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ESTIMATION OF STREAM FLOW AND SEDIMENT YIELD USING HEC-HMS MODEL

(ON RIFT VALLEY BASIN OF GIDABO RIVER, ETHIOPIA)

A THESIS SUBMITTED AND PRESENTED TO;

The School of Graduate Studies of Addis Ababa University in partial fulfillment for the degree of Masters of Science in Civil Engineering under Hydraulics Engineering

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This is to certify that the thesis prepared by Samuel Molla, entitled: Estimation of Stream Flow and Sediment Yield (Case study; Rift Valley Basin of Gidabo River, Ethiopia) and submitted in partial fulfillment of the requirements for the degree of Master of Sciences in Civil and Environmental Engineering (Major in Hydraulic Engineering) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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CERTIFICATION

The undersigned certify that I read the Thesis; Estimation of Stream Flow and Sediment Yield (Case study; Rift Valley Basin of Gidabo River, Ethiopia) and here by recommend for acceptance by the Addis Ababa University in partial fulfilment of the requirements for the degree of Masters of Science.

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DECLARATION AND COPY RIGHT

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DEDICATION

I dedicated this thesis to my beloved brother, **Tena Assab Adigo,** who had not... by now. Brother may God rest your soul always in peace.

ABSTRACT

Stream flow and sediment yield modeling of watersheds is very essential to solve water associated problems, and alleviate reservoirs sedimentation problems caused by the soil erosion of the catchment. This study is intended to estimate the amount of stream flow and sediment yield in Gidabo river catchment, situated in the rift valley basin of Ethiopia with the help of the Soil Moisture Accounting (SMA) model and Modified Universal Soil Loss Equation (MUSLE) found in the HEC-HMS model respectively and also to recommend appropriate sediment yield reduction measures. The catchment land use, land slope, soil and hydro – meteorological data were used to characterize the hydrology of the study area. The catchment and river network of GRB have been delineated and its properties were extracted using the Digital Elevation Model (DEM) of Gidabo basin by using Geographical Information System (GIS). To account for computing runoff volume, direct runoff, base flow and flow routing, Soil Moisture Accounting (SMA), Clark unit hydrograph, Recession and Muskingum-cunge methods were used respectively for representing the hydrological processes of the GRB. The sediment yield of the catchment in this study was estimated by using the calibrated and validated stream flow with the help of Modified Universal Soil Loss Equation of the HEC-HMS model. The land cover and soil map have been used to estimate the impervious area, maximum infiltration rate, surface storage, and MUSLE factors. The HEC-HMS model calibration of this study was done by using the meteorological and hydrological data of the years from 1997 to 2002 and validation of the model was done by using the data of the years from 2003-2006 on a daily basis time step for stream flow and monthly time step for the sediment yield and the performance of the model was from good to very good. The calibration of the HEC-HMS model of this study at the outlet of the watershed (Maesso station) gives the Nash-Sutcliffe Efficiency, NSE =0.67, 0.67 and a coefficient of determination R2 = 0.72, 0.76 and validation test of the model gives NSE =0.69, 0.67 and R2 = 0.79, 0.8 for the estimated stream flow and sediment yield respectively. Based on these performance results, the computed value of both flow and sediment yield shows good agreement with the observed value. Due to lack of observed stream flow from the year 2007, the estimation of the stream flow and sediment yield from 2007 to 2017 was computed by using the parameters found in the calibration and validation period. In this study, the HEC-HMS model simulates the average annual stream flow and average annual sediment yield of 12.64 m3/s and 114,317.17 tons/year for the calibration and validation period of 1997 to 2006, 10 m3/s and 115,124.7 tons per year for the years 2007 to 2017 and 11.32 m3/s and 114,720.93 tons per year for the years 1997 to 2017 respectively at the outlet of the watershed (Maesso station).

