following	a	wet	day
PCPD	=	average	number	of	days	of	precipitat	in	month	

**Table 5.6** Total Monthly Precipitation Data (1986 - 2015).

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Yearly PCP
1986	0	48.2	81.7	115	151	256	232.5	133.8	163	88.6	13.9	47.4	1330.8
1987	26.4	88.5	157.7	59.8	188	204	185.5	180	136	116	45.6	51.9	1439.6
1988	81.3	59	30.9	87.1	182	165	184.6	294	292	172	1.5	0	1549.1
1989	27.8	46.8	138.2	179	102	179	232	213.3	204	107	28.3	161.3	1618.3
1990	24.6	46	132.9	56	194	320	279.6	280.2	245	22.9	92.5	18.7	1711.7
1991	79.4	80.9	61.9	169	110	223	199.7	244.3	140	50.7	7.8	78.1	1443.6
1992	28.4	56.4	55.9	162	144	287	212.2	356	175	180	69.7	35.6	1761.6
1993	78.7	80.8	119.7	237	237	225	188.7	262.6	171	174	3	0.3	1777.4
1994	0.9	28.2	96.5	153	213	274	255.4	159.2	177	11.1	18.1	10.5	1397.3
1995	8.2	17.2	74	193	115	163	181	216.4	141	48.5	30	126.1	1313.7
1996	40.8	23.4	135.5	203	175	197	231.5	91	248	23.9	93.1	40.4	1502.1
1997	66	0	68.7	178	275	237	122.4	256	148	337	243	36.1	1966.7
1998	102.5	22.4	96.5	93.2	184	223	248.4	306.7	200	201	46.5	1.4	1724.4
1999	29.8	0.7	82.4	71.8	214	175	136.1	102.3	131	198	1.3	2	1143.8
2000	0	1	39.3	195	238	154	265.9	158.7	255	244	46.8	24.9	1621.9
2001	16.2	12.9	85.9	117	341	299	312.3	160.8	183	163	75.8	3.8	1771.4
2002	68.9	5	91.2	89.7	137	242	149.7	234.9	165	79.6	8.1	138.4	1409.7
2003	28.7	61.3	86.9	111	12.2	272	186.7	150.9	239	91.7	29.9	14.6	1285.3
2004	51	28.4	46.1	131	162	128	216.3	219.4	201	133	67.3	84.2	1468.1
2005	44.5	0.5	193.8	141	174	177	273.5	227.8	229	68.3	29.7	0	1559.6
2006	15.8	77.1	181.8	110	212	207	327.2	240.2	170	91.1	128	100.2	1860.1
2007	37.5	51	104.1	122	196	143	247.4	177	256	50.8	5.9	0	1390.2
2008	34	12.3	39.4	113	249	238	209.8	236.8	133	186	92.9	6.3	1550.9
2009	63	29.5	79.8	103	244	160	149.6	304.7	209	92.2	78.4	67.7	1581.3
2010	27.3	88.4	67.4	101	193	395	181.3	203.5	187	37	96.2	10.5	1587.1
2011	24.1	7.5	39.3	151	193	311	189.9	192.1	270	10.3	105	26	1518.9
2012	2.1	1.8	55.8	155	119	335	223.9	132.7	251	32.8	77.4	57.7	1442.9
2013	34.9	31.3	109.4	95.8	306	193	151.5	255.2	183	168	115	1	1644.2
2014	17.8	16.8	115.3	123	127	117	271.3	265.6	142	127	123	25.9	1472.6
2015	6.1	16.9	77.5	176	127	123	127.1	243.2	254	127	155	127.1	1560.6



**Figure 5.5** Total annual precipitation (1986-2015)

From the figure 5.5 we can deduce that the year 1997 is the wettest year and the year 1999 is the driest year in the period from 1986-2015. It is evident that, a maximum 24 hour rainfall of 1966.70 mm was recorded during the largest observed storm in around the watershed.

**Table 5. 7** Average daily precipitation in a month (1986 -2015).

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1986	0	1.72	2.64	3.83	4.86	8.5	7.5	4.32	5.44	2.9	0.46	1.53
1987	0.85	3.16	5.09	1.99	6.05	6.8	5.98	5.81	4.53	3.8	1.52	1.67
1988	2.62	2.03	1	2.9	5.86	5.5	5.95	9.48	9.73	5.6	0.05	0
1989	0.9	1.67	4.46	5.96	3.3	6	7.48	6.88	6.8	3.5	0.94	5.2
1990	0.79	1.64	4.29	1.87	6.25	11	9.02	9.04	8.15	0.7	3.08	0.6
1991	2.56	2.89	2	5.63	3.53	7.4	6.44	7.88	4.65	1.6	0.26	2.52
1992	0.92	1.94	1.8	5.39	4.63	9.6	6.85	11.48	5.84	5.8	2.32	1.15
1993	2.54	2.89	3.86	7.89	7.65	7.5	6.09	8.47	5.7	5.6	0.1	0.01
1994	0.03	1.01	3.11	5.11	6.85	9.2	8.24	5.14	5.9	0.4	0.6	0.34
1995	0.26	0.61	2.39	6.43	3.72	5.4	5.84	6.98	4.7	1.6	1	4.07
1996	1.32	0.81	4.37	6.77	5.64	6.6	7.47	2.94	8.27	0.8	3.1	1.3
1997	2.13	0	2.22	5.93	8.86	7.9	3.95	8.26	4.94	11	8.11	1.16
1998	3.31	0.8	3.11	3.11	5.92	7.4	8.01	9.89	6.66	6.5	1.55	0.05
1999	0.96	0.03	2.66	2.39	6.89	5.8	4.39	3.3	4.36	6.4	0.04	0.06
2000	0	0.03	1.27	6.49	7.67	5.1	8.58	5.12	8.51	7.9	1.56	0.8
2001	0.52	0.46	2.77	3.89	11.01	10	10.1	5.19	6.11	5.3	2.53	0.12
2002	2.22	0.18	2.94	2.99	4.43	8.1	4.83	7.58	5.51	2.6	0.27	4.46
2003	0.93	2.19	2.8	3.71	0.39	9.1	6.02	4.87	7.96	3	1	0.47
2004	1.65	0.98	1.49	4.36	5.22	4.3	6.98	7.08	6.7	4.3	2.24	2.72
2005	1.44	0.02	6.25	4.71	5.61	5.9	8.82	7.35	7.64	2.2	0.99	0
2006	0.51	2.75	5.86	3.68	6.82	6.9	10.6	7.75	5.66	2.9	4.25	3.23
2007	1.21	1.82	3.36	4.05	6.33	4.8	7.98	5.71	8.54	1.6	0.2	0
2008	1.1	0.42	1.27	3.76	8.03	7.9	6.77	7.64	4.45	6	3.1	0.2
2009	2.03	1.05	2.57	3.44	7.86	5.3	4.83	9.83	6.98	3	2.61	2.18
2010	0.88	3.16	2.17	3.38	6.22	13	5.85	6.56	6.22	1.2	3.21	0.34
2011	0.78	0.27	1.27	5.04	6.22	10	6.13	6.2	8.98	0.3	3.5	0.84
2012	0.07	0.06	1.8	5.15	3.83	11	7.22	4.28	8.35	1.1	2.58	1.86
2013	1.13	1.12	3.53	3.19	9.87	6.4	4.89	8.23	6.11	5.4	3.82	0.03
2014	0.57	0.6	3.72	4.1	4.1	3.9	8.75	8.57	4.74	4.1	4.1	0.84
2015	0.2	0.6	2.5	5.88	4.1	4.1	4.1	7.85	8.47	4.1	5.17	4.1

### 5.6.2.6 Temperature Data

The temperature data record was available from one weather station which is Jimma (Figure 5.6).

But, the temperature record from the station was incomplete and available for only few years.

Jimma station has a temperature record from 1986 to 2015. This is very important to use as input to the SWAT model as it requires the same length of year for both precipitation and temperature data. The daily maximum and minimum air temperature was available with some missing data. The missing data was filled using linear interpolation only for checking the trend of the air temperature over time. When this data was used as input to the SWAT model again the filling of the missing data was left for the SWAT itself by replacing the missing values with -99.

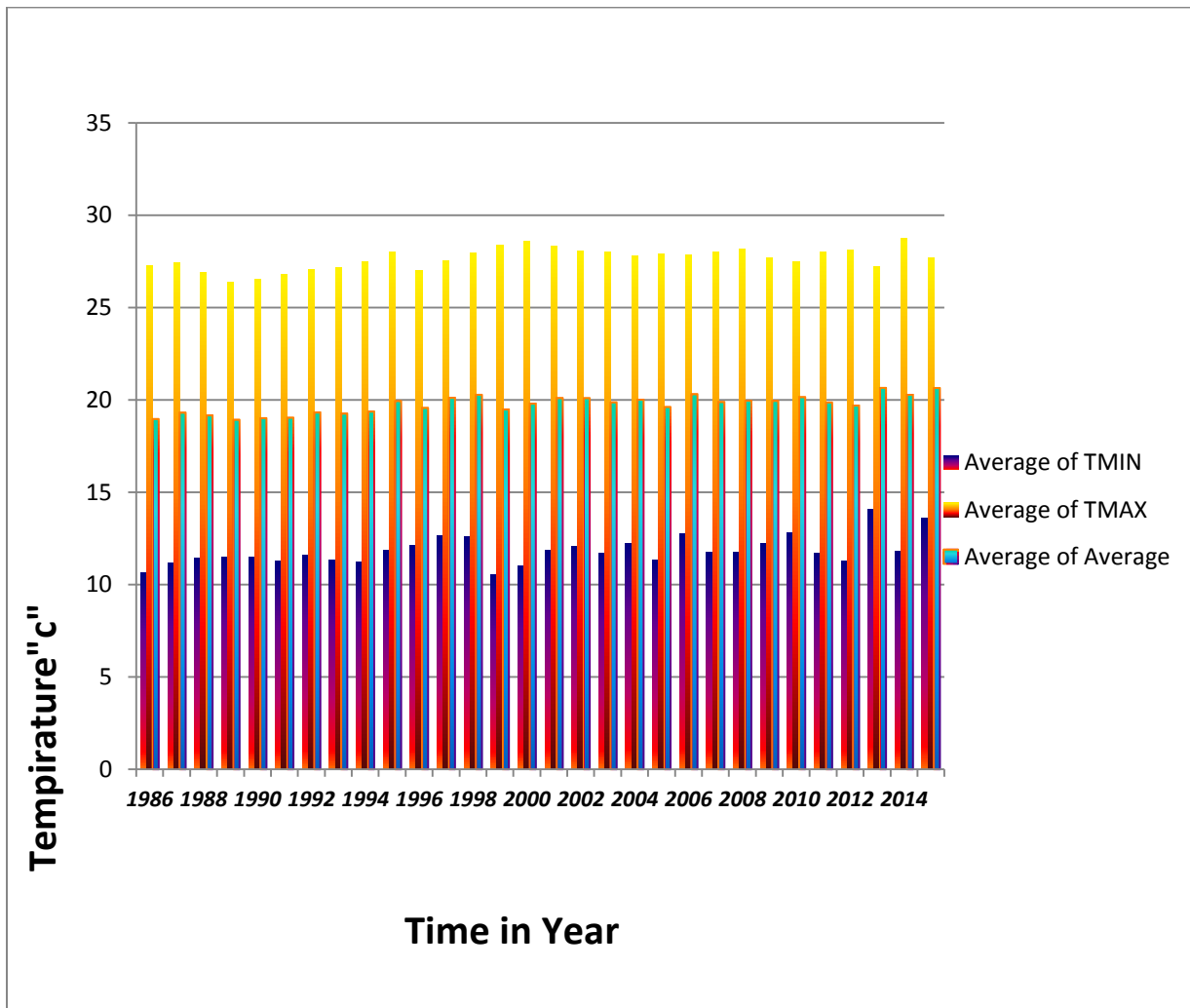


Figure 5.6 Daily maximum/minimum air temperature at Jimma station

## 5.7 Sediment Data

The daily observed sediment data for the watershed was taken from ministry of water, irrigation and electricity at the gauging stations established Asendabo station within the watershed.

These months for which the measurement was made were in the Months of the mentions year from 1990 to 2014 shows the average yearly discharge and sediment concentration measured at Gilgel Gibe-I Watershed.

