



ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

Estimation of Sediment Yield Using SWAT Model and Reduction Methods

**(A Case Study of the Middle Awash Multipurpose Dam, Awash River Basin,
Ethiopia)**

By

Saba Kidane Gebrekristos

A Thesis Submitted and Presented to the School of Graduate Studies of Addis Ababa University in partial fulfilment of the requirement for the Degree of Masters of Science in Civil Engineering (Hydraulic Engineering Stream)

Advisor

Daneal Fikresillassie (PhD)

February, 2024

Addis Ababa, Ethiopia

Addis Ababa University
Addis Ababa Institute of Technology
School of Civil and Environmental Engineering

Estimation of Sediment Yield Using SWAT Model and Reduction Methods
(A Case Study of the Middle Awash Multipurpose Dam, Awash River Basin, Ethiopia)

By
Saba Kidane

A Thesis Submitted and Presented to the School of Graduate Studies of Addis Ababa
University in Partial Fulfilment of the Degree of Masters of Science in Civil Engineering
(Hydraulic Engineering Stream)

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

Estimation of Sediment Yield Using SWAT Model

(A Case Study of the Middle Awash Multipurpose Dam, Awash River Basin, Ethiopia)

A thesis submitted to the school of graduate studies in partial fulfilment of the requirements for the Master of Science degree in civil and engineering (Hydraulics engineering stream)

By

Saba Kidane Gebrekristos

Approval by Board of Examiners

Daneal F/Sillasse

Advisor

Daneal F/S

Signature

15/4/2024

Date

Getachew Berhane

Internal Examiner

[Signature]

Signature

30/04/2024

Date

Dereje Hailu

External Examiner

Dereje H.

Signature

08/05/24

Date

Chairman (Department Of Graduate Committee) Signature

Date

Abrham Gebre (Dr.)
Dean, School of Civil &
Environmental Engineering



CERTIFICATION

I, the undersigned, certify that I have read and here by recommend for acceptance by Addis Ababa Institute of Technology a thesis entitled **Estimation of Sediment Yield using SWAT Model and Reduction Methods (A Case Study of the Middle Awash Multipurpose Dam, Awash River Basin, Ethiopia)** in partial fulfilment of the requirement for the degree of master of science in civil engineering (Major Hydraulic Engineering).

Daneal FTS

Dr. Daneal Fikresillassie

(Supervisor)

May 22nd / 2024

Date

DECLARATION

I, Saba Kidane Gebrekristos, declare that this thesis entitled “**Estimation of Sediment Yield using SWAT Model and Reduction Methods (A Case Study of the Middle Awash Multipurpose Dam, Awash River Basin, Ethiopia)**” is my own original work and I am the sole author. The work has not been presented elsewhere for any assessment. The materials that have been used from other sources are well acknowledged and referred properly.



Saba Kidane Gebrekristos

DEDICATION

I would like to dedicate this study in memory of my mother **Kidist Yemane Birhan Gebrekidan** and my father **Kidane Gebrekristos Kidanu!**

I wish I could cherish this moment with you to the fullest!

ACKNOWLEDGEMENT

To begin with, I am grateful to the almighty God who provides me this opportunity to proceed with success and for all the wonderful things he did in my entire life.

Then, I would like to express my wholehearted gratitude to my advisor, Dr. Daneal F.Sellassie, for his priceless support of my MSc. Research work, for his profound guidance and constant encouragement. His guidance helped me in all the time of research and writing of this thesis.

Besides my advisor, I would like to express my heartfelt appreciation to Dr. Belete Berhanu for his valuable support and comments about the watershed and SWAT model.

I am also thankful to my employer Assosa University for the chance they gave me to further study a postgraduate program at Addis Ababa University.

My sincere appreciation also goes to all staff members of the Ministry of Water and Energy Particularly Hydrology and GIS Departments, National Meteorological Service Agency, Addis Ababa Water and Sewage Authority, and Water and Land Resource Center for their appreciable support in providing me hydrological, meteorological, digitized and other relevant data for my thesis work.

I also wish to extend my gratitude to others who helped me in one way another to carry out my research throughout remarkable encouragement, advice, material support and collaboration in every aspect. In particular, I am grateful for Hailu Asfaw, Samuel Tadesse, Firaol Chelchisa, Tesfanesh Worku, Samuel Ababu, Amir Kemal, Yibeltal Aragie and Hewan Molla.

Last but not least, I would like to thank my family; my brother Samuel Kidane and my little sisters Liya and Eyerusalem Kidane for their constant and never-ending concern, support and encouragement throughout my study.

Abstract

Sedimentation has been one of the critical challenges to create and sustain development opportunities for the poor families in Awash River Basin. Therefore, evaluating and understanding watershed sediment yield is vital to manage sediment related problems. Thus, this study used Middle Awash Multi-Purpose Dam (MAMD) catchment area to estimate sediment yield, to hotspot the most erodible sub-catchment area and assess the appropriate mitigation measurements to reduce the sediment load from the catchment. For the simulation of runoff and sediment yield from the MAMD watershed, the Soil and Water Assessment Tool (SWAT) model was applied. The total watershed has an area of 21,103.16 Km² and located in Afar Regional State and Oromiya Regional State, Awash River Basin, Ethiopia. The SWAT model is calibrated and validated using SWAT-CUP with uncertainty analysis SUFI-2 (Sequential Uncertainty Fitting) procedure using measured monthly flow and sediment data from Awash and Metehara Gauge Stations. Using a data from 1993 to 2006 for calibration and 2007 to 2013 for validation, both results showed a good match between the measured and simulated flow and sediment. Flow calibration gives a coefficient of determination (R^2) and Nash-Stucliffe simulation coefficient (NS) of 0.67 and 0.62 respectively. Flow validation gives R^2 and NS of 0.65 and 0.63 respectively. Sediment calibration gives R^2 and NS of 0.67 and 0.62 respectively. Sediment validation also gives R^2 and NS of 0.69 and 0.69 respectively. Thus, the model performed well in simulating the flow and sediment for the study area. The estimated sediment result shows that the average annual sediment load at the outlet of the watershed was 40.32 ton/year. In this study, sub-basin 14 sub-basins were found to be a sediment prone areas having an annual sediment load that varies from 10.01 to 169.94ton/ha/year. Also, the model was applied to examine the Best Practice Management (BMP) scenario under the change of 25%, 35% and 50% Agricultural land use type to forest land, and other recommended scenarios to reduce the production of sediment. The investigation showed that the conversion of 25%, 35% and 50% of Agricultural land to forest land can reduce the total sediment yield by 26.59%, 34.15% and 45.76%, respectively. The implementation of Filter Strips, Grassed Waterways, Terracing, and Contouring can reduce the mean annual sediment yield at the outlet by 67.19%, 81.80%, 84.30% and 59.25%, respectively. The application of Terracing has high sediment reduction potential than other best management practices.

Key words: *Middle Awash Multi-Purpose Dam, Sediment Yield, SWAT, SWAT-CUP, BMP*

Table of Contents

ACKNOWLEDGEMENT	i
Abstract	ii
List of Figures	vii
List of Tables	ix
Abbreviations and Acronyms	xi
1. INTRODUCTION	1
1.1. Background	1
1.2. Statement of the problem	3
1.3. Research Questions	4
1.4. Objective of the Study	4
1.4.1. General Objective	4
1.4.2. Specific Objectives	4
1.5. Significance of the Study	5
1.6. Thesis Layout	5
2. LITERATURE REVIEW	6
2.1. Concepts and Definitions of Soil Erosion	6
2.2. Watershed Management	7
2.3. Reservoir Sedimentation	7
2.3.1. Sediment Transport Modes	8
2.3.2. Sediment Yield Estimation	8
2.3.3. Spatial and Temporal Variability of Sediment Yield	10
2.3.4. Sediment Management Scenario	11
2.4. Hydrological Models: Types and Selection of Models	12

2.5.	SWAT Model Description	14
2.6.	Model Calibration and Validation.....	16
2.6.1.	SWAT-CUP (SWAT Calibration and Uncertainty Procedure)	16
2.7.	Previous Applications of SWAT Model	17
3.	MATERIALS AND METHODS.....	19
3.1.	Description of the Study Area.....	19
3.1.1.	Geographical Location of the Study Area	19
3.1.2.	Topography.....	20
3.1.3.	Climate.....	20
3.2.	Tools and Data Availability	21
3.2.1.	General.....	21
3.2.2.	Digital Elevation Model (DEM).....	23
3.2.3.	Soil Map.....	24
3.2.4.	Land Use Land Cover Map.....	25
3.2.5.	Slope Class.....	27
3.2.6.	Reservoirs in the Watershed	28
3.2.7.	Major Headwork/Diversion Sites for Water Abstraction in the Watershed	30
3.2.8.	Meteorological Data.....	33
3.2.9.	Hydrological Data.....	35
3.3.	Data Quality Analysis	37
3.3.1.	General.....	37
3.3.2.	Meteorological Data Analysis.....	37
3.3.3.	Hydrological Modeling using SWAT Model	42
3.3.4.	Selected Sediment Reduction Management Scenarios	45

3.3.5.	SWAT Model Setup.....	47
3.3.6.	SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation	51
4.	RESULT AND DISCUSSION	56
4.1.	General	56
4.2.	Stream Flow Modeling.....	56
4.2.1.	Sensitivity Analysis of Stream Flow	56
4.2.2.	Model Calibration for Stream Flow	59
4.2.3.	Model Validation for Stream Flow	61
4.3.	Sediment Yield Modeling	62
4.3.1.	Sensitivity Analysis for Sediment Yield.....	62
4.3.2.	Model Calibration for Sediment Yield	64
4.3.3.	Model Validation for Sediment Yield.....	66
4.4.	SWAT Model Outputs of Water Balance Elements.....	67
4.5.	Spatial and Temporal variability of Sediment Yield in the Watershed	68
4.5.1.	Spatial Distribution of Sediment Yield.....	68
4.5.2.	Temporal Variability of Sediment Yield	72
4.6.	Sediment Yield Reduction Method.....	74
4.6.1.	Scenario I: Baseline Scenario	75
4.6.2.	Scenario under LULC Change: Conversion of 25%, 35% and 50% Agricultural Land to Forest Land	79
4.6.3.	Scenario IV: Filter Strip.....	81
4.6.4.	Scenario V: Grassed Waterway	82
4.6.5.	Scenario VI: Terracing.....	83
4.6.6.	Scenario VII: Contouring.....	84

4.7. Comparison and Evaluation of BMPs	85
5. CONCLUSION AND RECOMMENDATION	87
5.1. Conclusion.....	87
5.2. Recommendation.....	89
References.....	90
Appendixes	94

List of Figures

Figure 2-1 SWAT Hydrological Process Considerations (Tyagi et al, 2013)	15
Figure 2-2 A schematic linkage of the five optimization programs and ArcSWAT	17
Figure 3-1 Location of the Study Area	20
Figure 3-2 Conceptual Framework of the Study.....	22
Figure 3-3 DEM of MAMD Watershed.....	23
Figure 3-4 Soil Map of the Proposed MAMD Watershed.....	25
Figure 3-5 Land Use Land Cover Map of MAMD Watershed.....	26
Figure 3-6 Slope Classes of MAMD Watershed	27
Figure 3-7 Meteorological and Hydrological Guaging Stations of MAMD.....	34
Figure 3-8 Mean Monthly Rainfall of the Selected Stations	34
Figure 3-9 Sediment Rating Curve of MAMD Watershed at Metehara Gauge Station	36
Figure 3-10 Double-Mass Curve of the Selected Meteorological Stations	39
Figure 3-11 Homogeneity Test for Selected Meteorological Station	40
Figure 3-12 Thiessen Polygon for the selected Stations with in the study area	41
Figure 3-13 Sediment Components of MAMD Watershed from SWAT Checker.....	45
Figure 3-14 Delineated Sub-basins of MAMD Watershed.....	48
Figure 3-15 Reservoirs and Headwork sites located in the Watershed	51
Figure 4-1 Sensitive Parameters of Streamflow from Global Sensitivity Analysis (OAT).....	59
Figure 4-2 Scatter Plot for the Observed and Simulated Stream Flow Hydrograph on Average Monthly Time step during the Calibration Period	60
Figure 4-3 Scatter Plot for the Observed and Simulated Stream Flow Hydrograph on Average Monthly Time step during the Validation Period	61
Figure 4-4 Sensitive Parameters of Sediment yield from Global Sensitivity Analysis (OAT)	64

Figure 4-5 Scatter Plot for the Observed and Simulated Sediment Yield Hydrograph on Average Monthly Time steps during the Calibration Period.....	65
Figure 4-6 Observed and Simulated Sediment Yield Hydrograph on Average Monthly Time steps during the Validation Period.....	66
Figure 4-7 Water Balance Ratios and Elements from SWAT Checker.....	67
Figure 4-8 Spatial Variability of Sediment Yield Map for the MAMD Watershed	71
Figure 4-9 Temporal Variation of Sediment Yield over the years	72
Figure 4-10 Temporal Variability of Sediment Yield with relation to Precipitation and Surface Runoff at the Outlet of the Catchment.....	73
Figure 4-11 Comparison of Sediment reduction by the selected BMPs at the critical Sub-basins	86

List of Tables

Table 3-1 Major Soil Types of the Watershed and their Percentage of Area Coverage.....	24
Table 3-2 Land Use Land Cover Classification of MAMD Watershed	26
Table 3-3 Slope Classes of MAMD Watershed.....	27
Table 3-4 Basic Reservoir Input Data for SWAT Model Use (MoWE, 2002; MoWR, 2006)	29
Table 3-5 Maximum Koka Dam Release in Mm ³ /month	29
Table 3-6 Existing Irrigation Schemes located within the Watershed (MoWR, 2006)	30
Table 3-7 Monthly Average Irrigation Water Demand for each Irrigation Schemes in Mm ³ (MoWR, 2006).....	31
Table 3-8 Location of Meteorological Stations within and around the Watershed (1990 - 2021)33	
Table 3-9 General SWAT Model Performance Rating for Recommended Statistics (Moriasi et al, 2007)	55
Table 4-1 Parameters used for Flow Sensitivity Analysis and their recommended ranges.....	57
Table 4-2 Summary of the most Sensitive Parameters of Flow and their Calibrated Values.....	58
Table 4-3 Summary of Calibrated Performance Criteria's for Observed and Simulated Average Monthly Flow.....	60
Table 4-4 Summary of Validated Performance Criteria's for Observed and Simulated Monthly Flow	62
Table 4-5 Parameters used for Sediment Yield Sensitivity Analysis and their recommended ranges	62
Table 4-6 Summary of the Most Sensitive Parameters of Sediment Yield and their Fitted Value for MAMD Watershed.....	63
Table 4-7 Summary of Calibrated Performance Criteria's for Observed and Simulated Average Monthly Sediment Yield.....	65
Table 4-8 Summary of Validated Performance Criteria's for Observed and Simulated Average Monthly Sediment Yield.....	67

Table 4-9 Water Balance Elements and their simulated Values (Baseline Scenario)	68
Table 4-10 Sediment Intensity Classification (Source: (Asmelash et al, 2016)).....	69
Table 4-11 Average Annual Sediment Yield of 87 Sub-basins.....	70
Table 4-12 Sediment Severity Class of the Sub-Basins.....	71
Table 4-13 Temporal Variability of Sediment Yield over the years	73
Table 4-14 Scenario Description and SWAT Parameters used in BMP (contouring, filter strips, grassed waterways and terracing)	75
Table 4-15 Sediment Yield and their Proportional area coverage from the total watershed	76
Table 4-16 Soil erosion prone at sub-basin level with their dominant LULC, soil type and average slope	77
Table 4-17 Annual Average Runoff under Different LULC Changes	81
Table 4-18 Annual Average Sediment Yield Reduction Under LULC Change.....	81
Table 4-19 Filter Strip default and modified parameters used in SWAT model	82
Table 4-20 Grassed Waterway default and modified parameters used in SWAT model	83
Table 4-21 Terracing default and modified parameters used in SWAT model.....	84
Table 4-22 Contouring default and modified parameters used in the SWAT model	85
Table 4-23 Summary of Sediment yield reduction effectiveness and rank of each BMPs Developed on MAMD Watershed.....	86

Abbreviations and Acronyms

AAT	All-at-a-Time (Global Sensitivity Analysis)
a.m.s.l	Above Mean Sea Level
BMP	Best Management Practice
DEM	Digital Elevation Model
DMC	Double Mass Curve
FAO	Food and Agricultural Organization
HRU	Hydrologic Response Unit
LULC	Land Use Land Cover
MoWE	Ministry of Water and Energy
MUSLE	Modified Universal Soil Loss Equation
NA	Not Available
NMA	National Meteorology Agency
NSE	Nash-Sutcliffe Model Efficiency Coefficient
OAT	One-at-a-Time (Local Sensitivity Analysis)
PBIAS	Percent Bias
R ²	Regression Correlation Coefficient or Coefficient of Determination
SCS-CN	Soil Conservation Service-Curve Number
SUFI-2	Sequential Uncertainty Fitting
SWAT	Soil and Water Assessment Tool
SWAT-CUP	SWAT Calibration and Uncertainty Procedure
USDA-ARS	United States Department of Agriculture-Agricultural Research Service
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
UTM	Universal Transverse Mercator Coordinate System
WGEN	Weather Generator
WLRC	Water and Land Resource Centre
WWDSE	Water Works Design and Supervision Enterprise

1. INTRODUCTION

1.1. Background

As water is a major and important issue in life that requires to be guarded and nurtured, it must be protected, defended and treated as its great value for humans as well as for all living and non-living things in our universe. World's fresh water has been altered and being used by humans. It has been seen as a renewable resource for energy or hydroelectric power generation, for irrigation and food security, for fishery, for drinking water supply and household purpose, for recreational, and for transportation purposes. This involves construction of dams and reservoirs all over the world for storage and flood control purposes. However, these man-made structures losses their storage capacity due to sedimentation. Sedimentation is an issue that affects their ability to perform these functions. It occurs when solid soil particles transported by streams and rivers and settles out of the water and accumulates in the reservoir bottom.

Reservoir sedimentation refers to the process of sediment accumulation in the bottom of a reservoir over time. This accumulation of sediment can lead to a number of serious problems related to the loss of storage capacity (Elba et al, 2017). These problems include reduced water storage capacity for hydroelectric power generation, reducing the amount of electricity that can be produced to the users; downstream users of irrigation system may get less water due to reduction in storage capacity; and similarly, this can lead to decrease crop yield and affect the regional economy. Also, sedimentation can harm the ability to control flood by reducing the water's depth and decrease the flow of water in the reservoir. As sediment accumulates over time, it reduces the available volume of water storage leading to storage loss. This can have various negative impacts on the watershed area (Fayera, 2015; Morris et al, 2009).

The main cause of sediment problem is accelerated by soil erosion. Soil erosion is a natural process in which soil and rock materials are gradually detached and moved from land surfaces by water, wind, ice or gravity (Santhosh, 2018). In this case, water erosion is the major influence that accelerates the soil erosion process. It is a removal of soil from land by running water. There are several causes of soil erosion and sedimentation; for instance poor land use practice, insufficient management of surface water runoff, failure to implement erosion control practices, natural features like steep slope, fragile soil and sparse vegetation, higher population densities leading to

increased land use intensity, deforestation, urbanization, improper tillage practice and inappropriate application of fertilizers (Negewo and Sarma, 2021; Markhi et al, 2019). Sediment yield and land degradation strongly interact with watershed's land use/land cover, soil type and slope classes (Gizaw and Kebede, 2019).

In Ethiopia, soil erosion resulting from over grazing, poor land management and deforestation is a significant problem due to undulating topography, steep topography and erosive rainfall enhanced under agricultural systems that limit protective soil covers (Elias et al, 2023). Various research findings have been conducted on the simulation of sediment yield and erosion transportation in various parts of Ethiopia (Tolche et al, 2021). Land degradation due to soil erosion is a major problem in our country (Tsegay, 2019).

Sedimentation is one of the critical challenges to create and sustain development opportunities for the poor families in Awash River Basin. While environmental change threatens sustainable management of natural resources, human interference into then to generate short-term needs can cause more harm and exacerbates environmental degradation (Awash Basin Authority, 2018). Sedimentation in reservoirs within the Awash River Basin is a significant concern and reduction of canal capacity due to siltation is indeed considered as a critical problem (Tesfu et al, 2021; Asmelash et al, 2017; Bishaw, 2015). Other hydraulic structures in the river basin have been reported: the average annual sediment yield is increasing, and sedimentation in canal systems and reservoirs poses significant challenges for farm areas (Tesfu et al, 2021).

Evaluating and understanding watershed sediment yield is important in order to manage sedimentation problems. It is considered as a pre-condition in managing land and watershed effectively. Hence, sediment spatial variability analysis has been used for identification of sediment prone areas in the catchment and sediment yield reduction is possible by providing soil conservation measures (Basson and Rooseboom, 1999). Reduction of soil erosion and adopting sediment control techniques are critically important for maintaining the storage capacity of the reservoir. The spatial variability of sediment yield can be evaluated using the semi-distributed model. Soil and Water Assessment Tool is a physical based semi-distributed watershed model widely used for hydrological and water quality modeling. It has a powerful tool capable of

characterizing various complex watershed processes and simulating a range of phenomena, including surface runoff, sediment yield, and sediment management practices (Arnord et al, 2012).

A previous study on Middle Awash Multipurpose Dam showed that reservoir capacities were affected by sedimentation (Tesfu et al, 2021). The bathymetric survey (Halcrow, 1989) revealed that the Koka reservoir experiences significant sedimentation, with an average annual rate of 25 Million m³/year (Tesfu et al, 2021). The Koka reservoir is located in the upstream side of the Middle Awash Multi-Purpose Dam. The Ministry of Water Resources (MoWR) indicated the Koka reservoir continues to lose a storage capacity at a significant rate with an average sedimentation rate of 12.08 Million m³/year (MoWR, 2002). A report from (Bishaw, 2015) highlights that sediment yield in the Awash River Basin, particularly near Merti Bridge, increases significantly during the rainy seasons. Sedimentation poses a fundamental challenge for farmers in Metehara Sugar State by reducing the capacity of irrigation canals and the height of storage reservoirs (Tesfu et al, 2021).

The Middle Awash Multipurpose Project was initiated primarily to control flood and protect the downstream community and infrastructure (Belay, 2022). It also serves to harness the water resources of the Awash River for irrigation. For this purpose, a potential site in the middle part of Awash River was selected (Awash Basin Authority, 2015). Thus, this study uses the Middle Awash Multipurpose Dam catchment area as a case study to estimate the sediment yield using the ArcSWAT2012 model. Model calibration and validation were performed using the SWAT-CUP, which provides a decision-making framework that incorporates a semi-automated approach capable of performing sensitivity, calibration, validation and uncertainty analysis (Arnold et al, 2012).

1.2. Statement of the problem

In Ethiopia, there are existing dam structures aimed at different purposes, such as irrigation and agriculture, for hydroelectric power generation, water supply and flood control. The dams impounded water for the listed purposes. However, the sediment in the reservoir of dams has not been managed for years. Sedimentation highly influences reservoir service years. Sedimentation can also reduce reservoir storage capacity (Tesfu et al, 2021).

Previous studies have highlighted the impact of sedimentation in the Middle Awash Multi-Purpose Dam watershed, with 30.65% of the watershed area affected by sediment (Tesfu et al, 2021). However, they have not proposed effective mitigation measures to reduce sediment yield in the watershed. This highlights a crucial gap in current understanding and management practices to reduce sediment yield in the watershed area. Hence, estimation of sediment yield and identification of sediment prone areas of the Middle Awash Multipurpose Dam watershed with respect to quantity is essential for identifying proper mitigation measures and sustainable utilization of the Middle Awash Multipurpose Dam Project.

1.3. Research Questions

- How much sediment yield is produced in MAMD catchment?
- Which sub-watersheds of the study area are erosion prone areas?
- What are the best mitigation measurements to reduce the accumulation of sediment in the Watershed?

1.4. Objective of the Study

1.4.1. General Objective

The overall objective of this study is to estimate the sediment yield of the Middle Awash Multipurpose Dam watershed area using the SWAT model and recommend appropriate sediment reduction measures.

1.4.2. Specific Objectives

- To estimate sediment yield of Middle Awash Multipurpose Dam catchment using SWAT model,
- To hotspot the most erodible sub-catchment area, and
- To assess the appropriate mitigation measures to reduce sediment yield of the watershed.

1.5. Significance of the Study

As previous studies indicate that the Awash watershed land-use change occurs at a faster rate than expected and results in a reduction in the capacity of the reservoirs and the capacity of channels (Melka, 2018), it is crucial to understand the application of hydrological models to study sediment transport and yield in the watershed at spatial and temporal scale (Adeogun et al, 2018) and (Markhi et al, 2019). This study enables the development of various management scenarios to reduce the sediment inflow to the watershed. This study aims to address the application of the SWAT model to estimate the catchment sediment yield, hotspot of the most erodible sub-catchments, and to evaluate different conservation practices to reduce the yield of sediments, and the output of this research will be used by other scholars as an input for further study in planning, developing and managing of water resources in the Middle Awash Multipurpose Dam watershed.

1.6. Thesis Layout

These thesis organization contains six chapters:

- Chapter 1 provides a brief introduction about sediment yield and its effect in a global and regional context, also it includes the overall introduction, general and specific objectives of the study is clearly stated in this chapter, and statement of the problem that initiates this study and the significance of this study is well addressed in this chapter.
- Chapter 2 discusses different literatures about concepts and definitions of soil erosion, reservoir sedimentation, watershed management, selection of hydrological models, model calibration and validation, and previous experiences related with this study.
- Chapter 3 contains a detail description of the study area i.e., geographical location, land use, soil types, topography and climate, deals with the sources and analysis of all data used, reservoir information's, the overall materials and methodology of this study was well elaborated to achieve the specific objectives.
- Chapter 4 discusses the results and findings of SWAT model simulation and further discuss about how the model simulates the sediment yield and identifies the sensitive parameters using performance evaluation methods with graphs and tables of the output of the model.
- Chapter 5 finalizes by addressing conclusion and recommendations for future work. The references and appendixes are also attached at the end of this paper.

2. LITERATURE REVIEW

2.1. Concepts and Definitions of Soil Erosion

To begin with the definition of (Hillel, 2003) soil can be defined as the weathered and fragmented outer layer of the earth's terrestrial surface. It is formed initially through the disintegration and decomposition of mineral material contained in exposed rocks by physical, chemical and biological processes (Athanas et al, 2020). Erosion can be defined as the displacement of soil particles by wind or water. Soil erosion by water increases when water at the soil surface exceeds water infiltration (Hillel, 2003). Soil can be transported from a place by splashing or by the effect of raindrops on the soil surface. Then, sheet erosion will be created as the soil particles dislodged by the raindrops on the soil surface. Most of the time sheet erosion develops into rill erosion and after the formation of rill erosion; small and slow channels will be formed. Once these channels are developed, gully erosion occurs (Philor, 2011).

One of the most common issues facing the world is soil erosion, which is a complex dynamic process that exposes underlying soil and causes siltation in reservoirs and natural streams (Verma et al, 1995). It occurs the detachment of the productive surface soil particles, transported and accumulated in a distant place. Soil erosion is a major driver of reduced agricultural productivity, as it diminishes soil fertility, disrupts soil structure and impairs water infiltration and retention. Therefore, it is a major cause of reduced agricultural productivity and water pollution (Lal, 1998) and (Zhu et al, 2013). The impacts of soil erosion on agricultural productivity and water pollution are discussed by (Morgan, 2005) on both on-site and off-site situations. Among the on-site effects, the soil erosion can lead to the redistribution of soil particles with in the field, eroded soil are washed away from agricultural fields, due to erosive forces of water the soil structure can be broken down and decrease the infiltration rate, and erosion often results in the loss of organic matter, nutrients and soil fertility. On the other hand, the off-site effects are due to the accumulation of sediment in rivers, lakes and reservoirs carried by runoff from eroded fields, which increases the flood risks, blockage of irrigation canals and shortened design life of reservoirs (Morris et al, 2009).

The rate of soil erosion in a catchment depends on climate, land use and various number of landscape characteristics such as slope, topography, soil type, vegetation and drainage condition

(Marttila, 2010). Erosion increases siltation in the reservoirs and results the loss of storage. Due to these reason management and reduction of soil erosion is important. The scientific approach for modeling of soil erosion and watershed management based on defined objective criteria is crucial to reduce the loss of storage in reservoirs (Haregeweyn et al, 2006; Tamene et al, 2006).

2.2. Watershed Management

Watershed are also called a drainage basin or catchment area. It is defined as the area in which all water flows into a common outlet USGS (2019). A hydrological watershed is an area from which runoff flows to a common point in the drainage system. Every stream, tributary, or river has an associated watershed and small watershed aggregates together to become a large watershed (Wani, 2009). According to (FAO, 2017), the term watershed management refers to a human action aimed at ensuring the sustainable use of natural resources. Watershed management has a long history of addressing complex problems and providing solutions that supports integration, collaboration and interactions among various natural processes such as land use, water and the ecosystem of the watershed.

Watershed management provides a framework for understanding and reconciling the interconnections among various land-use systems and for collaborative action and decision-making in the face of competing claims on resources, especially water resources (FAO, 2017). Watershed usually delineated from surface topography. It consists of interconnected networks of surface watercourses and underground aquifers. An intense understanding of scientific management of soil, vegetation covers and water is crucial for mitigating erosion and preventing rapid siltation in reservoirs, lakes and rivers (Agidew, 2018).

2.3. Reservoir Sedimentation

The term sedimentation is the process whereby soil particles eroded and transported by flowing water and deposited as a layer of solid particles in a water bodies such as rivers and reservoirs (Tundu, 2018). It is a quite complex process that varies with watershed sediment yield, rate of transportation and mode of deposition (Ezugwu, 2013). The deposition of sediment in the reservoir is known as Reservoir Silting or Reservoir Sedimentation. The deposition of the sediment will automatically reduce the water storing capacity of the reservoir, and if this process of deposition

continues longer, a stage is likely to reach when the whole reservoir may get silted up and become useless (Garg, 1987). Sedimentation is then, the major concern in the conservation, development and utilization of soil and water resources (Vanoni, 1975).

2.3.1. Sediment Transport Modes

The sediment process in a watershed can be divided into three main categories: sediment production, sediment transport and sediment deposition. Sediment production is the first part of the sediment cycle and comprises of weathering and erosion of surfaces in a catchment (WRC Project, 2020). The transport of sediment in rivers can be in the form of bed load and suspended load, depending on catchment parameters such as slope and vegetation, flow conditions such as discharge and depth, and sediment characteristics i.e., size and shape (Jeong et al, 2021). The entire sediment load is subdivided by the source or mode of transport from the origin. The entire load is classified as the bed material load and wash load. Sediment transport in rivers occurs as a combination of bed load, suspension transport and a fine-grained wash loads (Vijay, 2017). The coarsest sediments are transported as bed load by rolling and bouncing (saltating), always remaining close to the river bed (Paul, 1980). Finer fractions of sediments are lifted well above the river bottom by the water turbulence and carried for substantial distance without touching the bed (Basson & Rooseboom, 2007).

2.3.2. Sediment Yield Estimation

2.3.2.1. Sediment Yield

According to (Morris et al, 2009), sediment yield is the amount of sediment exported by a watershed basin over a specified period of time, which is the amount that will enter a reservoir located at the downstream limits of its tributary watershed (Ndomba, 2008). The estimation of watershed sediment yield is essential for design of dams, debris basins, canals and other structures, as well as for evaluating various land management practices USDA (1972).

In this case, the existing data can be used efficiently by constructing formal stochastic models of sediment yield which have structures dependent upon the runoff process, rainfall process and other factors governing detachment, entrapment, transport and deposition of sediment (Woolhiser, 1975). The sediment load of a stream can be evaluated by using either a short-term or a long-term

analysis. The short-term analysis is conducted and performed on a daily basis by focusing on the magnitudes and variability of sediment transport during rainfall events. While, long-term analysis aims to estimate the overall sediment yield of streams and it provides the average annual sediment load (Julien, 1998). The long term sediment load analysis can be widely used for reservoir sedimentation, sediment budget and degradation studies.

2.3.2.2. Sediment Transport Equation for Daily Sediment Load and Annual Sediment Load

Sediment transport theories describing initiation of movement, transportation and deposition of sediment from the basis of studies concerning reservoir sedimentation (Annandale, 1987). Depending on the theories, the sediment transport equations has been developed in order to use the equations to control the conveyance volume of sediment for a set of flow condition. The primary stage in evaluating sediment transport is to select a single or additional available equation in order to use it in solving the problem. Sediment transport is a complex phenomenon that the existing formulas are often invalid to predict (Yang, 2020). Some of the methods that can be used in evaluating sediment transport can be complex, because the selection is not as easy as it looks since the results of the different formulas or equations can give drastically different results. The study of (Bagnold, 1977) confirmed that the initial consideration is important and crucial to decide what portion of sediment transport is needed to be estimated and evaluated.

Estimating the amount of sediment that is going to be transported out of watershed has been using a method called Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The equation considers different factors including rainfall erosivity index, soil erodibility factor, topographic factor, vegetation factor and erosion control practice factor. Later then, (Williams, 1985) developed the Modified Universal Soil Loss Equation (MUSLE). The USLE uses the rainfall as an indicator of erosive energy while MUSLE uses the amount of runoff to simulate erosion and sediment yield (Phuong, 2017). The MUSLE (Williams, 1985) is given by:

$$Sed = 11.8 (Q_{surf} * q_{peak} * Area_{HRU})^{0.56} * K_{USLE} * C_{USLE} * P_{USLE} * L_{USLE} * CFRG ... Eq. 2$$

Where, *Sed* is the sediment yield on given day (metric ton/ha), EI_{USLE} is the rainfall erosion index (0.017 m-metric ton cm/ (m²hr)), K_{USLE} is the USLE soil erodibility factor (0.013 metric ton m² hr./ (m³-metric ton cm)), C_{USLE} is the USLE concealment and organization issue, P_{USLE} is the USLE

provision repetition factor, L_{USLE} is the USLE topographic factor and, $CFRG$ is the coarse piece issue . Q_{surf} is the surface runoff volume (mm), q_{peak} is the highest excess degree (m/s^3), $Area_{HRU}$ is the area of the HRU (ha) and other variables in the equation carries the same meaning as described in the above equation.