Keywords: Continuous modeling, Calibration and Validation, stream flow, sediment yield and HEC-HMS model

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LIST OF ACRONYMS AND ABBREVIATION

DEM	Digital Elevation model
ENS	Efficiency of Nash-Sutcliffe
ET	Evapo-transpiration
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modelling System
HEC-GeoHMS	Hydrologic Engineering Center-Geospatial Hydrologic Modelling System
GIS	Geographic Information System
GRB	Gidabo River Basin
IDW	Inverse Distance Weighting
Km	Kilometres
MoWIE	Ministry of Water Irrigation and Energy
NMA	National Meteorological Agency
NSE	Nash- Sutcliffe efficiency
SMA	Soil Moisture Accounting
SNNPRS	Southern nation’s nationalities and peoples regional state
STM	Sediment transport module

CHAPTER ONE

1. INTRODUCTION AND BACKGROUND

1.1 General introduction

The two most important resources required for agricultural production of any country are soil and water. The net productivity of crops depends on the proper management and utilization of these two resources. Out of the above mentioned resources, water is very important to meet the industrial and urbanization demands, water is very scarce resource for agricultural production in almost all places across the world. To overcome the water related problems, extensive care should be given to the operation and management of reservoirs and watersheds. But in many cases, poor land use planning and land management practices during rapid development have adversely impacted the surface runoff quantities and quality through the reduction of land cover, loss of plant nutrients, deterioration of river water quality and an increase of impervious surface area.

Hydrological and soil data such as the minimum, the mean and maximum flow, annual sediment yield are the essential data for the design of the storage dam, reservoir simulation, flood protection works, irrigation works and intakes head works. A major challenge still remaining is the accurate prediction of the catchment runoff response to rainfall events and sediment yield. Numerous researches have used many methods to simulate, assess, and predict the effects of urbanization on hydrological response of the watersheds. Watershed management implies the judicious use of all land and water resources. Decision support tools can help in better development options for people to manage water, land and labour resources. One viable answer and approach to this challenge is the use of suitable hydrologic models for the efficient management of watersheds and ecosystems (Kishor Choudhari, 2014).

Stream flow, which may be variously referred to as runoff or river discharge or catchment or watershed yield is the total runoff contributed from surface, subsurface and ground water flow at a stream or channel network, which is normally expressed as a volume per unit of time. Surface flow is part of the flow contributed from overland flow before joining to the channel network where as sub surface flow is the flow contribution from soil moisture zone as interflow and ground water, is the water found in the saturated pores of soil and sediment or it is the water occupying all the voids within the a geologic stratum.

Sediment is the fragmented matter, mostly created by physical, chemical and organic weathering of rocks from the earth’s outer layer. Sediment yield is the displacement and accumulation of granular material by flowing water or the total sediment out flow from watershed that includes both bed and suspended materials, which finally causes sedimentation problem of many reservoirs. Sediment yields are directly associated to the erosion of soil of the catchment. Soil erosion is an ordinary process causing soil loss and generating sediment yield from the watershed area still in the lack of human alterations of land use.

A comprehensive knowledge and reliable estimation of stream water inflows, storage, outflows, and sediment yield from the catchment and their relationships is useful for sustainable water resources planning and management i.e., stream morphology, soil and water management planning, for reservoir sedimentation, for proper management to use the excess flow for the dependable supply of water of various water resource projects in a basin and manage the shortage in the time of drought. There are ranges of methods available to estimate the stream flow and sediment yield from watersheds, with observed data or by means of empirical and statistical techniques to estimate stream flow, generally known as hydrological models. Hydrological models are the simplified description of the real-world system which helps to visualize the response of the water systems due changes in meteorological events and land use of the catchment. Long-standing simulation of runoff from a watershed with a properly chosen and calibrated hydrological model helps the water resources assessment and planning for the development of the watershed. The kind of the modeling approach normally depends on the data availability, the purpose, and ease of use. Obtaining accurate and reliable results through a model is a big challenge and appropriate model selection of modeling methods is the viable solution. Modeling requires several input parameters such as topography, vegetation cover, soil characteristics, rainfall characteristics, etc., which are distributed in both time and space. Therefore a distributed rainfall- runoff model is more applicable than a lumped model which differs from lumped model in the use of domain. Dividing the watershed in to various smaller sub-watersheds will provide a semi distributed model by treating each sub basin as a lumped model, joining it with certain river reaches. A semi distributed model framework can be developed in the HEC-GeoHMS interface, an extension of ArcGIS which allows for the easy creation of the basic basin parameters of a hydrologic model based on topographic data. The HEC-HMS can be used for single event simulations or long term continuous simulations.