**Table 5.8 Average yearly observed discharge and sediment concentration @ G/Gibe-I**

Months	Gilgel Gibe-I Watershed (3602KM2)	
	observed (ppm)	Flow
15-Dec-1990	4476.5801	21.87
4-Aug-1990	6929.25	174.51
15-May-1993	109.25	3.72
10-Dec-2002	355.45	3.362
10-Dec-2003	1745.125	34.25
6-Apr-2003	3658.1499	66.25
29-Jan-2003	2099.25	33.25
8-May-2003	3312.48	199.26
12-Feb-2004	3472.5801	189.283
22-Aug-2009	1790.87	319.647
23-Aug-2010	150.75	104.23
5-Sep-2010	291.87	53.16
3-Oct-2011	1335.25	159.87
22-Jan-2013	7875.75	335.25
4-Nov-2013	4682.5801	89.25
26-Mar-2014	1519.25	3.642
22-Sep-2014	985.25	12.602

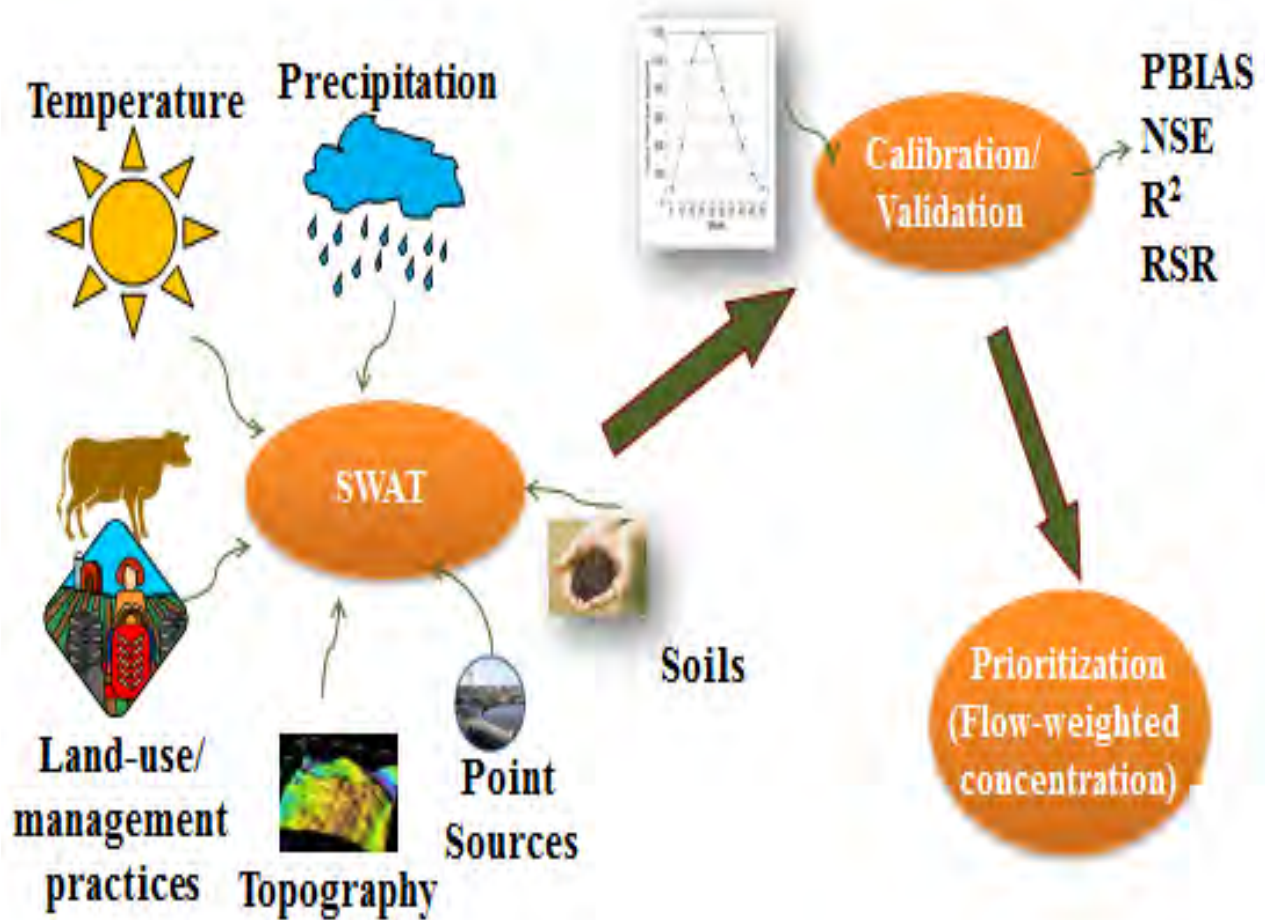


Figure 5.7 Summary of input data for SWAT model.

Table 5.9 Types and sources of data for Gilgel Gibe-I watershed and summary.

S.no	Data type	No.of sations	Data availability	Sources	Resolutions	
					Spatial	Temporal
1	Rainfall	8	1986_2015	NMSA	_	Daily
2	Tempirature	1	1986_2015	NMSA	_	Daily
3	Wind	1	1986_2015	NMSA	_	Daily
4	Solar Radiation	1	1986_2015	NMSA	_	Daily
5	RHD	1	1986_2015	NMSA	_	Daily
6	Flows	1	1989_2014	MoWIE	_	Daily
7	DEM	_	2009	MoWIE	30m*30m	_
8	Land use	_	2009	MoWIE	1km	_
9	Soil type	_	2009	MoWIE	1:50,000	_
10	Sediment	1	1990_2014	MoWIE	_	Daily

## 6. RESULTS AND DISCUSSIONS

### 6.1 Sensitive Parameters

The sensitivity analysis was done for flow and sediment separately since some parameters are sensitive to both flow and sediment, some sensitive to flow only and others sensitive to sediment only (Abbaspour et al., 2007). Therefore, it is wise to test the sensitivity of the parameters for flow and sediment separately. Sensitivity analysis was carried out before calibrating the model to save time during calibration. Identifying sensitive parameters enables us to focus only on those parameters which affect most the model output during calibration since SWAT model has a number of parameters to deal with. Some parameters do not have any influence on the model output while some may have little effect.

#### 6.1.1 Parameters sensitive to flow

The 20 parameters listed in Table 6.1 were used in sensitivity analysis for flow calibration. These parameters are used to calculate the amount of flow from the watershed. The parameter identification was done by using the daily flow data from 1988 to 2014. According to the result from the global sensitivity analysis, the curve number (CN2) was found to be the most sensitive parameter followed by Ground water revap coefficient (GW\_REVAP), effective Average slope steepness (HRU\_SLP) and all others as shown in Table 6.1.

**Table 6.1** Parameters rank based on P-value and t-stat.

S/NO.	Parameter Name	Description of parameters	t-Stat	P-Value	Range of Value	Rank
1	V_CN2.mgt	SCS runoff curve number	-14.94	9.91E-25	35-98	1
2	V_GW_REVAP.gw	Groundwater revap coefficient	8.1806	3.88E-12	0-0.2	2
3	V_HRU_SLP.hru	Average slope steepness	-6.799	1.80E-09	0-1	3
4	V_GW_DELAY.gw	Groundwater delay	5.9423	7.20E-08	0-500	4
5	V_ALPHA_BF.gw	Baseflow alpha factor	-4.26	5.60E-05	0-1	5
6	V_EPCO.bsn	Plant uptake compensation factor	2.4367	0.01707	0-1	6
7	:V_BIOMIX.mgt	Biological mixing efficiency	-1.462	0.1478014	0-1	7
8	V_OV_N.hru	Manning's "n" value for Overland flow	0.7829	0.4360353	0.01-30	8
9	V_CH_K2.rte	Effective hydraulic conductivity in the	0.6651	0.5079169	0.01-500	9
10	R_SOL_K(..).sol	Saturated hydraulic conductivity (mm/hr)	-0.619	0.5376019	0-2000	10
11	V_SURLAG.bsn	Surface runoff lag time	0.5542	0.5809776	1_24	11
12	V_RCHRG_DP.gw	Deep aquifer percolation fraction	0.5017	0.6172774	0-1	12
13	V_GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow to occur	-0.448	0.6551331	0-5000	13
14	V_ESCO.hru	Soil evaporation compensation factor	0.3444	0.7314608	0-1	14
15	:V_CH_N2.rte	Manning's "n" value for the main	-0.322	0.7485304	0.01-0.3	15
16	V_REVAPMN.gw	Threshold depth of water in the shallo	0.2382	0.8123301	0-1000	16
17	V_CANMX.hru	Maximum canopy storage	0.235	0.8147806	0-100	17
18	R_SOL_BD(..).sol	Moist bulk density	0.1826	0.819504	0-0.25	18
19	R_SOL_AWC(..).sol	Available water content of soil	0.1826	0.8555855	0-1	19
20	R_SOL_Z(..).sol	Soil depth (for each layer)	0.0167	0.9867137	0-3500	20

### **6.1.1.1 Global sensitivity analysis**

Global sensitivity analysis was done for the parameters shown in Table 6.1 According to the result from the global sensitivity analysis, the curve number (CN2) was found to be the most sensitive parameter followed by groundwater revap coefficient (GW\_REVAP), average slope steepness (HRU\_SLP), groundwater delay (GW\_DELAY), oil evaporation compensation factor (ESCO), Base flow alpha factor (ALPHA\_BF) and saturated hydraulic conductivity of soil layers were found to be most sensitive parameters in the order appearance. Ranking position as shown in Table 6.1 above.

Here, t-stat provides a measure of sensitivity and hence larger in absolute values are more sensitive. On the other hand, P-value indicates the significance of the sensitivity and hence a value close to zero has more significance. Therefore, ranking in both cases (t-stat or P-value) give the same result i.e. a parameter will have the same rank whether it is ranked based on the t-stat or P-value.

### **6.1.1.2 Local sensitivity analysis**

The local sensitivity analysis was carried out using the Latin-Hypercube One-Factor-at-a-Time (LH-OAT) sensitivity analysis method.

As described in earlier section this method should be performed for one parameter at a time only while the other parameters are fixed at a value of the best iteration. Then the parameter was varied independently and its effect on the model output was evaluated. Based on the analysis result groundwater delay (GW\_DELAY), average slope steepness (HRU\_SLP), groundwater revap coefficient (GW\_REVAP), oil evaporation compensation factor (ESCO), Base flow alpha factor (ALPHA\_BF), runoff curve number (CN) and saturated hydraulic conductivity of soil layers were found to be most sensitive parameters in the order appearance. On the other hand parameters such as Soil depth (SOL\_Z), available water content the soil (SOL\_AWC), Threshold depth of water in the shallow aquifer (REVAPMN), moist bulk density (SOL\_BD), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN) and threshold depth of water in the shallow aquifer for revap to occur (REVAPMN) were found to be least sensitive. The remaining parameters have moderate effect on the model output. In general, the global sensitivity analysis and the local sensitivity analysis produce different result. Therefore, attention was given to most sensitive parameters during model calibration process.

### **6.1.2 Parameters sensitive to sediment**

Once it is shown that the flow was accurately represented by the model the focus is shifted to the calibration of the model for sediments. This involves changing parameter values that control sediment generation within the model.

The sediment parameters used for calibration are selected based on previous SWAT modeling studies including Santhi et al.(2001), and Van Liew et al., (2007).

The most sensitive parameters for erosion simulations were: USLE support practice factor (USLE\_P), average slope steepness (HRU\_SLP), USLE soil erodibility factor (USLE\_K), USLE cover and management factor (USLE\_C) channel re-entrainment exponent parameter (SPEXP),

channel re-entrainment linear parameter (SPCON), Biological mixing efficiency (BIOMIX), and channel cover factor (CH\_COV). These sediment parameters are used to compute the amount of sediment from a catchment (from upland) and from the channel (in stream sediment). The parameters that were used to evaluate the sensitivity to sediment are shown in Table 6.2

**Table 6.2** Parameters highly sensitive to sediment.

S/NO.	Parameter Name	Description of parameters	t-Stat	P-Value	Range of Value	Rank
1	:V_USLE_P.mgt	USLE support practice factor	36.8493744	7.25E-55	0-1	1
2	:V_HRU_SLP.hru	Average slope steepness	20.6671742	2.56E-35	0-1	2
3	:R_USLE_K(..).sol	USLE soil erodibility factor [t.ha.h./{ha.MJ.mm}]	6.50404116	4.77E-09	0-0.65	3
4	:R_USLE_C(..).plant.dat	USLE cover and management factor	-3.1047103	0.00257048	0.001-0.5	4
5	:V_BIOMIX.mgt	Biological mixing efficiency	1.33141151	0.18653181	0-1	5
6	:R_RSDIN.hru	Initial residue cover [kg/ha]	1.25513966	0.21278905	0-10000	6
7	:R_LAT_SED.hru	Sediment concentration in lateral flow and groundwater flow	-1.0483525	0.29737989	0-5000	7
8	:V_CH_COV1.rte	Channel erodibility factor	0.44430498	0.65792535	0.05-0.6	8
9	:V_SLSUBBSN.hru	Average slope length	0.34464895	0.73119006	10-150	9
10	:V_SPEXP.bsn	Exponential re-entrainment parameter	-0.1444533	0.88547666	1-1.5	10
11	:V_SPCON.bsn	Linear re-entrainment parameter for channel sediment routing	0.13253221	0.89486939	0.0001-0.01	11
12	:V_CH_COV2.rte	Channel cover factor	0.07078338	0.94373262	0.001-1	12

From the list of parameters in One-factor-at-a-time (OAT) sensitivity analysis was applied. OAT keeps the value of other parameters constant or fixed to the best simulation value of the last iteration and vary the value of one parameter at a time. Then, the value of the Sum of the Squares of the difference of the measured and simulated values after Ranking (SSQR) was compared to rank the parameters.

The parameters used in the sensitivity analysis are related to the corresponding transport component. Therefore, the parameters can be categorized in to upland factors which affect the landscape component of the sediment transport and channel factors which affect the channel component of the sediment transport. Parameters such as *KUSLE*, *CUSLE*, *PUSLE*, *BIOMIX*, *RSDIN*.