Over a period of time, an amount of eroded sediment can be discharged by a stream at any given point and also enters to a reservoir which is located in the tributary watersheds (Vanoni, 2006). A sediment yield can be influenced by different factors; such as geology, climate, drainage density, slope and human disturbance in different activities. In that case, every single parameter or a combination of parameters explains the wide variability of sediment yield (Morris et al, 2009). The widely used unit for sediment yield is tones/ha/year. The sediment load can be estimated or determined by using long term or short term analysis. The short term analysis of sediment can be performed on a daily basis, while the long term sediment analysis estimates the amount of sediment yield by a stream annually (Julien, 1998). It gives the average annual sediment load of a watershed and can be used for reservoir sedimentation, sediment budget and further degradation studies.

A daily sediment load can be estimated using the sediment rating curve method. It is a product of the daily mean discharge, the average total sediment concentration and a unit conversion factor. It can be expressed by using:

$$Q_s \left(\text{metric} \frac{\text{tons}}{\text{day}} \right) = 0.0864 C_s \left(\frac{\text{mg}}{\text{l}} \right) * Q_{\text{Water}} (\text{m}^3 / \text{sec}) \dots \dots \dots \text{eq. 3.2}$$

Where, Q_s is the total sediment discharge in tons/day, $C_s \left(\frac{\text{mg}}{\text{l}} \right)$ is the average total sediment concentration in mg/l, and Q_{Water} is the daily mean water discharge in m^3/sec .

On the other hand, the long term analysis can be done by using the summation approach that utilizes the mass curve method to determine the cumulative sediment load as a function of times in years (Julien, 1998).

2.3.3. Spatial and Temporal Variability of Sediment Yield

A study stated that one of the principal concerns across a wide range of disciplines dealing with river basin studies is the enormous variation in spatial and temporal patterns of erosion, sediment transport, sediment storage and sediment yield (Campbell, 1992). Both sediment yields and runoff

are the aggregation of a spatially and temporally heterogeneous system in which, because of the variation of the parameters within the system increases complexity and spatial dimensions, new variables, new relationships and as a rule, lead to the identification of new problem (Philip, 1975) and (Haggett et al, 1965).

In Ethiopia, the spatial and temporal distribution of precipitation and surface runoff varies all over the country causing significant spatial variation in soil erosion and sediment yield (Negewo and Sarma, 2021). Recent studies (Asmelash et al., 2017; Avcı et al, 2023; Leta et al, 2023; Elias et al, 2023), demonstrated the spatial and temporal variations of sediment yield using the SWAT model and identified the most sediment prone sub-watersheds for further management analysis. These studies demonstrated that the model was successful in simulating watershed erosion.

2.3.4. Sediment Management Scenario

Once the model evaluation is carried out, analyzing the spatial distribution of water balance components and soil erosion status throughout the watershed becomes crucial to provide the priority of sub-watersheds for implementing soil conservation measures (Himanshu et al, 2019). Soil conservation practices, also known as best management practices (BMP) (Mwangi et al, 2015; Himanshu et al, 2019; Lam et al, 2011). The BMP's can help to prevent soil erosion and enhance water quality by lowering the sediments and other pollutants (Nepal, 2022). In order to reduce the soil erosion impacts, it is required first to determine the sources area of sediment yield (Wu et al, 2014). The sediment prone sub-catchments can be identified using ArcSWAT simulated annual average sediment yields (Singh, 1995; Srinivasan, 1998).

Similar to the simulation of stream flow, soil loss, sediment output, and water quality, SWAT model can also simulate for evaluation of BMP's with significant precision in large watersheds on a daily time step (Jha and Gassman, 2013). SWAT has been widely used because of its robust algorithms for simulation of hydrologic system, sediment and pollutant transport, and its comprehensive database on agricultural management practices (Arnold et al, 1998). Several studies worldwide assessed the effectiveness of BMP's using SWAT model and demonstrated the model satisfactory performance (Himanshu et al, 2019; Liu et al, 2019; Parajuli and Nepal, 2022; Briak et al, 2019); and as well as in our country (Dibaba, 2021; Leta et al, 2023; Tesema et al, 2020; Sufiyan, 2014; Sofonyase, 2020; Tolche et al, 2021).

SWAT can simulate 8 different types of management operations (Neitsch et al, 2012). Terracing operation, contouring, filter strip, grassed waterways, fire, strip cropping, residue management and tile drainage are the management operations in SWAT model. The BMP can be identified by changing SWAT parameter values depend on the previous findings in any watershed and sediment yield calibration (Chekol et al, 2007; Tesema et al, 2020; Tolche et al, 2021). The widely used BMP's in Awash River basin are Filter strip, Terracing, Grassed waterways and contouring. The implementation of 5 m filter strip, terracing, contouring and grassed waterways are used for this study for the reduction of sediment yield in each sub-basin.

2.4. Hydrological Models: Types and Selection of Models

To manage any system, it requires a model to predict the future behavior and response to perturbation. All models are born as mental images and depending on the situation they may grow in complexity to include graphics, desktop calculations, numerical simulations and physical scale modeling (Morris et al, 2009). A model is process of organizing, synthesizing and integrating component parts into a realistic representation of the prototype (Nina, 2016). The real world or prototype hydrologic systems are complex and their behavior is analyzed with models which are greatly simplified. In engineering analysis, this uncertainty is offset by applying informal or formal safety factors to convert approximate modeling results into acceptable design parameters.

In this case, estimation of sediment is important in a wide spectrum of practical studies for planning, design and operation of water resource structures. The measurement and sampling of sediment transportation from the watershed area is very lengthy and costly. For that matter, usages of hydrological models are another option and important one. Sediment-runoff models have been used by different researchers over decades. However, the applications of the variable models are highly dependent on the purposes for which the modeling is made.

The many rainfall-runoff models are carried out purely for research purposes to enhance knowledge about hydrological system, and the other types of models are developed and employed as a means of tools for simulation and prediction to allow decision makers to solve the hydrological problems (Campling, 2002). According to (Todini, 2007), hydrological models can be categorized in to three main types: lumped, semi-distributed and distributed models.

Parameters of lumped hydrologic models do not vary spatially within the basin and the basin response can be evaluated only at the outlet without the explicit accounting for the response of individual sub-basin (Beven, 2000). The parameters of lumped model often do not represent physical features of hydrologic process and involve certain degree of empiricism (Martinec, 1975). The parameters of distributed hydrologic models are fully allowed to vary in space at a resolution usually chosen by the user (Wang et al, 2007). Semi-distributed models play a crucial role in accurately representing the hydrological process within a river basin. These models require a significant amount of data for parameterization in each grid cell. They are particularly useful for capturing complex physical process and can provide high levels of accuracy when properly applied. One major advantage is that they allow for partial variation of parameters in space by dividing the basin into smaller sub-basins. There are also two main types of semi-distributed models i.e., kinematic wave theory models which includes models such as Hydrologic Engineering Centre-Hydrologic Modeling System (HEC-HMS), Soil and Water Assessment Tool (SWAT), Hydrologiska Byråns Vattenbalansavdelning (HBV), Water Evaluation and Planning (WEAP) tool, and probability distributed models which includes a model like topographically based model, TOPMODEL.

The approach was chosen for this study due to its more physically-based structure compared to lumped models as well as its less demanding input data requirements compared to fully distributed models (Ponce, 1989). In selecting a hydrological model, there are several criteria that must be considered. These include the specific hydrologic processes to be modeled the desired output availability and cost of input data and the overall accuracy of the model. The criteria's must be research dependent based on the own specific requirements and needs. Among the semi distributed hydrological models the Soil and Water Assessment Tool (SWAT) has been selected for this study due to different acceptable reasons. The main reasons for selecting SWAT model for this research purpose is that the model has been used for land use and cover change impact assessment in different parts of the world as well as Ethiopia, the model simulates the major hydrological process in a watershed, the model allows for several different basin delineation in different scales, it can also easily incorporate changes in land use and land cover, the model is less demanding on input data, multiple calibration methods are readily available, the model is open source and freely

available, and also the model has been used and tested for prediction of sediment yield with satisfying results (Arnold et al, 1998; Gassman et al, 2007).

2.5. SWAT Model Description

The soil and water assessment tool (SWAT) is a semi-distributed continuous-time process-based model designed to evaluate the effects of different management decisions on water resources and non-point source pollution in large river basins (Arnold et al, 2012). It is also a physically based simulation model operating at the watershed scale able to simulate hydrology erosion and sediment transport. The model was developed by USDA-ARS to operate on a daily time step and is designed to predict the impact of land use and management on water, sediment and agricultural chemical yields in watersheds with varying soils, land use and management practices over long period of time (Neitsch, 2005).

The major model components are weather, hydrology, soil properties, temperature, nutrients, and plant growth, pesticides, bacteria and pathogens, and land management (Neitsch et al, 2009). The modeling or estimation of flow and sediment transport of the watershed is done by dividing the watershed into sub-basins, which are then further subdivided into Hydrologic Response Units (HRU's) that consists of a homogenous land use, management, topographical and soil characteristics (Irina, 2012). The HRU's are very helpful; for better estimation of sediment, flow and pollutants from the sub basin since they are unique combinations of land use, soil type and slope. Sub-basins within a watershed have a specific geographic positions and are spatially related to each other while Hydrological Response Units (HRUs) do not have a spatial identity and only represent a percentage of a sub-basin area (Gassman et al, 2007). However the connection between HRUs and sub-basins allows for continuous modeling of water quality and stream flow generation (Haverkamp et al, 2005).

The SWAT model has an interface in ArcGIS for the definition of watershed hydrologic features and storage (Winchell et al, 2010). Because of the ArcSWAT extensions of ArcGIS, SWAT has a graphical user interface and it enables the model consequently loading required datasets on elevation, land use and weather, which are compatible with ArcGIS (Winchell et al, 2010). The model gained worldwide recognition and was tested in many similar studies (Irina, 2012). To

create SWAT dataset, the interface needs to access ArcGIS compatible raster and vector dataset, and the database files provides certain types of information about the watershed (Sofonyase, 2020).

SWAT’s hydrologic components are based on water balance equations with factors such as soil water, surface runoff, interception, precipitation, evaporation, percolation and base flow, all taken into account. The model also includes routing of water and sediment in the channel network of the watershed (Arnold et al, 2012). The model simulates the hydrologic cycle based on the following water balance equation (Neitsch, 2005):

$$S_{wt} = S_{wo} + \sum(R_{day} - Q_{sur} - E_a - W_{seep} - Q_{gw}) \dots \dots \dots Eq.3$$

Where, S_{wt} - is the final soil water content (mm), S_{wo} is the initial soil water content for a day (mm), t is time (days), R_{day} is the amount of precipitation (mm), Q_{surf} is the amount of surface runoff (mm), E_a is amount of evapotranspiration (mm), W_{seep} is seepage from the bottom soil layer (mm), and Q_{gw} is the groundwater flow on a day (mm).

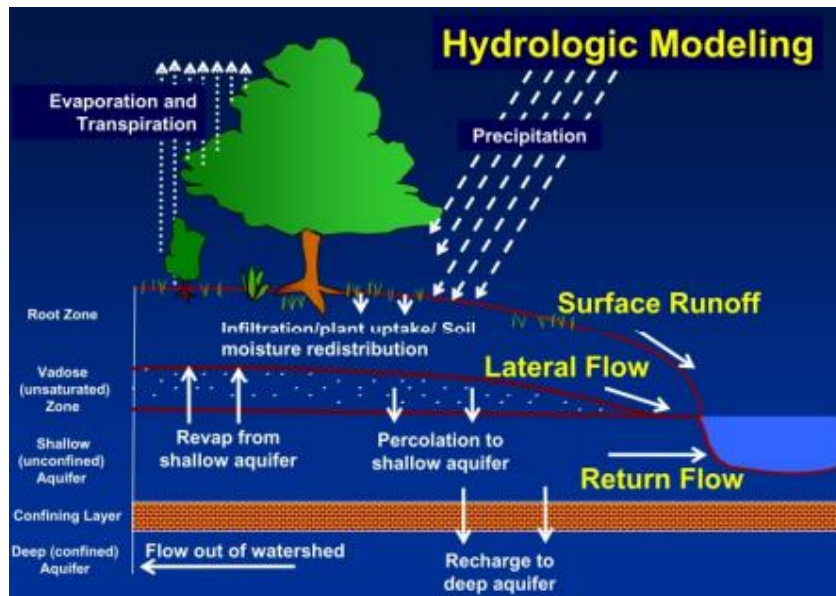


Figure 2-1 SWAT Hydrological Process Considerations (Tyagi et al, 2013)

Also SWAT uses the SCS curve number procedure methods for analysis of surface runoff and it is the most commonly used method in SWAT model for estimating surface runoff (Neitsch et al., 2009). The SCS curve number equation is:

program can run sequential uncertainty fitting (SUFI-2), the generalized likelihood uncertainty estimation (GLUE), Marcov Chain Monte Carlo (MCMC), Particle Swarm Optimization (PSO) and parameter solution (Para Sol). The program guides the input files necessary for running a calibration program. The SUFI2 algorithm is suitable for calibration and validation of SWAT model because it represents uncertainties of all sources (Yang et al, 2008) .

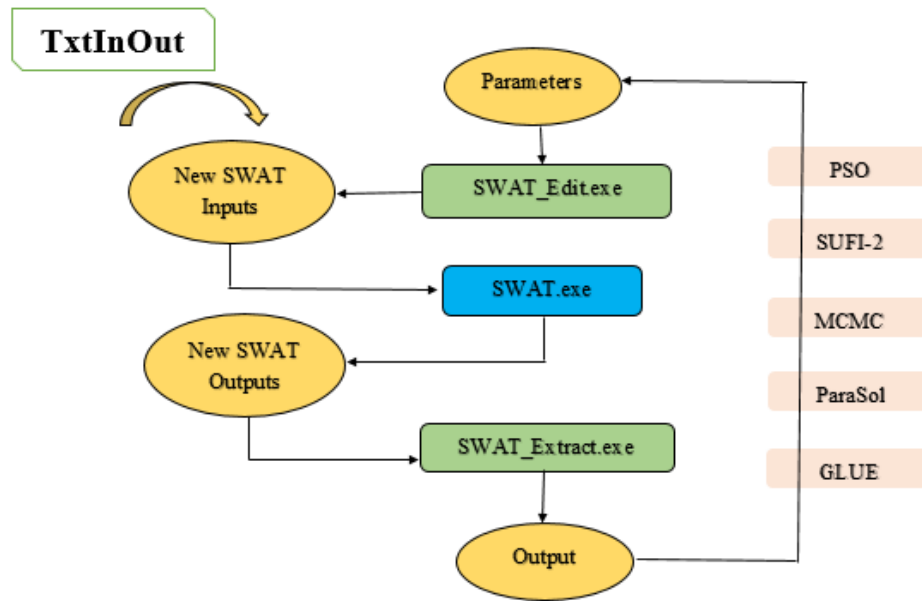


Figure 2-2 A schematic linkage of the five optimization programs and ArcSWAT

2.7. Previous Applications of SWAT Model

SWAT has been successfully used by researchers around the world for estimating sediment yield on a daily and monthly basis including in Ethiopia (Awulachew, 2008; Setegn et al, 2008; Gessese, 2008; Mwangi et al, 2015). Studies have confirmed the accuracy of the model in predicting streamflow and sediment yield with the model performing well in complex watersheds. For example in the Blue Nile river basin and Lake Tana the model accurately simulated streamflow and sediment yield (Awulachew, 2008; Setegn et al, 2008). In Legedadi Reservoir the model was able to predict sediment yield with an impressive Nash-Sutcliff Efficiency of 80% (Gessese, 2008). Researchers suggest that SWAT could be utilized to analyze different management scenarios and inform soil and water conservation strategies. In the Awash River Basin siltation of canals and reservoirs is a major problem (Halcrow, 1989).

Recent studies have utilized SWAT to calibrate, validate and analyze uncertainties related to sediment yield (Samuel, 2022; Tolche et al, 2021; Yibeltal, 2022; Fayera, 2015; Tesema et al, 2020). These studies have successfully identified the most influential hydrological parameters and provided valuable insights on sediment yield and performance evaluation. Estimation of sediment yield in the Mille watershed under climate change, estimation of sediment yield and reduction methods in Upper and Middle Awash river basin, estimation of sediment yield in Kesseme dam and Legedadi dam have all been studied using SWAT with good results in terms of performance evaluation and management scenarios. Also the SWAT model was tested for the prediction of sediment yield in Anjeni-gauged watershed and predicted annual average sediment yield of 24.6 tons/ha successfully (Setegn, 2010). The SWAT model was used in Kesseme dam watershed based on the available geo-spatial and hydro-meteorological data of the watershed and successfully identified areas with highest sediment yields.

A study by (Tesfu et al, 2021) utilized a multi-site calibration technique to identify and estimate sediment yield and uses SWAT-CUP to calibrate and validate flow and sediment parameters in the proposed Middle Awash Dam watershed. The model was able to accurately estimate the mean annual sediment yield of 7.23 ton/ha/year at the outlet with an average annual sediment yield of 12.8 million tons from 1992 to 2014 and about 30.65% of the total watershed area is identified as a critical sediment source area. Their findings also highlighted the need for watershed management strategies to reduce sediment problems in the area. Overall semi-distributed models are a powerful tool for representing complex hydrological process within a river basin. Despite their high data requirements, they can provide accurate results when properly applied. The use of tools such as SWAT-CUP can further improve the accuracy and reliability of these models. In Ethiopia SWAT has been successfully utilized in various studies to estimate sediment yield and inform management strategies. Further research and application of this model in different watersheds can help mitigate the impact of sedimentation on water resources and ecosystem.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

Ethiopia has 12 River Basins and Awash Basin is one of them. Awash Basin originates from the central highland and drains towards Djibouti, crossing the East African Rift Valley. The River Basin has a Total Drainage Area of 112,696km². There are various water resource developments in the basin i.e., Koka Dam Project, Kesem-Kebena, Fentale, Welenchiti and Tendaho Projects mainly planned for irrigation development in the Basin. Later, the Awash Basin Authority in its Growth and Transformation Plan Program anticipates the development of flood control project in Middle Awash area by constructing multipurpose dam which can also be used for water supply and for the irrigation of existing command area in Amibara project which is around 40,000ha of land (WWDSE, 2016).

The Middle Awash Multi-Purpose Project (MAMPP) was launched with the main goal of controlling floods and protecting the downstream community and infrastructures. Additionally, it aims to utilize the water resource of the Awash River for irrigation purposes. For this purpose, a suitable location in the middle part of the Awash River was identified and selected (WWDSE, 2015).

3.1.1. Geographical Location of the Study Area

The Middle Awash Multipurpose Dam is located in Afar National Regional State and Oromiya Regional State, around Awash town, at about 220km northeast of Addis Ababa on main Awash Rivera about 10km upstream of the Addis Ababa-Djibouti main road bridge. Basin wise, the project is located in Awash River Basin with geographical coordinates of 990798 UTM Northing and 620689 UTM Easting at the center of the dam (WWDSE, 2016). The total catchment area of the MAMD is 21,103.16km². The elevation of the study area ranges from 4201m to 832m a.m.s.l.

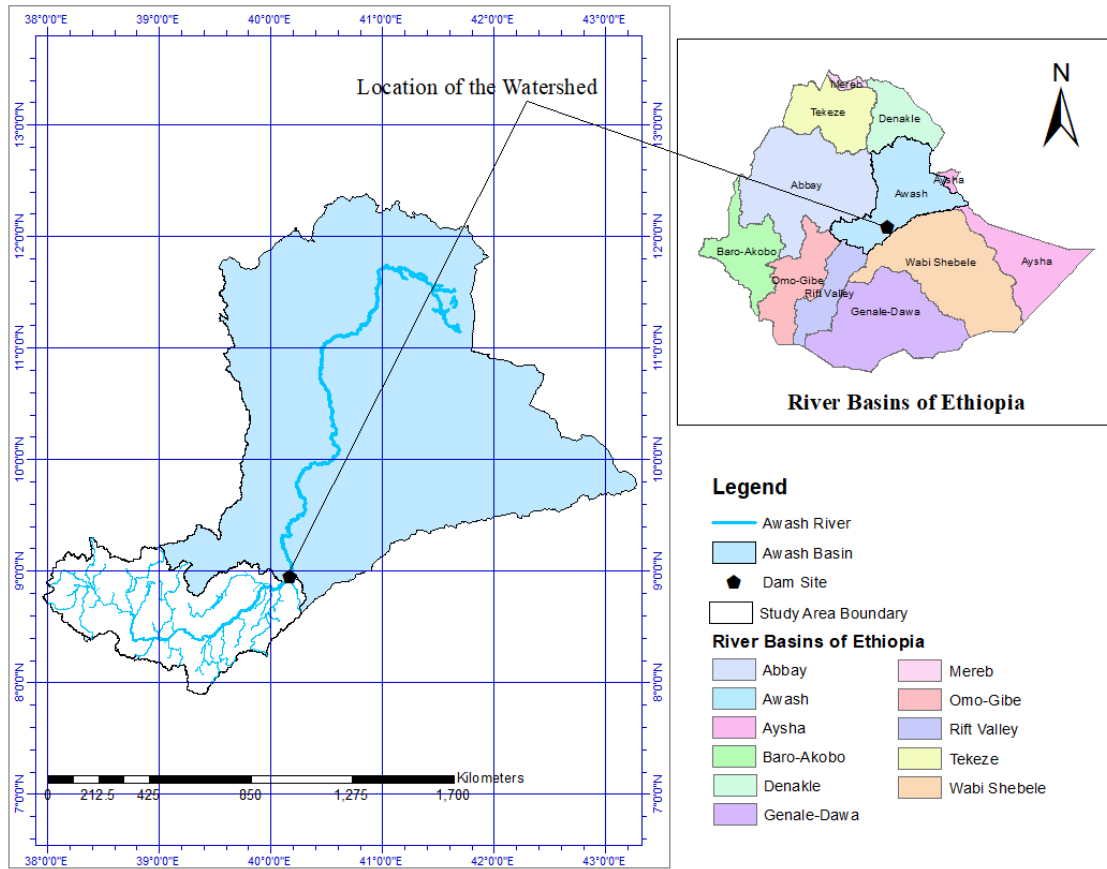


Figure 3-1 Location of the Study Area

3.1.2. Topography

Generally, the Awash Basin topography is characterized as Plateau and Rift Valley, widening to the North into the Afar Triangle. The source of the Awash starts at an altitude of around 2500 m.a.s.l in plateau to the west of Addis Ababa. The basin is characterized by heterogeneous topographic feature such as small hilly watersheds and flood plains. The Middle Awash Multipurpose Dam Project is located in the Main Ethiopian Rift (MER) of Afar Depression (WWDSE, 2016).

3.1.3. Climate

The basin can generally be described as temperate at higher elevation and tropical at lower elevations. However, due to the distinctive aspects of the highland climate, it is better to describe it using the local climatic zone that defines along with the elevation (WWDSE, 2015). The “Kolla” zone prevails in areas where the elevation is below 1800m and annual temperature varies from 20°C to 28°C. Whereas, “Woina Dega” zone is for the areas that are between 1800m and 2400m,

and the annual average temperature ranges from 16⁰C to 20⁰C. The last one is the “Dega” zone, which prevails in areas that are located above 2400m and the average annual temperature ranges from 10⁰C to 16⁰C.

Also, there are three mainly seasons in the basin namely: Kiremt, Bega and Belg. The main rainy season known as “Kiremt”, is from June to September. About 70% to 90% of the annual total rainfall occurs during this season. Also the “Kiremt” season receives a minimum sunshine hour, the variation of the daily temperature is low and the relative humidity is high. Whereas, the dry season known as “Bega” starts in October and extends up to January. During this season, maximum sunshine hours are received, the daily temperature variation is high and the relative humidity is low. Lastly, the minor rainy season known as “Belg” is from February to May. During “Belg” season, a minor rainfall occurs and the range of temperature is very high (WWDSE, 2015).

3.2. Tools and Data Availability

3.2.1. General

In order to achieve the aim of this research, it is vital to identify the main tools and input data's. ArcGIS 10.4.1 Software with SWAT2012 model interface database, SWAT-Checker, WGEN and SWAT-CUP software has been used as a tool to prepare and execute the input data's for SWAT model. WGEN was used to generate the weather data's collected from National Meteorology Agency and SWAT-CUP was used to calibrate and validate the model outputs using observed data. Spatial, meteorology and hydrology data was used as inputs to SWAT model to characterize the sediment yield of MAMD watershed.

In this study, different types of hydro-meteorological data have been collected and used from NMA and MoWE. Some of the data collected from NMA and MoWE are: Relative humidity, Actual sunshine hour, Precipitation or rainfall, Maximum, minimum and average temperature, Wind speed (vertical and horizontal wind speed), Discharge or flow data, Sediment concentration, and Elevation, latitude and longitude of each stations. Also there are four reservoirs (Koka, Gefersa, Legedadi and Dire Reservoirs) within the watershed area. The volume and surface area of each reservoir was used in the delineation process. The overall conceptual framework structure of the study is as shown below:

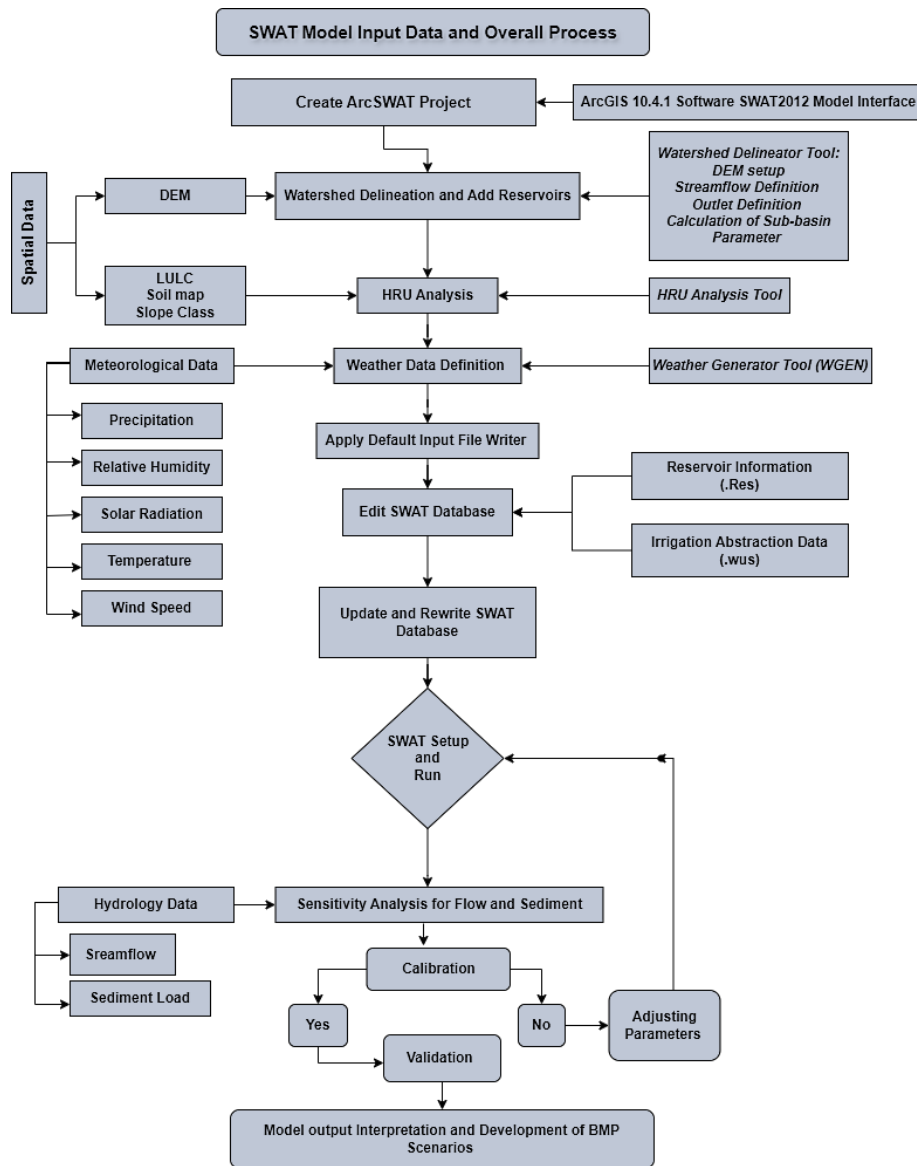


Figure 3-2 Conceptual Framework of the Study

Vital information needed for this study includes details about the features of the watershed such as its topography, land use and land cover, soil, weather patterns and management practices. The data was collected from various governmental and non-governmental organizations. The type of data required were spatial data such as DEM, Land use and land cover maps, soil type maps with corresponding hydraulic properties daily climate variables such as rainfall, temperature, relative humidity, wind speed and sunshine hours, as well as daily discharge and sediment concentration data for the MAMD Watershed. The study utilized a semi-distributed hydrological model that relies on hydro-meteorological and spatial data.

3.2.2. Digital Elevation Model (DEM)

A downloaded DEM of 30-Meter resolution from United States Geological Survey (USGS), Shuttle Radar Topography Mission (SRTM) for watershed network definition was used from <https://earthexplorer.usgs.gov/>. DEM is used to define the topography of the watershed which describes the elevation of a given area and used in SWAT model with the land use/land cover data and soil map to delineate the watershed. Furthermore, the DEM is the main input data for the entire process and it can be used to further divide the watershed into several sub watersheds and Hydrological Response Units (HRU's).

In this study, a DEM of 30m by 30m resolution was used to delineate the Middle Awash Multipurpose Dam watershed and for future HRU analysis. The Figure 3:2 below shows the digital elevation model of MAMD watershed.

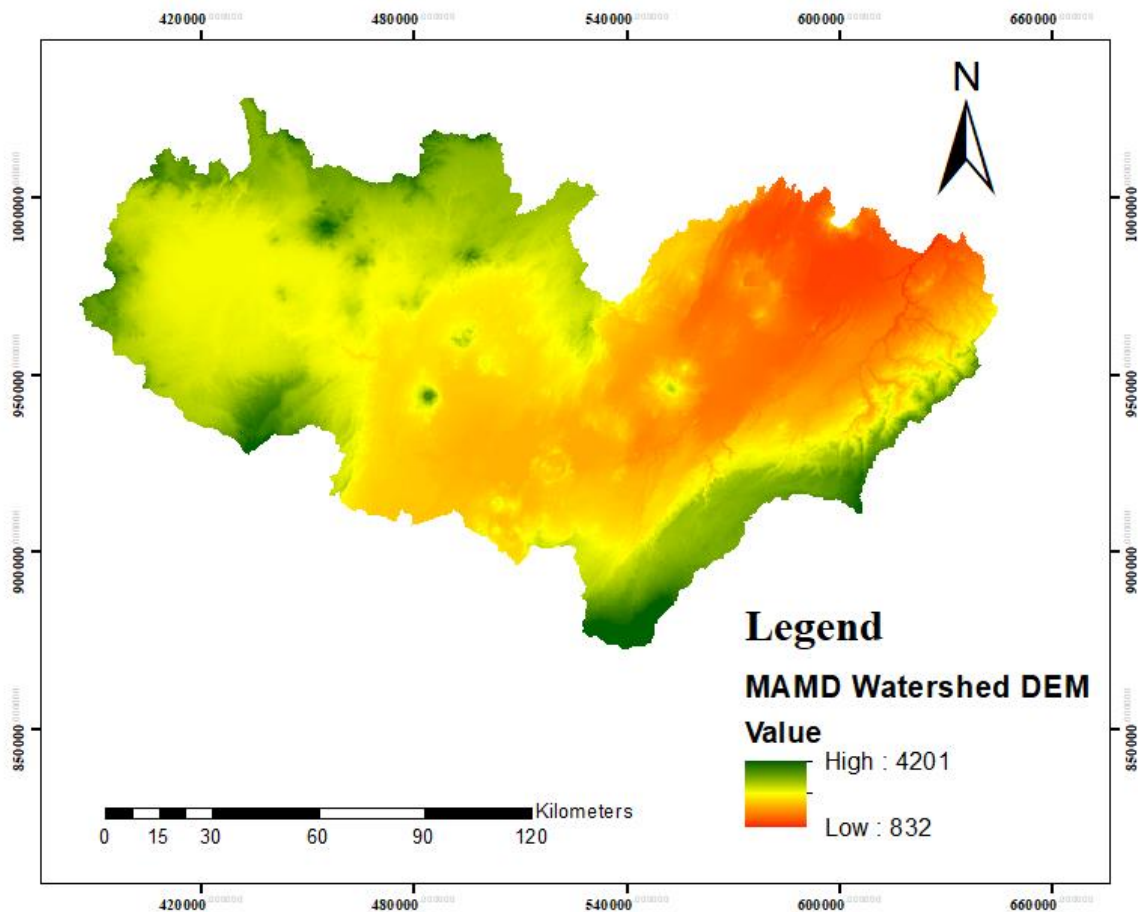


Figure 3-3 DEM of MAMD Watershed

3.2.3. Soil Map

In the SWAT model, the soil data of the watershed plays a crucial role in estimating sediment yield. The characteristics of the soil such as erodibility, hydraulic conductivity, infiltration capacity and etc. greatly impact the water balance and sediment yield from the watershed. Therefore. A high-resolution soil map was used to increase the accuracy of the model predictions.