The HEC-HMS 4.4 which included a new sediment transport module (STM) with simulation components for surface erosion, channel sediment transport, reservoir sediment routing and in-stream sediment routing. The sediment transport module in the HEC-HMS was planned based on the applicable understanding of hydrology, geomorphology, hydraulics, and concepts of surface and sediment transport. Soil erosion is the process of degradation of the top layer of soils by mechanical forces of wind or water. A lot of property and money is lost in Ethiopia due to on and off-site effects such as loss in agricultural productivity, blockage of conveyance of irrigation channel, etc. One of the most important dataset for modeling soil erosion and quantifying the sediment yield is the stream flow. Stream flow data can be obtained from gauges installed in a stream or be simulated / projected using a hydrological model.

This research uses the HEC-GeoHMS model to visualize special information, perform special analysis, file watershed characteristics and define sub-basins and streams. The HEC-HMS 4.4 was used to simulate long term hydrologic and sediment yield in the Gidabo river basin, rift valley basin of Ethiopia. The HEC-HMS model was calibrated based on the observed stream flow and total suspended solid (TSS) data from the Measso gauge station and validated with an alternate time-series representing the toughness of the new sediment transport capabilities.

Due to the complexity of hydrologic cycle, mathematical model and geospatial analysis means are necessary for studying hydrological process and responses to changes of climatic condition and land use. For this reason, to examine the sediment yield of Gidabo dam watershed with respect to the amount of stream flow is crucial for the appropriate and sustainable exploitation of Gidabo dam Irrigation Project. A suitable study of the stream flow and sediment yield of the watershed is important for management of sedimentation and consumption of water source. If stream flow and sediment yield of the catchment are not investigated, the life of Gidabo dam reservoir will be diminished as a result of sedimentation related problems (MoWE, 2010).

This thesis is intended to provide estimation of stream flow for future water resource management of Gidabo catchment and to estimate the sediment yield of Gidabo river catchment. Therefore, to address the above circumstances, watershed management strategies should be provided, to reduce land degradation and to increase the productivity of the watershed area as well as the life span of the Gidabo irrigation dam project.

1.2 Statement of the problem

Before planning any project on water resources in a certain river basin, first it is essential to estimate and evaluate the total available water resource and the sediment yield of that basin. Full utilization of the available water potential is not possible due to the topographical, hydrological, the need for allowing certain amount of water to flow in the river for maintaining the river regime and other constraints.

Gidabo is one of the sub basins of the rift valley lakes basins of Ethiopia with a potential for satisfying the demand of existing and proposed projects on the basin and downstream water users. Better understanding of the basin characteristics is necessary in Gidabo Basin, which is possible with knowing full potential of the available water and land resources and predicting the sediment yield of the basin. Increasing demands for irrigation water combined with changing land use practices, climate change and variability and now a day's an increase in demand for sources of clean water pose significant problem to the water resources of Gidabo.