## 6.2 Model Calibration and Validation

### 6.2.1 Model calibration for flow

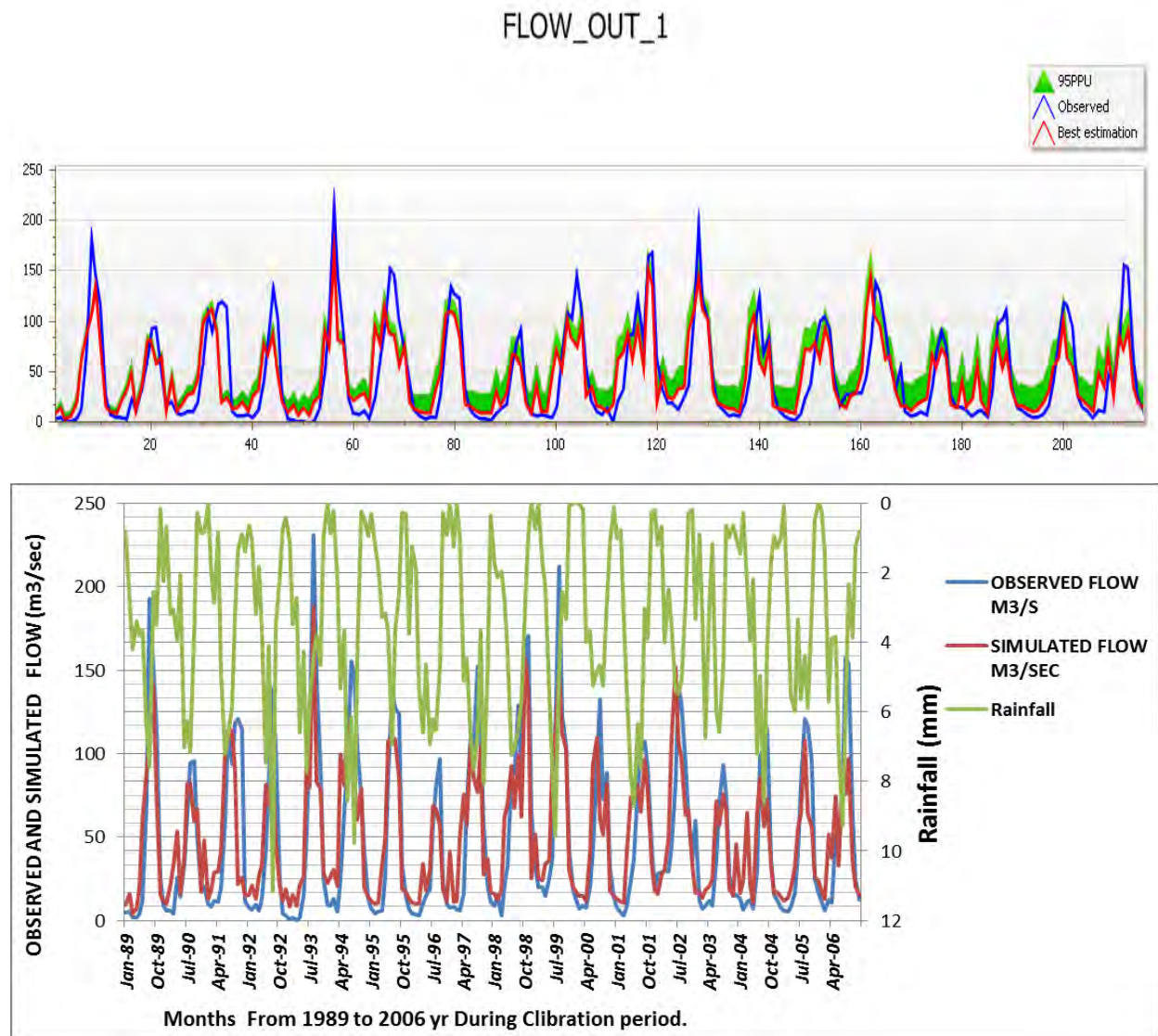
The objective of calibration and validation was to maximize the model efficiencies and finally using the parameter obtained through those calibration techniques. The calibration of SWAT model for runoff was done by using the Monthly observed runoff data at the outlet of the study watershed (Gilgel Gibe-I watershed) for the years 1989- 2006. The simulated and observed daily discharge at the outlet of the watershed were plotted for visual comparison in Figure 6.1. The model was calibrated by using the values of parameters that were identified as highly

sensitive to runoff as it was described under sensitivity analysis section by SWAT-CUP software. At the initial run of the model i.e. model run using the default values of parameters, there were three major problems in the water balance of the shallow aquifer (SWAT considers only shallow aquifer water balance): **a) Low surface runoff, b) High lateral flow and c) Low base flow (inter flow or return flow).** Fixing these problems was quite challenging task.

**Low surface runoff was adjusted by:**

- Increasing the curve number (CN2),
- Decreasing the soil available water content (SOL\_AWC), and
- Decreasing the soil evaporation compensation factor (ESCO).

High lateral flow is related to the saturated hydraulic conductivity of the soil layers.



**Figure 6.1** Comparison of observed and simulated monthly runoff at the outlet of Gilgel Gibe-I watershed for calibration period 1989-2006.

**Table 6.3** Summary of stat txt of the model for calibration period.

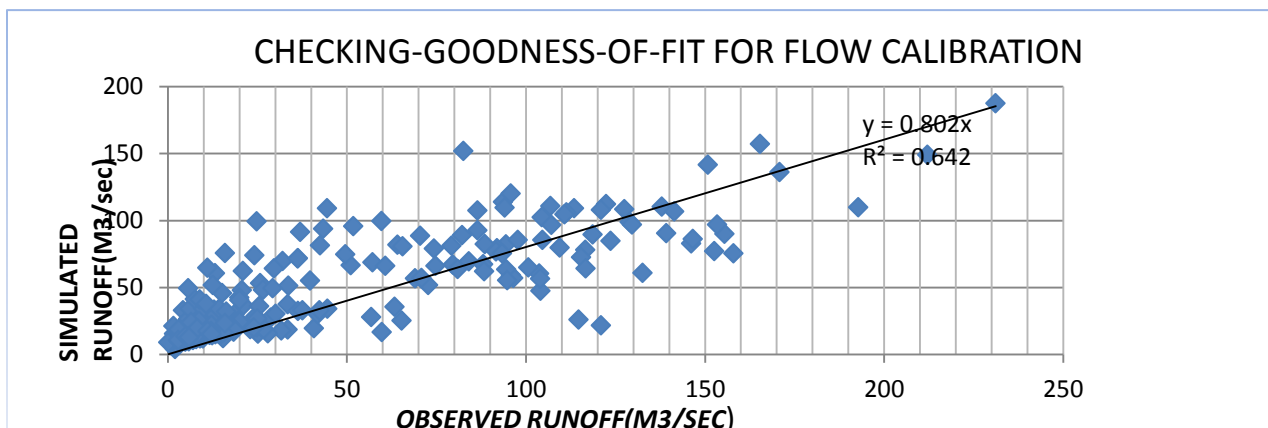
Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	Mean_sim(Mean_obs)
FLOW_OUT_1	0.24	0.32	0.68	0.67	0.4130	8.1e+002	2.0e+002	0.4	0.69	0.57	0.00	1.00	49.04(49.24)

For a soil with multi-layers, if the hydraulic conductivity of the soil layer at the surface is high and the hydraulic conductivity of the soil layers at shallow depth is impermeable or semipermeable, then the rainfall will percolate vertically until it encounters the impermeable layer. Then it starts ponding above the impermeable layer and forms a saturated zone of water i.e. Perched aquifer. Due to low hydraulic conductivity of the lower layers compared to the top layer, the lateral flow was high. Therefore, the hydraulic conductivity of the first layer was decreased to lower the lateral flow. Decreasing the soil hydraulic conductivity also increase the surface runoff by lowering infiltration rate.

**Low base flow was adjusted by:**

- Decreasing the deep percolation loss (decrease threshold depth of water in shallow aquifer required for the base flow to occur, GWQMN,
- Decrease groundwater revap coefficient , GW\_REVAP, and
- Increasing threshold depth of water in shallow aquifer for revap to occur, REVAPMN.

After all these adjustments in SWAT model, the simulation was done and parameters were calibrated using auto calibration tool (SUFI2 in SWAT\_CUP) and the calibrated parameters were updated in the model and the final simulation was run. The model is reasonably responding to the rainfall event. The coefficient of determination (*R2*) value for daily runoff for the calibration period was 0.68 and the Nash-Sutcliffe coefficient of efficiency (ENS) for the same period was found to be 0.67. From Table: 6.3 one can see that the *R2* value of 0.68 and ENS value of 0.67 indicates that the performance of the model in predicting is well and the observed runoff and the dispersion of simulated runoff are very close to each other.



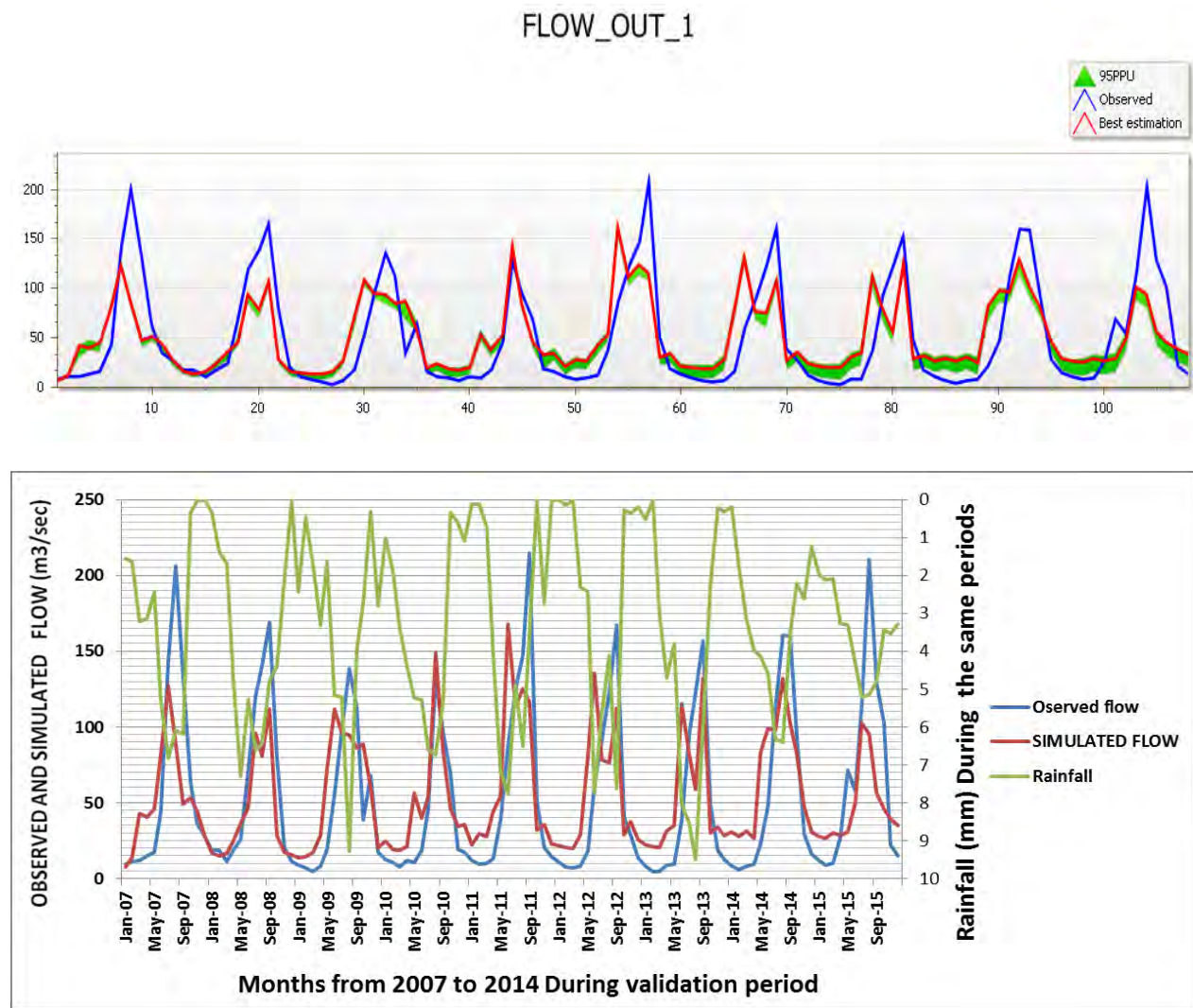
**Figure 6.2** Goodness-of-fit for observed and simulated runoff during calibration period.

### 6.2.2 Model Validation for flow

Validation is a process of proving the performance of model. Validation is carried out for time periods different from calibration period, but without any further adjustment of calibrated parameters. The model validation was carried out for Monthly runoff for the year 2007 to 2014. As shown on Table: 6.3 the value of coefficient of determination ( $R$ ) and the Nash-Sutcliffe efficiency (NS) for Monthly runoff in 2007 to 2014 were 0.58 and 0.57 respectively. The observed and simulated daily runoff for the year 2007 to 2014 is shown in *Figure 6.3*

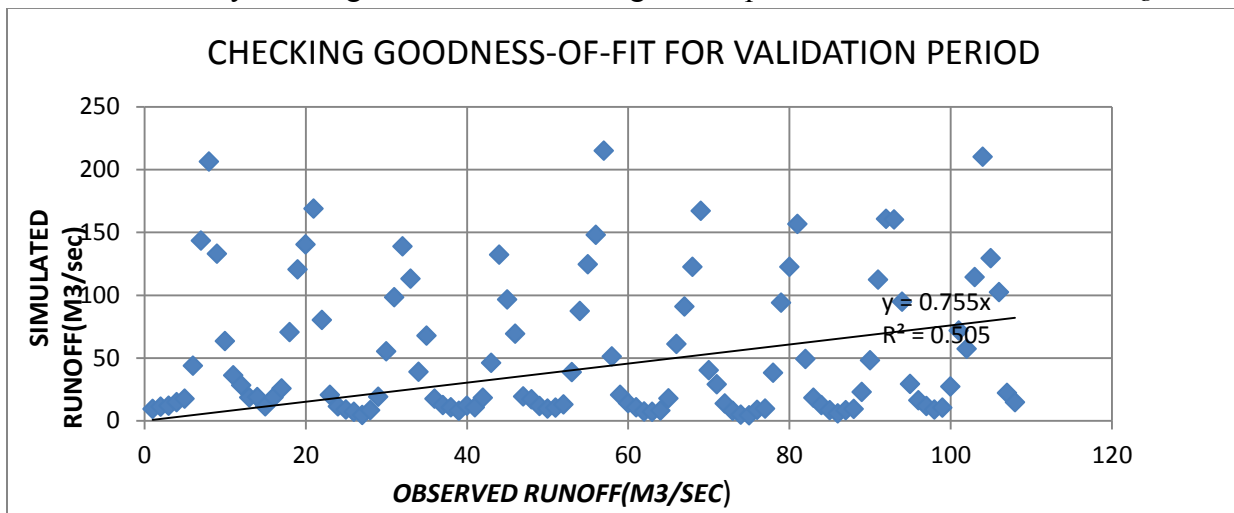
**Table 6.4 Summary of stat txt of the model for validation period.**

Variable	p-factor	r-factor	R2	NS	br2	MSE	SSQR	PBIAS	XGE	RSR	MNS	VOL_FR	Mean_sim(Mean_obs)
FLOW_OUT_1	0.23	0.20	0.58	0.57	0.2960	1.3e+003	3.6e+002	-1.5	0.59	0.65	0.00	0.99	54.10 (53.29)



**Figure 6.3** Comparison of observed and simulated monthly runoff at the outlet of Gilgel gibe-I watershed model for validation period 2007-2014.

From *Figure 6.3* the graph of the observation value is rather smooth on these dates. On contrary to this, the model responded well to these rainfall events. The goodness-of-fit of observed and simulated monthly discharge for 2007-2014 using scatter plots can be visualized from *Figure 6.4*.