The soil map of the study area was obtained from the Water and Land Resource Centre (WLRC) and the Harmonized World Soil Database was used to insert the major soil type's physical and chemical properties into the SWAT user soil database (FAO, 2002). With the soil map, a SWAT compatible lookup user table has prepared in order to be used in the model. Table 3:1 below shows the major types of soils with their percentage of area coverage obtained from the ArcSWAT model.

Table 3-1 Major Soil Types of the Watershed and their Percentage of Area Coverage

<i>No.</i>	<i>Soil Name</i>	<i>Area (km²)</i>	<i>Area Coverage (%)</i>
1.	Calcic Fluvisols	72.30	0.34
2.	Calcic Xerosols	193.30	0.92
3.	Chromic Cambisols	311.05	1.47
4.	Chromic Luvisols	1154.57	5.47
5.	Chromic Vertisols	520.35	2.47
6.	Dystric Cambisols	27.63	0.13
7.	Dystric Nitisols	415.21	1.97
8.	Eutric Cambisols	2269.91	10.76
9.	Eutric Fluvisols	947.13	4.49
10.	Eutric Nitisols	1155.16	5.47
11.	Eutric Regosols	528.72	2.5
12.	Haplic Phaeozems	94.13	0.45
13.	Leptosols	1032.37	4.89
14.	Luvic Phaeozems	855.87	4.06
15.	Mollic Andosols	1048.39	4.97
16.	Orthic Acrisols	99.63	0.47
17.	Orthic Luvisols	546.17	2.59
18.	Orthic Solonchaks	431.45	2.04
19.	Pellic Vertisols	6124.14	29.02
20.	Vertic Cambisols	2036.82	9.65
21.	Vitric Andosols	1041.91	4.94
22.	Water body	196.96	0.93
	Total	21103.16	100.00

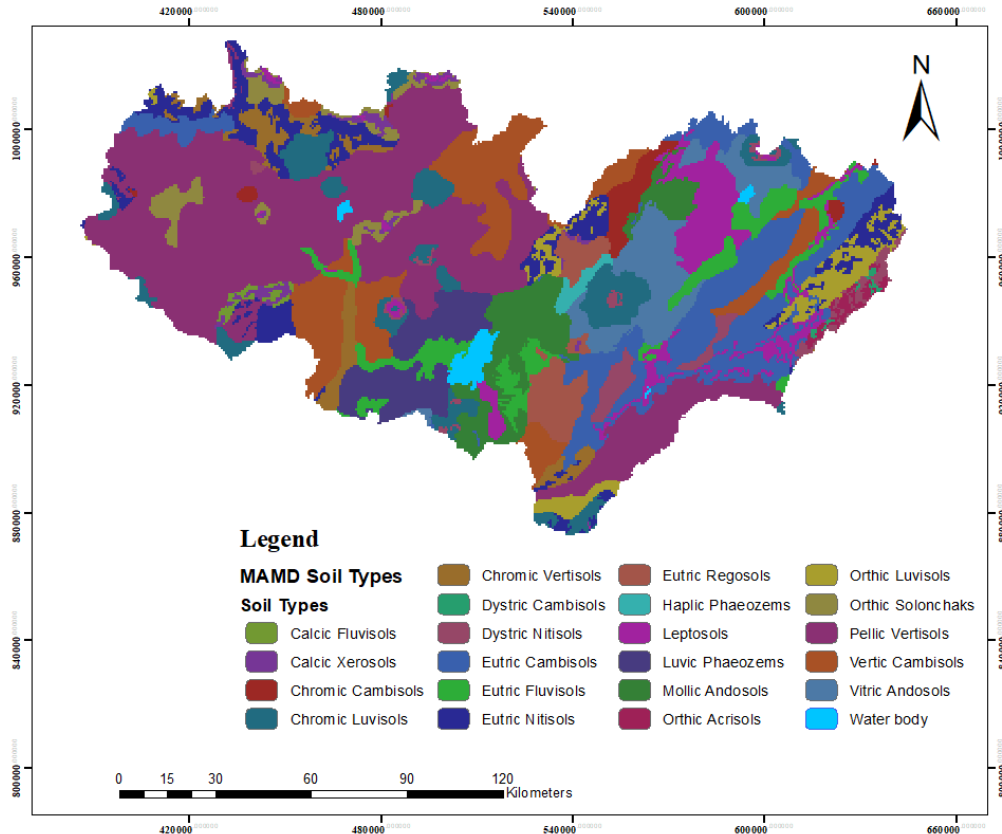


Figure 3-4 Soil Map of the Proposed MAMD Watershed

3.2.4. Land Use Land Cover Map

The other factor that greatly influences the hydrological properties of a watershed that is required by SWAT model is Land Use/Land cover map. It is used to describe the sub basins and HRU classifications. The LULC data in combination with the soil data will generate the hydrologic characteristics of the watershed and generates multiple HRU's within each sub watersheds during the ArcSWAT overlay process. A 2016 Middle Awash Multipurpose Dam watershed LULC map was obtained from WLRC and the table below shows the original land use land cover and percentage coverage over the watershed.

Table 3-2 Land Use Land Cover Classification of MAMD Watershed

No.	LULC Name	SWAT Code	Area (km ²)	Area Coverage (%)
1.	Water Body	WATR	251.17	1.19
2.	Forest-Mixed	FRST	2162.88	10.25
3.	Forest-Deciduous	FRSD	748.86	3.55
4.	Range-Grasses	RNGE	2017.90	9.56
5.	Built Area: Settlements	URBN	595.30	2.82
6.	Bare Ground	BARR	986.52	4.67
7.	Wetlands-Mixed	WETL	16.74	0.08
8.	Forest-Evergreen: Afroalpine	FRSE	67.83	0.32
9.	Range-Brush	RNGB	2236.90	10.61
10.	Agricultural Crops (Cropland)	AGRR	12019.05	56.95
Total			21103.16	100.00

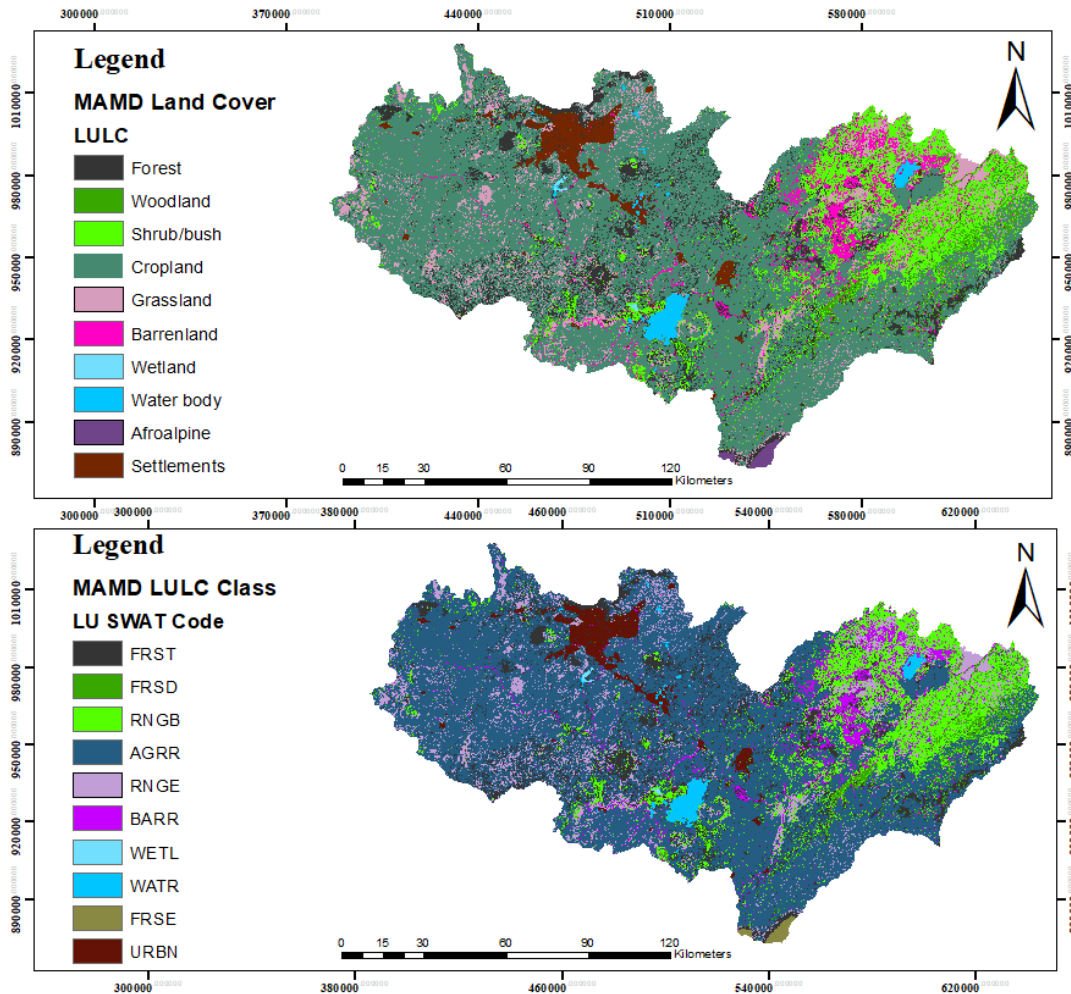


Figure 3-5 Land Use Land Cover Map of MAMD Watershed

3.2.5. Slope Class

To define the Hydrological Response Units (HRUs), the slope of the land was classified into five levels. The digital elevation model (DEM) was used to generate a slope map for this purpose. The SWAT model offers the flexibility to choose the slope classification method (Arnord et al, 2012). For this study, FAO (2006) land slope classification were used to classify the slope into five categories: 0 – 2%, 2 – 5%, 5 – 15%, 15 – 30% and > 30% for best sediment yield analysis as shown in the Figure 3:5 below.

Table 3-3 Slope Classes of MAMD Watershed

<i>No.</i>	<i>Slope Class (%)</i>	<i>Area (km²)</i>	<i>Area Coverage (%)</i>
1.	0 – 2	2348.29	11.13
2.	2 – 5	6024.93	28.54
3.	5 – 15	8345.65	39.55
4.	15 – 30	2776.79	13.16
5.	> 30	1607.49	7.62
Total		21103.16	100.00

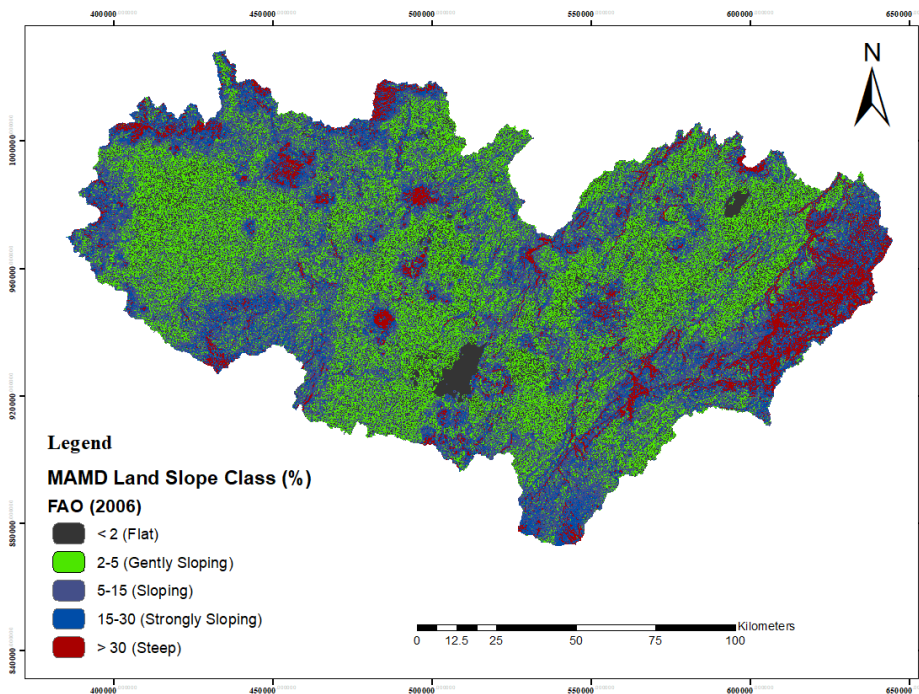


Figure 3-6 Slope Classes of MAMD Watershed

3.2.6. Reservoirs in the Watershed

SWAT delineation process includes adding reservoirs to the SWAT project manually, if there any. Within Middle Awash Multi-Purpose Dam watershed, four well known reservoirs are found: Koka, Gefersa, Legedadi and Dire Reservoirs.

The Koka dam was originally constructed for hydropower generation and has a capacity of 43.2 MW. The construction was completed in 1960 with a storage capacity of 1850 Mm³ and a surface area of 177 km² (MoWR, 2006). The available storage capacity for Koka reservoir is 1188 Mm³, which represents about 36% of loss of storage capacity in 1999 due to sedimentation. The construction of Gefersa dam in 1944 aimed to provide clean water to Addis Ababa city. To meet the increasing water demand and sediment control, additional reservoirs, Gefersa II and III were built in 1960 and 1966, respectively (MoWR, 2006). The entire Gefersa reservoir system covers an area of 130.5ha with a catchment area of 53.5km². It has a storage capacity of 8Mm³ and can supply 30,000m³/day of water to Addis Ababa city (MoWE, 2002).

Legedad Dam and Treatment Plant were established in 1970 to supply clean water to Addis Ababa. The reservoir has a capacity of 86Mm³ and a surface area of 510ha. It's a catchment area is 207.3km² and it can supply 50,000m³/day of water (MoWE, 2002). In 1998 the Dire Reservoir was constructed to expand the Legedadi water supply system and meet the city's increasing water demand. It covers an area of 165ha and has a total catchment area of 77.5km². The combined Legedadi and Dire water supply system has a capacity to supply 165,000m³/day of water to the city.

The reservoirs in the watershed was considered during the SWAT model simulation and all the required reservoir input data was prepared and entered as SWAT model as requested. The table below shows the required information and are collected from (MoWE, 2002; MoWR, 2006).

Table 3-4 Basic Reservoir Input Data for SWAT Model Use (MoWE, 2002; MoWR, 2006)

<i>Dam/ Reservoir</i>	<i>Dire</i>	<i>Legedadi</i>	<i>Gefersa</i>	<i>Koka</i>	
Location	Longitude	38.934	38.962	38.942	39.156
	Latitude	9.148	9.068	9.068	8.468
Year of become operational: IYRES		1998	1970	1944	1960
Reservoir surface area when filled up to emergency spillway: RES_ESA (ha)		181.5	561	143.55	19470
Reservoir volume when filled up to emergency spillway: RES_EVOL (10 ⁴ m ³)		2090	9460	880	130680
Reservoir surface area when filled up to principal spillway: RES_PSA (ha)		165	510	130.5	17700
Reservoir volume when filled up to principal spillway: RES_PVOL (10 ⁴ m ³)		1900	8600	800	118800
Initial reservoir volume: RES_VOL (10 ⁴ m ³)		1900	8600	800	102800

In SWAT model, the above information about the reservoirs is going to be used and variables referring to the principal spillway can be thought of as variables referring to the normal reservoir storage volumes, while the variables referring to the emergency spillway can be thought of as variables referring to the maximum reservoir storage volumes (Neitsch et al, 2012). For this study, an addition of 10% from normal reservoir storage volume is taken as a maximum reservoir storage volume (Dile et al, 2023).

When utilizing the SWAT model for simulating the hydrology of a watershed containing a dam, the release parameters from the dam are essential inputs for accurately representing the flow regime of the downstream. These parameters are collected from MoWR in a monthly basis (MoWR, 2006).

Table 3-5 Maximum Koka Dam Release in Mm³/month

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Koka Release	101.43	105.18	108.94	93.07	92.49	93.07	59.08	48.89	33.62	91.19	84.84	67.03

3.2.7. Major Headwork/Diversion Sites for Water Abstraction in the Watershed

Allocation and consideration of diversions sites for irrigation abstraction is vital in order to enhance the SWAT models ability to simulate the overall hydrology process. The extent and detailed information of the water abstraction, greatly affect the overall SWAT model output (Basson, 2006). For this study, water abstraction locations were carefully determined and considered during the simulation of SWAT model.

The Awash basin has been the most extensively studied river basin due to its strategic location accessibility and abundant land and water resources. It is currently the most developed and utilized part of Ethiopia in terms of irrigated agriculture (Ayalneh, Woldu, Gebremedhin, Tadesse, & Peden, 2007). Several potential irrigation development areas have been identified in the basin (Halcrow, 1989). Also, a surface water study team of Addis Ababa Institute of Technology made a field visit to upper valley of Awash river basin from November 20th to 26th, 2015. They visited the area between Koka dam and Awash River Gauge station at Metehara in the upper valley of Awash Basin (Awash Basin Authority, 2017).

Between the sub-basins of the project area, there are a lot of small, medium and large scale irrigation developments. Most of the small scale irrigation developments are owned by local farmers, while the medium and large scale irrigations are developed by both private commercial companies and government. For this study, the overall status of the diversion structures and monthly average irrigation water demand for each sites was taken from the source table provided by (MoWR, 2006).

Table 3-6 Existing Irrigation Schemes located within the Watershed (MoWR, 2006)

No.	Name of the Irrigation Scheme	River	Location		Area Irrigated (ha)
			Easting (m)	Northing (m)	
1	Awash Melakasa Wonji Masfafia (Welenchiti Intake)	Awash	537042	928508	3500
2	Doni Kombe Diversion	Awash	560612	939374	400
3	Nurahera	Awash	571848	946877	3000
4	Fentale Kawa New Proposed Location (Golgota Diversion)	Awash	578356	956551	7600
5	Abadiska	Awash	525570	934496	680

6	Merti Jeju	Awash	573837	948207	2340
7	Merti Methara(Right Bank Diversion)	Awash	597461	968854	7122
8	Africa Juice	Awash	562513	941057	300
9	Tibila	Awash	558358	937446	2340
10	Abadir Diversion Methara (Left Bank)	Awash	596191	966031	3117
11	Dodota(Wonji shewa pumping station)	Awash	534021	926873	6000
12	Waka Mia(Pump2)	Awash	530992	932190	6559
13	Wonji(Pump1) station	Awash	525426	934544	5928
14	Waka Tio	Awash	527827	933801	600
15	Keleta	Keleta	544579	919034	2842

Table 3-7 Monthly Average Irrigation Water Demand for each Irrigation Schemes in Mm³ (MoWR, 2006)

<i>Name of the Irrigation Scheme</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
Awash Melakasa Wonji Masfafia (Welenchiti Intake)	40.2	36.3	40.2	38.9	40.2	38.9	40.2	40.2	38.9	40.2	38.9	40.2
Doni Kombe Diversion	1.2	1.1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Nurahera	14.7	13.3	14.7	14.3	14.7	14.3	14.7	14.7	14.3	14.7	14.3	14.7
Fentale Kawa New Proposed Location (Golgota Diversion)	32.1	29.0	32.1	31.1	32.1	31.1	32.1	32.1	31.1	32.1	31.1	32.1
Abadiska	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Merti Jeju	8.6	7.7	8.6	8.3	8.6	8.3	8.6	8.6	8.3	8.6	8.3	8.6
Merti Methara(Right Bank Diversion)	21.4	19.4	21.4	20.7	21.4	20.7	21.4	21.4	20.7	21.4	20.7	21.4
Africa Juice	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Tibila	18.7	16.9	18.7	18.1	18.7	18.1	18.7	18.7	18.1	18.7	18.1	18.7
Abadir Diversion Methara (Left Bank)	10.7	9.7	10.7	10.4	10.7	10.4	10.7	10.7	10.4	10.7	10.4	10.7
Dodota(Wonji shewa pumping station)	22.6	20.4	22.6	21.9	22.6	21.9	22.6	22.6	21.9	22.6	21.9	22.6
Waka Mia(Pump2)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Wonji(Pump1) station	13.4	12.1	13.4	13.0	13.4	13.0	13.4	13.4	13.0	13.4	13.0	13.4
Waka Tio	0.5	0.4	0.5	0.4	0.5	0.4	0.5	0.5	0.4	0.5	0.4	0.5
Keleta	2.8	3.9	5.5	4.5	3.3	3.9	0.0	0.0	6.8	10.5	7.3	5.6

Using the recent report (Awash Basin Authority, 2017; MoWR, 2006), the above major diversion/headwork sites existing situations are presented. The Wonji-Shoa pumping station is the first large scale water abstraction site from Awash River downstream of Koka Dam. The station supplies water for sugarcane development farm of Wonji Sugar Factory. The structure consists of 8 pumps with 6 each capacity of 750l/sec and 2 with capacity of 390l/sec. Also, in the Wonji area there are about 5 out-grower's associations that grows sugarcane and supply to Wonji Sugar Factory. Some of the major out-growers (6559ha) are: Kuruftu Farm Association, Boku Farm Association, Adulala Farm Association, Waka Mia Farm Association and Waka Tio Farm Association.

The Awash Melkasa Diversion work (Welenchiti Intake) is also a part of Wonji Sugar Factory Expansion System and it has a gravity intake without major structure on Awash River (MoWR, 2006). It designed to supply water for about 15,000ha sugarcane development but currently it supplied only for 3500ha of sugarcane farm. The design discharge capacity of intake and main canal at the head is 15m³/sec. The Tibila Intake and Fentale Kawa diversion weirs are also one of the large scale farm constructed for local community and partly supply to Africa Juice farm (Awash Basin Authority, 2017). The Tibila headwork has a gravity intake without major structure on Awash River and designed to supply water for about 8000ha. However, currently it only supplies for 2340ha of irrigation farm. The Fentale Kawa diversion weir is designed to supply water for about 18,000ha irrigated development, but so far the only 7600ha is developed.

Nuraera diversion weir is owned by Upper Awash Agro-Industry Plc and it is supplying an area of 3000ha farm with a maximum discharge capacity of 5.5m³/sec. Keleta Irrigation water supply extracts water from Awash River and irrigates only 2842ha of land out of the predesigned 5000ha of land the Boru Dodota spate irrigation scheme. Lastly, Metehara Sugar Factory sugarcane development system has two diversion weirs: Abadir and Merti. Both structures have a side weir as major structure on Awash River to divert water to Abadir and Merti Farm. The Abadir and Merti was designed to supply water for about 3117ha and 7122ha sugarcane developments, respectively.

3.2.8. Meteorological Data

Daily meteorological data for all parameters within and around the MAMD watershed was obtained from National Meteorology Agency (NMA). From a total of 14 stations, 6 were selected for further analysis using the Weather Generator (WGEN) due to their high-quality data. These stations are considered principal stations and provide the necessary data for all meteorological parameters such as precipitation, temperature, relative humidity, sunshine hour and wind speed. Thus, this stations have been used as a weather generator to generate the data for other stations with low quality of data. The meteorological data's from NMA was a daily time series data starting from 01, January 1990 to 31, December 2021.

Table 3-8 Location of Meteorological Stations within and around the Watershed (1990 - 2021)

<i>No.</i>	<i>Station Name</i>	<i>Latitude</i>	<i>Longitude</i>	<i>Elevation</i>	<i>Meteorological Parameters</i>					
					<i>RF</i>	<i>Tmax</i>	<i>Tmin</i>	<i>RH</i>	<i>SS</i>	<i>WS</i>
1	Addis_Ababa_Bole	8.981081	38.79871	2354	√	√	√	√	√	√
2	Addis_Ababa_Obs	9.01891	38.7475	2386	√	√	√	√	√	√
3	Debre_Zeit	8.733333	38.95	1900	√	√	√	√	√	√
4	Metehara	8.865	39.921	952	√	√	√	√	√	√
5	Nazeret	8.557	39.284	1648	√	√	√	√	√	√
6	Nuraera	8.67	39.775	1141	√	√	√	√	√	√
7	Asgori	8.795	38.335	2072	√	√	√	NA	NA	NA
8	Awash_7_Kilo	8.989167	40.165	934	√	√	√	NA	NA	NA
9	Bologiorgis	8.838	39.3585	1967	√	NA	NA	NA	NA	NA
10	Chefedonsa	8.972	39.128	2402	√	√	√	NA	NA	NA
11	Ginchi	9.01667	38.1333	2132	√	NA	NA	NA	NA	NA
12	Koka_Dam	8.471	39.157	1625	√	√	√	NA	NA	NA
13	Mojo	8.609	39.114	1771	√	√	√	NA	NA	NA
14	Welenchiti	8.666	38.427	1457	√	√	√	NA	NA	NA

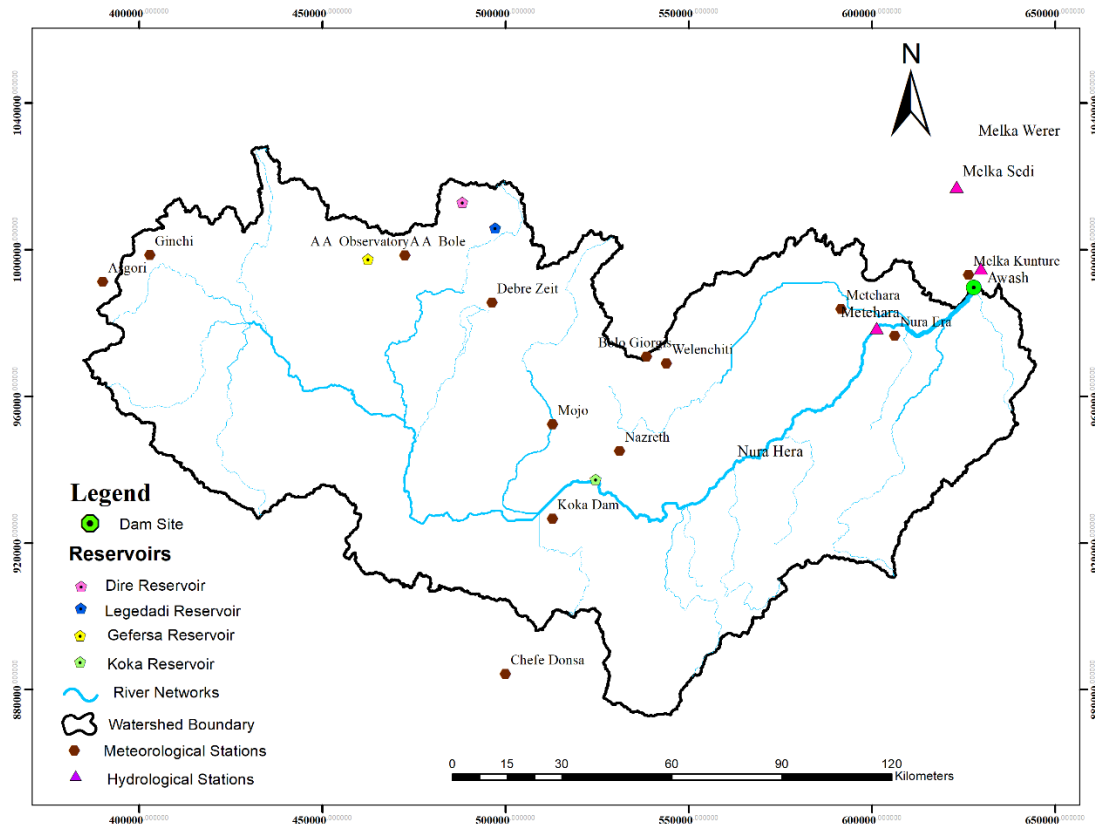


Figure 3-7 Meteorological and Hydrological Gauging Stations of MAMD

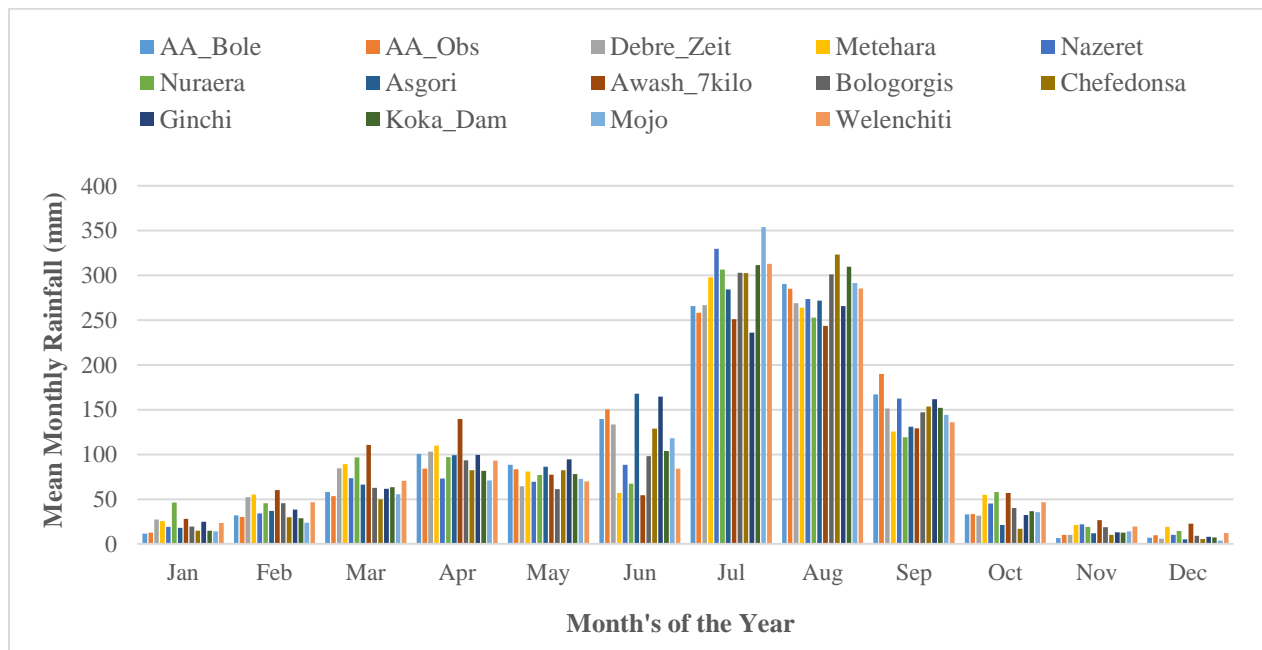


Figure 3-8 Mean Monthly Rainfall of the Selected Stations

3.2.9. Hydrological Data

3.3.8.1. Stream Flow Data

Daily streamflow data was collected from the Ministry of Water and Energy (MoWE), Hydrology Directorate to calibrate and validate the SWAT model of the MAMD catchment. Streamflow data is crucial for accurately calibrating and validating the model. In this study three gauge stations were selected (Awash Metehara, Awash Awash and Awash Melka Sedi) with a period of 21 years (1993-2013) for the recorded data. Due to scarcity of data, the Metehara and Melka Sedi gauge stations were used to fill the missing data from the Awash Awash gauge station. The Metehara and Melka Sedi stations are located within the study area and have better data availability compared to the Awash gauge station which is located at the dam site. The streamflow data from the Awash gauge station was used to calibrate and validate the SWAT model. Based on the extent of calibration and validation of the SWAT model, the data was arranged as per requirement of the SWAT model.

3.3.8.2. Sediment Data

Sediment data is essential for managing water resources and protecting against negative impacts. It is commonly used to assess long-term sediment yield in the watershed. The amount of sediment deposited in a reservoir depends on the rate of erosion in the watershed and the ability of the stream system to transport the eroded material (Gottschalk, 1934). The rate of erosion is influenced by the hydro-physical characteristics of the watershed (WWDSE, 2015).

For this study, the collected sediment data from MoWE has a various missing data. The recorded data's do not include all the days, months and years. Due to the gap and absence of long period of sediment data, the flow sediment rating curve method is used to fill the missing data. Although, no sediment concentration data at the dam site was available and makes the process to use alternative options. The Metehara gauging station is located approximately 25km upstream of the dam site and has adequate sediment concentration data. Therefore, an equation for sediment rating curve was developed for Metehara station in order to estimate daily sediment load (ton/ha) at the dam site. This approach was recommended by (Tesfu et al, 2021) as the Metehara gauge covers around 90% of the MAMD watershed area. The remaining 10% of ungauged area has relatively similar soil, land use and topography characteristics.

Since the sediment data from the MoWE is sediment concentration (mg/l), it required to be changed in to sediment load (ton/day) to create the sediment curve and used for the further analysis. When sediment load and discharge data pairs from many events are superimposed they create a scatter plot of the type commonly used to construct Sediment Rating Curves (Morris et al, 2009). To ensure that the sediment concentration data is qualified for the development of sediment rating curve, it is essential to check the temporal coverage of various seasons and the data ranges (high to low). For the sediment rating curve, data's can be approximated by using the mathematical power relation as shown below:

$$Q_s = a * Q_{Water}^b \dots \dots \dots eq. 3.1$$

Where, Q_s : is the suspended sediment transport in tons/day, Q_{Water} : is daily discharge in m^3/sec , and 'a' and 'b' are regression coefficient and exponent respectively or fitted parameters. A study suggested, 'a' and 'b' are related to river basin characteristics such as topographic relief and runoff (Jonathan, 2014). Although, they can vary significantly in time owing to sediment availability in the watershed.

The suspended sediment can be computed by using rating curve and a time series of discharge data. The product of discharge and discharge-weighted concentration equals load during the computational interval, and daily sediment load Q_s in metric tons can be computed using the equation below:

$$Q_s = 0.0864 C_s Q_{Water} \dots \dots \dots eq. 3.2$$

Where, Q_s is the sediment load in ton/day, Q_{Water} is the stream flow in m^3/sec , C_s is the sediment concentration in mg/l, and 0.0864 is a conversion factor.