In Gidabo River Catchment especially along with the major river, enormous socio-economic activities are being carried out and a lot of fresh settlements both rural and urban are coming in to reality and the already available ones are increasing in population size at escalating rate. Due to the expansion of farm lands, production of wood charcoal, production of fire-wood and settlements, most of the river banks of the Gidabo river catchment are cleared (MoWE, 2010). Human settlements, deforestation, and agricultural development in the watershed directly connected to land use change of the catchment. This land use change of the catchment will cause an outcome on the hydrology and sediment yield of the catchment. The Gidabo river catchment experience harsh land degradation and soil erosion due to extensive dry seasons in some parts of the catchment, geological nature and heavy rain, bringing huge amount of sediment in the watershed systems. This land degradation in the watershed results in reduction of reservoir storage capacity and hence leading to shortage of water supply which ultimately causes negative impact on the lives of the community. The final fate of every reservoirs is to turn into full of sediment, the extent of time that this takes depends on the sedimentation rate and how fine the problem is addressed equally during the planning phase and from the time when reservoir sedimentation is happening (Yared Buruk Tedla, 2011).

Since stream flow and sediment yield of the basin are fundamental information that contributes to the basin's sustainable use of the water for various uses and sedimentation reduction in the watershed, it is essential to estimate of stream flow and sediment yield at the watershed of Gidabo.

In the earliest versions of HEC-HMS, modeling of the catchment precipitation-runoff processes with a complete choice of components for meteorology, canopy, surface runoff, channel routing, base flow, reservoirs, and diversions were the meeting points. But in recent times, sediment transport module components have been added in the HEC-HMS model for representing land surface erosion, channel erosion and transport and sediment yield estimation in general.

This study is intended to quantify the stream flow and the increase of sediment yield of the study area river catchment for sustainable water resource, to make appropriate decision to the existing and future socio-economic developments, to develop strategies and recommendations for preventing future aggradations in vicinity of the dam and to check the appropriateness of the HEC-HMS hydrological model simulations in the Gidabo catchment.

1.3 Research questions

This research answers the following research questions:

1. How much stream flow available in the Gidabo River basin?
2. How much sediment yield produced per annum from the Gidabo river basin to the Gidabo watershed outlet?
3. How well can the continuous (SMA) model in HEC-HMS simulates stream flow and sediment yield in the catchment or how the performance of the model is to estimate the stream flow and sediment yield?

1.4 Research objectives

1.4.1 General objective

The general aim of this research is to estimate the stream flow and sediment yield within Gidabo river basin using continuous HEC-HMS model, check the performance of the model and to recommend appropriate sediment reduction measures.

1.4.2 Specific objectives

- To estimate the stream flow of the Gidabo river catchment,
- To estimate the sediment yield in the Gidabo river catchment,
- To assess the appropriate mitigation measures to reduce sediment yield of the watershed,

Expected outcome of the research are as follows:

1. Calibrated hydrological model of Gidabo river catchment,
2. Estimated average yearly stream flow and sediment yield of Gidabo river catchment,
3. Mitigation measures to reduce sediment yield of the river catchment.

1.5 Scope of the study

The extent of this research is restricted to the estimation of stream flow and sediment yield using HEC-HMS model. This research did not consider assessment of stream flow and sediment yield by using another model and in addition, it did not consider the impact of land cover land use modification on the sediment yield. In general, the objective of this research is to estimate the stream flow and sediment yield of the catchment by using Hydrologic Engineering Center Hydrologic Modeling System model and to recommend remedial measures to alleviate the sediment yield in the catchment.

1.6 Organization of the Thesis

This research has been structured in to five chapters. Chapter one describes the introduction, the general and specific objective and the problem of statement of the study. Chapter two describes the different definition of the literatures, significant topics, earlier studies associated to this research. Chapter three describes the location, land use, soil type and the geographical descriptions of the study area, the data collection from various sources and its processing in the model setup and it depicts methodology of the hydrologic model, how the research goes through to achieve its objectives and the how the initial parameters of the model can be selected. Chapter four discusses the results of the HEC-HMS model for the study area and talks about how the model can simulate the stream flow and sediment yield by using different performance evaluation methods and illustrates in graph and table the calibrated and validated outputs of the hydrological HEC-HMS model. It also mentions the limitations and uncertainties encountered in this study. Chapter five of this thesis states the conclusions and recommendations part of the research. And finally some selected input and output data of the model are attached in the final pages of the paper in the Appendix.