**Figure 6.4** Goodness-of-fit for observed and simulated Monthly runoff for validation period 2007-2014.

The graphical comparison of the observed and simulated runoff at the outlet of the Gilgel gibe-I sub-watersheds shown on *Figure 6.4* show that the model is good predicted at mostly during peak flows. Workers such as Spruill et al., (2000), Chu and Shirmohammadi (2004) showed that the SWAT model was unable to simulate an extremely wet year or poorly predicted peak flows and hydrograph recession rates. The value of coefficient of determination ( $R$ ) and the Nash-Sutcliffe efficiency (NS) were found to be 0.58 and 0.57 respectively for the watershed. The model predicted well for sub-watershed during validation period of 2007-2014.

The spatially and temporally distributed data should be used in the development of SWAT project to get a good result. The SWAT model looks for rain gauges or precipitation station close to the center of each sub basin to generate runoff. Therefore, having precipitation station distributed throughout the watershed helps the model to better predict the runoff from each sub basin. It is obvious that rainfall distribution may not be uniform throughout the watershed and as the sub basin gets far from the precipitation station, it is likely to have higher or lower rainfall intensity than the precipitation recording station and this could affect the runoff generated by the model. Therefore, rain gauge density is also very important input requirement.

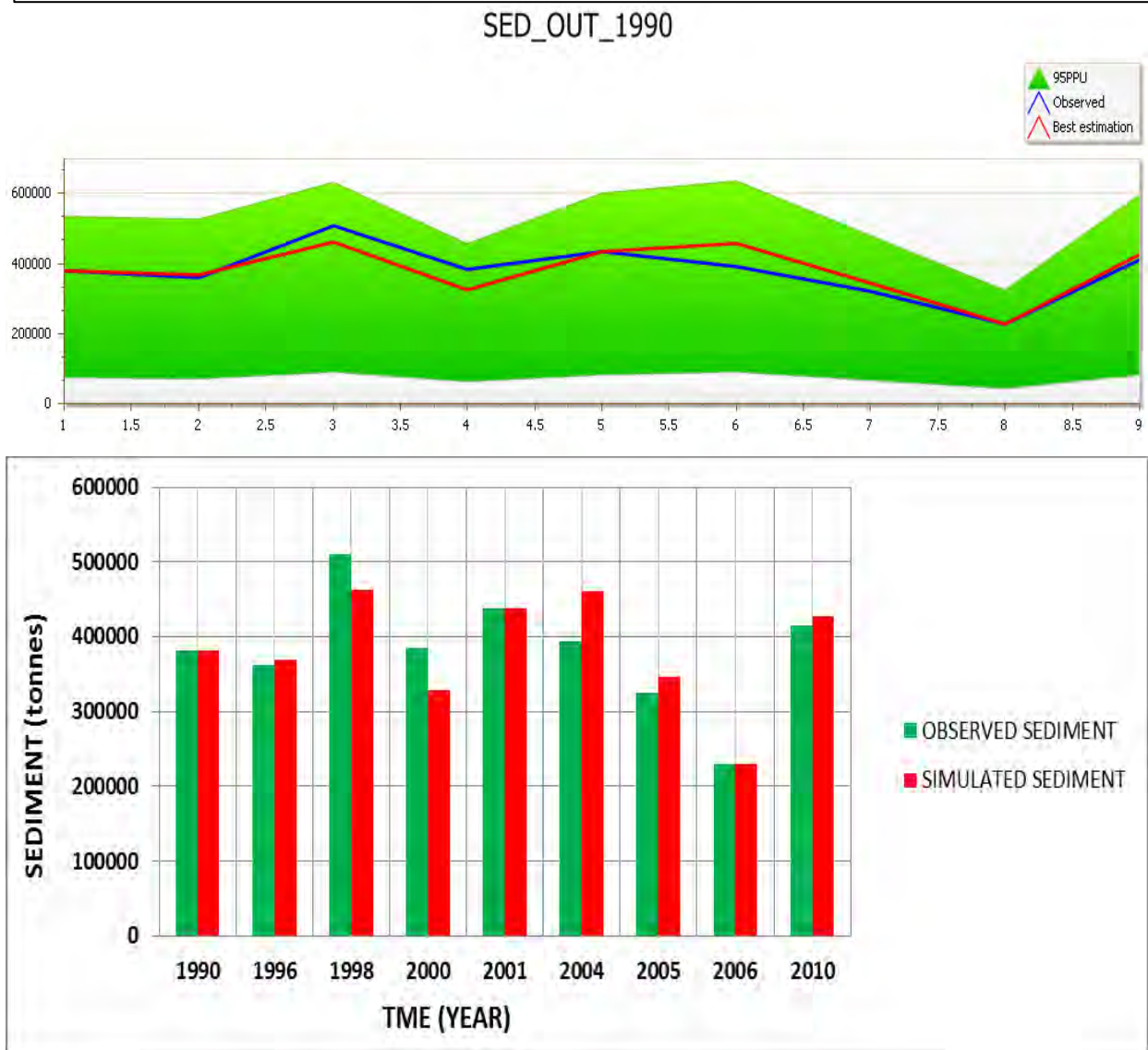
Sensitivity analysis is performed to select important model parameters; manual calibration is performed for stream flow using measured data at Upper Ribb gauging station for a period of 1985-1994. It is shown that the model could adequately represent stream flow for monthly time steps. It is shown that the model performed well with ENS and  $R^2$  0.812, 0.817 respectively. The model is validated for the stream flow for the period of 1995-2004. The model performed well monthly time steps with ENS and  $R^2$  0.8 and 0.817 respectively. (Tensay, 2011)

### 6.2.3 Model calibration for sediment

SWAT model was first calibrated and validated to flows, then to sediment. The model was calibrated for sediment by comparing annual model simulated sediment load against annual measured sediment load for the period 1990 to 2010. The model was calibrated for observed sediment data for the calibration period (1990-2010) of monthly time step with value of coefficient of determination ( $R^2$ )(0.79) and the Nash-Sutcliffe efficiency (NSE) (0.78).

**Table 6.5 Summary of results for behavioral parameters for sediment calibration.**

Variable	p-factor	r-factor	R2	NS	bR2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL_FR	--- Mean_sim(Mean_obs)
SED_OUT_1990	1.00	6.28	0.79	0.78	0.6774	1.2e+009	5.4e+008	-0.1	0.88	0.47	0.54	1.00	382922.22 (382451.56)



**Figure 6.5** Comparison of observed and simulated yearly sediment load from Gilgel gibe –I for calibration period 1990 to 2010 year.

The observed and the simulated values of the sediment yield were plotted against each other to determine the goodness-of-fit criterion of the model sub-catchments (Figure 6.6). The coefficient of determination ( $R^2$ ) and the Nash-Sutcliffe efficiency were found to be 0.79 and 0.78 respectively. Between 1.0 (perfect fit) and  $-ve$  infinitive. Since the NS coefficient is sensitive to extreme values (as it squared the difference of observed and simulated values), it might yield sub-optimal results when the dataset contains large outliers.

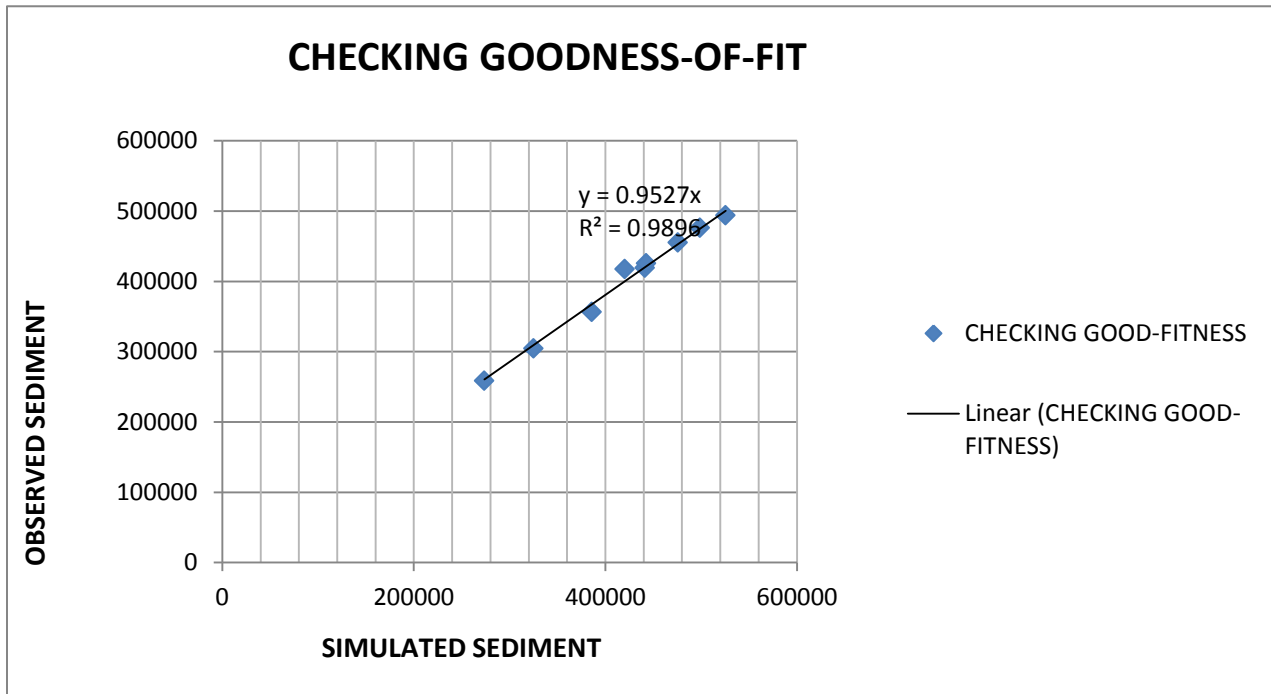


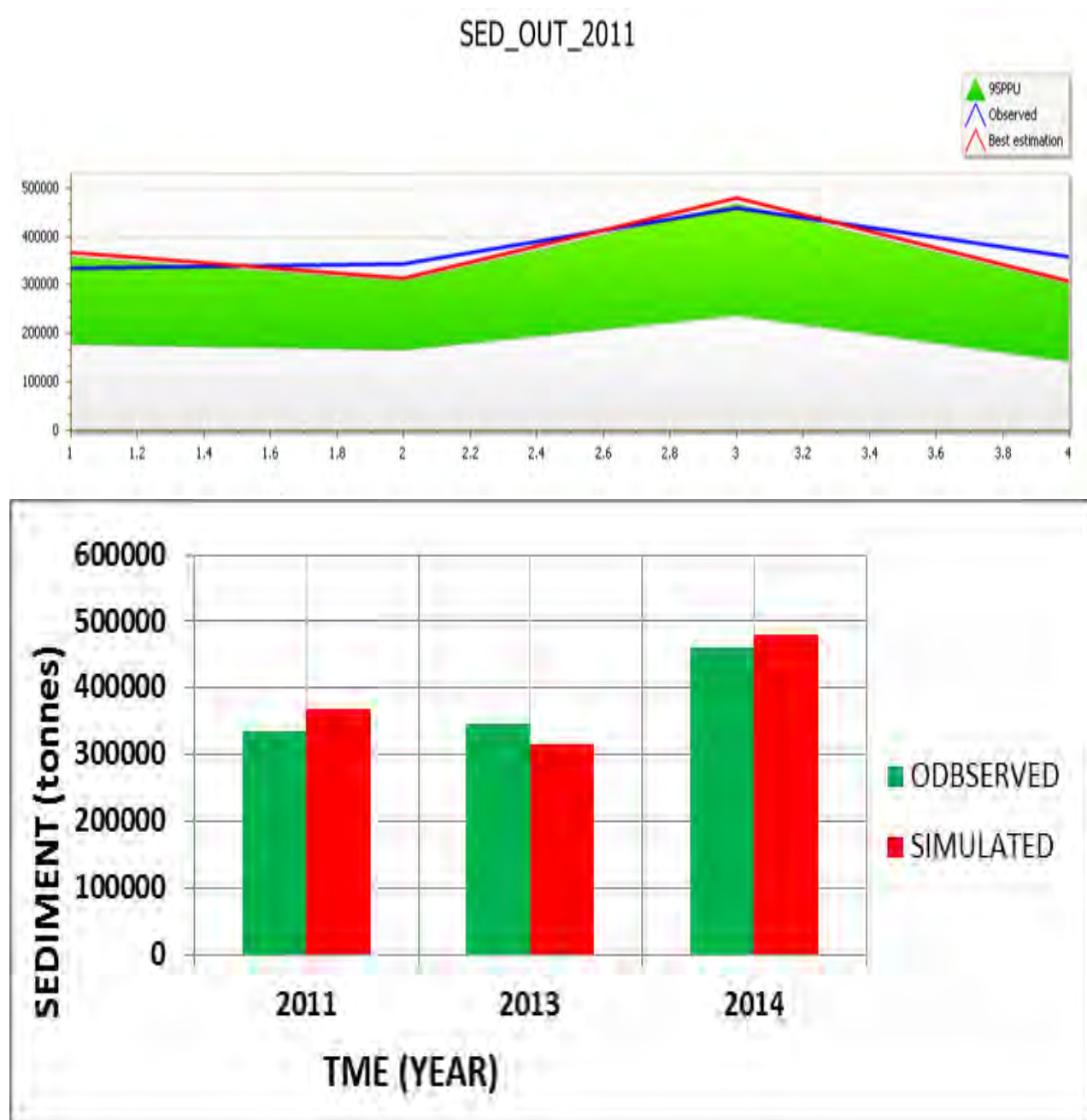
Figure 6.6 Goodness-of-fit for observed and simulated yearly sediment load from Gilgel Gibe-I watershed.

### 6.2.4 Model validation for sediment

The model was validated for the period 2011 to 2014 with-adjusted values during calibration.

**Table 6.6 Summary of results for behavioral parameters for sediment validation.**

Variable	p-factor	r-factor	R2	NS	br2	MSE	SSQR	PBIAS	KGE	RSR	MNS	VOL FR	Mean_sim(Mean_obs)
SED_OUT_2011	0.50	3.63	0.76	0.48	0.6304	1.3e+009	5.0e+008	1.7	0.59	0.72	0.20	1.02	369200.00(375688.75)



**Figure 6.7** Comparison of observed and simulated yearly sediment load from Gilgel Gibe-I for validation period 2011 to 2014 year.

The model was validated for observed sediment data for the validation period (2011-2014) of monthly time step with value of coefficient of determination ( $R^2$ )(0.76) and the Nash-Sutcliffe efficiency (NSE) (0.48) and PBIAS value of (1.7).