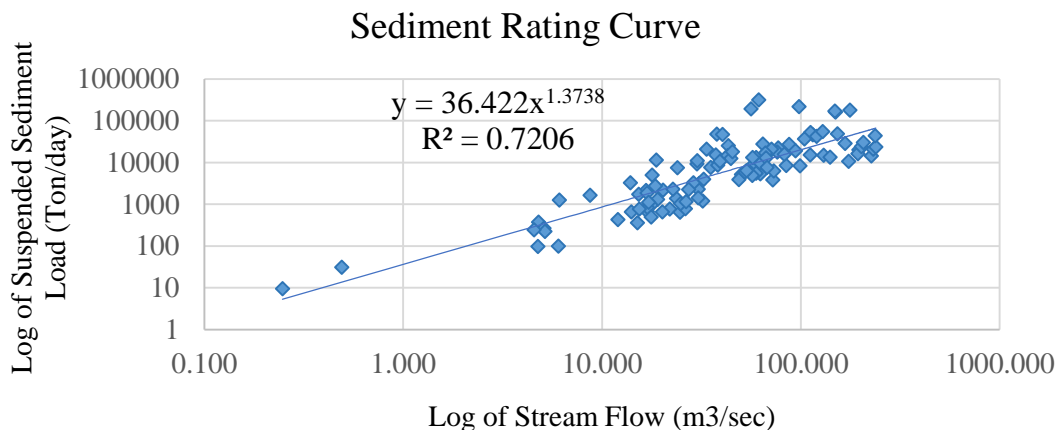


Figure 3-9 Sediment Rating Curve of MAMD Watershed at Metehara Gauge Station

After plotting the sediment rating curve, the relation between the stream flow and suspended sediment load for Metehara gauge station expressed in equation developed by using the sediment rating curve is $Q_S = 36.422 * Q^{1.3738}$. This equation is used to calculate the daily Sediment load harvest for the Awash gauge station.

3.3. Data Quality Analysis

3.3.1. General

Any water resource development and management studies are depending on hydrological and meteorological data's. Before inputting the hydro-meteorological data into SWAT model, analyzing its quality, consistency and homogeneity is important. Missing data is a common data quality decreasing factor due to lack of appropriate records and shifting of the station location. This might lead to incorrect and ambiguous results that may contradict with the actual situation (Subramanya, 2008).

3.3.2. Meteorological Data Analysis

The daily meteorological data obtained from NMA have missing points in their time series for all stations. All the 14 stations do not have full daily observed recorded data. The 6 principal stations (i.e., Addis Ababa Bole gauge station, Addis Ababa Observatory gauge station, Debre Zeit gauge station, Metehara gauge station, Nazeret gauge station and Nuraera gauge stations) has at least data with the 5 weather parameters which are required by SWAT model. However, they have missing data's. The other 6 stations are with secondary data only (precipitation and temperature) and the remaining two stations do have only a precipitation data.

For this study, missing values were estimated from other stations around the missing record station by considering the assumptions of at least three closed and evenly spaced stations with the missing record station. For this case the gauge stations were classified in to three groups: stations in the upper, lower and middle part of the watershed.

3.4.2.1. Filling Missing Data

Except for the rainfall, Weather Generator Model (WGEN) developed by (Sharply, 1990) was used to complete missing daily weather data. The WGEN was prepared based on a long term daily

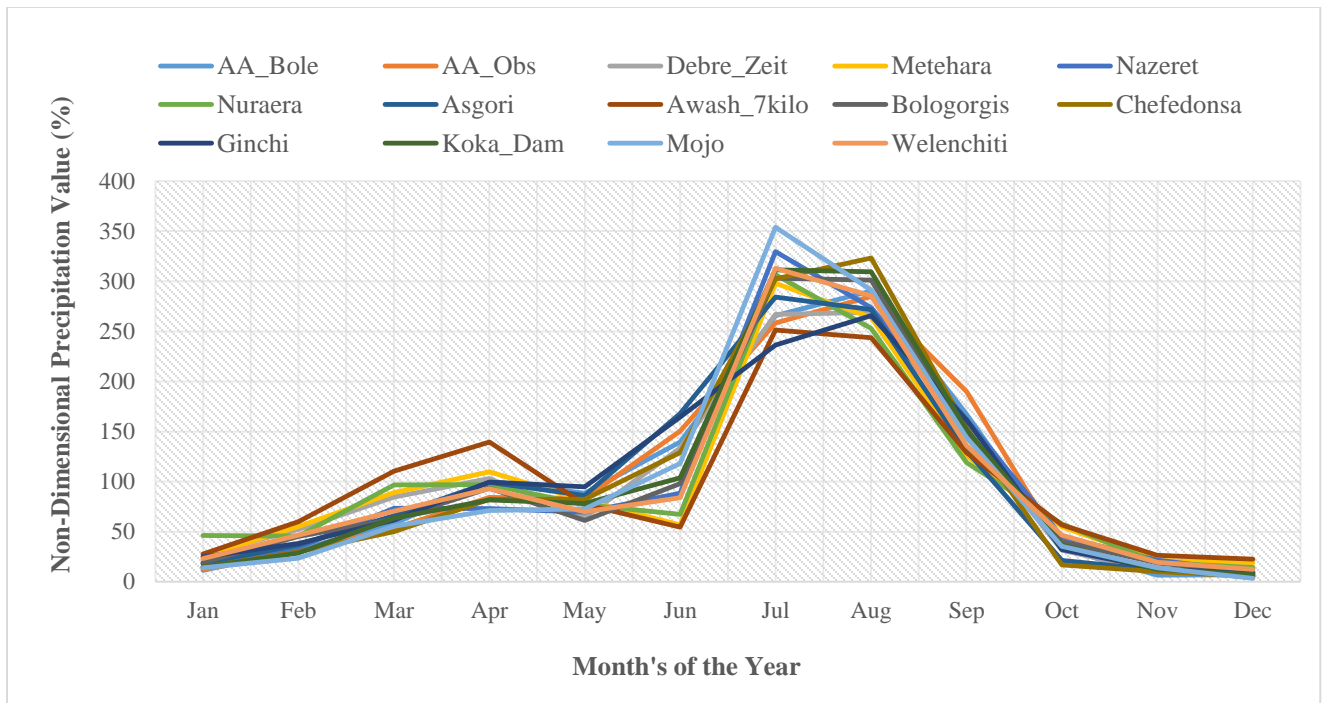


Figure 3-11 Homogeneity Test for Selected Meteorological Station

3.4.2.3. Areal Precipitation Estimation and Relationship to Hydrologic Modeling

A precipitation can be measured by using different types of rain gauges. These rain gauges' measure precipitations at a point. A single point precipitation measurement is quite often not a representative of the volume of the precipitation falling over a given catchment area (Subramanya, 2008). To accurately estimate areal precipitation a dense network or combination of point measurements is necessary. According to (Subramanya, 2008), precipitation measurements can be converted to Areal estimates using various techniques such as the Arithmetic or Station Average Method, Isohyetal Method and Thiessen Polygon Method. For this study Thiessen Polygon technique was adopted to estimate areal precipitation of the MAMD watershed using ArcGIS 10.4.1. It is another graphical technique which calculates station weights based on the relative areas of each measurement station in the Thiessen polygon network.

Rainfall varies in intensity and duration from one place to other, hence rainfall recorded by each station should be weighed according to the area (polygons) it is assumed to influence. The individual weights are multiplied by the station observation and the values are summed to obtain the areal average precipitation (Subramanya, 2008; Singh, 1994). If there are n station with rainfall

value $P_1, P_2, P_3, \dots, P_n$ and $A_1, A_2, A_3, \dots, A_n$ are the area of the respective Thiessen polygons, the average rainfall over the catchment P_{avg} is computed as:

$$P_{avg} = \sum_{i=1}^n P_i \left(\frac{A_i}{A} \right) \quad \text{Where, } \left(\frac{A_i}{A} \right) \text{ is the weight factor for each station.}$$

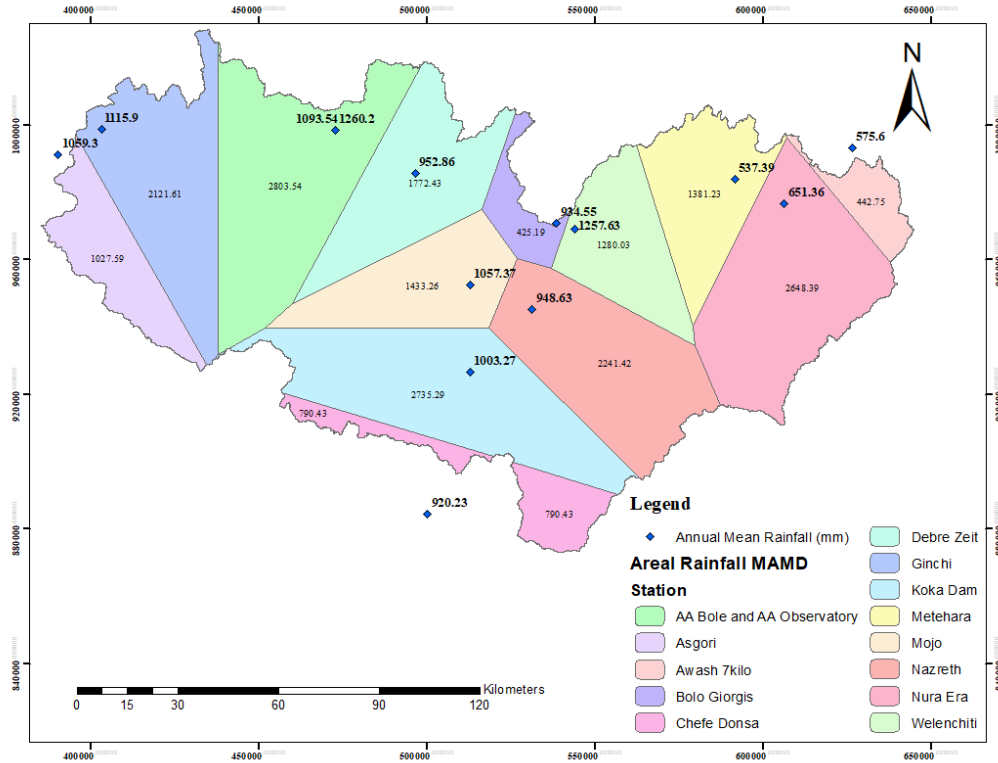


Figure 3-12 Thiessen Polygon for the selected Stations with in the study area

3.4.2.4. Outlier Test Analysis

The problem of outliers is of major concern when dealing with extreme events. In statistics, an outlier is a single observation far away from the rest of the data that can lead to unrealistic mathematical and hydrological conclusions (Galiatsatou, 2007). In order to reduce the effect of the outliers, it's better to check for the bigger outliers early. According to Log Person III, a standard error less than 10% is acceptable.

In the present study, daily rainfall of 14 stations from MAMD Watershed for a time period of 32 years (1990-2021) is analyzed using Log Person III method. The equation below can be used to detect the outliers from the gathered and filled data's:

$$\text{Higher Limit, } Y_h = Y_{mean} + K_n * \delta_{n-1} \dots \dots \dots \text{eq. 3.6}$$

$$\text{Lower Limit, } Y_l = Y_{mean} - K_n * \delta_{n-1} \dots \dots \dots \text{eq. 3.7}$$

$$\text{Upper Limit of Rainfall} = 10^{Y_h} \dots \dots \dots \text{eq. 3.8}$$

$$\text{Lower Limit of Rainfall} = 10^{Y_l} \dots \dots \dots \text{eq. 3.9}$$

$$\text{Check for Variance, } \alpha = \left(\frac{\delta_{n-1}}{(\sqrt{N}) * Mean} \right) * 100 \% \dots \dots \dots \text{eq. 3.10}$$

Where, Y_h and Y_l is the higher and the lower outlier threshold in log unit, K_n is the critical deviate taken from table for sample N (2.7338 for 32 years of Data), δ_{n-1} is the standard deviation of the logs of the rainfall sample and Y_{mean} is the mean of the log of the rainfall sample.

For all the 14 stations the outlier test was done and there is no data that is rejected according to Log Person III formula in MAMD watershed.

3.3.3. Hydrological Modeling using SWAT Model

The SWAT model is a basin-scale and continuous-time simulation tool that operates on a daily time step. It is specifically designed to assess the effect of management practices on water, sediment and agricultural chemical yields within watersheds (Arnold et al, 2012). The model characterized by its physically approach, computational efficiency and capability for long-term continuous simulation (Gassman et al, 2007). The model was initially developed by the U.S. Department of Agricultural Service in the early 1990s and has been continuously modified and upgraded (Arnold et al, 2012). SWAT is widely used to predict and analyze the response of hydrological processes such as flow and sediment yield to changes in land cover, climate and land management practices across diverse watershed sizes, ranging from small to large and complex (Gassman et al, 2007).

The major components of the SWAT model include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management (Arnold et al, 2012). The model employs a hierarchical approach dividing a watershed into smaller sub-watersheds and further dividing them into hydrologic response units (HRUs). This allows the model to balance computational efficiency with representing the natural variability of the watershed (Srinivasan et al, 2015). HRUs are comprised of homogenous land use, management practices, topography and soil characteristics represented as a percentage of the sub-watershed

area (Arnold et al, 2012). Biophysical processes such as surface runoff and sediment yield are calculated at the HRU level and then aggregated to the sub-basin level for overall estimates (Dile et al, 2020).

3.4.3.1. Hydrological Component of SWAT Model

Various hydrological components are evaluated and estimated in SWAT based on the water balance equation at the soil layer (Neitsch et al, 2009). The equation below illustrates the water balance equation to determine the hydrological components of the watershed:

$$SW_t = SW_0 + \sum_{i=1}^t (R_{day} - Q_{surf} - Ea - w_{seep} - Q_{gw}) \dots \dots \dots eq. 3.11$$

Where, SW_t is the final soil water content (mm), SW_0 is the initial soil water content in day i (mm), t is the time (days), R_{day} is the amount of precipitation in day i (mm), Q_{surf} is the amount of surface runoff in day i (mm), Ea is the amount of Evapotranspiration in day i (mm), w_{seep} is the amount of percolation in day i (mm), and Q_{gw} is the amount of return flow in day i (mm).

To estimate daily surface runoff, the soil conservation service (SCS) curve number (CN) is used in the SWAT model along with Muskingum routing techniques to route flow into channels. The SCS curve number utilizes daily precipitation data for simulation. For the observed maximum and minimum temperature, solar radiation, relative humidity and wind speed daily data, Penman-Monteith method is adopted to estimate the potential evapotranspiration (Winchell et al, 2010). For this study, potential evapotranspiration is estimated using the Penman-Monteith method.

Surface runoff volumes and peak runoff rates are simulated for each HRU using daily rainfall data. The surface runoff in the watershed can be estimated by using SCS curve number method as shown:

$$Q_{surf} = \frac{(R_{day} - I_a S)^2}{(R_{day} - I_a + S)} \dots \dots \dots eq. 3.12$$

Where, Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstraction which includes surface storage, interception and infiltration before runoff (mm), and S is the retention parameter (mm) and defined by the following equation:

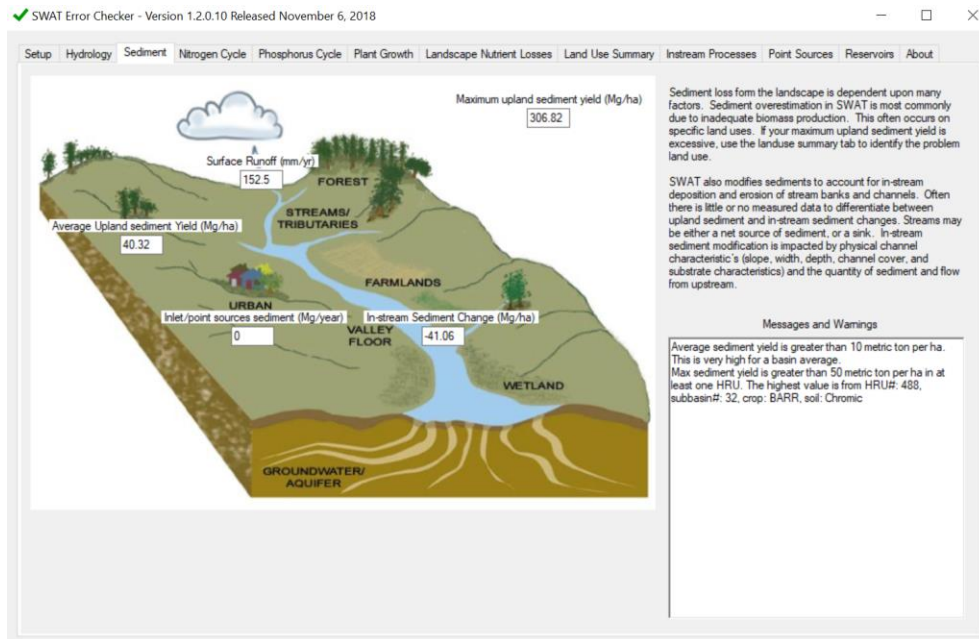


Figure 3-13 Sediment Components of MAMD Watershed from SWAT Checker

3.3.4. Selected Sediment Reduction Management Scenarios

The sediment yield analysis is an essential function of the SWAT model and a primary objective of this study is aiming to assess effective mitigation measures for reducing sediment yield in the watershed. SWAT is able to explore different land management scenarios and interventions to modify the water balance and reduce sediment yield (Dile et al., 2023). The variability in sediment yield across space and time is influenced by land use land cover, soil and topography in the watershed. Identifying the best management practice (BMP) to reduce the sediment load was involved in this study and it enables the researchers, stakeholders and government authorities make a decision to apply the better management practice for the highly erosion prone areas of the watershed.

The selected conservation measures used for this study are:

- A scenario under land use land cover impact (Conversion of 25%, 35% and 50% of agricultural land to forest land use type)
- Grassed waterway
- Filter strips
- Terracing, and
- Contouring

The parameters for these scenarios have been adjusted and added to the scheduled management operation (.ops) input file upon the sub-basin SWAT setup section and the scenario under the land use land cover management was done by reducing the land use type to a certain percent to another land use type under the HRU definition- Land Use Refinement option.

3.4.4.1. Baseline Condition

A baseline scenario is the condition with no BMP's and is a calibrated model condition that reflects the current situation of the model simulation (Kefay et al, 2022). This scenario is used as a reference for comparison of the effectiveness of the selected management options and their reduction capacity. This condition helps to understand the effect of each BMPs simulation result.

3.4.4.2. Grassed Waterway

Grassed waterways are defined as a channel of water having a grass that is to reduce surface runoff and sediment yields. This management scenario was modeled in SWAT by modifying model parameter in the scheduled management option (MGT_OP_7). There are some parameters to be adjusted while using the grassed waterway management scenario; length (GWAT_L), average slope (GWAT_S), depth (GWAT_D), average width (GWAT_W), Manning's roughness coefficient (GWAT_N) and linear factor for the channel sediment routing (GWAT_SPCON). By adjusting this parameters in the .ops SWAT input, it increases sediment trapping and reduces the flow velocity (Husen, 2020). Hence, it reduces sediment yield at the channel output. For this study, the parameter setup was adjusted and simulated with an average width of 30m and depth was calculated using $(3/64) * GWAT_W$, and a 25% channel slope reduction $0.75 * HRU_SLP$.

3.4.4.3. Filter Strips

The scenario under filter strip has a major effect of filtering and trapping the incoming sediment and stream flow in a given plot of land. A filter strip is a dense vegetation that put along the edge of the channel to decrease the entry of sediment, fertilizer, germs and pesticides into a surface runoff (Haregeweyn et al., 2020; Kefay et al, 2022). SWAT provides a parameter to modify the edge-of-field filter strips through the FILTERW which is in the MGT (management) input table. It is the width of the filter strip (FILTERW) is the appropriate SWAT model parameter that affects filter strip scenario. For analysis, the SWAT model can simulate the FILTERW from 1m to 30m

includes stream definition, outlet/inlet definition, selection and definition of a watershed outlet, and calculation of sub-basin parameters. Using a 30m DEM, the project setup is assigned to meters and the size of sub-basins is carefully determined by setting a threshold area or minimum drainage area needed for stream initiation after the accumulation process (Yared, 2011). By selecting threshold area of 15,000ha and by manually adding the location of outlet point at Middle Awash Multi-purpose dam, the entire watershed was delineated into 87 sub-basins and the total area of the watershed is 21,103.16km². In addition, the delineation process includes manually adding the location of Koka, Geferesa, Dire and Legedadi reservoirs.

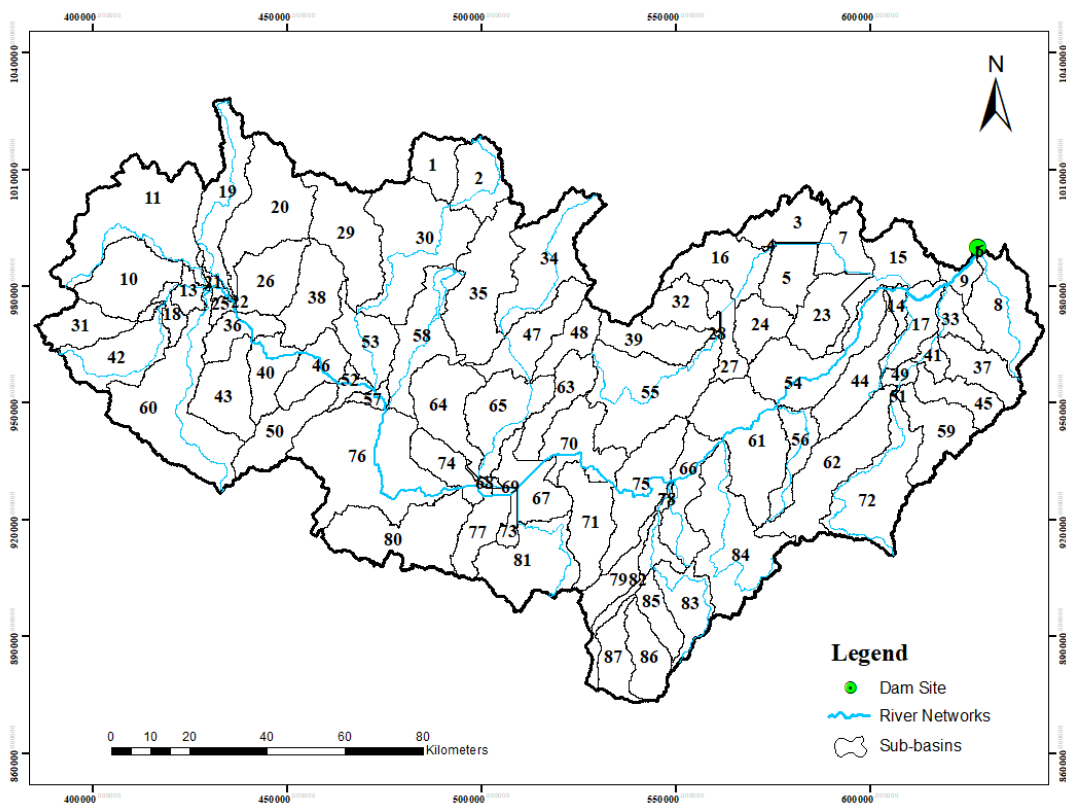


Figure 3-14 Delineated Sub-basins of MAMD Watershed

3.4.5.2. Hydrologic Response Units

In SWAT, HRUs area defined as unique combinations of land cover, soil, and slope classes distributed over a sub-watershed (Srinivasan et al, 2015). The HRU tool in ArcSWAT 10.4.1 helps to load land use, soil and slope maps to the project. The Land Use and soil maps were overlapped 98.96% and 98.67% with the delineated watershed, respectively. Using the FAO land slope classification, 5 slope classes were created: 0-2% (flat), 2-5% (gently sloping), 5-15% (sloping),

15-30% (Strongly sloping) and >30% (steep). Finally, the LULC, soil and slope maps are reclassified and created an overlay in order to correspond with the parameters of the SWAT database.

In this study, a threshold of 15% of land cover, 10% of soil and 10% of slope defined the HRU's for the MAMD watershed model. Anything less than threshold percentages given to those definitions will be eliminated or removed from the process and the rest is distributed in the watershed area. Finally, the MAMD watershed HRU development resulted in 1235 HRU's.

3.4.5.3. Weather Data Definition and Importing Climate Data

SWAT requires daily data for precipitation, maximum and minimum air temperature, solar radiation, wind speed and relative humidity. These values are obtained from observed data recorded by the National Meteorological Agency (NMA) and any missing data is generated using a Weather Generator (WGEN) program. WGEN input files contain statistical data used to generate representative daily climate data for all sub-basins with at least 20 years of records recommended for accurate parameter calculations (Neitsch et al., 2009). In the SWAT project missing values for each parameter (except precipitation) are entered as -99 and excluded from the WGEN statistics calculation.

For this study, daily weather data from principal or first-class stations were used for input into the weather generator including Addis Ababa Bole, Addis Ababa Observatory, Debre Zeit, Metehara, Nazreth and Nuraera with 32 years of recordings were used as input to determine the values of weather generator parameters. Each station location, elevation and data were exported to the WGEN and created a .txt file for each weather parameters that SWAT can understand. Finally, the WGEN allows to calculate the overall statistics of the 6 stations. Before getting this information to the SWAT model, the calculated WGEN statistics must be added to the SWAT database for the 6 stations. As the SWAT model developed based on US, introducing the stations by importing an excel file to the database is the primary step. The excel file was generated using the WGEN model to create the WGEN_user in SWAT database.

Besides the first class stations, the remaining second and third class station data were arranged as a .txt file to be imported while modeling. After inserting the .txt files which contains information

about the weather parameters of each stations to the SWAT model, the SWAT allows to write SWAT Database tables and then under the edit SWAT input, the reservoir input parameters were added for each reservoirs within the watershed. Since the climatic data required by the model consists of PCP, Maximum/Minimum TMP, SLR, WND and HMD, they were imported on the ArcSWAT modeling process at the stage of write input table right after HRU analysis is done.

3.4.5.4. Write Reservoir and Headwork Information

After the climate data were entered in the SWAT model at the stage of input table and writing the SWAT database is done, the reservoir information for each four reservoirs was added under edit SWAT input section. The commissioned year of the reservoirs (IYERS), volume of normal (Principal) reservoir storage (PVOL) and volume of maximum (Emergency) reservoir storage (EVOL) in (10^4 m^3), Surface area of the reservoir in both storage conditions in (ha) were added as per required by SWAT model. Dire, Legedadi, Geferesa and Koka Dam reservoir information were collected from MoWE (MoWE, 2002). When adding reservoir information is done, SWAT model requires to rewrite all the database tables. Simulation of 32 years of data will continue after inserting all the input data are completed.

When entering the reservoir data is completed, the next step is to write all the headwork/diversion data of each sites. Under Edit SWAT Input, there is an Edit Sub-Basin Input section. By clicking the Edit Sub-Basin Input, a selection to choose the input table is available. The data entry for all the headwork sites was done using the Water Use (. wus) selection with their belonging sub-basin. For instance, Merti is located in sub-basin 23, Fentale and Abadir are located in sub-basin 54, Nurahera, Merti Jeju amd Africa Juice belongs to sub-basin 61, Tibila and Abadiska belongs to sub-basin 66, Wonji-Shoa, Waka Mia and Waka Tio are located in sub-basin 70, Dodota Wonji Shoa and Awash Melkasa are located in sub-basin 75, and the remaining Keleta belongs to sub-basin 82.

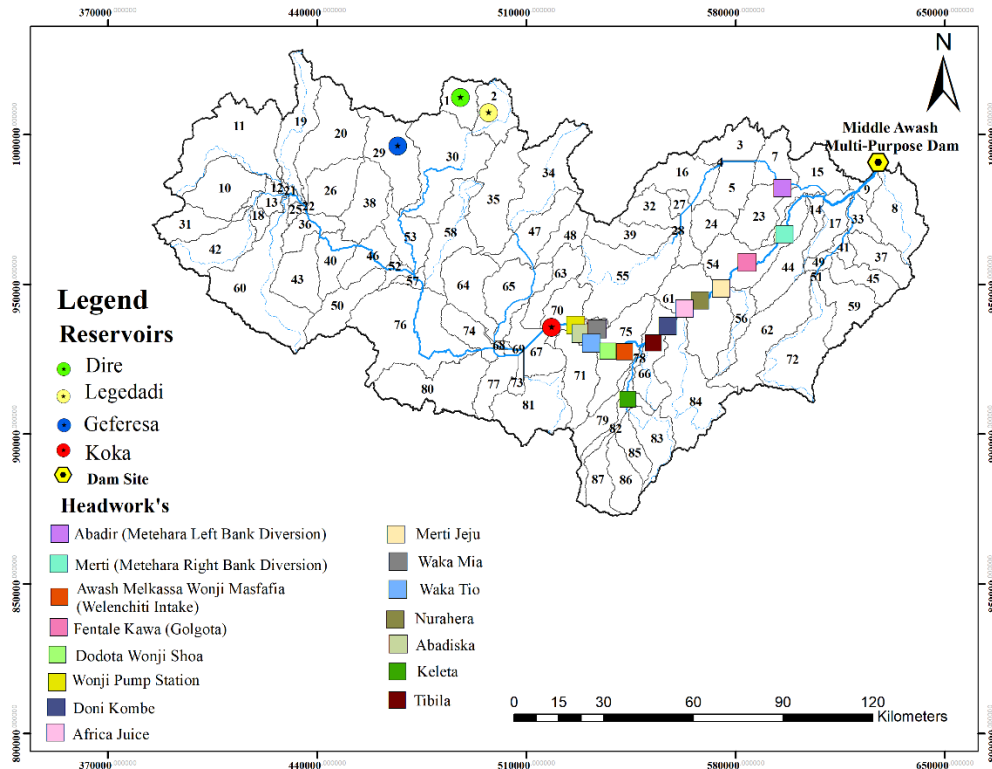


Figure 3-15 Reservoirs and Headwork sites located in the Watershed

3.3.6. SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation

3.4.6.1. SWAT Simulation

Simulation in the SWAT model involves creating and analyzing a prototype of a physical model to predict its performance in the real world (Tesfaye, 2021). Input parameters for SWAT must be process-based and realistic within a certain uncertainty range. After inputting all required parameters, the model is run with a warm-up period of three years (1990-1992) to generate reasonable initial values. A warm-up period allows variables such as soil moisture, reservoir levels, vegetation conditions, etc. to reach values independent of initial conditions. This period should be 2-5 years and use at least 10% of available data.

For this study, a 32-year meteorology data was available from NMA and a 3 year of warm-up period was taken. When finishing the model run, the model was checked using SWAT-Checker software and therefore the result from simulation is checked if it has a warning. After that, the model was used for further analysis. Evaluation of model prediction towards flow and sediment yield is vital through sensitivity analysis, model calibration and model validation.

3.4.6.2. Sensitivity Analysis

Sensitivity and uncertainty analysis are essential components of applying the SWAT model. Sensitivity analysis identifies the most influential input parameters on SWAT output (Gassman et al, 2007). This information helps to understand which processes have the greatest impact in the study area and can reduce the number of parameters needed for calibration by eliminating non-sensitive parameters (Abbaspour et al, 2017). It is the process of determining how sensitive the model output can be to the selected input parameters.

There are two types of sensitivity analysis: *one-at-a-time* (OAT) or *local* sensitivity analysis, and *all-at-a-time* (AAT) or *global* sensitivity analysis. OAT involves changing one parameter while holding others constant while AAT changes all parameters and requires more runs but can provide more reliable results (Abbaspour et al, 2017).

For this study, sensitivity analysis was conducted using the Sequential Uncertainty Fitting (SUFI-2) algorithm in SWAT Calibration and Uncertainty Program (SWAT-CUP). SWAT-CUP is an interface for SWAT sensitivity analysis, auto-calibration, and uncertainty analysis that can implement several calibration algorithms using SUFI-2, Particle Swarm Optimization (PSO), GLUE, Parameter Solution (ParaSol), and Marcov Chain Monte Carlo (MCME) methods. SUFI-2 is an optimization algorithm within SWAT-CUP used to estimate uncertainties in model parameters, driving variables and conceptual models (Abbaspour et al, 2017). Therefore, an average monthly stream flow and sediment load data of twenty-one years (1993-2013) of Awash gauge station was used to identify the most sensitive parameters (i.e., parameters with smaller p-value and larger t-stat are considered to be most sensitive) through a global sensitivity analysis or AAT.

3.4.6.3. Model Calibration

Model calibration aims to minimize the difference between simulated and observed data by carefully selecting input parameters within their respective uncertainty analysis (Abbaspour et al, 2017). Model calibration is performed by selecting values for model input parameters within their respective ranges of uncertainty by comparing model predictions with the observed data (Kouchi, 2017).

In this study, streamflow and sediment load calibration were performed using the SWAT-CUP SUFI-2 algorithm. Different statistical tests were used to evaluate streamflow and sediment output during this process with the regression correlation coefficient (R^2) and the Nash-Sutcliffe model efficiency (NSE) coefficient, which are the most commonly used statistics to check the SWAT predictions (Nash and Sutcliffe, 1970).

In a typical scenario, the data collected through observation is divided into two separate datasets, one for calibration and one for validation. This approach was also adopted for the MAMD watershed where the available data on streamflow and sediment were divided into two groups for the purpose of calibration and validation. In order to accurately calibrate the model, 2/3 of the available data was used, while the remaining 1/3 was dedicated for the validation process. The calibration period which began on January 01, 1993 and ended on December 31, 2006 was chosen for this study.

3.4.6.4. Model Validation

Once the calibration process is completed the next step is the validation of the model. This step involves assessing the accuracy of the model's simulations and verifying if it is capable of producing reliable results. Validation serves to build confidence in the calibrated parameters (Abbaspour et al, 2017). The validation procedure is done using parameters which was set in the calibration process under an independent dataset. A dataset starting from January 01, 2007 to December 31, 2013 was used to perform the validation process.

3.4.6.5. Model Performance Evaluation

Model performance evaluation is a process of using tools and techniques that evaluates how well simulated values represent measured observations over a specified time period. The systematic and dynamic behavior of the model can be seen by displaying simulated and observed data on the same coordinate system, and this allows the modeler to see whether the model is over-predicted or under-predicted (Chala, 2022). The performance of the model was evaluated using mathematical statistical measures during both the calibration and validation periods. Two commonly used methods, the regression correlation coefficient or coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (NSE) coefficient were employed to assess the goodness fit of the model.