The model is then calibrated with sediment flow data that is taken from rating curve equation measured during (1986-1987). Model parameters were selected that control sediment generation processes for calibration. It is shown that suspended sediment concentration at Upper Ribb river watershed could be represented by SWAT model with ENS and  $R^2$  0.59 and 0.78 respectively.

The model is validated for a period of (2000-2001).The model could adequately represent suspended sediment concentrations at Upper Ribb river watershed ENS and  $R^2$  0.52 and 0.57 respectively.(Tensay,2011)

### 6.2.5 Sediment load

**Table 6. 7** Summary of simulated and observed sediment load of the watershed 1990 to 2010.

Year	Summary of Gilgel Gibe -I Watershed sediment load	
	Observed sediment(tonnes)	Simulated sediment(tons)
1990	381248	381400
1996	362485	369600
1998	510487	463300
2000	385648	329300
2001	438562	437500
2004	393560	461400
2005	325123	345700
2006	229203	230300
2010	415748	427800
Total sed- load	3442064	3446300
Watershed Area	3602Km <sup>2</sup>	3602Km <sup>2</sup>
Spesific Yield(tons/km <sup>2</sup>	955.598 ton/km <sup>2</sup>	956.774ton/km <sup>2</sup>

The total observed and simulated sediment yield (load) from Gilgel Gibe-I sub-catchment during the period from 1990 to 2010 was 3,442,064 tons and 3,446,300 tons respectively.

The specific sediment yield based on the observed and simulated sediment load by SWAT model from Gilgel Gibe-I watershed of area 3602 km<sup>2</sup> was 955.598 tons/km<sup>2</sup> and 956.774 tons/km<sup>2</sup> respectively. Based on this result, the SWAT model gives quite good estimation of the sediment yield from the catchment. The result shows that the model prediction was promising as it closely estimates the sediment yield.

In the same manner, the total annual simulated sediment load from watershed for 9 calibrating years was estimated using the SWAT model was 3,442,064tons/9yr=382,451.556 tons. The annual specific sediment yield from the watershed can be calculated as the ratio of the total annual sediment yield to the area of the watershed and the value is 106.178 tons/km<sup>2</sup>/yr.

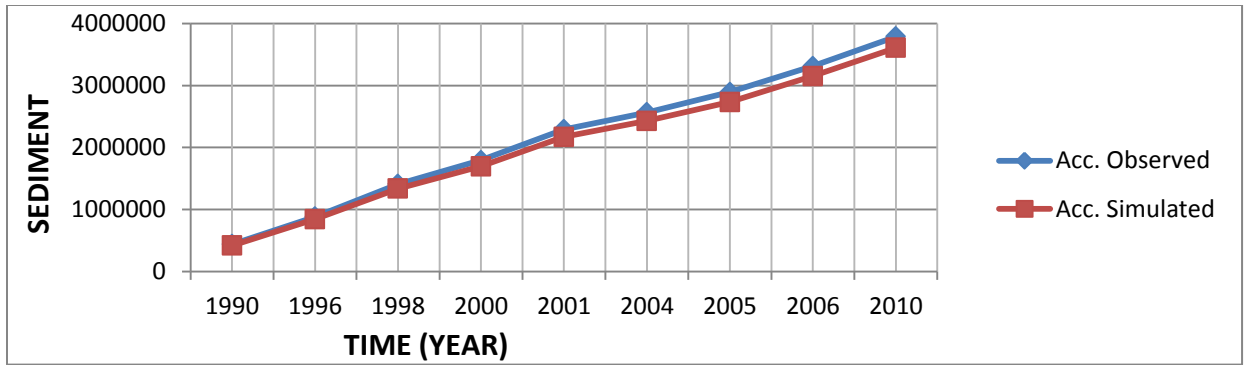


Figure 6.8 Accumulated observed and simulated sediment at Gilgel Gibe-I 1990-2010.

## 6.2.6 Sediment concentration

In addition to sediment load or sediment yield from a basin, SWAT also simulates the concentration of sediment in mg/kg or ppm(parts per million) from a basin. The relationship between sediment concentration and discharge will be presented in the next section.

### 6.2.6.1 Concentration and discharge

The concentration of suspended sediment in the stream is related to the amount of discharge flowing in the river. But, this may not be the case in the area where gully erosion, land sliding and mass wasting are dominant factors that add sediment to the river. This is because of the fact that land slide or mass wasting add a large amount of sediment to the river in a single event. Therefore, the relationship between sediment concentration and discharge depends on the catchment slope characteristics. The maximum and average sediment concentration and discharge of Gilgel Gibe-I watershed 1990-2014 as simulated by SWAT is shown in Table 6.8.

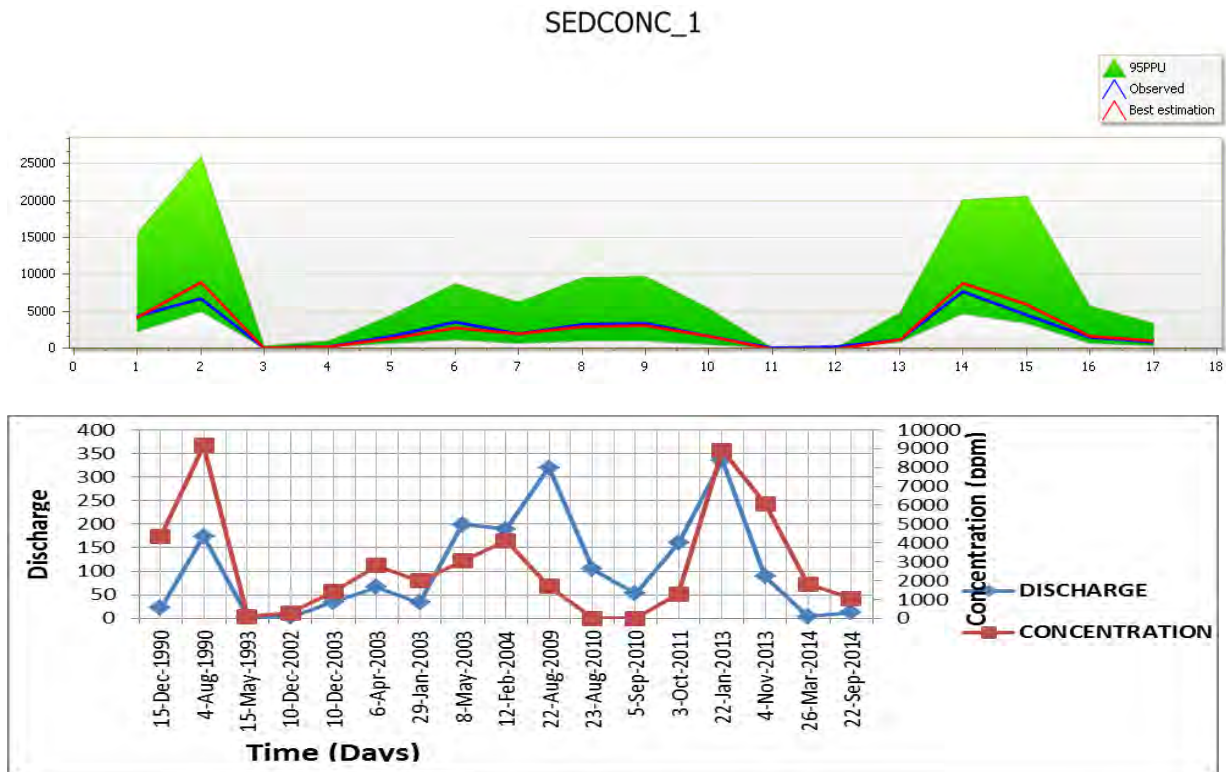
Table 6.8 Summary of sediment concentration by weight during 1990-2014.

Months	Gilgel Gibe-I Watershed	
	observed (ppm)	Simulated (ppm)
15-Dec-1990	4476.5801	4365
4-Aug-1990	6929.25	9161
15-May-1993	109.25	103.5
10-Dec-2002	355.45	289.3
10-Dec-2003	1745.125	1404
6-Apr-2003	3658.1499	2804
29-Jan-2003	2099.25	2001
8-May-2003	3312.48	3043
12-Feb-2004	3472.5801	4124
22-Aug-2009	1790.87	1698
23-Aug-2010	150.75	0
5-Sep-2010	291.87	0
3-Oct-2011	1335.25	1291
22-Jan-2013	7875.75	8919
4-Nov-2013	4682.5801	6075
26-Mar-2014	1519.25	1831
22-Sep-2014	985.25	1049

The time series concentration and discharge for Gilgel Gibe-I sub-watershed is shown in Figure shows that the sediment concentration in the stream is high where the discharge is high. The observed time series of concentration and discharge (Figure 6.9) shows that there is high sediment concentration (8919ppm) on 22-Jan-2013 for a discharge of 335.25 m<sup>3</sup>/s.

**Table 6.9 Time series of sediment concentrations by weight and discharge Gilgel Gibe-I**

Months	Gilgel Gibe-I Watershed		
	observed (ppm)	Simulated (ppm)	Flow
15-Dec-1990	4476.5801	4365	21.87
4-Aug-1990	6929.25	9161	174.51
15-May-1993	109.25	103.5	3.72
10-Dec-2002	355.45	289.3	3.362
10-Dec-2003	1745.125	1404	34.25
6-Apr-2003	3658.1499	2804	66.25
29-Jan-2003	2099.25	2001	33.25
8-May-2003	3312.48	3043	199.26
12-Feb-2004	3472.5801	4124	189.283
22-Aug-2009	1790.87	1698	319.647
23-Aug-2010	150.75	0	104.23
5-Sep-2010	291.87	0	53.16
3-Oct-2011	1335.25	1291	159.87
22-Jan-2013	7875.75	8919	335.25
4-Nov-2013	4682.5801	6075	89.25
26-Mar-2014	1519.25	1831	3.642
22-Sep-2014	985.25	1049	12.602



**Figure 6.9 concentrations by weight and discharge G/Gibe 1990-2014 simulated and observed.**

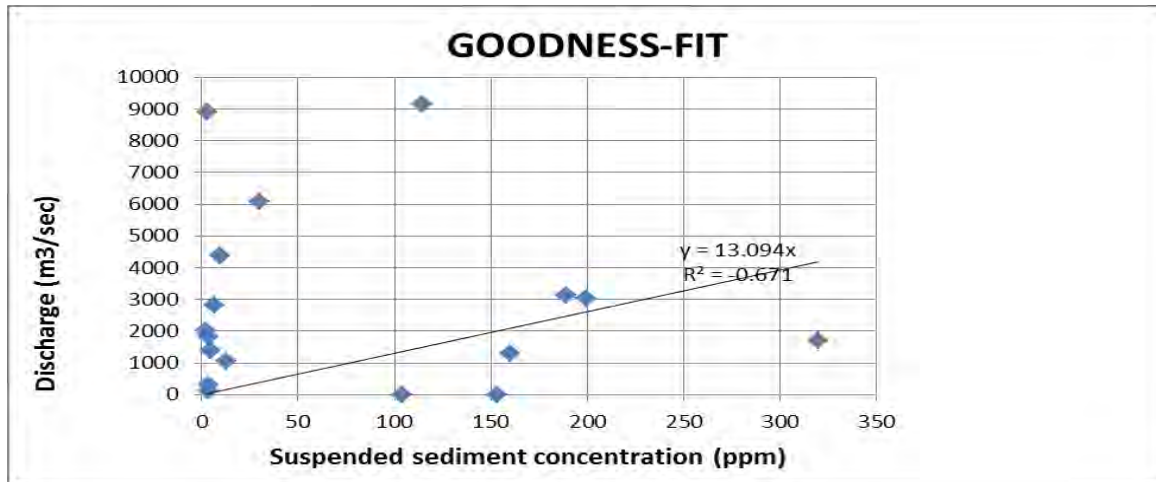


Figure 6.10 Goodness-of-fit of simulated sediment concentration by weight and discharge.

The correlation between sediment concentration and discharge of the watershed shows good correlation since  $R^2 > 0.5$ .

### 6.2.7 Comparison with Previous Studies and Estimates from Other Reservoir

Before calibration proceeds, the performance of the model was evaluated from the initial simulation with model default parameter values. The monthly simulations of Mille watershed were resulted Coefficient of determination ( $R^2$ ), Nash – Sutcliffe Coefficients (NSE) and percent of bias (PBIAS) of 0.44, 0.40, and 17% respectively. The result shows the performance indicator was below the acceptable limits, i.e.  $R^2 > 0.6$ ,  $NSE > 0.5$  and  $PBIAS < \pm 15\%$  (Santhi et al., 2001). After each simulation, the model goodness-of-fit was evaluated and the model performance after adjusting all the above parameters shows the  $R^2$ , NSE and PBIAS in monthly basis indicates 0.88, 0.84 and 1.2% respectively.

After adjustment of all the above parameters, the Mille watershed the monthly simulations were results Coefficient of determination ( $R^2$ ), Nash – Sutcliffe Coefficients (NSE) and percent of bias (PBIAS) of 0.82, 0.8 and 14% respectively. The simulation result in daily time step the  $R^2$ , NSE and PBIAS were 0.55, 0.48 and 65.4% respectively (Table 5-8). So, in the daily time step the estimation of sediment yield by the model were under the acceptance limit of the SWAT developers recommendation (i.e.  $R^2 > 0.6$ ,  $NSE > 0.5$  and  $PBIAS < \pm 20\%$  Santhi et al., 2001).

The model over predicted the sediment yield from Chitlang Khola sub-catchment compared to the observed sediment yield.

On 19th of July the model predicted 358.3 tons of sediment yield whereas the measured sediment on the same date was only 2.9 tons per given hours while rainfall event on 19th of July 2004 was 67.5 mm. Therefore, the model responded well for rainfall event. The total observed and simulated sediment yield from Chitlang Khola sub-catchment of 21.5 km<sup>2</sup> area was 937 tons and 1262 tons respectively. The specific sediment yield for Chitlang Khola sub catchment of

21.5 km<sup>2</sup> area was 57.6 tons/km<sup>2</sup> compared to the specific sediment yield of 43.5 tons/km<sup>2</sup> calculated by Sangroula (2005).

The coefficient of determination (R<sup>2</sup>) and the Nash-Sutcliffe efficiency were found to be 0.54 and 0.53 for Palung Khola and 0.40 and 0.1 for Chitlang Khola. The range of Nash-Sutcliffe efficiency varies between 1.0 (perfect fit) and Since the NS coefficient is sensitive to extreme values (as it squared the difference of observed and simulated values), it might yield suboptimal results when the dataset contains large outliers.(Lemma,2015)

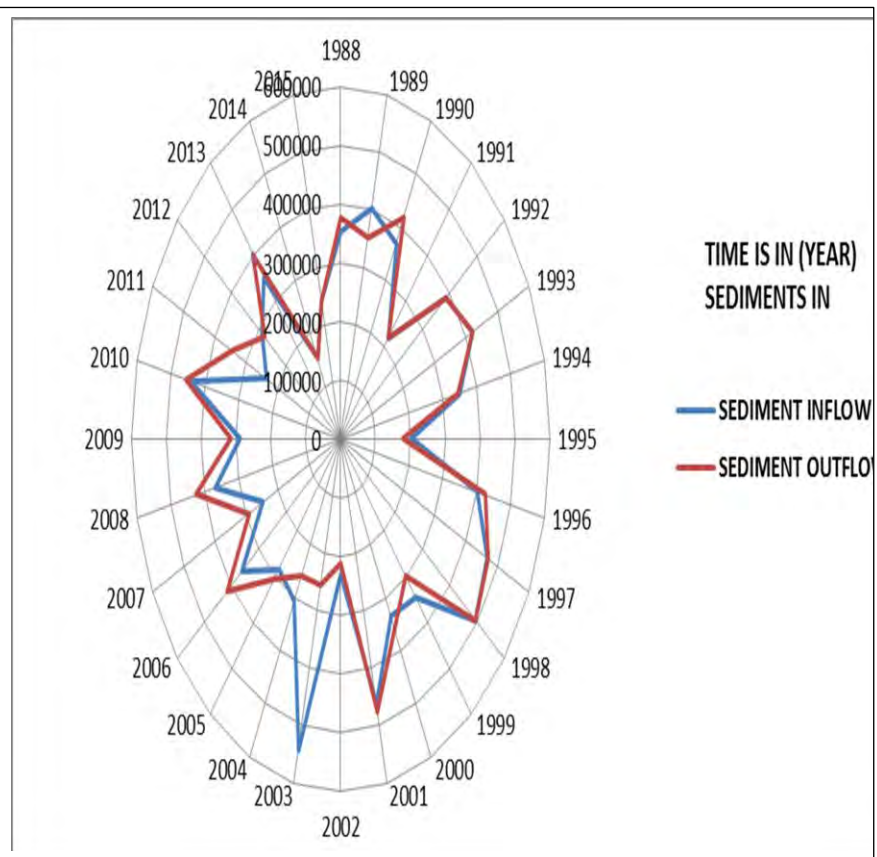
The mean annual sediment load estimates by USBR (1964) and BCEOM (1999) for the Ribb dam site were 260,000 ton (363 ton/km<sup>2</sup>/year) and 490,000 ton (675 ton/km<sup>2</sup>/year) respectively. Design report of MoWE estimate 897 ton/km<sup>2</sup>/year based on the 1964 -2005 data it is higher than the above mentioned estimates for the dam site.

Bathymetric survey conducted on Legedadi and Gefersa reservoirs in 1979 and 1989 showed mean annual sediment deposition of 760 ton/km<sup>2</sup>/year and 1,200 ton/km<sup>2</sup>/year, respectively. The Hydrology Department of the MoWR conducted bathymetric survey on Angerb reservoir (a tributary of Megech River with watershed area 48 km<sup>2</sup>) and found that a mean annual sediment deposition of 0.14 Mm<sup>3</sup> estimated over ten years (1995-2004), taking the density of sediment as 1.2 gm/cc the sediment yield is 3500 ton/km<sup>2</sup>/year, which is very high. Studio Pietrangeli (2005) gave a comparison of total sediment load estimate for five hydropower reservoirs. Mott MacDonald (2004) estimated 57 665 ton/year (350 tons/km<sup>2</sup>/year) sediment deposition in Koga reservoir.

In this study SWAT model estimate of Ribb Dam reservoir sediment load of 72.79 ton/km<sup>2</sup>/year is very much less than the previous studies at dam site but very close to study of BCEOM (1999) for Upper Ribb River near Debre Tabor which is down stream of dam site

**Table 6. 10** Propagation of sediment inflow and **outflow from simulated watershed.**

YEAR	SED_INtons	SED_OUTtons
1988	352100	377400
1989	403500	351900
1990	367800	419400
1991	220100	220100
1992	386300	386300
1993	420300	420300
1994	350200	346700
1995	202800	180400
1996	402500	425500
1997	466700	469500
1998	494000	494000
1999	346400	298500
2000	332900	356400
2001	463500	476300
2002	229700	210900
2003	542400	256200
2004	306200	258500
2005	283000	304300
2006	361900	417600
2007	247200	291700
2008	367700	425200
2009	288000	313800
2010	442100	455000
2011	237100	344800
2012	288600	278200
2013	352400	401700
2014	153100	153100
2015	241900	241900



**Figure 6. 11** Propagation of sediment inflow and outflow from simulated watershed.

At 1998 year the sediment inflow is the highest of the watershed which is 494000 tones.

### 6.3 Land use/land cover and management scenarios

Scenarios are reasonable and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about key driving forces and relationships.

**Table 6. 11** Land use summary to determine erosive area

Setup	Hydrology	Sediment	Nitrogen Cycle	Phosphorus Cycle	Plant Growth	Landscape Nutrient Losses	Land Use Summary	Instream Processes	Point Sources	Reservoirs	About		
Summary By Reported Landuse													
	LULC	AREA km2	CN	AWC mm	USLE_LS	IRR mm	PREC mm	SURQ mm	GWQ mm	ET mm	SED th	NO3 kgh	ORGN
▶	AGRC	2,686.30	79.15	70.40	1.02	0.00	1,412.62	284.73	481.99	600.36	1.51	4.14	
	FRSD	821.80	66.00	88.09	1.67	0.00	1,548.12	39.22	723.46	676.95	0.06	0.14	
	RNGE	94.04	76.46	66.18	0.70	0.00	1,558.38	279.92	529.14	701.77	0.95	0.06	

1.51

Agricultural land close grown is the most vulnerable area affected by erosion and then to the sediment and the scenario should done to replace Agricultural land close grown by forest to reduce sediment.

Land use refers to human activities that are directly related to land, making use of its resources and interfering in the ecological processes that determine the functioning of land cover (Niehoff et al., 2002). Land cover refers to the surface appearance of the landscape, which is mainly affected by its use its cultivation and the seasonal phenology (Niehoff et al., 2002). Land use/land cover patterns are highly dynamic and rarely in a stable equilibrium (Niehoff et al.2002). Therefore, analyzing the effect of land use/land cover change on the hydrology and sediment transport is one of the essential parts of this study. To do this it is necessary to develop scenarios or to see land summary that reflect the changes made to the watershed land use.

Identifying erosion prone areas in the watershed enables the watershed management to be applied to the proper areas to reduce the sediment yield. Spatial analysis of sediment prone areas is one of the many tasks SWAT can do while modeling sediment. SWAT is powerful in spatial visualization of sub-basin or HRU level detail so that one can see which area produces high sediment and which area produces less.

Based on the watershed area delineated by Arc SWAT and the land use adopted in this study Gilgel gibe-I watershed consists of about 69% of agricultural land, about 22 % of forest cover about 7 % of Range grass and about 2% is other land use. The scenario development was made by changing the agricultural land to forest cover by 10%, 30%, 50%, 70%, 100%, and two best Management Practices (BMP): applying filter strip and terracing. These scenarios were developed to evaluate the sediment yield change from the watershed. Applying filter strip and terracing (stone bunds) in low slope areas of the catchment could give potential effect of BMPs (Betrie et al., 2011).

- ✚ Filter Strips: A filter strip is a strip of dense vegetation located to intercept runoff from upslope pollutant sources and filter it. Filter strips increase sediment deposition by reducing overland flow velocity before it joins the tributary and main channel. Filter strips reduce sediment, nutrients, bacteria, and pesticides, but do not affect surface runoff in SWAT (Arnold et al., 2012). Filter strip was applied to the land slope between 0 and 25%.
- ✚ Terracing: a terrace is an embankment within a field designed to intercept runoff and prevent erosion. It is constructed across slope on a contour. Terracing in SWAT is simulated by adjusting both erosion and runoff parameters (Arnold et al., 2012). The USLE practice (TERR\_P) factor, the slope length (TERR\_SL) factor and curve number (TERR\_CN) were adjusted to simulate the effects of terracing. Like filter strip, terracing was also applied the land slope between 0 and 25%.

The scenarios are:

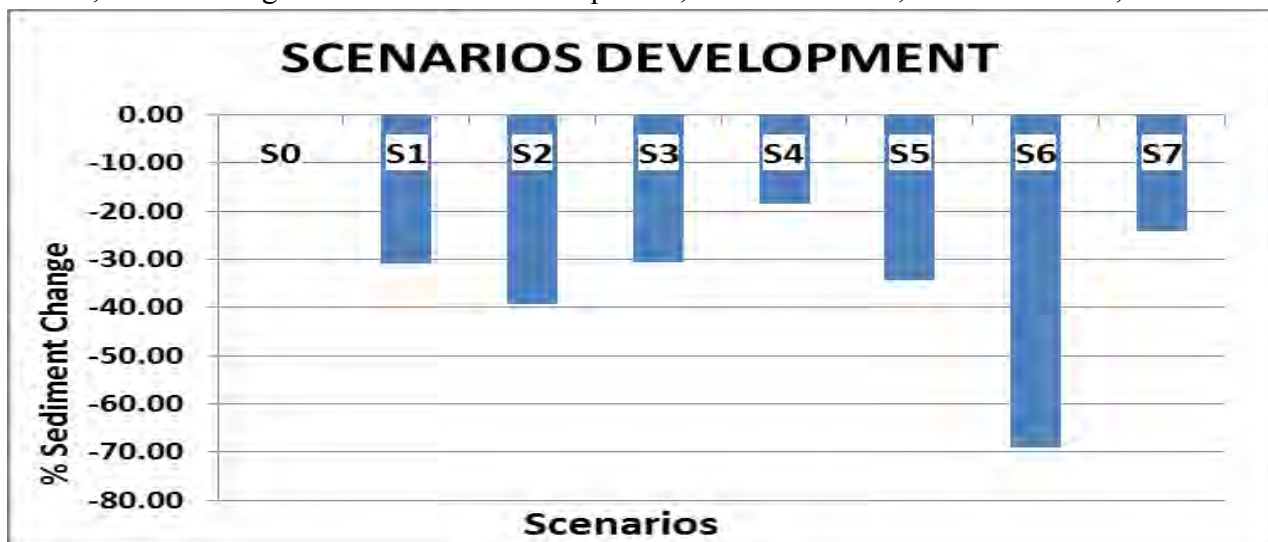
1. Scenario\_1: 10% of agricultural land is changed to forest
2. Scenario\_2: 30% of agricultural land is changed to forest
3. Scenario\_3: 50% of agricultural land is changed to forest
4. Scenario\_4: 70% of agricultural land is changed to forest
5. Scenario\_5: 100% of agricultural land is changed to forest
6. Scenario\_6: Applying filter strip to agricultural and forest area between a slopes of 0 to 25%
7. Scenario\_7: Applying terracing to agricultural and forest area between slopes of 0 to 25%

The result from the simulation was summarized in Table 6.12.

**Table 6.12** Summary of scenario development result.

Scenarios	Period (2008-2015)		
	Total annual sediment load (tons)	Average sediment yield (tons/Km2/yr)	Sediment change (%)
S0	425200	118.0455303	0.00
S1	313800	87.11826763	-30.93
S2	455000	126.3187118	-39.20
S3	344800	95.72459745	-30.59
S4	278200	77.23486952	-18.49
S5	401700	111.521377	-34.29
S6	153100	42.50416435	-69.02
S7	241900	67.15713493	-24.27

Where, S0 is the original land use/land cover pattern, S1 is scenario 1, S2 is scenario 2, &etc



**Figure 6.12** Comparison of change of sediment load.

## 7. Conclusions and Recommendations

### 7.1. Conclusions

SWAT model for Gilgel Gibe-I watershed was compiled and calibrated and then validated for stream flow and suspended sediment concentrations. The watershed parameters were derived from DEM resulting in 15-sub-basins, Sub-basins were further broken down in to hydrological response units based on the land use and soil data. This resulted in 72 HRU's. In this study, a conceptual, distributed parameter, continuous time, river basin model, SWAT2012 was used to simulate runoff and sediment from Gilgel Gibe-I watershed of river basin in Omo.

Sensitivity analysis is performed to select important model parameters; Automatic calibration SWAT CUP is performed for stream flow using measured data at Asendabo gauging station for a period of 1989-2006. It is shown that the model could adequately represent stream flow for monthly time steps. It is shown that the model performed well with ENS and R2 0.68 and 0.67 respectively for flow calibration.

The model was validated for the stream flow for the period of 2007-2014. The model performed well monthly time steps with ENS and R2 0.58 and 0.57 respectively.

The model is then calibrated with sediment flow data that is taken from ministry of water resource and energy during (1990-2010).

It is shown that suspended sediment concentration Asendbo station river watershed could be represented by SWAT model with calibration value R2 and ENS 0.79 and 0.78 respectively.

The model was validated for a period of (2011-2014) and the model could adequately represent suspended sediment concentrations at Gilgel Gibe-I river watershed R2 value 0.76 and NS 0.48.

The calibrated and validated SWAT model for Gilgel Gibe-I watershed can then be used to assess the impact of land use changes, management practices, and climate change impacts on flow and sediment dynamics in the watershed.

The global sensitivity analysis of the SWAT parameters showed that runoff is most sensitive to curve number (CN), followed by Ground water revap coefficient (GW\_REVAP), effective Average slope steepness (HRU\_SLP). The sensitivity analysis of the SWAT parameters showed that sediment yield is most sensitive to upland factors such as USLE soil erodibility factor (USLE\_K), USLE cover and management factor (USLE\_C) and USLE support and practice factor (USLE\_P).