4. RESULT AND DISCUSSION

4.1. General

After the SWAT model simulation was completed for 32 years (starting from January, 1990 to December, 2021), the model was calibrated and validated on average monthly basis. The first three years of modeling period has been used for a warm-up period (starting from January, 1990 to December, 1992). The watershed area was subdivided into 87 sub-basins based on the defined 15,000ha threshold area and 1235 HRU's depend on the combination of land cover, soil types, and slope and threshold area. The whole SWAT model simulation was performed for both stream flow and sediment yield data. Also, the simulated stream flow and sediment yield was calibrated and validated at the outlet of the MAMD watershed using Awash gauge station time series dataset.

Before jumping to calibration and validation, sensitivity analysis was performed. Sensitivity analysis is vital to calibrate the model and the sensitivity analysis for this study was carried out to identify the most influential parameters. These parameters have a huge impact on the output variable of the SWAT model project. In this case, different parameters for both sediment and flow has been selected and identified as sensitive parameters for MAMD watershed. As (Yang et al, 2008) indicates, some of the parameters can be sensitive for both sediment and flow, and some can be sensitive to sediment only and flow only. In this study, the sensitivity analysis was performed separately for flow and sediment.

4.2. Stream Flow Modeling

4.2.1. Sensitivity Analysis of Stream Flow

Prior to calibrating the model, sensitivity analysis was carried out with 22 SWAT parameters for flow. These parameters were selected based on previous studies in the Awash Basin (Dile et al., 2023; Tesfu et al, 2021; Asmelash et al., 2017; Bayisa, 2019; Samuel, 2022), as well as the SWATCUP user manual (Abbaspour, 2015). A period from January, 1993 to December, 2006 was taken to test the sensitivity of each parameter.

Table 4-1 Parameters used for Flow Sensitivity Analysis and their recommended ranges

Rank	Parameter Name	Description of Parameter	Initial Range Value		t-Stat	P-Value
			Minimum	Maximum		
1	R__CN2.mgt	SCS runoff curve number	-0.2	0.2	9.00	0.00
2	V__CH_K2.rte	Effective hydraulic conductivity of main channel alluvium	-0.01	500.00	-4.83	0.00
3	V__OV_N.hru	Manning's "n" value for overland flow	0.00	1.00	-1.75	0.08
4	V__HRU_SLP.hru	Average slope steepness	0.00	1.00	-1.69	0.09
5	V__EPCO.hru	Plant uptake compensation	0.00	1.00	1.67	0.10
6	V__ALPHA_BF.gw	Baseflow alpha factor	0.00	1.00	1.53	0.13
7	V__GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow to occur	0.00	5000.00	-1.52	0.13
8	V__CH_N2.rte	Manning's "n" value for the main channel	-0.01	0.30	-1.29	0.20
9	V__GW_REVAP.gw	Groundwater revap coefficient	0.02	0.20	-1.26	0.21
10	V__ESCO.hru	Soil evaporation compensation	0.00	1.00	1.18	0.24
11	V__REVAPMN.gw	Threshold depth of water in the shallow aquifer for revap to occur	0.00	500.00	-0.96	0.34
12	V__RCHRG_DP.gw	Deep aquifer percolation fraction	0.00	1.00	0.61	0.54
13	R__SOL_K(..).sol	Saturated hydraulic conductivity	-0.25	0.25	-0.56	0.58
14	R__SOL_Z(..).sol	Soil depth	-0.25	0.25	-0.53	0.60
15	V__BIOMIX.mgt	Biological mixing efficiency	0.00	1.00	0.49	0.62
16	R__SOL_AWC(..).sol 1	Available water content of soil	-0.25	0.25	-0.48	0.63
17	V__RES_K.res	Hydraulic conductivity of the reservoir bottom	0.00	1.00	0.33	0.74
18	R__SLSUBBSN.hru	Average slope length	10.00	150.00	-0.25	0.81
19	V__GW_DELAY.gw	Groundwater delay	30.00	450.00	0.22	0.83
20	V__CANMX.hru	Maximum canopy storage	0.00	10.00	-0.19	0.85
21	R__SOL_BD(..).sol	Moist bulk density	-0.50	0.60	-0.16	0.87
22	V__SURLAG.bsn	Surface runoff lag time	0.05	24.00	0.00	1.00

*The qualifier (r__) refers to a relative change in parameter where the default values are multiplied by 1 plus a factor in the parameter range, while (v__) refers to the substitution of the default parameter by a calibrated value. The extensions (i.e., .mgt, .gw, .sol, .rte, .bsn, .sub) indicates the SWAT parameter family.

Among the above parameters, the first 6 parameters show relatively high sensitivity which has less value of P-value, 5 parameters showed relatively medium sensitivity and the rest 11 parameters shows less sensitivity than the others or they are negligible for further calibration and validation use.

Table 4-2 Summary of the most Sensitive Parameters of Flow and their Calibrated Values

<i>No.</i>	<i>Parameter Name</i>	<i>Description of Parameter</i>	<i>Minimum value</i>	<i>Maximum value</i>	<i>Calibrated Value</i>
1	R__CN2.mgt	SCS runoff curve number	0.2010	0.4382	0.3801
2	V__CH_K2.rte	Effective hydraulic conductivity of main channel alluvium	42.9499	92.1209	68.2730
3	V__OV_N.hru	Manning's "n" value for overland flow	0.5424	0.7129	0.6830
4	V__HRU_SLP.hru	Average slope steepness	0.4918	0.5846	0.4960
5	V__EPCO.hru	Plant uptake compensation	0.3985	0.6081	0.5581
6	V__ALPHA_BF.gw	Baseflow alpha factor	0.1475	0.2444	0.1819
7	V__GWQMN.gw	Threshold depth of water in the shallow aquifer for return flow to occur	2134.6506	3334.7952	3112.7683
8	V__CH_N2.rte	Manning's "n" value for the main channel	0.0743	0.0841	0.0769
9	V__GW_REVAP.gw	Groundwater revap coefficient	0.0999	0.1172	0.1055
10	V__ESCO.hru	Soil evaporation compensation	0.4583	0.5694	0.5011

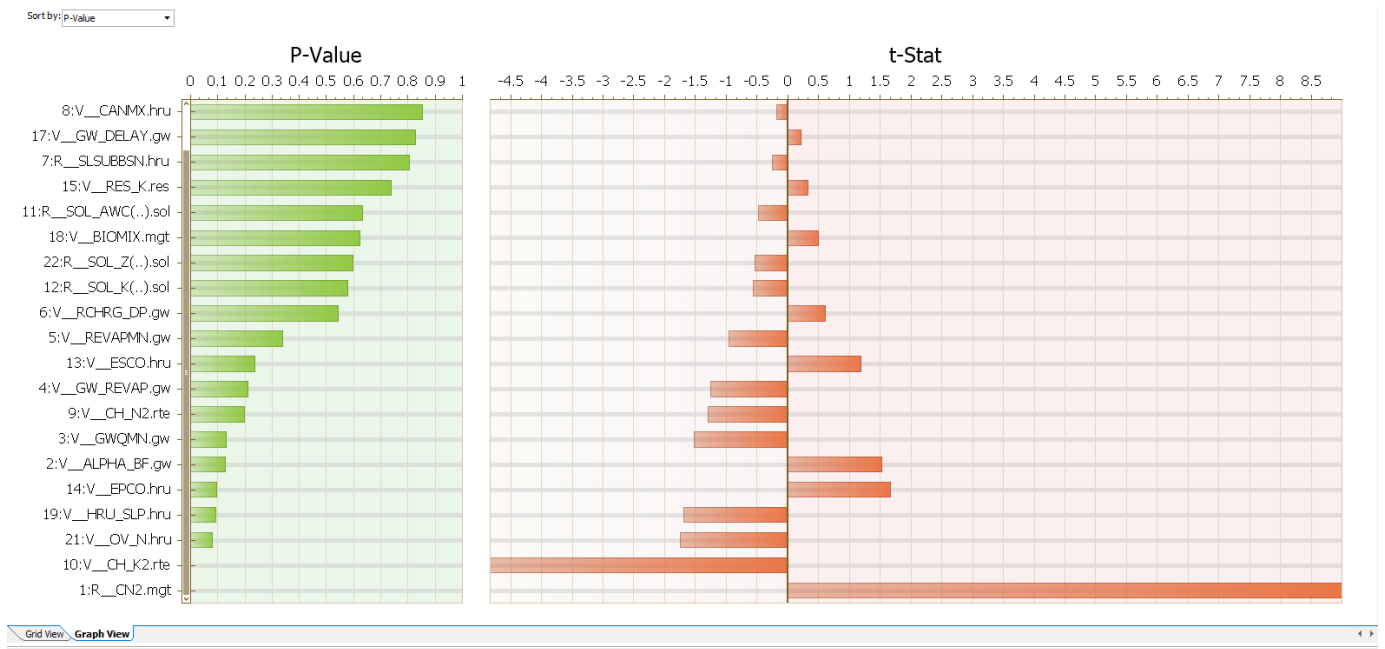


Figure 4-1 Sensitive Parameters of Streamflow from Global Sensitivity Analysis (OAT)

4.2.2. Model Calibration for Stream Flow

The main objective of this study was to estimate sediment yield and recommend appropriate mitigation measures. The sediment outflow from each sub-basin is influenced by factors such as surface runoff, soil properties, stream discharge and stream flow velocity (Welde & Gebremariam, 2017). Therefore, it is crucial to calibrate the model for streamflow. It is a mandatory step to calibrate the stream flow. Therefore, the calibration of SWAT model for the stream flow was performed using average monthly observed stream flow data of Awash gauge station. The available stream flow data from Awash gauge station was from January, 1993 to December, 2013. A period starts from January, 1993 to December, 2006 was taken for calibration purpose and during the calibration process the simulated average monthly flow matched well with the observed average monthly flow data. Also, the objective function, coefficient of determination (R^2) and other performance evaluation criteria's (NS and PBIAS) has been met. The figure below shows monthly calibrated flow results at Awash gauge station and the table below shows the overall performance of the model during the calibration process.

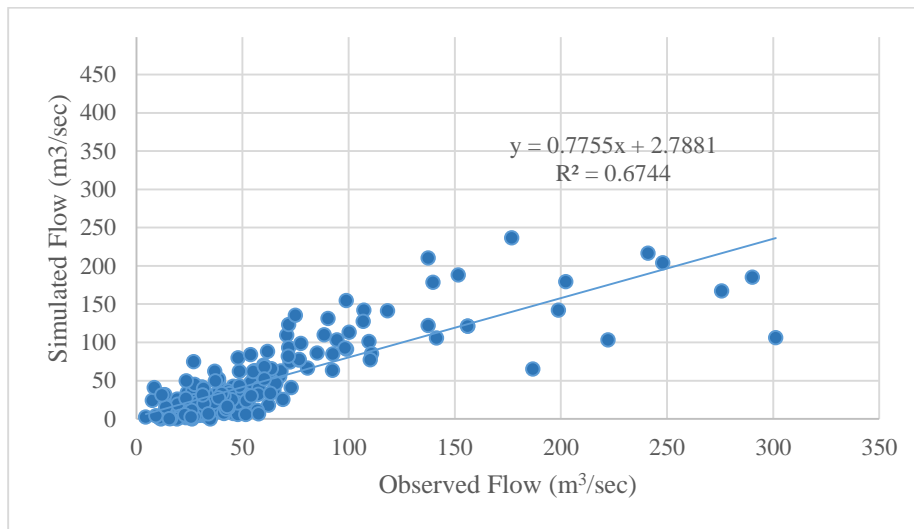
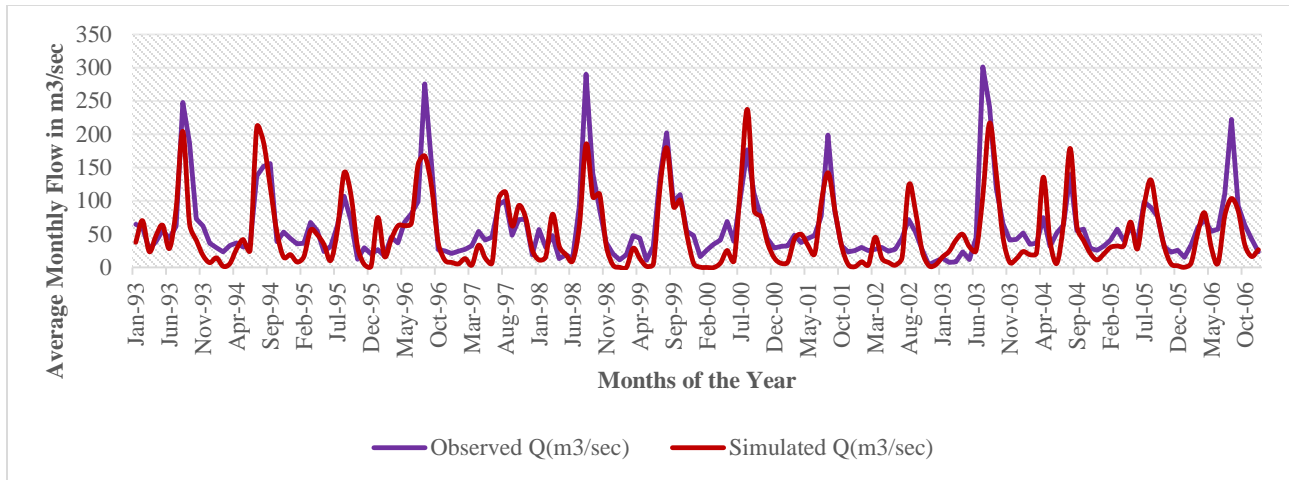


Figure 4-2 Scatter Plot for the Observed and Simulated Stream Flow Hydrograph on Average Monthly Time step during the Calibration Period

Table 4-3 Summary of Calibrated Performance Criteria's for Observed and Simulated Average Monthly Flow

Calibration Period	Average Flow (m ³ /sec)		Model Performance Indicators		
	Observed	Simulated	R ²	NS	PBIAS
1993 - 2006	61.49	50.47	0.67	0.62	17.9

4.2.3. Model Validation for Stream Flow

Once the model was calibrated, the validation process was carried out using the same input parameters and ranges as in the calibration process. This involved running the SWAT model for the period of January, 2007 to December, 2013 without making any changes. The results of the validation process including R^2 , NS, and PBIAS indicated a good fit for the model. The monthly validated flow result from SWAT-CUP can be seen in the figure below and the overall performance of the model during the validation is shown in the table below.

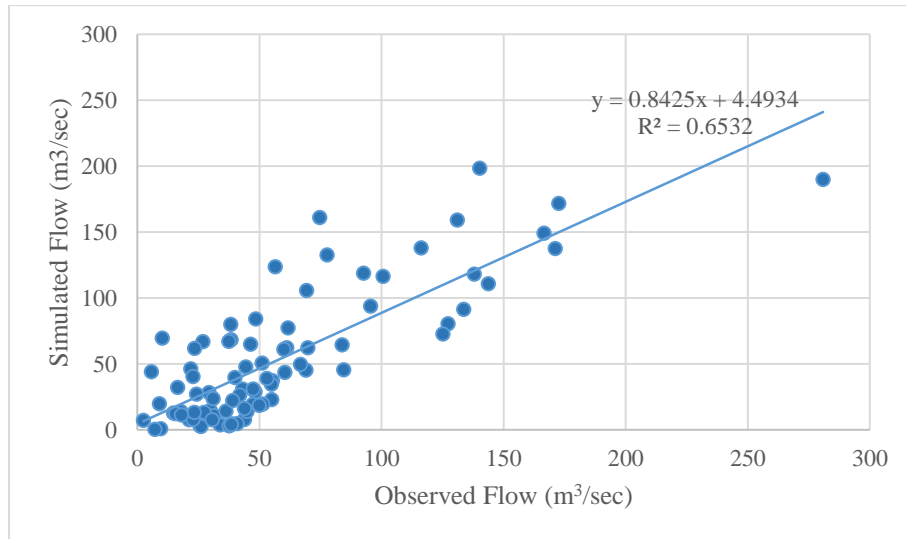
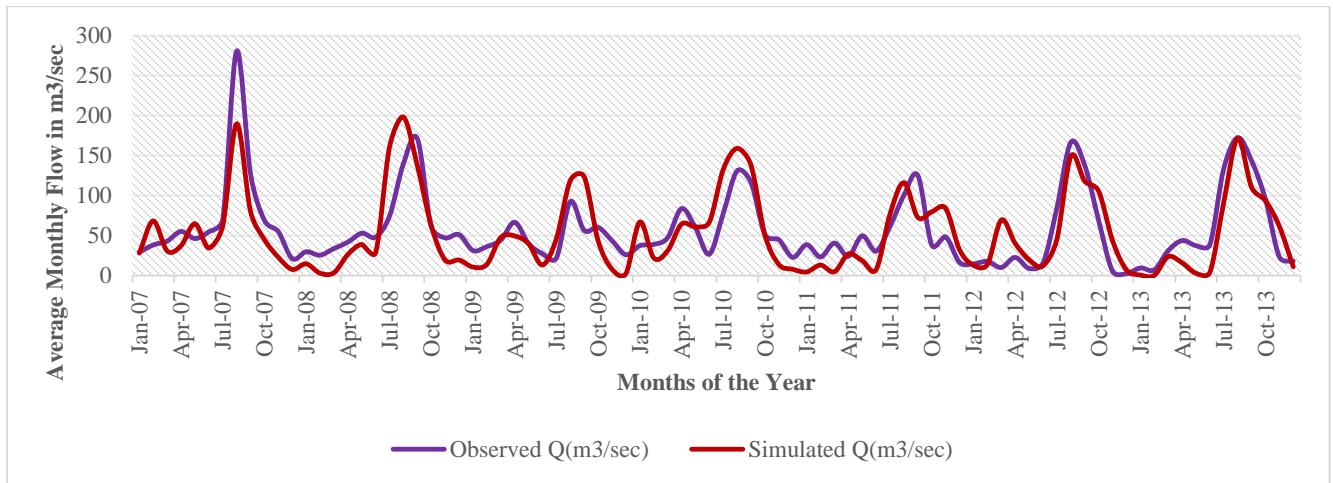


Figure 4-3 Scatter Plot for the Observed and Simulated Stream Flow Hydrograph on Average Monthly Time step during the Validation Period

Table 4-4 Summary of Validated Performance Criteria's for Observed and Simulated Monthly Flow

Validation Period	Average Flow (m ³ /sec)		Model Performance Indicators		
	Observed	Simulated	R ²	NS	PBIAS
2007 - 2013	57.91	53.28	0.65	0.63	8.0

4.3. Sediment Yield Modeling

4.3.1. Sensitivity Analysis for Sediment Yield

After the stream flow calibration and validation was represented carefully and accurately by the model, the next step is to find the sensitive parameters for sediment flows and calibrating and validating the model will take place. Sensitivity analysis, as discussed in the above sections, enables to spot the most influential parameters that affect the sediment flow. Since there is less sediment data from MoWE-Hydrology Department, sediment rating curve equation was developed using Metehara's sediment rating curve by computing with the stream flow data of Awash gauge station. Similar to the sensitivity analysis of flow, a period of 1993 to 2007 was taken to perform the sensitivity analysis for sediment yield.

Table 4-5 Parameters used for Sediment Yield Sensitivity Analysis and their recommended ranges

Rank	Parameter Name	Description of Parameter	Initial Range Value		t-Stat	P-Value
			Minimum	Maximum		
1	V__LAT_SED.hru	Sediment intensity in LAT and GW	0.00	4000.00	11.18	0.00
2	V__USLE_P.mgt	USLE support practice factor	0.00	1.00	3.90	0.00
3	R__CN2.mgt	SCS runoff curve number	-0.2	0.2	3.13	0.00
4	V__SED_CON.hru	Sediment concentration in runoff	0.00	5000.00	2.45	0.01
5	V__CH_COV2.rte	Channel cover factor	-0.05	1.00	-1.90	0.06
6	V__CH_COV1.rte	Channel erodibility factor	-0.05	1.00	-1.58	0.11
7	V__RES_NSED.res	Equilibrium sediment concentration of reservoir	0.00	5000.00	1.56	0.12

8	V__RSDIN.hru	Initial residue cover [kg/ha]	0.00	1000.00	-1.18	0.24
9	V__SPEXP.bsn	Re-entrained channel sediment routing	1.00	1.50	1.17	0.24
10	V__CH_ERODMO(..).rte	channel erodability factor	0.00	1.00	-0.55	0.59
11	R__USLE_K(..).sol	USLE soil erodibility factor	0.00	0.65	-0.53	0.59
12	V__SPCON.bsn	Parameter for channel sediment routing	0.00	0.01	0.51	0.61
13	V__SLSUBBSN.hru	Average slope length	10	150	-0.47	0.64
14	V__BIOMIX.mgt	Biological mixing efficiency	0.00	1.00	0.32	0.75
15	V__HRU_SLP.hru	Average slope steepness	0.00	1.00	-0.19	0.85
16	V__RES_SED.res	Initial sediment concentration of reservoir	0.00	5000.00	-0.09	0.93

From the above SWAT parameters related with sediment, LAT_SED, USLE_P , CN2, SED_CON, and CH_COV2 shows relatively high sensitivity, CH_COV1, RES_NSED, RSDIN, and SPEXP shows relatively medium sensitivity and the remaining parameters are found to be less sensitive or negligible for sediment yield. The following table shows all the parameters used for sensitivity analysis with their recommended ranges.

Table 4-6 Summary of the Most Sensitive Parameters of Sediment Yield and their Fitted Value for MAMD Watershed

<i>No.</i>	<i>Parameter Name</i>	<i>Description of Parameter</i>	<i>Minimum value</i>	<i>Maximum value</i>	<i>Calibrated Value</i>
1	V__LAT_SED.hru	Sediment intensity in LAT and GW	-60.12	1112.07	664.68
2	V__USLE_P.mgt	USLE support practice factor	-0.304	0.099	-0.027
3	R__CN2.mgt	SCS runoff curve number	0.094	0.217	0.154
4	V__SED_CON.hru	Sediment concentration in runoff	2689.65	3572.82	3294.62
5	V__CH_COV2.rte	Channel cover factor	-0.564	-0.010	-0.504
6	V__CH_COV1.rte	Channel erodibility factor	0.408	0.640	0.448
7	V__RES_NSED.res	equilibrium sediment concentration of reservoir	2831.98	3976.80	3593.29
8	V__RSDIN.hru	Initial residue cover [kg/ha]	533.66	1002.89	783.13
9	V__SPEXP.bsn	Re-entrained channel sediment routing	1.145	1.359	1.150
10	V__CH_ERODMO(..).rte	channel erodability factor	0.184	0.784	0.213

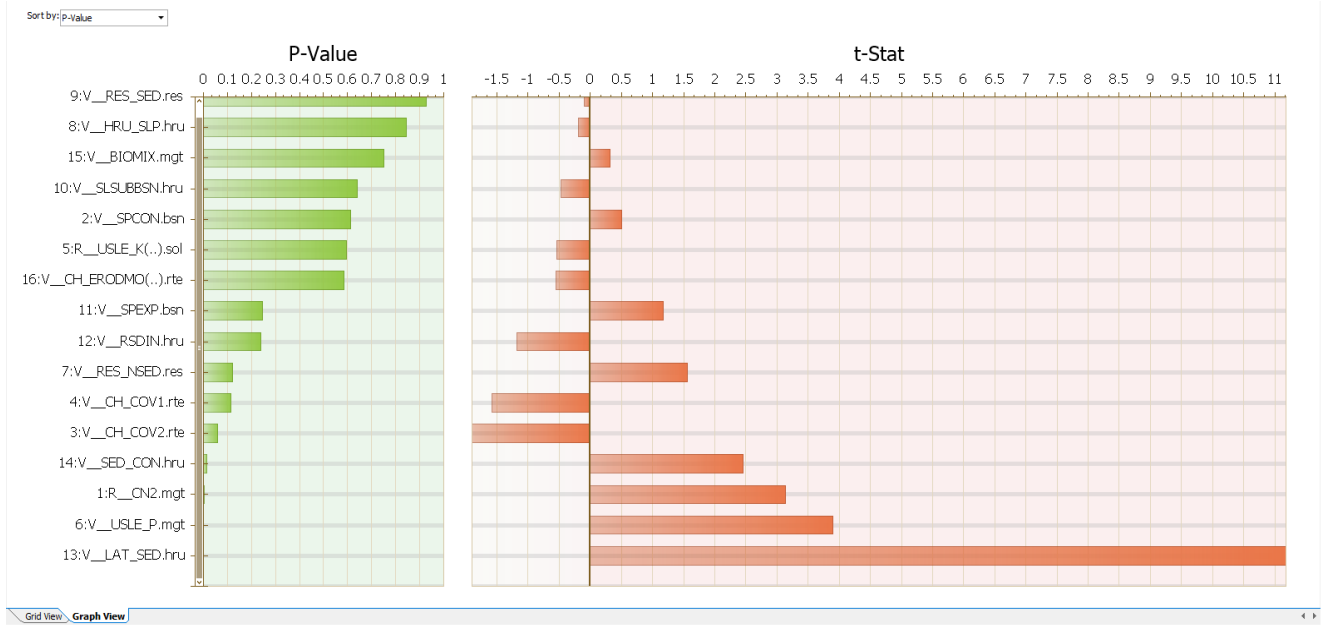


Figure 4-4 Sensitive Parameters of Sediment yield from Global Sensitivity Analysis (OAT)

4.3.2. Model Calibration for Sediment Yield

The parameters highly sensitive to sediment yield were identified during the sensitivity analysis and using those parameters, model calibration was performed. Similar to the stream flow calibration process, the first three years (1990 – 1992) were excluded for the model warm-up period from the calibration process. Hence, using a monthly time series data from January, 1993 to December, 2006 the calibration process was performed. After the calibration process is done, the results show a good fit with the observed and simulated values of sediment as well as with the values of performance criteria's (i.e., R^2 , NS, and PBIAS). The figure below shows the simulated and observed sediment yield from SWAT-CUP and the table shows the overall performance of the model during the calibration process.

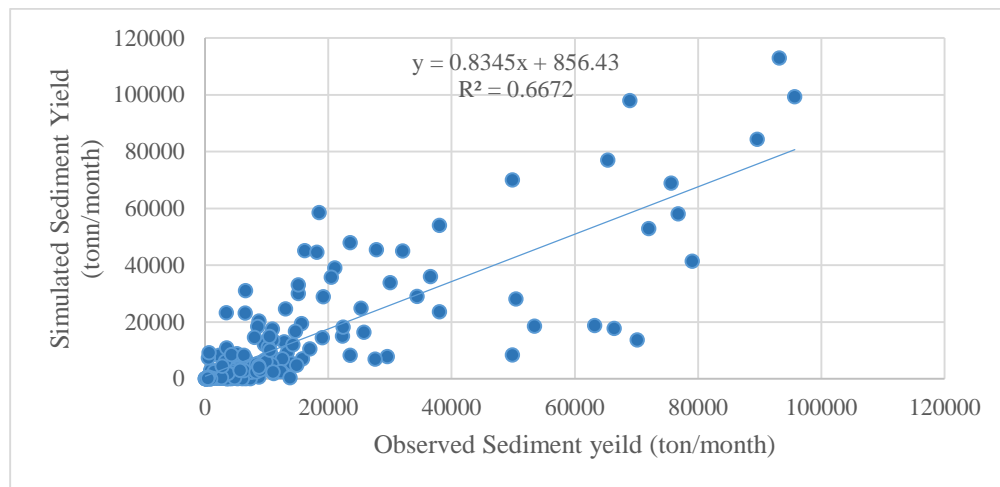
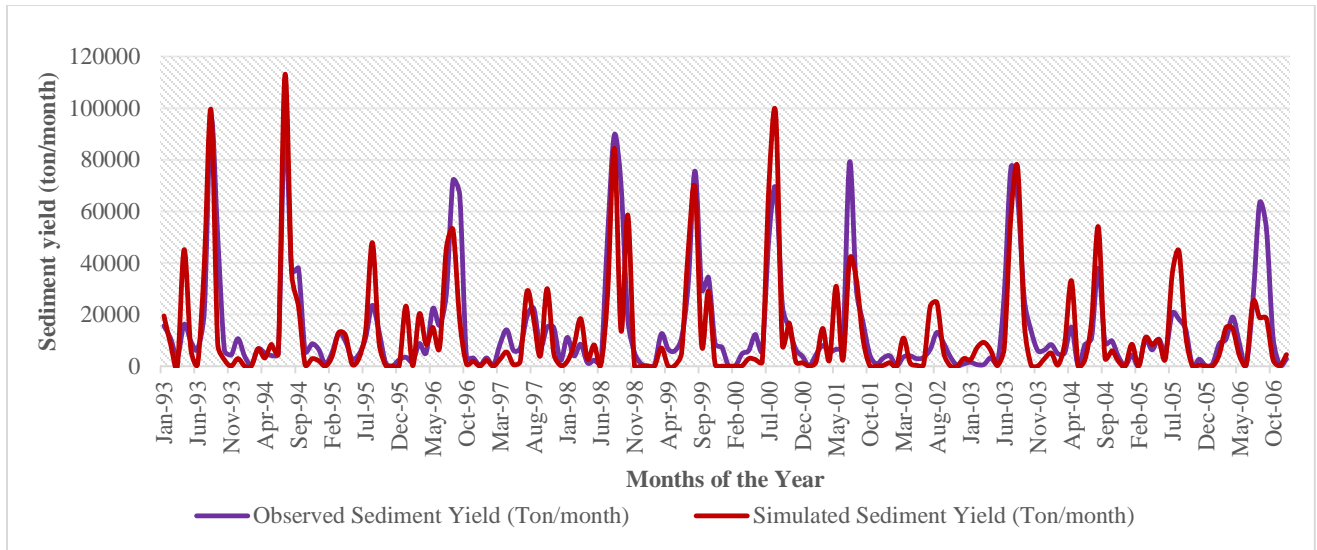


Figure 4-5 Scatter Plot for the Observed and Simulated Sediment Yield Hydrograph on Average Monthly Time steps during the Calibration Period

Table 4-7 Summary of Calibrated Performance Criteria's for Observed and Simulated Average Monthly Sediment Yield

Calibration Period	Average Sediment Yield (Ton/Year)		Model Performance Indicators		
	Observed	Simulated	R ²	NS	PBIAS
1993 – 2006	14575.47	13019.94	0.67	0.62	10.7

4.3.3. Model Validation for Sediment Yield

After the SWAT-CUP model monthly sediment yield calibration process is done, using observed or sediment rating curve generated data from January, 2007 to December, 2013 model validation was performed without any further adjustment of parameters. Similar with the calibration, model validation process estimated and observed statistical values of sediment yield results with close agreement between the simulated and the observed sediment yield. Also, the following figure shows the SWAT-CUP model monthly observed and simulated sediment yield and the table shows the overall performance of the model during validation process.

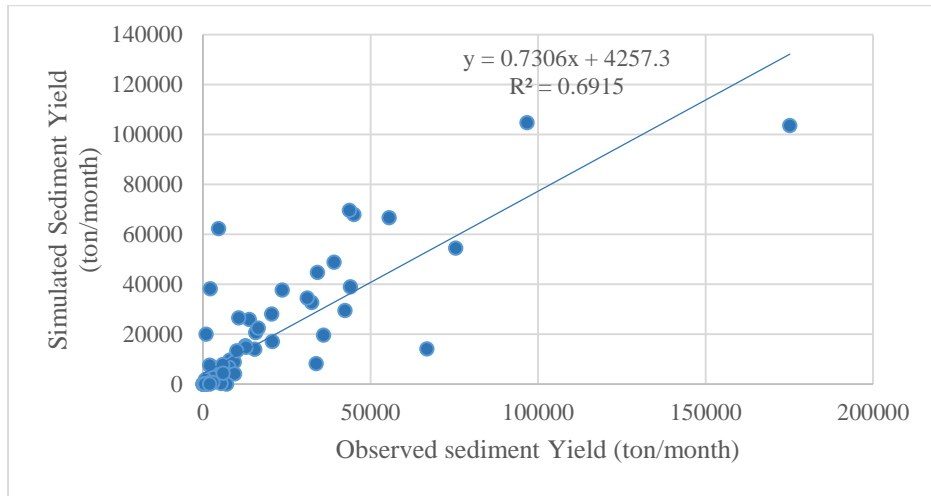
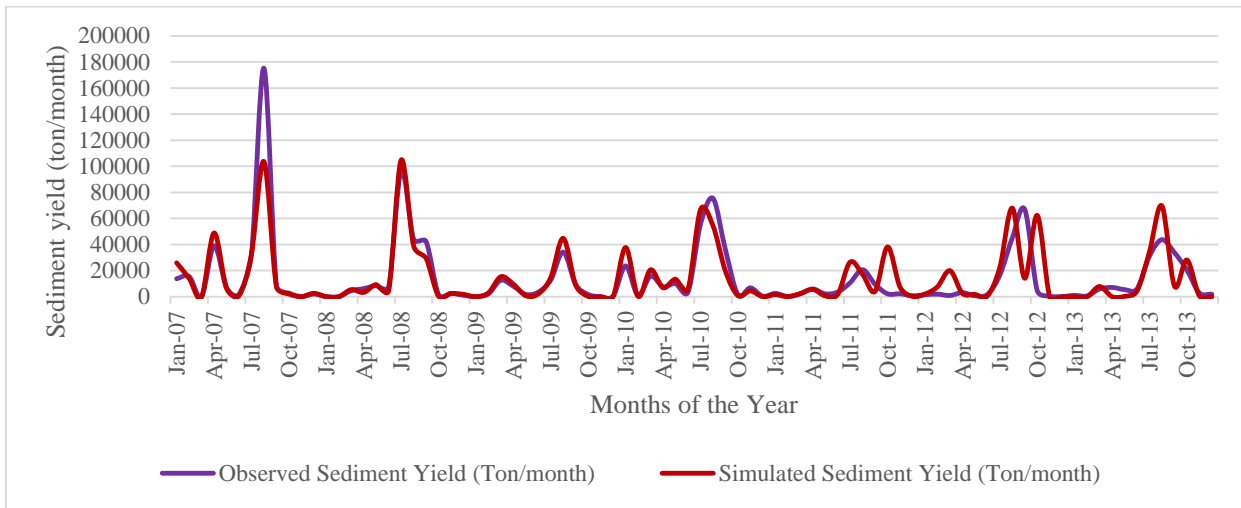


Figure 4-6 Observed and Simulated Sediment Yield Hydrograph on Average Monthly Time steps during the Validation Period

Table 4-8 Summary of Validated Performance Criteria's for Observed and Simulated Average Monthly Sediment Yield

Validation Period	Average Sediment Yield (Ton/Year)		Model Performance Indicators		
	Observed	Simulated	R ²	NS	PBIAS
2007 - 2013	14318.67	14718.85	0.69	0.69	-2.8

4.4. SWAT Model Outputs of Water Balance Elements

From the table below, a 28% of annual precipitation is converted into a stream flow and 38% of the stream flow infiltrates to the shallow aquifer which later joins the streams in the form of base flow. Also, about 62% of the total flow is contributed by the surface runoff.

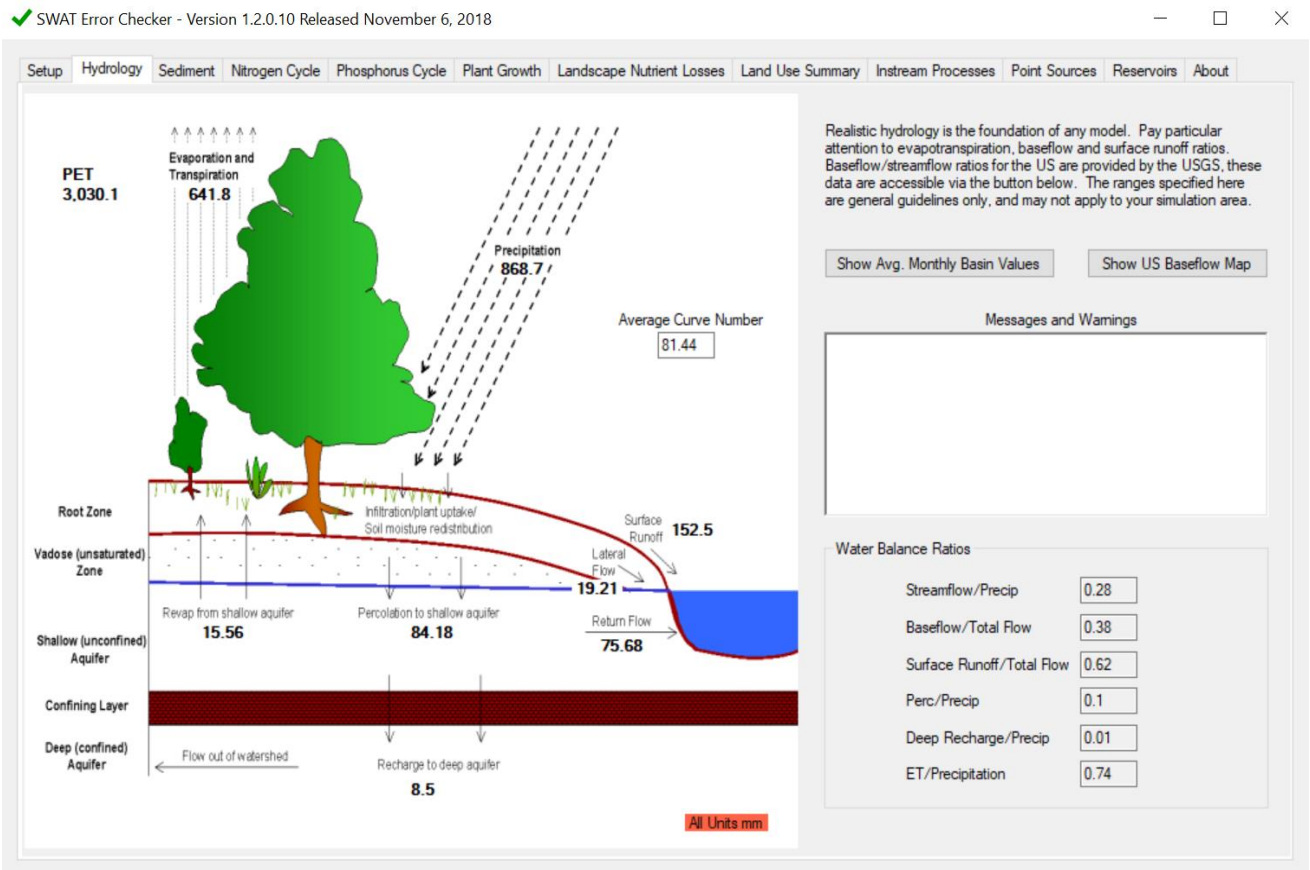


Figure 4-7 Water Balance Ratios and Elements from SWAT Checker

Table 4-9 Water Balance Elements and their simulated Values (Baseline Scenario)

<i>No.</i>	Model Output		Water Balance Ratios	
	<i>Water Balance Elements</i>	<i>Simulated Values (mm)</i>	<i>Water Balance Elements</i>	<i>Simulated Values</i>
1	Precipitation	868.7	Streamflow/Precipitation	0.28
2	Evapotranspiration	641.8	Baseflow/Total Flow	0.38
3	Surface Runoff	152.50	Surface Runoff/Total Flow	0.62
4	Lateral Flow	19.21	Percolation/Precipitation	0.1
5	Return Flow	75.68	Deep Recharge/ Precipitation	0.01
6	Percolation to Shallow Aquifer	84.18	ET/Precipitation	0.74
7	Revap from Shallow Aquifer	15.56		
8	Recharge to Deep Aquifer	8.50		
9	Stream Flow	255.92		
10	Baseflow	75.68		
11	Transmission losses	0		

4.5. Spatial and Temporal variability of Sediment Yield in the Watershed

Identification of sediment yield at the sub-basin scale is important to prioritize the locations of sub-basins with greater sediment rates for different land management actions. It helps to use and choose the best management practices based on the severity of erosion in each sub-basins. Using the average annual yield of sediment transport from SWAT output, for all the time steps in metric ton can be used to identify the simulated annual sediment values for each sub basins. Also, the sediment hotspot locations can be generated using the estimated average annual sediment yield of the watershed (Leta et al, 2023).

4.5.1. Spatial Distribution of Sediment Yield

One important aspect of watershed management is identifying areas with high sediment yield in order to prioritize locations for land management actions. This can be achieved by using the average annual yield of sediment transport from SWAT output in metric tons for different time

steps. It allows for the selection of appropriate management practices based on the severity of erosion in each sub-basin.

In this study, SWAT successfully delineated 87 sub-basins of MAMD watershed and simulated sediment yield for each sub-basin. After the calibration and validation of the model is completed, the model successfully simulated for a period of 32 years (1990-2021). By taking the simulated results of a calibrated and validated model, the highest, moderate and lowest erosion prone areas were identified.

The map shows 14 severe sediment prone sub-basins with 10.01 to 169.94 ton/ha sediment yield, 17 sub-basins identified as moderately eroded areas with a sediment yield value from 4.79 to 9.48 ton/ha, 16 sub-basins have an acceptable distributed sediment yield value from 3.07 to 4.21 ton/ha, and the rest 40 sub-basins are identified as a very low sediment prone areas with a varying value of sediment yield 0 to 2.99 ton/ha. The table below shows the spatial distribution of sediment yield in MAMD watershed.

The variation of sediment yield from the SWAT model predicted a value range from 0 to 169.94 ton/ha/year with an average of 6.72 ton/ha/year. A classification of Sediment yields for each sub-basin were considered as very low, acceptable, moderate and severe (very high). The table below shows the five classes of sediment intensity classes.

Table 4-10 Sediment Intensity Classification (Source: (Asmelash et al, 2016))

No.	Sediment Yield (ton/ha/year)	Sediment Intensity Class
1	< 3.0	Very low
2	3.0 - 4.5	Acceptable Sediment Yield
3	4.5 – 10.0	Moderate
4	> 10.0	Severely Affected by sediment Yield

According to some literatures and studies, sediment yield and their ranks were classified into three categories. Sub-watersheds with a sediment yield greater than 11 ton/ha/year were classified under high sediment prone areas, a sediment yield with 5 to 11 ton/ha/year were classified under moderate prone areas, and sub-watersheds with less than 5 ton/ha/year were classified under low prone areas (Rose, 1994). A study by (Asmelash et al, 2016) also classified the sediment prone

areas with a sediment yield rank of 0 to 3 ton/ha/year as low priority area, 3 to 4.5 ton/ha/year as acceptable priority area, 4.5 to 9 ton/ha/year as moderate prone area and greater than 9 ton/ha/year as a sub-basin with the highest sediment yield accumulation. The acceptable sediment yield in sub-basin level is less than 10 ton/ha/year (*Morgan, 2005*).

Table 4-11 Average Annual Sediment Yield of 87 Sub-basins

<i>Sub basin</i>	<i>Area (km²)</i>	<i>Sediment Yield Distribution (ton/ha/yr)</i>	<i>Sub basin</i>	<i>Area (km²)</i>	<i>Sediment Yield Distribution (ton/ha/yr)</i>	<i>Sub basin</i>	<i>Area (km²)</i>	<i>Sediment Yield Distribution (ton/ha/yr)</i>
1	165.8	7.36	30	623.34	3.96	59	268.47	16.28
2	224.9	1.41	31	202.76	5.46	60	708.87	3.86
3	218.74	11.11	32	175.54	22.19	61	541.03	3.07
4	9.0522	2.35	33	102.94	1.29	62	484.99	6.79
5	199.86	11.55	34	470.83	2.57	63	205.19	12.71
6	3.0366	0.26	35	491.34	3.27	64	327.63	2.16
7	196.07	3.62	36	148.03	2.84	65	334.83	3.83
8	382.87	3.20	37	196.58	6.58	66	261.02	4.79
9	70.62	1.07	38	298.63	5.16	67	238.1	1.94
10	345.95	2.62	39	229.7	2.84	68	17.662	0.01
11	708.49	3.20	40	187.78	9.19	69	2.4201	0.00
12	1.3779	2.07	41	62.524	0.97	70	283.66	2.95
13	67.066	1.32	42	314.4	1.66	71	288.68	1.55
14	46.868	0.36	43	281.88	5.03	72	466.16	8.34
15	279.24	1.63	44	264.97	0.50	73	55.328	2.33
16	292.84	3.60	45	167.57	3.86	74	169.29	0.92
17	178.1	0.34	46	194.11	15.06	75	378.22	3.71
18	64.856	1.16	47	284.13	6.88	76	804.08	3.93
19	331.96	2.26	48	150.58	11.64	77	171.46	1.73
20	486.57	3.44	49	45.459	0.57	78	15.876	2.33
21	32.598	0.89	50	251.05	10.33	79	159.34	2.79
22	0.0027	1.40	51	0.945	169.94	80	482.22	1.18
23	249.62	9.48	52	55.14	10.19	81	408.17	2.99
24	164.22	6.96	53	231.46	3.78	82	150.06	5.18
25	28.526	1.49	54	428.98	5.00	83	219.34	10.01
26	262.45	2.41	55	606.94	2.76	84	566.25	5.05
27	146.17	7.99	56	165.74	5.36	85	124.04	16.11
28	4.0833	0.96	57	41.583	4.21	86	197.25	15.39
29	411.23	3.70	58	354.31	2.92	87	171.12	17.75

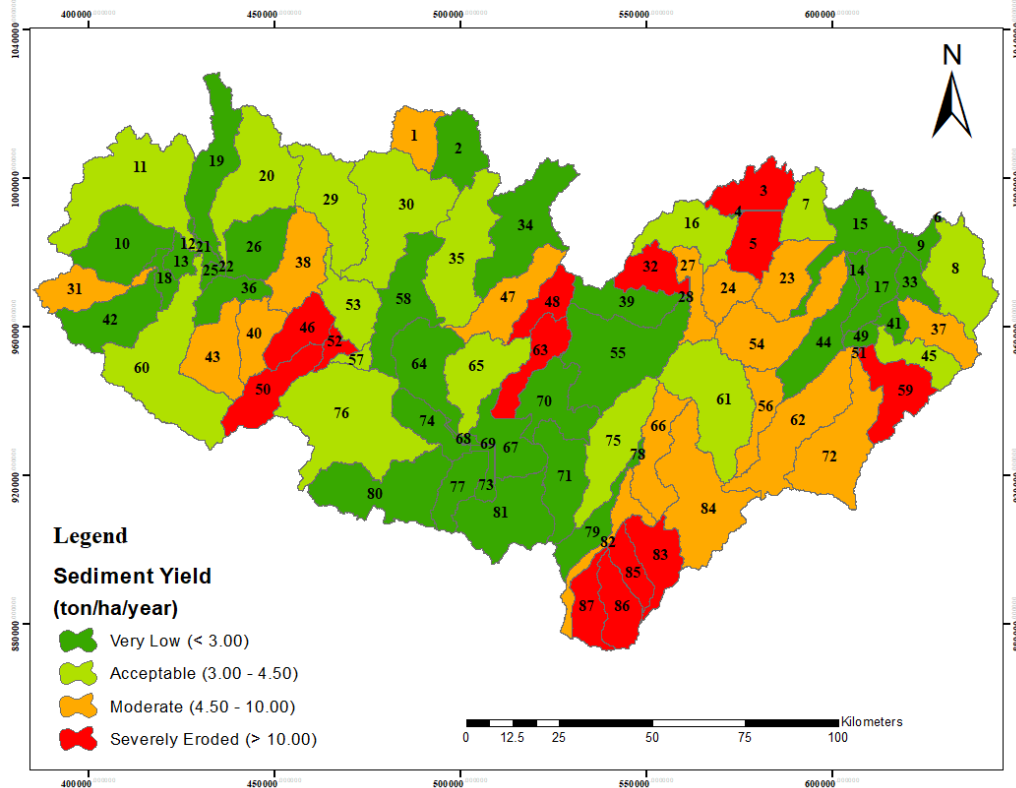


Figure 4-8 Spatial Variability of Sediment Yield Map for the MAMD Watershed

Table 4-12 Sediment Severity Class of the Sub-Basins

No.	Sed_YLD (ton/ha/year)	Severity Class	No. of Sub-basins	Sub-basins	Total Area Coverag (km ²)	Area (%)
1.	> 10	Severely Eroded	14	3, 5, 32, 46, 48, 50, 51, 52, 59, 63, 83, 85, 86, 87	2431.38	11.52
2.	4.5 - 10	Moderately Eroded	17	1, 23, 24, 27, 31, 37, 38, 40, 43, 47, 54, 56, 62, 66, 72, 82, 84	4700.77	22.28
3.	3 - 4.5	Acceptable Sediment	16	7, 8, 11, 16, 20, 29, 30, 35, 45, 53, 57, 60, 61, 65, 75, 76	6800.39	32.22
4.	< 3	Very low sediment	40	2, 4, 6, 9, 10, 12, 13, 14, 15, 17, 18, 19, 21, 22, 25, 26, 28, 33, 34, 36, 39, 41, 42, 44, 49, 55, 58, 64, 67, 68, 69, 70, 71, 73, 74, 77, 78, 79, 80, 81	7170.63	33.98
Total					21103.1638	100.00

4.5.2. Temporal Variability of Sediment Yield

Temporal variations of sediment yield refer to the sediment generated from the watershed on an annual monthly or daily basis. Hotspot locations for sediment can be identified by using the estimated average annual sediment yield for the entire watershed. This estimation takes into account various factors such as the size of the watershed, land use and land cover conditions, soil classes, slope and climatic conditions (Ayana, 2012). In this study, the temporal variation of sediment yield was evaluated annually in tons/ha/year. This information is crucial for understanding the overall sediment dynamics within the watershed and developing effective management strategies.

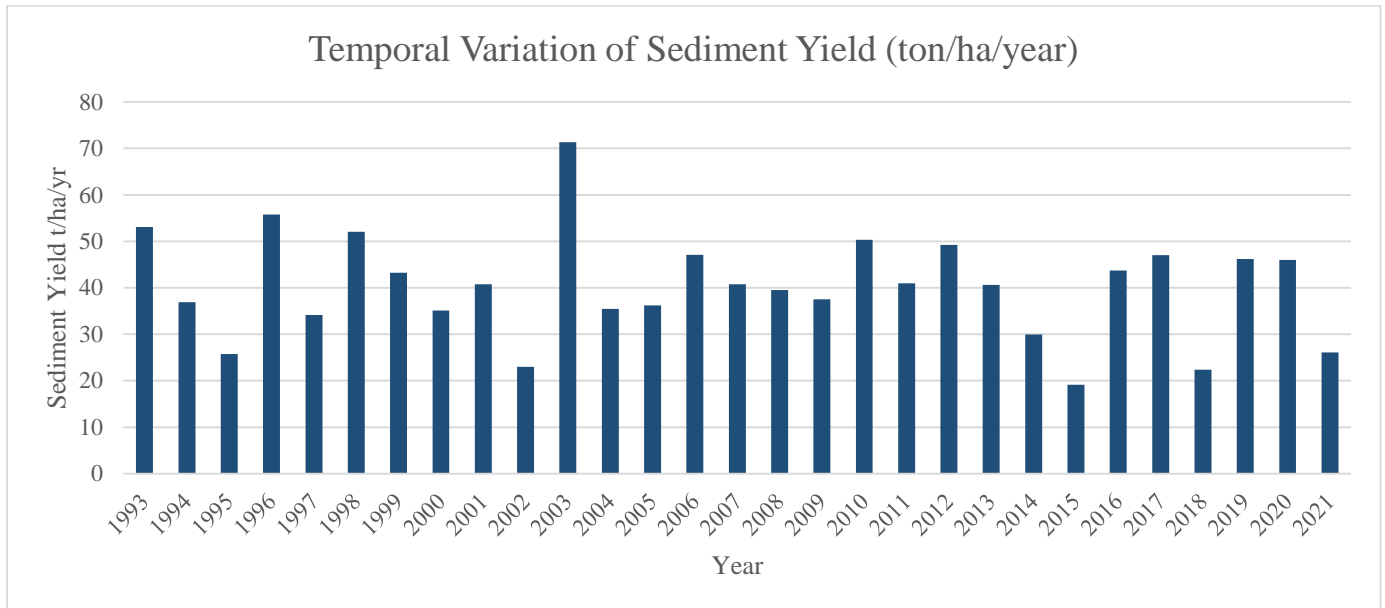


Figure 4-9 Temporal Variation of Sediment Yield over the years

The annual average sediment yield for the years 1993-2021 varies from 19.11 ton/year to 71.33 ton/year. The annual average sediment yield is calculated using SWAT model and computed to be 40.32 ton/year. The rates of sediment yield over each sub basins vary depend on the climatic, soil types, land use land cover conditions and slope classes.

Table 4-13 Temporal Variability of Sediment Yield over the years

No	Year	Temporal Variation of Sediment Yield (ton/ha/year)	No	Year	Temporal Variation of Sediment Yield (ton/ha/year)
1	1993	53.12	16	2008	39.54
2	1994	36.93	17	2009	37.49
3	1995	25.75	18	2010	50.33
4	1996	55.76	19	2011	40.93
5	1997	34.13	20	2012	49.25
6	1998	52.06	21	2013	40.65
7	1999	43.23	22	2014	29.92
8	2000	35.1	23	2015	19.11
9	2001	40.77	24	2016	43.69
10	2002	22.96	25	2017	47.02
11	2003	71.33	26	2018	22.4
12	2004	35.43	27	2019	46.22
13	2005	36.24	28	2020	45.97
14	2006	47.09	29	2021	26.07
15	2007	40.75			

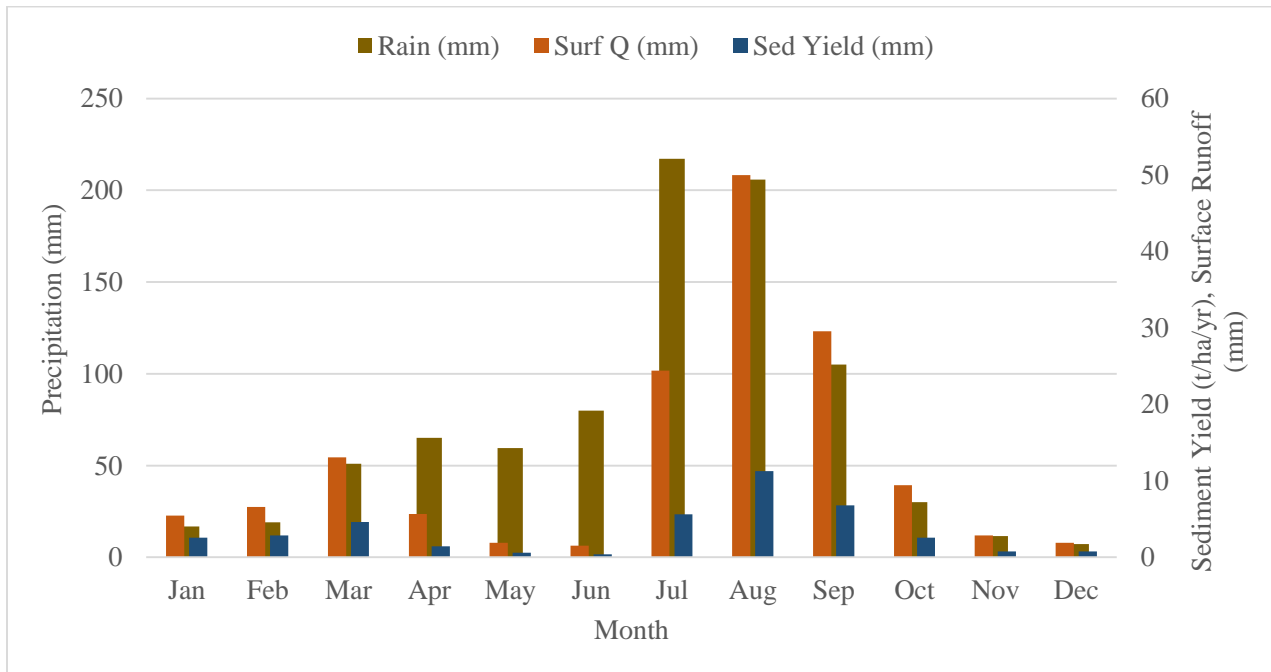


Figure 4-10 Temporal Variability of Sediment Yield with relation to Precipitation and Surface Runoff at the Outlet of the Catchment

4.6. Sediment Yield Reduction Method

The outlined objective of this study is to assess sediment yields and to examine various scenario development using SWAT model to reduce the generation of sediment from the watershed. A spatial variability of sediment source map shows the erosion prone areas/sub-basins. Using the output generated from the SWAT model and the identified sediment hotspot areas, developing sediment reduction method for severely affected sub-basins took place. This process allows to apply and adopt improved management practices in the watershed. Hence, the selection of appropriate sediment management measures was identified based on similar research literatures conducted in Ethiopia as well as in Africa. Refereeing some of the literatures in country wise (Kefay et al, 2022; Dibaba, 2021; Tolche et al, 2021; Yibeltal, 2022; Fikirte, 2019; Alemayehu, 2021; Abraham, 2021; Hussen, 2020), the best management practices considered to be effective for this study are conversion of 25%, 35% and 50% of Agricultural area to Forest land, a 5m width filter strip, grassed waterway, terracing and contouring. All these best management scenarios were developed and compared with baseline scenario according to their effectiveness of sediment reduction in the watershed.

In this study, two scenarios were identified to be applied to reduce sediment yield in the entire watershed. The first one is a scenario developed based on the land use land cover. Three effective scenarios were considered during this study. Since the watershed of MAMD is dominated by Agricultural land use type, which was the main contributor of sediment yield from the total sediment yield resulted from the other land use types. A conversion of agricultural land use type to the Forest land use was applied. The second scenario is developed based on the driving forces of sediment or soil erosion. In this section, the BMP's are related with the topography factor such as Filter strips, grassed waterways, contouring and terracing.

For the BMP's related with the land use land cover types, the conversion of the AGRR (agricultural lands) was done using the Land Use Refinement (Optional) section to split the agricultural lands from each dominating Sub-basins into the forest lands in different percentages (25%, 35% and 50%). While, the BMP's related with the topography factor has their own recommended value ranges in the SWAT manual (Neitsch et al., 2009). The table below shows the recommended values of each parameters and their descriptions.

Table 4-14 Scenario Description and SWAT Parameters used in BMP (contouring, filter strips, grassed waterways and terracing)

<i>BMP Type</i>	<i>Field Parameter Name</i>	<i>Value Range</i>	<i>Definition</i>
Contouring	CONT_CN	20-100	Initial SCS curve number II value
	CONT_P	0-1	Contouring USLE P Factor
Filter Strip	VFSI	0-1	Flag for the simulation of filter strips
	VFSRATIO	0-300	Ratio of field area to filter strip area (ha ² / ha ²)
	VFSCON	0.25-0.75	Fraction of the HRU which drains to the most concentrated ten percent of the filters strip area (ha ² / ha ²)
	FILTERW	01 - 10m	width of edge of field filter strip (m)
	VFSCHE	0-100	Fraction of the flow within the most concentrated ten percent of the filter strip which is fully channelized (dimensionless)
Grassed Waterways	GWATI	0-1	Flag for the simulation of grass waterways
	GWATN	0.001-0.5	Manning's n value for overland flow
	GWATL	0-10000	Length of grassed waterway (km)
	GWATW	0-1000	Average width of grassed waterway (m)
	GWATD	0-10	Depth of grassed waterway channel from top of bank to bottom (m) (3/64*GWATW)
	GWATS	0-1	Average slope of grassed waterway channel (m)
	GWATSPCON	0-1	Linear parameter for calculating sediment in Grassed waterways (default 0.005)
Terracing	TERR_P	0-1	USLE practice factor adjusted for terraces
	TERR_CN	20-100	Initial SCS curve number II value
	TERR_SL	0-100	Average slope length (m)

4.6.1. Scenario I: Baseline Scenario

The Baseline scenario is the watersheds existing condition and assumed to reflect the current land management practice without conservation measures (Mesfin et al, 2019). For every scenario, a simulation period from 1990 to 2021 runs (including 3 years of warm-up period) to provide a

reliable basis for comparison of the other scenario results. After simulating the SWAT model with the calibrated parameters and their value, the sediment load output was obtained from the SWAT output table. The entire watershed average annual sediment load at the reach outlet was 40.32 ton/ha/year and 14 number of sub-basins were identified as a critical sediment prone areas. Among the selected sediment prone sub-basins, 14 were identified as severely affected areas with potential erosion (10.01 to 169.94 t/ha/year), 17 sub-basins were moderately affected areas (4.79 to 9.48 t/ha/year), and the remaining sub-basins are identified as acceptable and low sediment prone areas (0 to 4.21 t/ha/year). These critical sub-basins cover about 23.6% of the total watershed area. Also a study by (Tesfu et al, 2021) reported about 30.65% of the total watershed area is identified as a critical sediment area. The sediment yield for 24 identified high and moderate sediment prone areas were indicated from the SWAT output. Applying the best management practices to reduce sediment in this critical sub-basins is vital.

From the simulation result, the proportional area of different sediment yield rate is illustrated in the table below. A 33.98% area from the total watershed has 0 to 3.00 ton/ha/year, 32.22% of area has a sediment yield of 3 to 4.5ton/ha/year, 22.28% of area is covered by sediment yield of 4.5 to 10ton/ha/year and the rest 11.52% area is accounted with the highest sediment yield greater than 10ton/ha/year.

Table 4-15 Sediment Yield and their Proportional area coverage from the total watershed

No.	SED_YLD (ton/ha/year)	Area (km ²)	Area (%)
1	0.00 – 3.00	7170.63	33.98
2	3.00 – 4.50	6800.39	32.22
3	4.50 – 10.00	4700.77	22.28
4	> 10.00	2431.38	11.52
Total		21103.16	100.00

Table 4-16 Soil erosion prone at sub-basin level with their dominant LULC, soil type and average slope

<i>Critical Subbasin</i>	<i>Subbasin Area (km²)</i>	<i>Covered Area (km²)</i>	<i>SWAT Dominant LULC</i>		<i>SWAT Dominant soil class</i>			<i>Mean slope (%)</i>	<i>Sed_Yield (ton/ha/year)</i>
			<i>Major LULC</i>	<i>Coverage (%)</i>	<i>Soil Type</i>	<i>Area (km²)</i>	<i>Coverage (%)</i>		
51	0.95	0.67	RNGB, BARR, FRSD	70.76	Eutric Fluvisols	0.90	94.76	14.66	169.94
32	175.54	87.95	AGRR, BARR, FRST	50.10	Chromic Cambisols, Eutric Nitisols,	152.5	86.89	11.83	22.19
87	171.12	131.97	AGRR, FRSE	77.12	Chromic Vertisols, Orthic Luvisols, Pellic Vertisols	158.8	92.81	10.89	17.75
59	268.47	258.08	AGRR, FRST, RNGB, FRSD	96.13	Orthic Acrisols, Dystric Nitisols, Leptosols, Orthic Luvisols, Eutric Cambisols, Dystric Cambisols	263.8	98.28	13.20	16.28
85	124.04	100.96	AGRR	81.39	Pellic Vertisols, Chromic Vertisols, Eutric Cambisols	93.25	75.18	11.96	16.11
86	197.25	179.63	AGRR, FRSE, FRST	91.07	Chromic Vertisols, Pellic Vertisols, Eutric Nitisols, Orthic Luvisols	192.7	97.68	11.37	15.39
46	194.11	173.58	AGRR, RNGE	89.42	Pellic Vertisols	149.7	77.11	8.89	15.06
63	205.19	153.60	AGRR	74.86	Pellic Vertisols	133.6	65.13	10.23	12.71
48	150.58	144.97	AGRR, FRST	96.27	Pellic Vertisols, Vertic Cambisols	135.7	90.11	9.86	11.64
5	199.86	142.75	RNGB, BARR	71.42	Leptosols, Mollic Andosols	138.6	69.33	9.54	11.55
3	218.74	183.19	BARR, RNGB, RNGE	83.75	Eutric Cambisols, Leptosols, Vitric Andosols	131.2	59.96	12.18	11.11
50	251.05	245.23	AGRR, FRST, RNGE	97.68	Eutric Nitisols, Vertic Cambisols, Pellic Vertisols	159.9	63.71	11.76	10.33

52	55.14	42.38	AGRR, FRST	76.86	Vertic Cambisols, Eutric Fluvisols	28.77	52.17	14.58	10.19
83	219.34	205.62	AGRR, RNGB, FRST	93.75	Pellic Vertisols, Eutric Cambisols, Orthic Luvisols	179.6	81.89	16.25	10.01
23	249.62	199.79	AGRR, RNGE, RNGB	80.04	Leptosols, Eutric Fluvisols	159.1	63.73	8.13	9.48
40	187.78	176.67	AGRR, RNGE	94.08	Pellic Vertisols, Calcic Xerosols	158.9	84.62	10.06	9.19
72	466.16	442.76	AGRR, BARR, FRST, FRSD, RNGB	94.98	Pellic Vertisols, Eutric Cambisols, Leptosols, Eutric Fluvisols	381.6	81.87	26.81	8.34
27	146.17	136.54	AGRR, RNGB, BARR, FRST	93.41	Vitric Andosols, Chromic Cambisols	65.37	44.72	7.68	7.99
1	165.8	144.82	AGRR, FRST, RNGE	87.35	Pellic Vertisols, Chromic Luvisols, Orthic Solonchaks	101.8	61.42	18.72	7.36
24	164.22	141.31	BARR, RNGB, RNGE	86.05	Mollic Andosols, Vitric Andosols, Leptosols	81.69	49.74	6.07	6.96
47	284.13	273.24	AGRR, FRST	96.17	Vertic Cambisols, Pellic Vertisols	261.7	92.11	7.80	6.88
62	484.99	458.49	AGRR, RNGB, FRST, FRSD	94.54	Eutric Cambisols, Leptosols, Dystric Nitisols, Pellic Vertisols	363.4	74.94	13.67	6.79
37	196.58	194.51	AGRR, RNGB, RNGE, FRST, FRSD	98.95	Eutric Cambisols, Eutric Nitisols, Orthic Acrisols, Orthic Luvisols, Dystric Cambisols, Dystric Nitisols	134	68.17	37.92	6.58
31	202.76	182.49	AGRR, RNGE	90.00	Pellic Vertisols, Chromic Luvisols, Orthic Solonchaks	159	78.44	12.31	5.46

4.6.2. Scenario under LULC Change: Conversion of 25%, 35% and 50% Agricultural Land to Forest Land

In Ethiopia, agriculture has been playing a crucial role in decreasing hunger and poverty. This agricultural growth also requires improved technologies, irrigation, roads and marketing plans (Yibeltal, 2022). In the study area, agricultural practice is dominant and results with tremendous soil erosion and sedimentation problem. A condition like this for the future, will result land degradation and it could endanger the sustainability of agriculture and the availability of natural resources.

Due to population growth and expansion of farm land, a loss of forest and other vegetation cover increases. It causes enhanced erosion rates in the area (Tefera et al, 2002). Before land degradation weakens the capability of land resources to perform essential services and function as ecosystem, conversion of the dominating agricultural land use type to forest land is a success in reducing the runoff, soil erosion, downstream siltation and increase in crop production (Gashaw, 201; Hussen, 2020).

For this study area, the HRU simulation results Agricultural land use is about 15,009.26km² (71.12%), Range brushes lands are 2,272.38km² (10.77%), Forest mixed lands area is 1,373.29km² (6.51%), Range grass lands are 841.75km² (3.99%), and the remaining areas are under Bare lands with 628.51km² (2.98%), Forest Deciduous with 224.56km² (1.06%), Settlement area with 492.40km² (2.33%), Water bodies and Forest-Evergreen lands with an area of 198.48km² (0.94%) and 62.47km² (0.3%), respectively. This indicate the overall watershed is dominated by 71.12% of agricultural land and it indicates the catchment is under pressure of agricultural activities which can easily affected by erosion (Hussen, 2020). This will also result in reduction of the life span of the reservoir.