In general, if most of the sediment added to the channel is caused by gully erosion and landslide, then the SWAT prediction could not match with the observation as it only considers only rill and sheet erosion by MUSLE equation.

The specific sediment yield based on the observed and simulated sediment load by SWAT model from the watershed of area 3602 km<sup>2</sup> was 955.598 tons/km<sup>2</sup> and 956.774 tons/km<sup>2</sup> respectively.

The annual specific sediment yield from the watershed can be calculated as the ratio of the total annual sediment yield to the area of the watershed and the value is 106.178 tons/km<sup>2</sup>/yr.

Applying filter strip and terracing (stone bunds) in low slope areas of the catchment could give potential effect of best management practice.

## 7.2 Recommendations

The reliability of data is of primary importance for carrying out any modeling studies.

Therefore, the statistical reliability and dependency of this data needs to be checked prior to its application.

Short period of runoff and sediment yield record of observation data was used in this study.

Using longer period of runoff and sediment data will improve the calibration result.

Using spatially distributed rainfall data could have increased the accuracy of the simulation result.

The way of holding data in our country specially DEM, Land use/land cover and Soil map was of poor quality and no one updating them. Therefore, this might greatly affect the output results, water balance and sediment yield and representative and high resolution geospatial data is recommended to improve the result.

The calibrated model can be used for further analysis of the effect of climate and land use change as well as other different management scenarios on stream flows and soil erosion.

MoWR must collect data on river flow and sediment data on daily basis @ bottom outlets.

After complete silting-up, reservoirs can be used for cultivation or a forestation. Sediments could also be used for other purposes such as material for the tile/ceramics/brick industry, improvement of poor agricultural lands, etc. If it is decided to dispose of sediment from a reservoir or silt /sediment trap, it will be necessary to determine the composition and properties of the settled sediments and identify possible users/uses.

Finally I suggest that since SWAT is efficient model in estimating sediment yield from watershed and sediment concentration in stream different researchers have to use SWAT before planning and design of reservoirs.

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# Appendices

## Appendix A

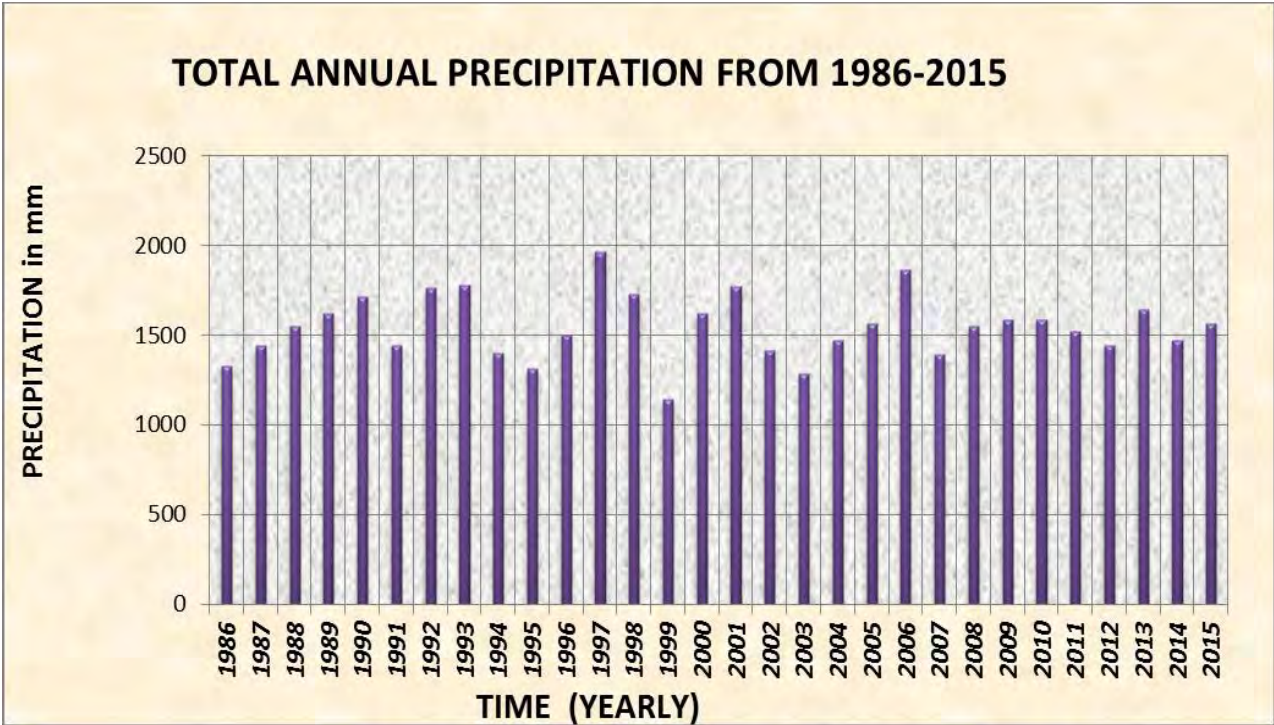


Figure A.1 Total annual precipitation from (1986-2015)

## Appendix B

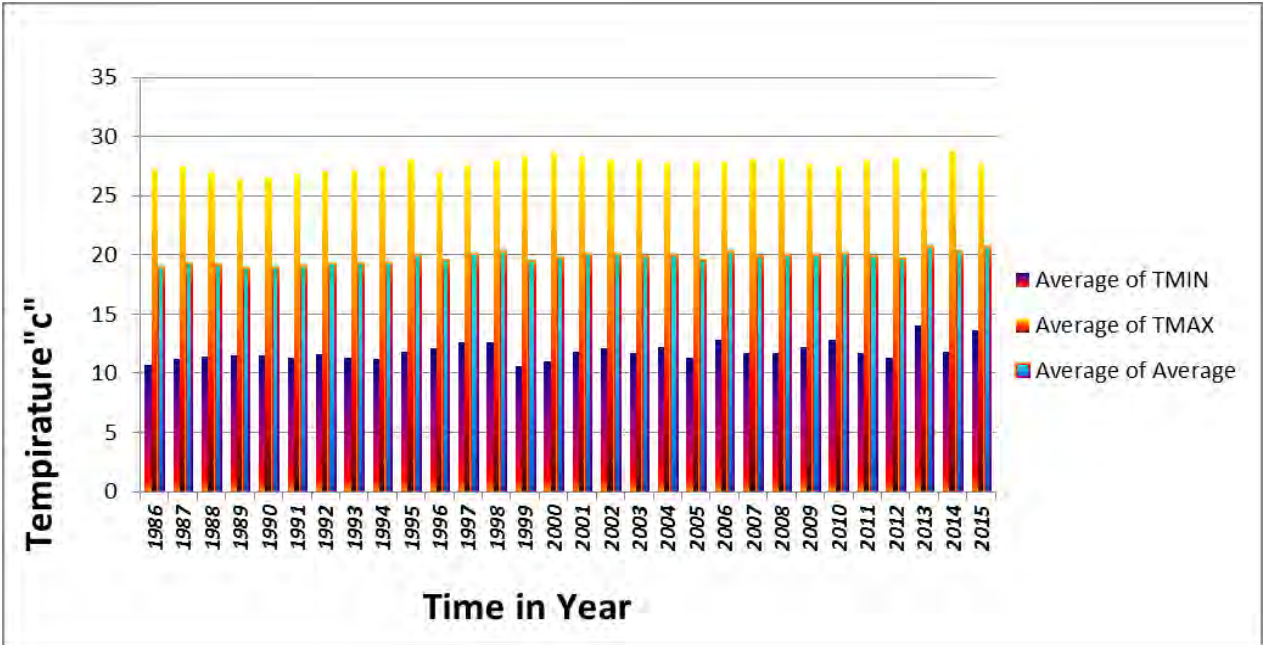


Figure B.1 Daily maximum/minimum air temperature at Jimma

Appendix C

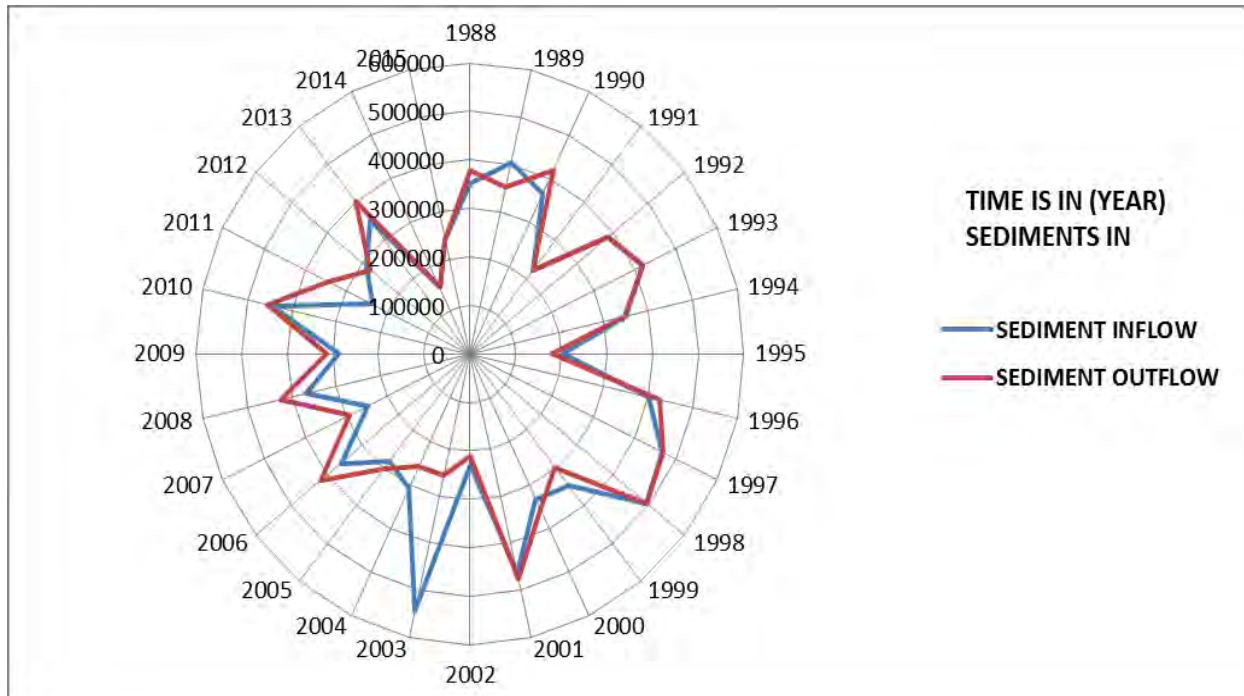


Figure C.1 Propagation of sediment inflow and outflow from simulated watershed.

Appendix D

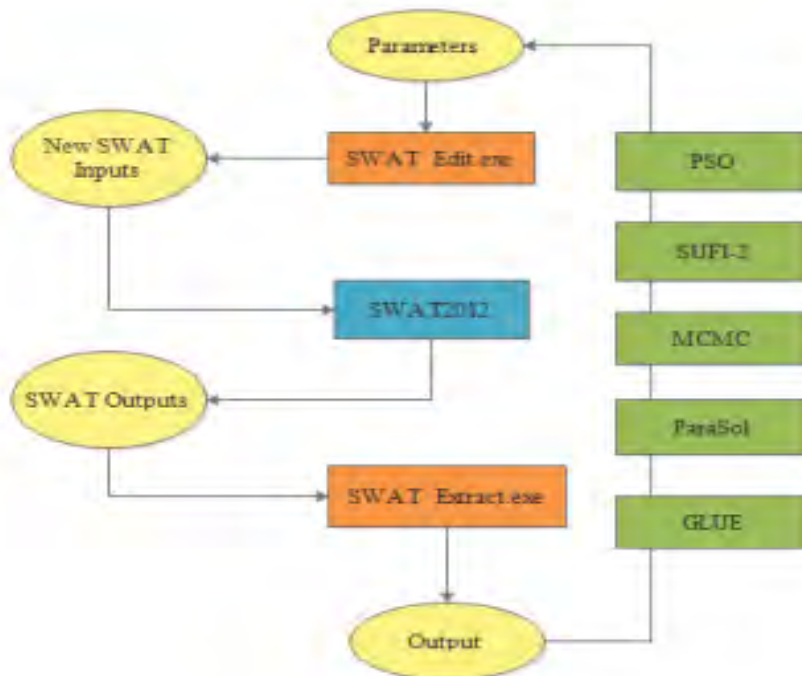


Figure D.1 Overall programmed structures of SWAT\_CUP/ The link between SWAT (orange), SWAT (green), and SUFI2 (yellow)The entire algorithm is run by two batch files:

SUF12\_pre.bat and SUF12\_post.bat (Modified from user manual for SWAT\_CUP by Abbaspour, 2007)

Table A.2 Total Monthly Precipitation Data (1986 - 2015)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total Yearly PCP
1986	0	48.2	81.7	115	151	256	232.5	133.8	163	88.6	13.9	47.4	1330.8
1987	26.4	88.5	157.7	59.8	188	204	185.5	180	136	116	45.6	51.9	1439.6
1988	81.3	59	30.9	87.1	182	165	184.6	294	292	172	1.5	0	1549.1
1989	27.8	46.8	138.2	179	102	179	232	213.3	204	107	28.3	161.3	1618.3
1990	24.6	46	132.9	56	194	320	279.6	280.2	245	22.9	92.5	18.7	1711.7
1991	79.4	80.9	61.9	169	110	223	199.7	244.3	140	50.7	7.8	78.1	1443.6
1992	28.4	56.4	55.9	162	144	287	212.2	356	175	180	69.7	35.6	1761.6
1993	78.7	80.8	119.7	237	237	225	188.7	262.6	171	174	3	0.3	1777.4
1994	0.9	28.2	96.5	153	213	274	255.4	159.2	177	11.1	18.1	10.5	1397.3
1995	8.2	17.2	74	193	115	163	181	216.4	141	48.5	30	126.1	1313.7
1996	40.8	23.4	135.5	203	175	197	231.5	91	248	23.9	93.1	40.4	1502.1
1997	66	0	68.7	178	275	237	122.4	256	148	337	243	36.1	1966.7
1998	102.5	22.4	96.5	93.2	184	223	248.4	306.7	200	201	46.5	1.4	1724.4
1999	29.8	0.7	82.4	71.8	214	175	136.1	102.3	131	198	1.3	2	1143.8
2000	0	1	39.3	195	238	154	265.9	158.7	255	244	46.8	24.9	1621.9
2001	16.2	12.9	85.9	117	341	299	312.3	160.8	183	163	75.8	3.8	1771.4
2002	68.9	5	91.2	89.7	137	242	149.7	234.9	165	79.6	8.1	138.4	1409.7
2003	28.7	61.3	86.9	111	12.2	272	186.7	150.9	239	91.7	29.9	14.6	1285.3
2004	51	28.4	46.1	131	162	128	216.3	219.4	201	133	67.3	84.2	1468.1
2005	44.5	0.5	193.8	141	174	177	273.5	227.8	229	68.3	29.7	0	1559.6
2006	15.8	77.1	181.8	110	212	207	327.2	240.2	170	91.1	128	100.2	1860.1
2007	37.5	51	104.1	122	196	143	247.4	177	256	50.8	5.9	0	1390.2
2008	34	12.3	39.4	113	249	238	209.8	236.8	133	186	92.9	6.3	1550.9
2009	63	29.5	79.8	103	244	160	149.6	304.7	209	92.2	78.4	67.7	1581.3
2010	27.3	88.4	67.4	101	193	395	181.3	203.5	187	37	96.2	10.5	1587.1
2011	24.1	7.5	39.3	151	193	311	189.9	192.1	270	10.3	105	26	1518.9
2012	2.1	1.8	55.8	155	119	335	223.9	132.7	251	32.8	77.4	57.7	1442.9
2013	34.9	31.3	109.4	95.8	306	193	151.5	255.2	183	168	115	1	1644.2
2014	17.8	16.8	115.3	123	127	117	271.3	265.6	142	127	123	25.9	1472.6
2015	6.1	16.9	77.5	176	127	123	127.1	243.2	254	127	155	127.1	1560.6

## Appendix E

Table E.1 Average daily precipitation in a month from 1986 to 2015 is shown in below.