In this case, a scenario is developed to reduce the soil erosion by converting the agricultural land use type by 25%, 35% and 50% to the forest land use type. The reason for the selection of forest land use type is that forest lands have a vital role in ecological and economic benefits in terms of protecting the fragile environment and can be used as a source of fuel, charcoal, as well as a construction material (Yibeltal, 2022). They also contribute in enhancing the economic benefit of the country due to Coffee, fruits and fiber. In addition to this, forests split the raindrop into a tiny

droplets and that can barely detach soil particles and cause soil erosion. It also decreases the velocity of the rain drop before touching the ground and weaken the erosive force (Abraham, 2021)

The analysis of this scenarios were performed during the study and the baseline scenario was taken to compare the different land use analysis with the current condition.

❖ *Scenario (S₀): baseline scenario with a present land use types*

❖ **Scenario (S_I): Conversion of 25% of agricultural land to forest land**

The application of this scenario results in increment of forest land to 5982.06km² (28.35%) and agricultural lands reduced to 10,572.6 km² (50.1%). The simulation of this scenario showed a reduction of sediment yield from 40.32 ton/ha/year to 29.6 ton/ha/year (26.59%).

❖ **Scenario (S_{II}): Conversion of 35% of agricultural land to forest land**

The forest land shows an increment after changing the 35% of agricultural land. The forest land increased to 7418.1 km² (35.15%) and agricultural land reduces to 9076.34 km² (43.01%).

❖ **Scenario (S_{III}): Conversion of 50% of agricultural land to forest land**

After converting the half of the agricultural land to forest land, the agricultural land reduced to an area of 6843.28 km² (32.43%) and the forest land increased to 9572.81 km² (45.36%).

Under each LULC scenario, the runoff has been affected by the changes made on the catchment. The simulation result shows the reduction of runoff volume in each scenario. However, the curve number and the threshold depth of water in the shallow aquifer for return flow to occur was adjusted during the simulation of each scenario to make sure the water balance ratios are balanced and generated no error.

Table 4-17 Annual Average Runoff under Different LULC Changes

<i>Land use Scenario</i>	<i>Runoff (mm)</i>	<i>Difference</i>	<i>Change (%)</i>
<i>Scenario 0</i>	152.50	-	-
<i>Scenario I</i>	116.94	35.56	23.32
<i>Scenario II</i>	107.69	44.81	29.38
<i>Scenario III</i>	94.03	58.47	38.34

Likewise, the sediment yield changes due to each scenario application. As the percentage of agricultural land converted to forest land increases, the sediment yield decreases. For example, a half percent change of agricultural land showed in 45.76% reduction in sediment yield. But the upper and middle Awash watershed residents are highly dependent on crop production. Implementing this scenario could be difficult task. Hence, the residents in the watershed area can engage their selves in plantation of Eucalyptus species, coffee or other fruits. These species can require less labor for management and takes short period of time to harvest and gain immediate benefit for the farmers. Furthermore, the degraded agricultural land use types can be converted to plantation forests by diverting farmer’s lifestyle to other activities.

Table 4-18 Annual Average Sediment Yield Reduction Under LULC Change

<i>Land use Scenario</i>	<i>Sediment Yield (ton/ha/year)</i>	<i>Differences</i>	<i>Change (%)</i>
<i>Scenario 0</i>	40.32	-	-
<i>Scenario I</i>	29.60	10.72	26.59
<i>Scenario II</i>	26.55	13.77	34.15
<i>Scenario III</i>	21.87	18.45	45.76

4.6.3. Scenario IV: Filter Strip

Application of 5m filter strips results in reduction of the average annual sediment yield for critical sub-basins from 40.32 t/ha/year to 13.23 t/ha/year, with an average of 67.19% reduction capacity.

Table 4-19 Filter Strip default and modified parameters used in SWAT model

Sediment Reduction Method	Parameter	Default Values	Modified Values	Selected Sub-Basins
Filter Strip	VFSI	0	1	Only for critical Sediment Prone Sub-basins with AGRR, BARR, FRST, FRSD, RNGE, RNGB
	VFSRATIO	10	40	
	VFSCON	0.5	0.25	
	VFSCH	90	95	
	FILTERW	0	5	

Also a study by (Yibeltal, 2022) conducted estimation of sediment yield and assessing sediment reduction method in Guder sub-basin, reported that the average reduced annual sediment yield at the entire watershed level by 39.98% after application of filter strip. Other study by (Kefay et al, 2022) showed that a 1m filter strip application reduced the sediment yield by 17.48% reduction capacity. (Fikirte, 2019) successfully showed that the use of filter strip with a 10m width for 12 sediment prone areas brought 54.7% reduction capacity of sediment yield (from 14.8t/ha/year to 6.7t/ha/year) of Geba River catchment. Other similar research by (Tolche et al, 2021) has been found that the 5m and 10m filter strip results a reduction of sediment yield by 31.68% and 46.6%, respectively. A study by (Tesema et al, 2020) also adopted a 5m and 10m filter strips that leads to a reduction of sediment yield in the Kesem dam watershed by 59.16% and 72.67%, respectively. So that, the result of these study agrees with this studies.

4.6.4. Scenario V: Grassed Waterway

An application of grassed waterway for the critical sediment deposition of sub-basins with the width of 30 m, results in reduction of average annual sediment yield from 40.32 ton/ha/year to 7.34 ton/ha/year at the catchment level sediment reduced by 81.80%.

Table 4-20 Grassed Waterway default and modified parameters used in SWAT model

Sediment Reduction Method	Parameter	Default values	Modified Values	Selected Sub-basins
Grassed Waterways	GWATI	1	1	For all the critical Sediment source sub-basins with All Soil types and LULC Except, sub-basin 6,9,14,17,21,28,41,44,49,68,69 and 74 (Sub-basins with low sediment yield)
	GWATN	0.1	0.1	
	GWATL	1000	1000	
	GWATW	10	30	
	GWATD	1	1.406	
	GWATS	0.005	0.005	
	GWATSPCON	0.005	0.005	

The result of this study is in line with the previous findings of our country, as well as our continent Africa (Kefay et al, 2022; Yibeltal, 2022; Alemayehu, 2021; Fikirte, 2019; Mwangi et al, 2015; Tolche et al, 2021; Tesema et al, 2020). After simulation of grassed waterway for the selected critical sediment source sub-basins in the middle Awata watershed, (Kefay et al, 2022) successfully reduced the sediment yield by 38.18% (average annual sediment yield from 27.85t/ha/year to 17.21t/ha/year). A similar study by (Yibeltal, 2022) in Guder sub-basin, applied an average of 10m width of grassed waterway and successfully showed that a reduction of sediment yield by 59.93% capacity from the entire watershed.

Also (Alemayehu, 2021) conducted a study to predict sediment yield to lake Ziway reservoir and assessed a reduction methods using SWAT model. His study reported that application of grassed waterway reduces 58% of sediment yield at the watershed level. A study of modeling of Rainfall-Runoff process and sediment yield in Gaba River catchment by (Fikirte, 2019), showed 20.3% of an average annual sediment yield reduction after the application of grassed waterway at the entire watershed level. The result of these study slightly agrees with the above studies.

4.6.5. Scenario VI: Terracing

For this study, application of Terracing for the erosion prone sub-basins significantly reduced sediment yield rate by 84.30% (40.32 ton/ha/year to 6.33 ton/ha/year) at the basin level.

Table 4-21 Terracing default and modified parameters used in SWAT model

Sediment Reduction Method	Parameter	Default Values	Modified Values	Selected Sub-basins
Terracing	TERR_P	0.5	0.14	For the critical Sediment Source sub-basins
	TERR_CN	60	67	
	TERR_SL	20	40	

The practice of terracing in Gololcha Dam Reservoir, Upper Wabe-Shebelle River Basin (Hussen, 2020), results 42.82% reduction of sediment yield. A similar study by (Yibeltal, 2022), (Fikirte, 2019), (Mwangi et al, 2015) and (Alemayehu, 2021), accounts a reduction of average annual sediment yield by 61%, 78.8%, 85% and 72%, respectively after application of terracing for the critical sub-basins. A recent study by (Kefay et al, 2022), showed a reduction of sediment yield after implementation of terraces in the critical sub-basins. It reduced the mean annual sediment yield rate by 47.05% in the critical sub-basins and at the watershed level, the annual sediment yield was reduced by 30.09% from an average yield of 13.67t/ha/year to 9.42t/ha/year. According to the above studies, the result shows a good match.

4.6.6. Scenario VII: Contouring

An application of contouring on agricultural lands reduces speed and erosion movement by surface runoff. The parameters used in the SWAT model increases the surface roughness and slows down the movement of the surface runoff. Simulation of contouring on the highly affected sub-basins reduced the average sediment yield by 59.25% reduction capacity (from 40.32 t/ha/year to 16.43 t/ha/year).

Table 4-22 Contouring default and modified parameters used in the SWAT model

Sediment Reduction Method	Parameter	Default Values	Simulated Values	Selected Sub-Basins
Contouring	CONT_CN	60	75	All Agricultural lands for all Soil types
	CONT_P	0.5	0.7 for slope >15 %	
			0.6 for slope 6 - 15	Only for soil types Pellic Vertisols, Eutric Cambisols and Dystric Nitosols
			0.5 for slope 0 - 6	

This results of the study coincides with (Dibaba, 2021; Fikirte, 2019; Kefay et al, 2022; Hussen, 2020) findings in Ethiopia. The study by (Dibaba, 2021) conducted evaluation of best management practices in highland Ethiopia, Fincha catchment and a simulation of contouring in agricultural lands showed a reduction of sediment yield by 17.1% reduction capacity. A study by (Fikirte, 2019) accounts a reduced average annual sediment yield from 14.8t/ha/year to 5.7t/ha/year which is 61.57% reduction at a critical sub-basin level. This practice also reduced the sediment yield rate from an average annual sediment yield of 27.85t/ha/year to 18.54t/ha/year which accounts about 33.43% reduction in Awata watershed (Kefay et al, 2022). A finding by (Hussen, 2020) also showed a reduction of sediment yield by 33.66% in the watershed level of Gololcha. The result of this study also shows a slight agreement with the above studies.

4.7. Comparison and Evaluation of BMPs

Comparison of the analyzed management scenarios and selection of the best sediment reduction practice is important for the sediment prone areas. As shown in the figure below, sediment yield has been reduced after the adoption of filter strips, grassed waterways, terracing and contouring. As the figure illustrates, application of Grassed Waterways and Terracing are better in reduction of sediment deposition in the basin.

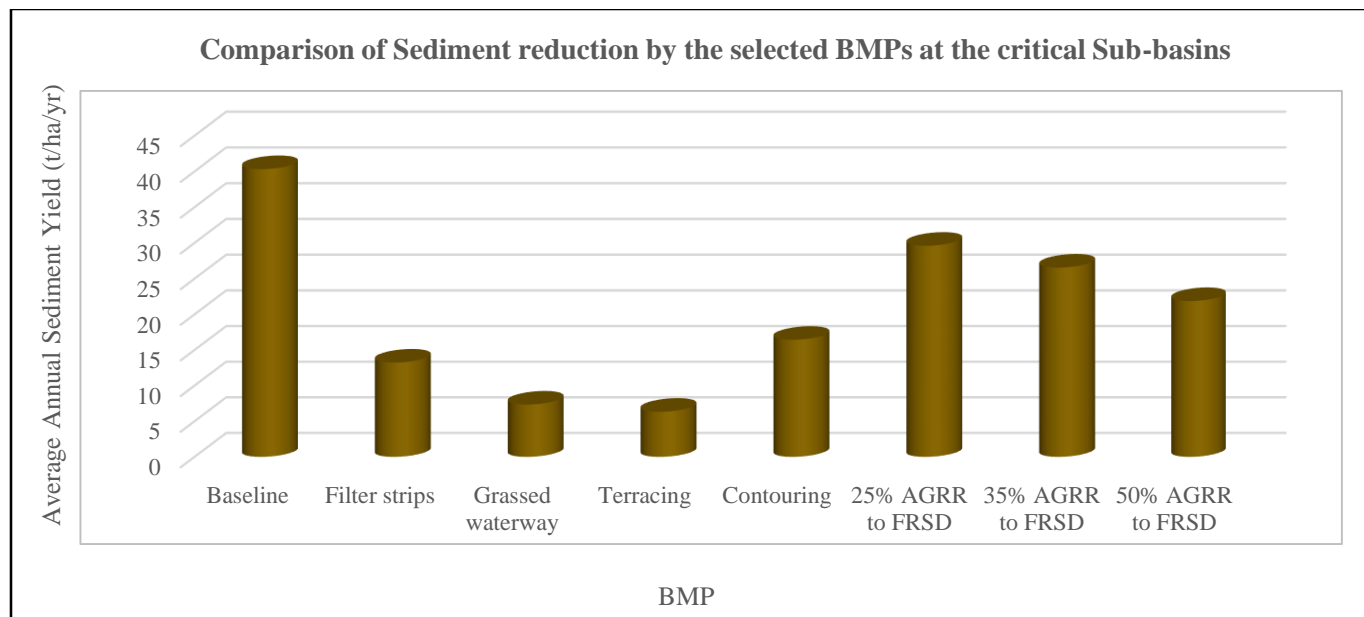


Figure 4-11 Comparison of Sediment reduction by the selected BMPs at the critical Sub-basins

Table 4-23 Summary of Sediment yield reduction effectiveness and rank of each BMPs Developed on MAMD Watershed

Rank	Types of BMP	Sediment Yield before BMP (t/ha/year)	Sediment Yield after BMP (t/ha/year)	Reduction Capacity (%)
-	Baseline	40.32	-	-
1	Filter strips	40.32	13.23	67.19%
2	Grassed waterway	40.32	7.34	81.80%
3	Terracing	40.32	6.33	84.30%
4	Contouring	40.32	16.43	59.25%

The table shows, among the other scenarios simulation of Terracing and Grassed Waterways Best Management Practice results in reduction of sediment yield at the watershed level by 84.30% (Annual average sediment yield of 40.32 ton/ha/year to 6.33 ton/ha/year) and 81.80% (from Annual average sediment yield of 40.32 ton/ha/year to 7.34 ton/ha/year). Application of Filter strip reduced the average annual sediment yield from the basin by 67.19%. The remaining contouring practice also shows a reduction of sediment yield by 59.25%. Thus, implementation of Terracing for the agricultural lands has significantly more sediment reduction capacity than the other scenarios. Application of Terracing on the critical prone areas has significant effect to reduce sediment yield.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Soil erosion is a natural process in which a driving force by water and other agents detached and transported from the parent material. Water is the major influencing agent that accelerates soil erosion due to several reasons such as poor land use practice, insufficient management of surface water runoff, lack of suitable soil conservation measures, unfavorable natural features and increased population pressure. These are the major causes of soil erosion and sediment problem in any watershed. Sedimentation is one of the critical challenges to create and sustain development opportunities in every water resource development and planning sectors. Evaluating and intense understanding of watershed sediment yield is vital in order to ease the design, planning and management projects of water resource.

In this study, SWAT2012 model was used for sediment yield simulation for Middle Awash Multi-Purpose Dam watershed. The model successfully delineated the watershed and sub-divided the watershed into 87 sub-basins with 1235 HRU (each with Unique combination of Soil, LULC and slope characteristics) including Dire, Legedadi, Gefersa, and Koka reservoirs. The total area of the catchment is 21,103.16km² and irrigation abstractions from Metehara to Koka was considered during the simulation of the SWAT model. The SWAT model for the MAMD catchment was then calibrated from 1993 to 2006 and validated from 2007 to 2013 in monthly basis using observed values of streamflow and sediment yield developed from the sediment rating curve to evaluate the performance of the model for simulation of sediment yield and streamflow using SWATCUP SUFI-2 algorithm. The statistical parameters for the model performance calibration and validation of streamflow displayed with $R^2 = 0.67$, NSE = 0.62, and PBIAS = 17.9, and $R^2 = 0.65$, NSE = 0.63, and PBIAS = 8.0, respectively. The simulation of result for sediment also showed a good calibration and validation statistical values with $R^2 = 0.67$, NSE = 0.62, and PBIAS = 10.7, and $R^2 = 0.69$, NSE = 0.69, and PBIAS = -2.8, respectively. During the calibration the CN2, CH_K2, OV_N, HRU_SLP, EPCO and ALPHA_BF were highly sensitive parameters for the streamflow simulation. While LAT_SED, USLE_P, CN2, SED_CON and CH_COV2 were highly sensitive for sediment load. After calibrating the SWAT model with the fitted values of the sensitive

parameters, the model predicted an average annual sediment yield of 40.32 t/ha/year at the outlet of the watershed for the given 32 years of simulation period.

The critical sediment source sub-basins were identified using the spatial variation map and HRU results. 14 sediments were highly affected by erosion (10.01 to 169.94 ton/ha/year). About 17 sub-basins are also moderately affected sub-basins by sediment (4.79 to 9.48 ton/ha/year). From the total catchment, 23.6% of the area is identified as a sediment prone area. In order to reduce the accumulation of sediment yield in sub-basin level, SWAT model was applied to evaluate the impact of the selected three land use land cover management scenarios and four sediment yield reduction BMP scenarios. The conversion of 25%, 35% and 50% Agricultural land to forest land results in reduction of sediment yield by 26.59%, 34.15% and 45.76%, respectively. The overall simulation of the SWAT model, after applying the modified parameters filter strips, grassed waterways, terracing and contouring on the hot spot areas of the catchment, the average annual sediment yield was reduced by 67.19%, 81.80 %, 84.30% and 59.25%, respectively. Among the BMP's, application of Terracing was the most effective sediment reduction method for all the sediment prone areas of the Middle Awash Multi-Purpose dam watershed.

In general, areas with high sediment yield require immediate action of soil conservation practices. The land use management scenarios can be implemented and reduce the erosion rate in the catchment. Also for sustainable management of sediment prone sub-basins in MAMD catchment, grassed waterways and terracing can be integrated.

5.2. Recommendation

In general, using SWAT model is challenging if the data is not good in terms of quality and quantity. The meteorological and hydrological data have a quite a lot missing data and it affects the model performance in predicting streamflow and sediment load. Hence, it is recommended to improve the data from gauging stations country wise in both quality and quantity and deploy more staff/data recorders to collect data in a regular basis.

The sediment load data at Awash gauge station was barely available and a Metehara Sediment rating curve was used in order to calibrate and validate the SWAT model. For future analysis, it is recommended that the Awash gauging station has its own recording station for some better predictions. Because studies need to rely on recent and accurate daily flow and sediment input data.

The developed and examined Best management practices showed the effective scenarios or interventions for sediment yield reduction for a specific sediment prone areas. Therefore, the study was able to show the effect of the application of each BMP and reduction of sediment load in a basin level. It is vital for the stakeholder in planning, design and implementation erosion and sediment yield reductions in the catchment. Hence, a systematic plan and intervention is required to reduce the rate of soil erosion in the watershed.

In this study, four different BMP was applied to reduce the sediment yield. But for the future studies, estimating the amount of sediment yield under other soil management and land use variables should be applied. Also, in order to examine the sediment yield and enhance the sediment reduction in the catchment further studies should be conducted using different hydrological models.

References

- Abbaspour et al, (2017). A Guideline for Successful Calibration and Uncertainty Analysis for Soil and Water Assessment: A Review of Papers from the 2016 International SWAT Conference. *Water*, 1-18. doi:doi:10.3390/w10010006
- Abbaspour, K. C. (2015). *SWAT Calibration and Uncertainty Programs - A User Manual*. Eawag: Swiss Federal Institute of Aquatic Science and Technology.
- Alemayehu, K. (2021). *Prediction of Sediment Yield to Lake Ziway Reservoir and Assessing Reduction Methods (Using Arc-SWAT)*. Addis Ababa, Ethiopia: Addis Ababa University.
- Arnold et al, (2012). SWAT: Model Use, Calibration and Validation. *American Society of Agricultural and Biological Engineers*, Vol. 55(4): 1491-1508.
- Asmelash et al, (2017). Sediment Inflow Estimation and Mapping its Spatial Distribution at Sub-Basin Scale: The Case of Tendaho Dam, Afar Regional State, Ethiopia. *Ethiopian Journal of Environmental Studies and Management*, 315-339.
- Avcı et al, (2023). Spatial-Temporal Response of Sediment Loads to Climate Change and Soil Conservation Practices in the Northern Aegean Watershed, Türkiye. *Water*, 15(13): 2461.
- Awash Basin Authority. (2015). *Middle Awash Flood Control and Irrigation Development Project: Hydrological Analysis Draft Final Report*. Addis Ababa, Ethiopia: Water Works Design and Supervision Enterprise.
- Awash Basin Authority. (2017). *Awash River Basin Water Allocation Modeling and Conflict Resolution Study Project: WP-1: Surface Water Resources Study Final Report*. Addis Ababa, Ethiopia: Addis Ababa Institute of Technology, Addis Ababa University.
- Awash Basin Authority. (2018). *Awash Basin Sedimentation Modelling Project: Executive Summary*. Dire Dawa, Ethiopia: Federal Democratic Republic of Ethiopia.
- Awulachew, S. B. (2008). A review of Hydrology, Sediment and Water Resource use in the Blue Nile Basin. *International Water Management Institute (IWMI)*, 81.
- Ayana, A. E. (2012). Simulation of Sediment Yield using SWAT Model in Fincha Watershed, Ethiopia. *Kasetsart Journal - Natural Science*, 046. 283-297.
- Basson and Rooseboom, G. R. (1999). *Dealing with Reservoir Sedimentation: Guidelines and case studies*. *International Commission on Large Dam Bulletin 115*. ICOLD bulletin 115.
- Bayisa, I. D. (2019). *Sediment Yield Modeling in Awash Melkasa Dam Watershed, Upper Awash River Basin, Ethiopia*. Jimma, Ethiopia: Jimma University.
- Belay, Y. G. (2022). *Comparison of HEC-HMS hydrologic model for estimation of runoff computation techniques as a design input: case of Middle Awash multi-purpose dam, Ethiopia*. 237. <https://doi.org/10.1007/s13201-022-01764-7>: Appl Water Sci 12.
- Betrie et al, (2011). Sediment management modeling in the Blue Nile Basin using SWAT model. *Hydrology Earth System Science*, v-15, 807-818. doi:10.5194/hess-15-807-2011.
- Beven, K. (2000). Rainfall-Runoff Modelling. *The Primer*. Wiley, 360.
- Bishaw, D. (2015). Determining Sediment Load of Awash River entering into Metehara Sugarcane Irrigation Scheme, Ethiopia. *Journal of Environment and Earth Science*, 13, 224-321.

- Chekol et al, (2007). Application of SWAT for assessment of spatial distribution of water resources and analyzing impact of different land management practices on soil erosion in Upper Awash River Basin watershed. *Catchment Lake Resource*, 110-117.
- Daba, T. (2017). *Sediment Problem of Gefersa Reservoir and the Appropriate Mitigation*. Msc Thesis, Addis Ababa University.
- Dibaba, W. D. (2021). Prioritization of Sub-Watersheds to Sediment Yield and Evaluation of Best Management Practices in Highland Ethiopia, Finchaa Catchment. *Land*, 10,650.
- Dile et al, (2023). Hydrological Modeling and Scenario Analysis for Water Supply and Water Demand Assessment of Addis Ababa City, Ethiopia. *Journal of Hydrology: Regional Studies*. doi:<https://doi.org/10.1016/j.ejrh.2023.101341>
- FAO. (2002). *Major Soils of the World*. Rome: Land and Water Digital Media Series Food and Agricultural Organization of the United Nations, CD-ROM.
- FAO. (2017). *Watershed Management in action - lessons learned from FAO field projects* . Rome: Food and Agriculture Organization of the United Nations.
- Fayera, G. T. (2015). *Predicting Sediment Yield of Didessa River Basin and Sedimentation of Arjo Didessa Reservoir*. Jimma, Ethiopia: Jimma University.
- Fikirte, S. D. (2019). *Modeling of Rainfall-Runoff Process and Sediment Yield using SWAT Model for Geba River Catchment, Ethiopia*. Jimma, Ethiopia: Jimma University.
- Gassman et al, (2007). The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. *American Society of Agricultural and Biological Engineers*, Vol. 50(4): 1211-1250.
- Gessese, A. (2008). *Prediction of Sediment Inflow for Legedadi Reservoir using SWAT Watershed and CCHEID Sediment Transport Models*. Faculty of Technology, Addis Ababa University.
- Gizaw and Kebede, (2019). Spatial and Temporal Distribution of Sediement Yield case study Nashe, Blue Nile Basin, Ethiopia. *Journal of Water Sustainability*, 9(2): 23-34.
- Halcrow, W. (1989). *Master Plan for the Development of Surface Water Resources in the Awash River Basin. Final Report, vol. 2*. Addis Ababa: Ethiopian Valleys Development Authority.
- Haregeweyn et al, (2022). Reduced runoff and sediment loss under alternative land capability based land use and management options in a sub-humid watershed of Ethiopia. *Journal of Hydrology: Regional Studies*, vol. 40, Article ID 100998.
- Hillel, D. (2003). *Introduction to Environmental Soil Physics* . Massachusetts, USA: Elsevier Academic Press.
- Hussen, M. H. (2020). *Sedimentation Modeling (Case study, Gololcha Dam Reservoir, Upper Wabe Shebelle River Basin, Ethiopia)*. Addis Ababa, Ethiopia: Addis Ababa University.
- Kefay et al, (2022). Prioritization of Susceptible Watershed to Sediment Yield and Evaluation of Best Management Practice: A Case Study of Awata River, Southern Ethiopia. *Hindawi Applied and Environmental Soil Science*, 1-16.
- Lam et al, (2011). The impact of agricultural best management practices on water quality in a North German. *Environmental Monitoring Assessment*, 183, 351-379.

- Lemma et al, (2019). Identifying erosion hotspots in lake tana basin from a multisite soil and water assessment tool validation: opportunity for land managers. *Land Degradation & Development*, vol. 30, no. 12, 1449–1467.
- Leta et al, (2023). Sediment yield estimation and evaluating the best management practices in Nashe watershed, Blue Nile Basin, Ethiopia. *Environ Monit Assess* 195.
- Liu et al, (2019). Evaluating Efficiencies and Cost-Effectiveness of Best Management Practices in Improving Agricultural Water Quality using Interested SWAT and Cost Evaluation Tool. *Journal of Hydrology*.
- Melka, L. (2018). *Sediment Yield Modelling using SWAT, Case study of Upper Awash Basin, Ethiopia* .
- Morgan R. (2005). *Soil Erosion and Conservation: 3rd ed.* Australia: National Soil Resources Institute: Cranfield University, Blackwell Publishing.
- Morris et al, (2009). *Reservoir Sedimentation Handbook, Design and Management of Dams, Reservoirs and Watersheds for Sustainable Use.* New York: McGraw-Hill.
- Morris, G. L. (1998). *Reservoir Sedimentation Handbook.* New York: McGraw-Hill Book Co.
- MoWE. (2002). *Water Sector Development Program: Main Report Volume I. p. 193.* Addis Ababa: Ministry of Water and Energy.
- MoWR. (2006). *Awash River Basin Flood Control and Watershed Management Study Project-Baseline Report 5: Flood Control, Drainage and Irrigation Development.* Addis Ababa, Ethiopia.
- MoWR. (2006). *Awash River Basin Flood Control and Watershed Management Study Project-Baseline Report 6: Sediment Sources and Control Measures.* Addis Ababa, Ethiopia.
- Mwangi et al, (2015). A modeling approach to evaluate the impact of conservation practices on water and sediment yield in Sasumua Watershed, Kenya. *Journal of soil water conservation*, 70, 75-90.
- Nash and Sutcliffe, J. A. (1970). River Flow Forecasting through Conceptual Models: Part I. A Discussion of Principles. *Journal of Hydrology: Vol. 10(3)*, 282-290.
- Neitsch et al, (2012). *Soil and Water Assessment Tool: Input/Output Documentation Version 2012.*
- Nina, K. A. (2016). *Megech Dam Reservoir Sediment Estimation using SWAT Model.* Addis Ababa University, Addis Ababa: MSc. Thesis.
- Samuel, T. (2022). *Estimation of Sediment Yield under the Impact of Climate Change (Case of Mille River Watershed, Lower Awash Sub-Basin, Ethiopia):* Addis Ababa University.
- Setegn, S.G. (2010). Modeling of Sediment Yield from Anjeni-Guaged Watershed, Ethiopia Using SWAT Model. *Journal of the American Water Resource Association (JAWRA)*, 514-526.
- Sofonyase, B. A. (2020). Estimation of Sediment Yield using SWAT Model: A Case of Soke River Watershed, Ethiopia. *International Journal of Engineering Research & Technology* .
- Sufiyan, A. (2014). *Sedimentation Yield Estimation from Upper Awash Watershed: Sedimentation into Koka Reservoir, Ethiopia.* Arba Minch: Arba Minch University.

- Tadesse, F. (2016). *Development of Water Allocation and Utilization System for Koka Reservoir under Climate Change and Irrigation Development Scenarios (Case Study Downstream of Koka Dam to Metahara)*. Addis Ababa, Ethiopia: Addis Ababa University.
- Tarekegn, F. (2012). *Prediction of Sediment Inflow to Gefersa Reservoir (Using SWAT Model) and Assessing Sediment Reduction Methods*. MSc. Thesis.
- Tesa et al, (2014). Predicting Runoff Yield using SWAT Model and Evaluation of Boru Dodota Spate Irrigation Scheme, Arsi Zone, Southeastern Ethiopia. *International Water Management Institute Books*.
- Tesema et al, (2020). Sediment Yield Estimation and Effect of Management Options on Sediment Yield of Kesem Dam Watershed, Awash Basin, Ethiopia. *Scientific African*.
- Tesfaye, G. (2021). *Runoff and Sediment Yield Modeling in Laga Dadi Reservoir and its Watersheds*. Addis Ababa: Addis Ababa University.
- Tesfu et al, (2021). Multi-Site Calibration of SWAT for the Spatial Distribution of Sediment Yield, Middle Awash Dam Watershed, Ethiopia. *Malaysian Journal of Society and Space*, 256-273.
- Tolche et al, (2021). Impacts of Management Scenarios on Sediment Yield Simulation in Upper and Middle Awash River Basin, Ethiopia. *Ecology & Hydrology*.
- Welde, K. & Gebremariam, B. (2017). Effect of land use land cover dynamics on hydrological response of watershed: Case study of Tekeze Dam watershed, northern Ethiopia. *International Soil and Water Conservation Research*, Volume 5, Issue 1, Pages 1-16.
- Williams, J. (1985). Sediment-yield prediction with universal equation using runoff energy factor. *In Present and prospective technology for predicting sediment yield and sources: Proceedings of the sediment yield workshop*.
- Wu et al, (2014). Representation of agricultural Best Management Practices in a fully distributed hydrologic model: A case study in the Luoyugou Watershed. *Journal of Resources and Ecology*, 5(2): 179-184.
- WWDSE. (2015). *Feasibility Study of Middle Awash Multi-purpose Project: Hydrological Study*. Addis Ababa, Ethiopia: Water Works Design and Supervision Enterprise.
- WWDSE. (2016). *Middle Awash Feasibility Study and Detail Design of Multi-purpose Dam Project Volume III, Annex III Site Specific Seismic Hazard Assessment Final Report*. Addis Ababa, Ethiopia: Water Works Design and Supervision Enterprise.
- WWDSE. (2016). *Middle Awash Feasibility Study and Detail Design of Multi-Purpose Dam Project: Geological and Geotechnical Investigation Final Feasibility Report, Volume III*. Addis Ababa, Ethiopia: Water Works Design and Supervision Enterprise.
- Yibeltal, A. (2022). *Estimation of Sediment Yield and Assessing Sediment Reduction Method (A case of Guder sub basin)*. Addis Ababa, Ethiopia: Addis Ababa Institute of Technology, Addis Ababa University.
- Zhu et al. (2013). Modeling Runoff and Soil Erosion in the Three-Gorge Reservoir Drainage Area of China using Limited Plot Data. *Journal of Hydrology*, 163-175.