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1986	0	1.72	2.64	3.83	4.86	8.5	7.5	4.32	5.44	2.9	0.46	1.53
1987	0.85	3.16	5.09	1.99	6.05	6.8	5.98	5.81	4.53	3.8	1.52	1.67
1988	2.62	2.03	1	2.9	5.86	5.5	5.95	9.48	9.73	5.6	0.05	0
1989	0.9	1.67	4.46	5.96	3.3	6	7.48	6.88	6.8	3.5	0.94	5.2
1990	0.79	1.64	4.29	1.87	6.25	11	9.02	9.04	8.15	0.7	3.08	0.6
1991	2.56	2.89	2	5.63	3.53	7.4	6.44	7.88	4.65	1.6	0.26	2.52
1992	0.92	1.94	1.8	5.39	4.63	9.6	6.85	11.48	5.84	5.8	2.32	1.15
1993	2.54	2.89	3.86	7.89	7.65	7.5	6.09	8.47	5.7	5.6	0.1	0.01
1994	0.03	1.01	3.11	5.11	6.85	9.2	8.24	5.14	5.9	0.4	0.6	0.34
1995	0.26	0.61	2.39	6.43	3.72	5.4	5.84	6.98	4.7	1.6	1	4.07
1996	1.32	0.81	4.37	6.77	5.64	6.6	7.47	2.94	8.27	0.8	3.1	1.3
1997	2.13	0	2.22	5.93	8.86	7.9	3.95	8.26	4.94	11	8.11	1.16
1998	3.31	0.8	3.11	3.11	5.92	7.4	8.01	9.89	6.66	6.5	1.55	0.05

1999	0.96	0.03	2.66	2.39	6.89	5.8	4.39	3.3	4.36	6.4	0.04	0.06
2000	0	0.03	1.27	6.49	7.67	5.1	8.58	5.12	8.51	7.9	1.56	0.8
2001	0.52	0.46	2.77	3.89	11.01	10	10.1	5.19	6.11	5.3	2.53	0.12
2002	2.22	0.18	2.94	2.99	4.43	8.1	4.83	7.58	5.51	2.6	0.27	4.46
2003	0.93	2.19	2.8	3.71	0.39	9.1	6.02	4.87	7.96	3	1	0.47
2004	1.65	0.98	1.49	4.36	5.22	4.3	6.98	7.08	6.7	4.3	2.24	2.72
2005	1.44	0.02	6.25	4.71	5.61	5.9	8.82	7.35	7.64	2.2	0.99	0
2006	0.51	2.75	5.86	3.68	6.82	6.9	10.6	7.75	5.66	2.9	4.25	3.23
2007	1.21	1.82	3.36	4.05	6.33	4.8	7.98	5.71	8.54	1.6	0.2	0
2008	1.1	0.42	1.27	3.76	8.03	7.9	6.77	7.64	4.45	6	3.1	0.2
2009	2.03	1.05	2.57	3.44	7.86	5.3	4.83	9.83	6.98	3	2.61	2.18
2010	0.88	3.16	2.17	3.38	6.22	13	5.85	6.56	6.22	1.2	3.21	0.34
2011	0.78	0.27	1.27	5.04	6.22	10	6.13	6.2	8.98	0.3	3.5	0.84
2012	0.07	0.06	1.8	5.15	3.83	11	7.22	4.28	8.35	1.1	2.58	1.86
2013	1.13	1.12	3.53	3.19	9.87	6.4	4.89	8.23	6.11	5.4	3.82	0.03
2014	0.57	0.6	3.72	4.1	4.1	3.9	8.75	8.57	4.74	4.1	4.1	0.84
2015	0.2	0.6	2.5	5.88	4.1	4.1	4.1	7.85	8.47	4.1	5.17	4.1

Appendix F

Table F.1 Mean monthly flows at the outlet of the Gilgel gibe-I watershed.

Years	Months											
	Jan	Feb	March	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
	FLOWS m3/sec											
1988	4.857489	5.105574	2.039053	1.783355	4.24926	13.18832	70.4857	192.7601	150.76	116.6149	25.20004	9.019735
1989	5.849428	6.154856	4.267875	25.78344	13.98706	33.47798	64.14803	94.43768	95.82238	51.08423	18.36299	20.73599
1990	10.04764	7.940152	11.86143	10.94198	20.01272	59.66288	113.4899	93.62213	148.6077	220.9368	114.6804	11.67607
1991	7.681395	6.469311	9.130401	5.662752	12.92783	42.4965	84.06485	139.2152	104.0518	24.8771	4.139907	3.194314
1992	0.77777	1.734335	0.166327	1.577907	14.59171	51.83203	109.4509	231.1698	146.1754	91.88489	24.44551	9.428475
1993	8.966685	13.01714	5.482365	24.84807	65.54804	95.71677	155.4026	146.6384	103.6992	74.27754	40.77045	12.3906
1994	7.22055	3.914544	5.220705	6.125905	26.55086	86.50264	157.8976	207.45	153.6359	33.48062	13.87632	7.110908
1995	3.977279	3.749888	3.089906	9.908393	14.51131	18.62208	57.13547	79.57666	96.48927	23.01369	9.770248	7.573878
1996	7.932715	6.481145	5.678903	15.97387	68.99313	111.2723	104.563	152.5458	110.8028	56.81135	21.16761	10.95454
1997	8.927055	15.40132	2.988646	20.9936	32.03224	86.41943	88.10631	128.9891	88.32426	165.3539	170.8472	65.30601
1998	33.66157	19.82029	20.013	14.38563	25.49033	36.9279	106.8716	212.0879	122.407	104.388	41.88886	18.21035
1999	12.25659	7.16384	8.901159	7.382464	20.01469	43.37238	94.03827	132.5382	72.6619	88.50856	31.72634	13.29107
2000	7.761286	4.51501	2.905056	8.874402	24.20452	36.35368	79.22235	100.6557	107.1352	91.65514	44.54793	18.62901
2001	27.96035	28.76516	30.08618	29.24946	44.46365	82.53609	141.3976	129.6332	94.5476	60.76926	36.32831	59.70208
2002	11.93254	7.177609	8.838388	11.8782	8.683566	36.22363	70.82954	93.36876	74.71386	26.7971	14.92503	15.14984
2003	12.95935	6.440249	11.02479	12.21419	7.007247	29.64893	97.71677	103.9684	115.3995	37.54947	15.54374	12.12841
2004	7.866481	5.824827	5.00566	8.176196	16.35741	39.7683	80.94779	120.9097	116.6795	94.79467	24.94957	15.96209
2005	11.16276	5.906456	12.53837	10.7236	49.56573	42.34449	82.2158	157.9148	153.3952	63.30855	24.03481	12.16159
2006	9.38365	11.26439	11.97316	14.78896	17.57449	43.83541	143.4731	206.2676	132.843	63.47388	36.0122	28.32136
2007	18.58701	18.70439	11.38177	18.6645	25.60996	70.48766	120.5069	140.2494	168.7296	80.21665	20.52443	11.32333
2008	8.892305	7.027032	4.621045	8.295919	19.07376	55.31114	98.25849	138.689	113.1502	38.90741	67.80069	17.60055
2009	12.30527	10.53535	7.814887	11.88585	10.72911	18.28686	46.01616	132.1743	96.43112	69.19419	19.38348	17.12557
2010	11.55903	9.538309	10.31392	13.06177	38.61548	87.22626	124.5133	147.9086	214.9927	51.26046	20.47347	14.05102
2011	10.56713	7.28462	7.157937	8.072699	17.71475	61.20142	90.80232	122.4349	167.1028	40.19196	28.90371	13.61307
2012	7.898123	4.838057	4.400461	8.652077	9.598173	38.10581	93.92241	122.5634	156.6957	49.22196	18.40516	12.50941
2013	8.473175	5.773127	8.259125	9.346176	22.83352	48.02144	112.1897	160.7732	160.0855	94.62588	29.33396	16.32942
2014	11.6072	8.884476	10.30833	27.3014	71.82164	57.26713	114.3454	210.1809	129.2929	102.3119	21.99717	14.82776

Table C.2 Propagation of sediment inflow and outflow from simulated watershed.

YEAR	SED_INtons	SED_OUTtons
1988	352100	377400
1989	403500	351900
1990	367800	419400
1991	220100	220100
1992	386300	386300
1993	420300	420300
1994	350200	346700
1995	202800	180400
1996	402500	425500
1997	466700	469500
1998	494000	494000
1999	346400	298500
2000	332900	356400
2001	463500	476300
2002	229700	210900
2003	542400	256200
2004	306200	258500
2005	283000	304300
2006	361900	417600
2007	247200	291700
2008	367700	425200
2009	288000	313800
2010	442100	455000
2011	237100	344800
2012	288600	278200
2013	352400	401700
2014	153100	153100
2015	241900	241900

**Table G.1 Average sediment yield (tons/ha) from the watershed.**

Sub-basin	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1988	377400	60710	20750	49140	53810	269500	159900	25530	133600	12030	145100	190800	70380	30590	49620
1989	351900	85160	16650	75680	45670	281900	160800	37110	123600	11620	132800	159900	67170	24060	38540
1990	419400	51910	24410	42330	53490	298000	194900	21910	171400	5708	156000	199200	34500	35520	56720
1991	220100	29090	18900	23930	35940	180500	117000	12420	104200	8409	104300	135900	53490	27430	43180
1992	386300	55150	19490	47340	55470	310300	204400	23730	180000	11870	153500	187900	70370	28270	45670
1993	420300	66760	20570	59560	59090	327700	207600	29220	177600	8190	123500	159900	49270	31220	48200
1994	346700	71330	13660	63250	51120	250900	137800	31050	107000	3245	66900	91830	19670	21690	32540
1995	180400	38210	15530	32470	25050	150400	95310	16550	80850	4595	61710	78750	29580	25920	35810
1996	425500	70550	19460	61930	50180	305400	184700	30730	149700	10070	152600	196300	60740	30730	46250
1997	469500	77390	26180	65050	67000	359700	220800	33320	186500	10880	169300	223700	64900	43320	61760
1998	494000	77970	25570	63780	58310	385300	254200	33650	219500	19210	216600	264700	116600	42300	61570
1999	298500	76890	10330	66010	33400	239900	136800	33480	102400	32670	140800	159200	108200	15110	22610
2000	356400	47980	18320	32560	33530	269600	190100	19160	170100	7462	148000	181100	43440	27640	40630
2001	476300	86950	22000	75930	62840	343900	201800	37840	163000	13940	159500	196600	80360	35440	51850
2002	210900	48990	14430	41800	27610	162700	98850	21250	81610	6453	84570	110100	35740	22950	32810
2003	256200	170500	12580	163600	31560	301000	153900	77750	94070	7131	101700	129300	40840	18980	28940
2004	258500	47020	17710	39980	35640	242200	127600	20330	85630	3259	70130	96240	20300	28200	41440
2005	304300	46310	23480	38470	41840	220500	130900	19700	107800	6422	97040	140500	40700	37100	52440
2006	417600	59280	24920	53610	57230	279800	168500	26160	141700	4333	135900	186500	27790	41830	58930
2007	291700	38270	12720	31890	37400	195400	123000	16420	106100	3058	91130	118500	19650	19750	29540
2008	425200	60320	19930	45360	50460	284600	176900	24860	151000	14760	164300	198800	89460	29870	46350
2009	313800	56440	20700	45150	42420	210600	124700	23880	105100	564	73020	109500	3012	32610	47750
2010	455000	75240	23630	65320	53080	338000	207600	32530	169200	15510	190900	237300	94630	38530	56090
2011	344800	27450	19210	22910	45860	199800	128300	11740	116200	503.8	61640	95880	2662	29920	46200
2012	278200	55670	17170	39640	37720	212400	122200	22460	98890	1660	65290	96860	10220	27020	40100
2013	401700	58830	21490	50440	58800	271900	159300	25310	133300	2002	92900	133800	11980	35250	49650
2014	153100	15240	11370	11380	28360	133200	90690	6237	84230	599.5	38950	59280	3351	17530	27170
2015	241900	14800	13850	11100	46460	222500	162000	6057	155700	4794	78130	103800	27890	21940	33370



Figure H.1 General Layout of the Gilgel gibe-I and II hydroelectric system.

(Source: ENEL/ELC, Gilgel Gibe Hydroelectric Project – Feasibility Study, (1998).)