Appendixes

Appendix A: Annual Average Monthly Rainfall for selected 14 stations in mm

No.	Stations	Month of the Year											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	AA_Bole	11.6	31.9	58.0	100.6	88.3	139.6	265.8	290.2	167.2	33.1	6.5	7.0
2	AA_Obs	12.6	30.1	53.3	84.3	83.3	150.3	258.2	284.8	189.8	33.4	10.2	9.7
3	Debre_Zeit	27.4	52.3	84.6	103.2	64.4	133.5	266.8	268.8	151.4	31.7	10.2	5.7
4	Metehara	25.4	55.3	89.1	109.7	81.0	56.8	297.9	263.8	125.7	54.9	21.3	19.1
5	Nazeret	18.9	34.2	73.5	73.2	69.4	88.6	329.5	273.5	162.3	45.0	21.8	10.0
6	Nuraera	46.2	45.7	96.7	97.1	76.9	67.4	306.4	253.0	119.1	57.9	19.3	14.4
7	Asgori	18.0	36.9	66.2	99.2	86.1	167.9	284.3	271.7	131.0	21.4	11.8	5.3
8	Awash_7kilo	27.9	60.2	110.4	139.5	77.4	54.5	251.2	243.7	129.1	56.8	26.5	22.8
9	Bologorgis	19.6	45.5	62.6	93.5	61.3	98.1	303.0	301.1	147.1	40.3	18.9	9.0
10	Chefedonsa	14.8	29.9	50.0	82.4	82.5	128.9	302.3	323.1	153.5	17.0	10.1	5.5
11	Ginchi	24.8	38.3	61.6	99.5	94.7	164.4	236.2	265.7	161.6	32.3	13.0	7.9
12	Koka_Dam	14.8	28.8	63.6	81.7	78.1	103.9	311.3	309.5	152.1	36.6	12.5	7.3
13	Mojo	14.0	23.6	55.4	71.0	72.7	118.1	353.9	291.3	144.1	35.6	14.0	3.6
14	Welenchiti	23.2	46.5	70.7	92.9	70.0	84.1	312.9	285.4	135.9	46.6	19.5	12.4

Appendix B: Simulated Average Monthly Basin Values of MAMD Catchment

Month	Rain (mm)	Surf Q (mm)	Lat Q (mm)	Water Yield (mm)	ET (mm)	Sed Yield (mm)	PET (mm)
Jan	16.85	5.48	0.48	13.62	8.6	2.59	249.38
Feb	19.12	6.59	0.51	13.76	11.56	2.86	255.67
Mar	50.92	13.07	0.87	21.08	86.97	4.63	296.02
Apr	65.17	5.65	0.72	12.87	142.34	1.44	276.5
May	59.5	1.91	0.66	8.77	100.99	0.59	281.9
Jun	79.91	1.52	0.91	7.91	64.58	0.38	251.16
Jul	217.19	24.41	4.91	34.72	78.81	5.62	215.65
Aug	205.81	49.99	5.19	61.54	69.97	11.29	220.26
Sep	105.06	29.58	2.94	40.28	45.78	6.81	230.73
Oct	30.1	9.43	1.15	19.31	17.63	2.56	267.41
Nov	11.64	2.88	0.52	11.63	8.5	0.76	243.06
Dec	7.3	1.92	0.35	10.31	5.99	0.77	240.1

Appendix C: HRU Analysis Report

SWAT model simulation Date: 3/29/2024 12:00:00 AM Time: 00:00:00
 MULTIPLE HRUs LandUse/Soil/Slope OPTION THRESHOLDS : 15 / 10 / 10 [%]
 Number of HRUs: 1235
 Number of Subbasins: 87

		Area [ha]	Area[acres]	
Watershed		2110316.0400	5214696.4506	
LANDUSE:		Area [ha]	Area[acres]	%Wat.Area
	Forest-Mixed --> FRST	137329.7556	339348.6925	6.51
	Agricultural Land-Row Crops --> AGRR	1500926.2753	3708863.8727	71.12
	Range-Grasses --> RNGE	84175.1071	208000.8984	3.99
	Range-Brush --> RRGB	227238.6403	561518.0422	10.77
	Barren --> BARR	62851.4928	155309.1813	2.98
	Forest-Deciduous --> FRSD	22459.0671	55497.4777	1.06
	Residential --> URBN	49240.0915	121674.7282	2.33
	Water --> WATR	19848.0741	49045.5836	0.94
	Forest-Evergreen --> FRSE	6247.5362	15437.9742	0.30
SOILS:				
	Calcic Xerosols	585.0134	1445.5974	0.03
	Chromic Luvisols	89016.3620	219963.8813	4.22
	Orthic Solonchaks	34167.9194	84430.6372	1.62
	Pellic Vertisols	720927.2805	1781447.3565	34.16
	Eutric Cambisols	240737.5366	594874.4897	11.41
	Leptosols	82313.3754	203400.4664	3.90
	Vitric Andosols	104328.7517	257801.5618	4.94
	Mollic Andosols	106729.4988	263733.9280	5.06
	Chromic Cambisols	30525.3771	75429.7332	1.45
	Eutric Fluvisols	64981.9453	160573.6359	3.08
	Eutric Nitisols	111748.3735	276135.8184	5.30
	Orthic Luvisols	46675.9968	115338.7220	2.21
	Dystric Nitisols	30902.0786	76360.5813	1.46
	Vertic Cambisols	201231.6588	497253.4904	9.54
	Chromic Vertisols	39529.3194	97678.9247	1.87
	Dystric Cambisols	1893.3300	4678.5130	0.09
	Eutric Regosols	65609.6168	162124.6435	3.11
	Orthic Acrisols	9061.3776	22391.1170	0.43
	Haplic Phaeozems	11567.7952	28584.6004	0.55
	Luvic Phaeozems	97935.3590	242003.1690	4.64
	Water Bodies	19848.0741	49045.5836	0.94
SLOPE:				
	30-9999	92893.4923	229544.4641	4.40
	15-30	203138.1716	501964.5788	9.63
	5-15	924381.0674	2284191.8367	43.80
	2-5	684823.2214	1692232.4212	32.45
	0-2	205080.0874	506763.1499	9.72

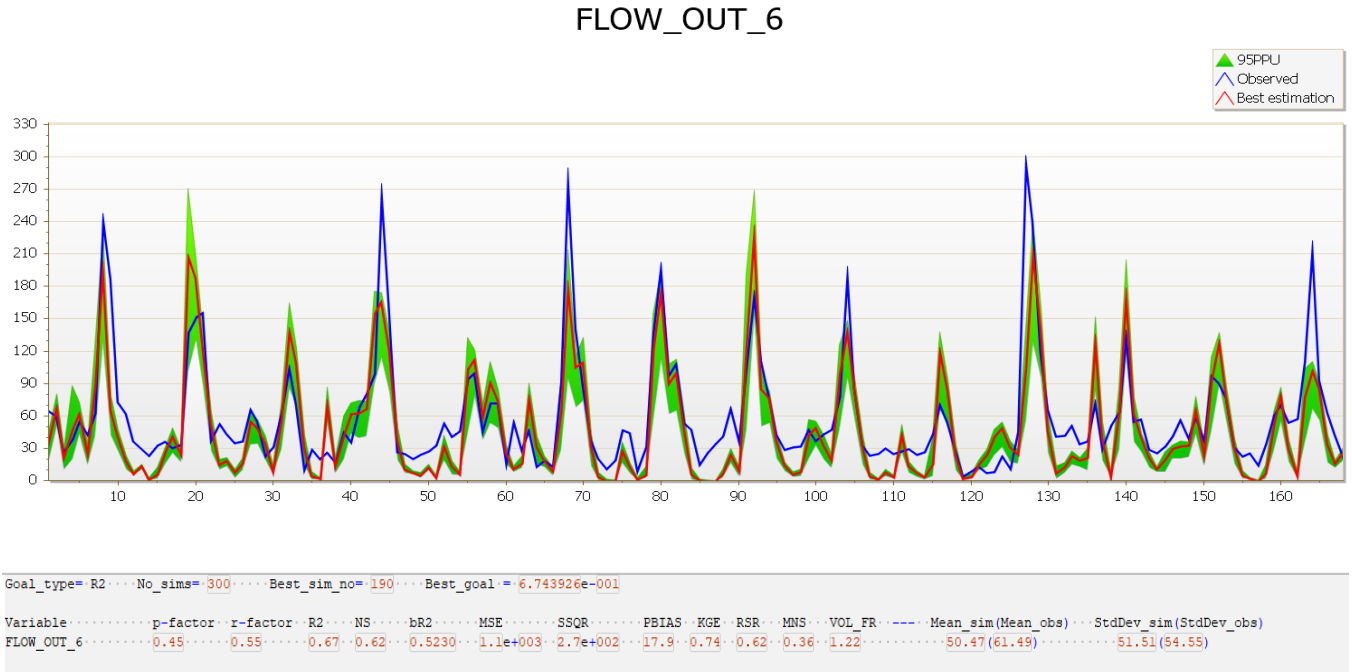
Appendix D: Monthly Observed Stream Flow Data of Awash Gauge station collected from MoWE and used for the development of Sediment Rating Curve in m³/sec

<i>Month Year</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
1993	64.93	59.97	27.44	38.73	55.68	43.52	61.89	247.99	186.80	73.04	62.26	36.56
1994	29.64	23.41	33.26	36.75	30.90	33.98	137.56	151.71	156.21	38.83	53.34	43.61
1995	35.60	36.50	67.56	55.26	23.94	31.76	62.82	107.28	70.90	12.61	29.73	20.54
1996	27.01	17.40	45.74	37.00	68.17	80.64	98.92	275.70	156.05	26.77	24.94	20.92
1997	24.41	27.43	32.79	54.24	41.50	45.74	94.61	100.35	48.51	71.83	72.40	19.31
1998	56.97	30.07	48.04	13.44	19.41	13.59	92.41	290.24	141.41	88.56	37.38	20.59
1999	11.63	19.13	47.91	44.21	10.83	31.40	137.51	202.29	99.04	109.67	54.04	47.79
2000	16.22	26.30	34.89	41.41	69.13	39.44	106.96	176.83	110.91	76.66	43.34	29.13
2001	31.57	32.39	48.63	37.30	43.87	47.90	77.50	198.87	85.24	33.00	23.73	25.58
2002	30.41	25.56	27.48	30.27	24.29	27.13	43.49	71.81	53.78	27.27	4.38	9.27
2003	13.84	7.56	8.51	23.50	12.16	45.11	301.30	241.13	118.38	65.83	41.20	42.32
2004	51.92	34.82	36.70	74.93	31.72	51.63	63.61	139.82	55.02	57.80	28.86	26.09
2005	31.91	41.32	57.42	40.28	60.26	38.85	98.32	90.35	76.72	31.24	22.79	25.75
2006	15.49	33.94	60.35	71.58	54.13	57.66	110.26	222.24	92.52	63.21	42.85	23.39
2007	29.35	38.35	43.12	55.24	46.37	54.90	69.78	280.82	127.24	69.09	54.96	21.19
2008	29.90	25.60	33.92	41.88	53.08	48.17	74.67	140.16	171.16	61.20	47.24	51.27
2009	31.36	36.32	44.35	66.78	39.96	27.39	21.89	92.57	56.45	60.37	43.81	26.07
2010	37.47	39.03	47.36	83.84	59.99	26.83	77.74	131.06	116.22	51.13	44.95	22.82
2011	38.75	23.30	40.79	24.24	49.84	30.61	61.66	100.65	125.16	38.18	48.50	16.48
2012	14.81	17.77	10.20	22.77	8.96	15.70	84.53	166.58	137.98	69.29	5.69	2.47
2013	9.59	7.19	31.04	43.84	37.54	38.54	133.68	172.57	143.73	95.54	23.48	18.06

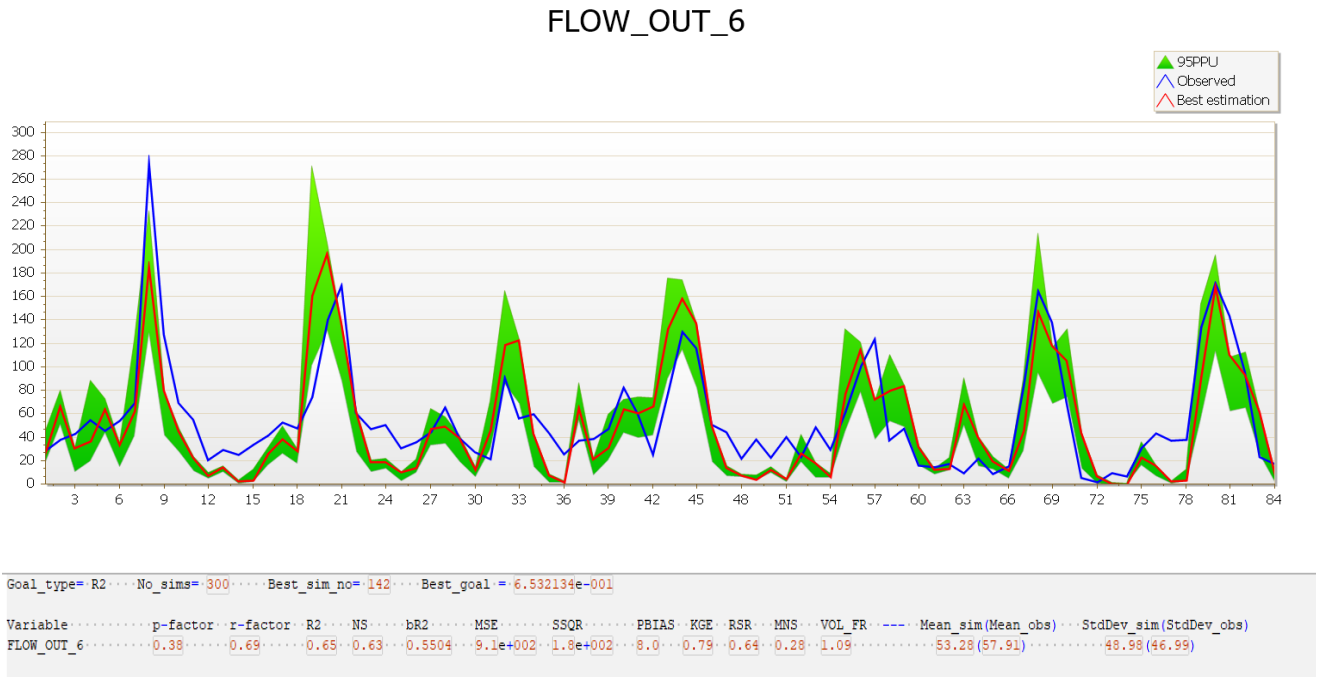
Appendix E: Monthly Sediment Data developed from the Rating Curve (ton) 1993-2013

Month Year	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
1993	15664.7	10719.0	3545.6	16219.9	9699.0	6604.4	21087.3	95726.3	49910.5	6153.2	4316.4	10671.0
1994	3887.1	519.3	6619.6	5171.9	4142.9	4691.5	93202.1	36598.9	38043.6	5785.2	8687.0	6564.2
1995	988.9	5214.3	12894.5	9672.3	2894.9	4635.2	10988.5	23594.6	13364.4	1190.9	111.7	2523.4
1996	3464.5	1871.3	8769.1	5208.7	22345.5	15844.1	27805.7	72039.2	66421.6	3477.1	3226.7	384.8
1997	3193.0	316.0	8573.1	14069.6	6091.1	6982.5	19188.3	22429.6	7568.5	15172.4	14907.9	2237.4
1998	11158.1	3994.0	8536.8	1311.0	2327.3	1332.5	50451.8	89627.9	70171.6	18520.3	5278.1	925.0
1999	116.6	616.5	12563.4	6662.8	5963.3	10860.4	32082.7	75649.4	29596.6	34424.6	8753.7	7392.3
2000	71.3	62.6	4813.7	6084.9	12314.7	6103.9	49891.0	68974.3	23572.9	14670.3	6517.1	3762.3
2001	185.3	4466.7	8028.9	5598.7	6602.8	7516.6	79105.3	30062.1	17021.3	4452.6	839.0	3139.5
2002	3998.8	132.2	3532.4	4030.7	2922.3	3399.7	6546.0	13101.5	8877.2	3588.7	278.7	924.5
2003	1502.9	587.0	691.1	3318.5	1237.7	27635.5	76796.3	65371.1	25794.1	13787.5	6043.7	6304.2
2004	8363.6	4798.8	5189.7	15150.9	235.9	8314.8	10968.5	38039.5	9001.5	9909.7	3712.4	223.5
2005	4294.3	169.5	10252.1	6336.1	10520.4	5717.3	20503.5	18179.7	14253.3	287.8	2699.0	164.3
2006	952.4	8729.1	10463.7	19058.5	8774.7	561.4	25345.1	63261.5	53487.7	11075.0	449.3	2779.1
2007	13785.0	15467.9	74.7	39081.0	7064.1	1880.0	32468.0	175131.4	8194.4	2812.3	94.4	2053.6
2008	76.06	81.3	4582.9	6175.7	8472.5	7470.4	96717.0	44038.2	42345.1	1560.1	2596.3	1091.2
2009	36.08	2199.9	12620.9	7946.9	1740.7	3537.9	12823.3	34161.6	9281.4	1689.2	44.9	531.1
2010	23606.6	969.2	15758.1	7686.2	10052.1	3424.3	55516.7	75460.0	36016.0	1535.0	6765.4	313.1
2011	2503.6	213.1	2168.4	5927.1	2216.2	3517.2	10697.8	20665.6	9438.7	2184.2	2205.6	712.9
2012	1472.4	1949.0	919.2	3078.6	760.0	1650.1	16501.6	45035.0	66871.7	4657.7	410.8	126.8
2013	964.7	557.0	5867.0	7072.6	5446.9	5997.7	31125.8	43706.7	33810.0	20453.7	2894.5	1957.1

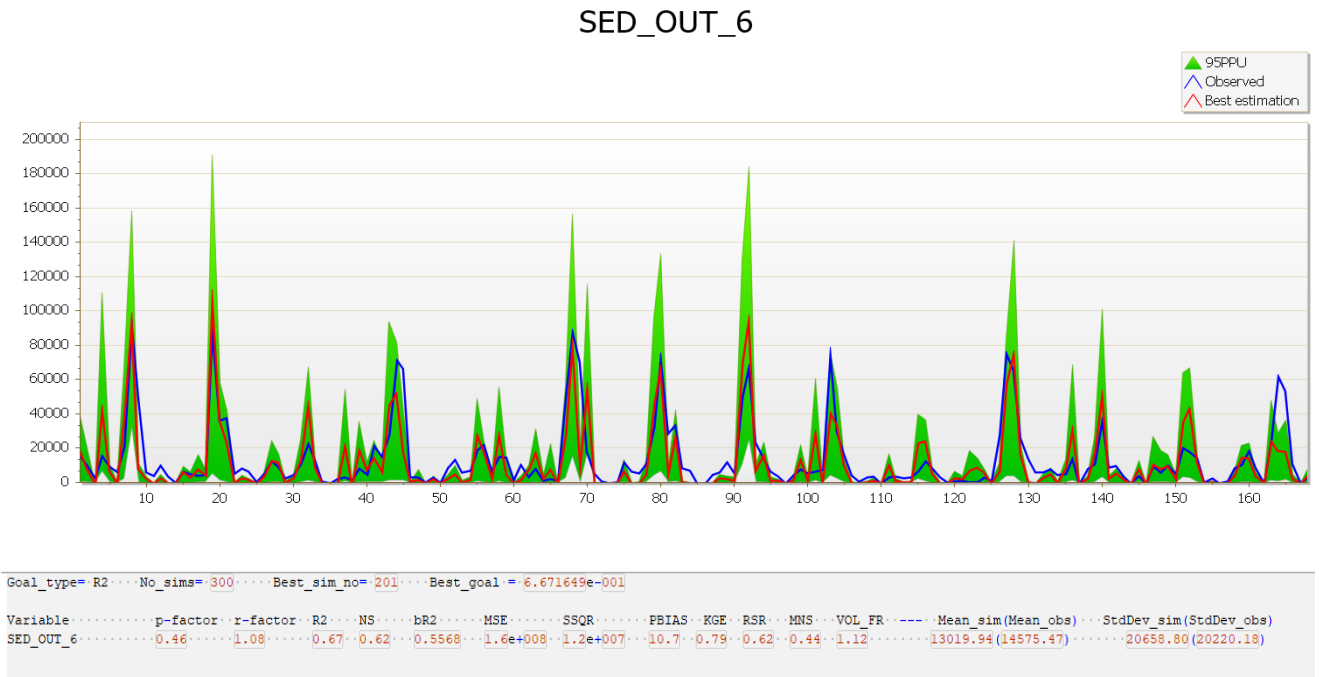
Appendix F: Figure of SWAT-CUP output 95PPU plot for flow calibration period (1993 to 2006) and summary statistic



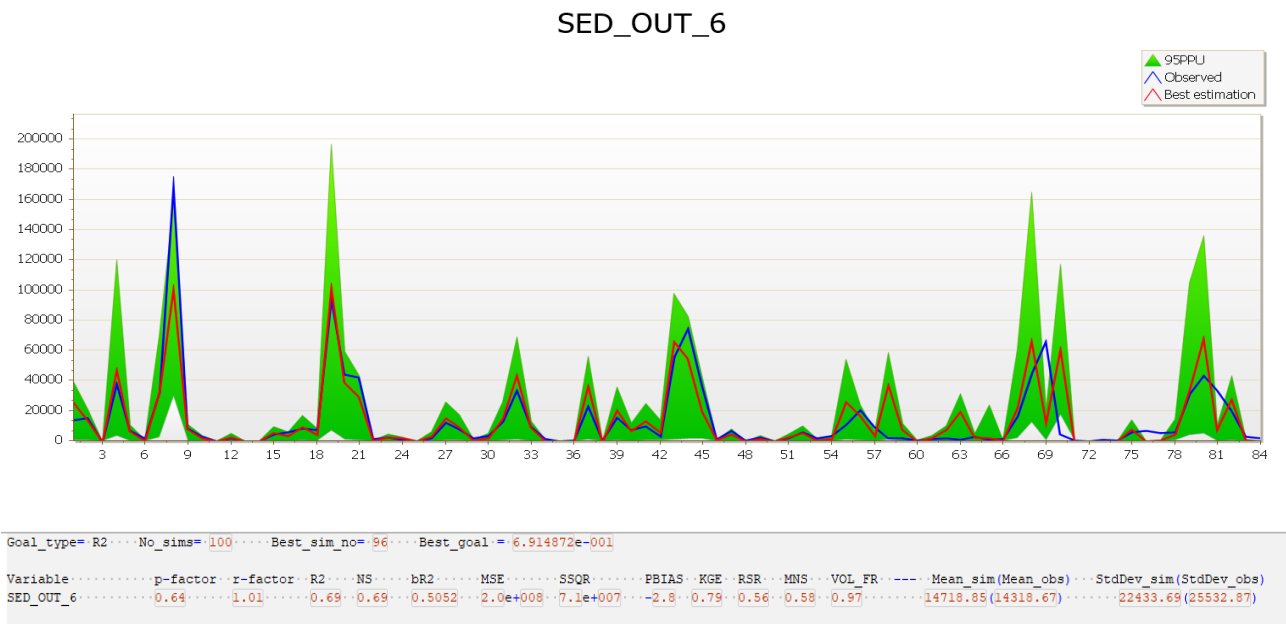
Appendix G: Figure of SWAT-CUP output 95PPU plot for flow validation period (2007 to 2013) and summary statistics



Appendix H: Figure of SWAT-CUP output 95PPU plot for Sediment calibration period (1993 to 2006) and summary statistics



Appendix I: Figure of SWAT-CUP output 95PPU plot for Sediment validation period (2007 to 2013) and summary statistics



Appendix J: Soil parameters of the study area according to FAO Soil Classification (FAO, 2002)

<i>No.</i>	<i>Name</i>	<i>FAO Name</i>	<i>HYDRP</i>	<i>TEXTURE</i>	<i>SOL_ZMX</i>	<i>SOL_Z</i>	<i>SOL_BD</i>	<i>SOL_AWC</i>	<i>SOL_K</i>	<i>SOL_ALB</i>	<i>USLE_K</i>	<i>Clay</i>	<i>Silt</i>	<i>Sand</i>
1	Calcic Fluvisols	Jc27-1a-108	B	C-C-CL	1300	200	1.1	0.11	25	0.1	0.22	50	34	13
						500	1.04	0.11	25	0.1	0.2	51	22	27
						1300	1.05	0.11	25	0.1	0.3	39	31	30
2	Calcic Xerosols	Xk32-3a-3573	D	C-C-C	1800	600	1.25	0.19	26	0	0.32	64.5	9	27
						1200	1.35	0.14	15	0.1	0.28	72	8	20
						1800	1.83	0.09	6.8	0.1	0.2	75	7	18
3	Chromic Cambisols	Bc46-3a-3005	C	LS-S-SL	1651	203	1.7	0.14	700	0	0.24	3	17	80
						813	1.7	0.06	600	0.1	0.24	3	1.5	96
						1651	1.6	0.13	54	0.2	0.32	10.5	26	64
4	Chromic Luvisols	Nh7-2-3c-853	B	SI-L-SIL-S	1800	210	1.45	0.22	38.4	0.1	0.3	11	67	22
						470	1.46	0.21	37.2	0.1	0.3	14	66	20
						1800	1.45	0.2	34.8	0.1	0.3	19	59	22
5	Chromic Vertisols	Vc1-1715	D	SI-L-CL	1750	1750	1.2	0.15	1000	0.1	0.1	36	54	10
6	Dystric Cambisols	Bd31-2c-11	C	C-C-CL	1000	300	1.1	0.092	20.22	0.0058	0.2552	28	31	41
						1000	1.2	0.092	12.93	0.1269	0.2552	33	26	40
7	Dystric Nitisols	Ne61-2-3a-5998	D	C-C-C	1651	203	1.35	0.2	7.9	0	0.49	35	48	17
						610	1.35	0.15	0.23	0	0.49	75	18	7.4
						1651	1.35	0.13	0.12	0.1	0.49	75	18	7.4
8	Eutric Cambisols	Be56-2-3a-456	B	ML-M	900	600	1.5	0.2	33.6	0	0.31	21	33	28
						900	1.46	0.18	40	0	0.34	13	46	41
9	Eutric Fluvisols	Fo94-2ab-556	B	CL-CL-C	1800	600	1.13	0.22	6.6	0	0.32	32	42	26
						1200	1.45	0.22	0.65	0	0.49	30	39	31
						1800	1.6	0.16	0.33	0.2	0.49	41	24	35
10	Eutric Nitisols	Nd3-1565	B	C-C-C	1500	1500	1.35	0.1	65.9	0.1	0.25	50	23	27
11	Eutric Regosols	Re65-1a-250	B	SL-C	1300	250	1.08	0.12	6.8	0.1	0.23	54	26	21
						750	1.15	0.19	7	0.1	0.22	74	16	11
						1300	1.17	0.19	7	0.1	0.22	72	16	13
12	Haplic Phaeozems	Hh1-1a-4721	B	SI-L-CL	1500	520	1.27	0.11	4.54	0.1	0.22	23	50	27
						800	1.28	0.11	5.16	0.1	0.22	60	25	15

13	Leptosols	Lp1-2a-5613	D	CL	500	1500	1.22	0.11	4.24	0.1	0.22	71	20	9
						500	1.44	0.19	287	0.1	0.21	35	38	27
14	Luvic Phaeozems	Hl5-3a-5759	C	C-C-C	1800	600	1.15	0.19	210	0.0	0.28	70	10	20
						1200	1.13	0.15	150	0.0	0.32	74	10	16
						1800	1.55	0.18	0.47	0.2	0.49	77	7	16
15	Mollic Andosols	Vc14-3a-261	B	SL-C-SCL	1250	120	1.1	0.12	6.23	0.2	0.2	55	30	0
						450	1.19	0.09	5	0.2	0.2	68	27	5
						700	1.14	0.2	9.34	0.2	0.3	30	60	10
16	Orthic Acrisols	Ao9-3b-5388	B	C-C-C	930	210	1.45	0.22	38.4	0.1	0.3	11	67	22
						470	1.45	0.22	38.4	0.1	0.3	11	67	22
						930	1.45	0.2	34.8	0.1	0.3	19	59	22
17	Orthic Luvisols	Lo81-1a-6574	B	C-C-C	1800	600	1.35	0.19	1.7	0.0	0.49	62.5	27	11
						1200	1.35	0.13	0.14	0.1	0.49	75	18	7.4
						1800	1.35	0.12	0.1	0.2	0.49	75	18	7.4
18	Orthic Solonchaks	Zo2-1a-389	B	SIL-CL	1500	1000	1.43	0.2	307	0.1	0.23	33	35	12
19	Pellic Vertisols	Vc40-3a-956	D	C-C-C	1800	600	1.35	0.2	7.9	0	0.49	76	8	16
						1200	1.35	0.15	0.23	0	0.49	70	11	19
						1800	1.35	0.13	0.12	0.1	0.49	79	7	14
20	Vertic Cambisols	Be64-1-2a-461	C	C-C-C	1320	1320	1.12	0.14	0.39	0.1	0.38	42	30	28
21	Vitric Andosols	Vc25-3a-263	B	SIL-L-CL	1500	100	1.43	0.2	307	0.1	0.23	33	35	12
						520	1.27	0.11	4.54	0.1	0.22	23	50	27
						800	1.28	0.11	5.16	0.1	0.22	60	25	15
						1500	1.22	0.11	4.24	0.1	0.22	71	20	9
22	Water Bodies	WATER-6997	D	WATR	25.4	25	1.72	0	260	0.2	0	0	0	0

Appendix K: Weather Generator Statistics for Metehara Station

<i>Parameters</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
TMPMX	31.61	33.17	35.05	35.59	36.60	37.01	33.44	32.46	34.06	33.97	32.45	31.22
TMPNN	14.60	16.19	18.33	19.62	20.18	21.77	20.48	20.11	19.74	16.67	14.78	13.31
TMPSTDMX	2.02	2.72	2.68	2.54	2.13	1.76	2.56	2.23	1.88	1.82	1.76	1.60
TMPSTDMN	4.13	3.72	3.27	2.25	2.05	1.91	1.60	1.32	1.85	3.15	3.38	3.87
PCPMM	11.02	21.78	38.65	46.06	35.13	23.86	129.23	114.43	52.76	23.84	8.94	8.30
PCPSTD	2.52	4.04	5.25	5.56	4.78	2.81	8.07	7.35	4.97	3.77	1.98	2.33
PCPSKW	9.16	7.44	5.99	6.75	8.99	5.61	3.04	3.13	5.06	8.10	9.60	11.01
PR W(1)	0.03	0.05	0.11	0.19	0.16	0.18	0.49	0.49	0.32	0.07	0.04	0.02
PRW(2)	0.45	0.51	0.39	0.42	0.36	0.27	0.54	0.52	0.46	0.50	0.33	0.45
PCPD	1.59	2.47	4.81	7.25	6.09	5.91	15.91	15.78	11.06	3.69	1.69	1.03
RAINHHMX	2.11	3.57	6.41	6.70	5.43	3.54	9.82	9.48	6.61	3.86	1.99	1.69
SOLARAV	41.99	45.18	45.97	45.39	45.66	43.54	39.91	40.73	42.28	43.96	42.81	41.33
DEWPT	0.56	0.55	0.53	0.55	0.52	0.49	0.60	0.65	0.60	0.53	0.53	0.55
WINDAV	1.56	1.72	1.63	1.47	1.40	1.97	2.04	1.71	1.34	1.29	1.33	1.38

Appendix L: Weather Generator Statistics for Addis Ababa Observatory Station

<i>Parameters</i>	<i>Jan</i>	<i>Feb</i>	<i>Mar</i>	<i>Apr</i>	<i>May</i>	<i>Jun</i>	<i>Jul</i>	<i>Aug</i>	<i>Sep</i>	<i>Oct</i>	<i>Nov</i>	<i>Dec</i>
TMPMX	9.02	38.75	2386	10	24.37	25.55	25.90	25.29	25.35	23.69	21.29	21.20
TMPNN	9.09	10.38	11.78	12.55	12.67	11.78	11.62	11.78	11.45	10.47	8.97	8.27
TMPSTDMX	1.55	1.90	2.02	2.10	2.03	2.13	1.71	1.75	1.56	1.48	1.37	1.38
TMPSTDMN	1.98	1.91	1.70	1.26	1.22	1.13	0.95	1.43	1.26	1.68	1.86	1.91
PCPMM	12.78	27.75	54.25	82.97	84.76	147.97	262.69	289.78	186.90	33.93	10.03	9.84
PCPSTD	2.39	3.67	5.99	6.59	6.69	6.83	9.10	9.99	9.55	5.15	2.28	2.97
PCPSKW	8.06	5.11	7.52	4.15	3.90	2.25	1.54	1.92	2.36	8.39	9.57	13.53
PR W(1)	0.04	0.09	0.16	0.25	0.21	0.49	0.64	0.92	0.46	0.09	0.04	0.03
PRW(2)	0.46	0.51	0.54	0.62	0.66	0.79	0.91	0.90	0.78	0.54	0.39	0.39
PCPD	2.19	4.28	7.81	11.81	11.81	20.97	27.13	28.00	20.22	4.97	1.91	1.28
RAINHHMX	2.16	3.87	7.52	8.47	9.09	8.38	10.68	12.93	11.51	6.04	1.87	2.60
SOLARAV	66.31	70.11	68.27	60.03	56.85	45.85	33.45	36.39	45.25	63.76	64.27	63.94
DEWPT	0.49	0.48	0.50	0.55	0.54	0.65	0.75	0.76	0.69	0.52	0.49	0.49
WINDAV	0.64	0.68	0.69	0.65	0.59	0.43	0.37	0.33	0.41	0.64	0.66	0.62

Appendix M: Definition of weather generator parameters

<i>Parameters</i>	<i>Definition</i>
TMPMX	Average maximum air temperature for month in 0C
TMPNN	Average minimum air temperature for month in 0C
TMPSTDMX	Standard deviation for maximum air temperature in month in 0C
TMPSTDMN	Standard deviation for minimum air temperature in month in 0C
PCPMM	Average amount of precipitation falling in month in mm/day
PCPSTD	Standard deviation for daily precipitation in month mm/day
PCPSKW	Skew coefficient for daily precipitation in month.
PR W(1)	Probability of a wet day following a dry day in the month.
PRW(2)	Probability of a wet day following a wet day in the month.
PCPD	Average number of days of precipitation in month in days
RAINHHMX	Maximum 0.5 hour rainfall in entire period of record for month in mm
SOLARAV	Average daily solar radiation in month in MJ/m ² -day
DEWPT	Average dew point temperature in month in 0C
WINDAV	Average wind speed in month in m/sec

Appendix N: Definitions of soil parameter

Soil Code	Definition
HYDGRP	Soil Hydrologic Group
TEXTURE	Texture of soil layer.
SOL_ZMX	Maximum rooting depth of soil profile in mm
NLAYERS	Number of layers in the soil.
SOL_Z	Depth from soil surface to bottom of layer in mm
SOL_BD	Moist bulk density in g/cm ³
SOL_AWC	Available water capacity of the soil layer in mm/mm
SOL_K	Saturated hydraulic conductivity in mm/hr
SOL_ALB	Moist soil albedo.
USLE_K	USLE equation soil erodibility (K) factor.
Clay	Clay content in %
Silt	Silt Content in %
Sand	Sand content in %