CHAPTER TWO

2. LITRATURE REVIEW

2.1 General overview

Hydrology is concerned with study of the motion of the earth's water through the hydrologic cycle, and the transport of constituents such as sediment and pollutants in the water as it flows. A hydrological model is a simplified simulation of the complex hydrological system. Hydrological modeling is one field of scientific activity which has developed the capability of delivering customized solutions through identifying a variety of arrangements or changes within a system to comply with both external and internal highly developed mathematical capabilities and versatile software tools. The precipitation-runoff process is a component of the hydrologic system; therefore, it is a valid approach to develop either 'detailed models' serving a wide range of modeling requirement, or "cost-conscious models" meeting a specific requirement. Since rainfall data is generally in abundance in comparison to runoff data, the attempt has always been to convert rainfall to runoff (Shimelis Behailu, 2004).

Soil loss can be defined as the deletion of the soil matter from its original location, i.e., from its former particular slope or progress. It can also be defined as the disconnection and movement of soil particles on a land escape profile. The total sediment outflow from the catchment during any given time is the sediment yield of that catchment.

The temporal and spatial knowledge on runoff, soil erosion and sediment yield of a catchment can give a useful point of view on the availability of runoff, rate of soil erosion, and soil loss in the watershed. The soil erosion and sediment yield processes of the catchment are affected by the temporal and spatial properties of the input variables which affect them and the land surface controls which include elevation, land cover, soil type and principal geology of the catchment. The major classification of erosion type is by erosive agents of water or wind, which causes the erosion of soil of the catchment. Sheet erosion, rill erosion and gully erosion are the main erosion types of the catchment. The rill and sheet erosion categorization is based on a theory of progressive erosion harshness. Sheet erosion, which is a consistent taking away of soil from the surface, is assumed to be the initial stage of the erosion course of action, and rates of the sheet erosion are assumed to be small. Since erosion becomes progressively more sever, rill erosion is assumed to start in and then the rill erosion develops to gully erosion, which produces profoundly incised streams (Mengistie Abate Beyene, 2017).

2.2 Rainfall runoff processes and Watershed characteristics

As soon as the precipitation reaches to the surface of the earth, the water that comprise of the stream flow reaches the stream channel in several ways. Some part of the water from the precipitation flows over the soil surface as the surface runoff and reaches to the stream channel after the occurrences as runoff. The other part of the runoff infiltrates through the soil surface and flows beneath the surface to the stream which moves slowly than the surface runoff water and contributes to sustained flow of the stream during times of dry period.

When the rain starts falling on pervious areas, there is an initial period during which; the rainfall is intercepted by the buildings, trees, shrubs, and other objects thus preventing from reaching to the earth's surface then the rainfall infiltrates in to the ground of the earth as infiltration. The rainfall finds other ways of countless small and large depressions to fill them at a stage of their overflow level, which is called depression storage.

After storage of depression is filled, the rain intensity exceeds the infiltration capacity of the soil and then the excess rainfall is created. After the demands of the interception, infiltration, depression storage and evapo-transpiration are satisfied, the residual precipitation which is called runoff occurs. Once the excess rainfall occurs, it accumulates to the ground as surface detention, then it flows down the slopes in to small channels as overland flow and then to the large channels which then flows to the watershed out let. Surface runoff occurs as a result of storms having rainfall excess.

The watershed is a collective of media between flux of water, nutrients, energy, etc., occurs. Examples of such media are: the soil formation, the ground water aquifers, the various water bodies, the plants etc. it is exactly the description of the movement of water and nutrients in and between those media that is sought in developing models (Shimelis Behailu, 2004).

2.2.1 Factors affecting stream flow and watershed characteristics

Apart from rainfall characteristics (i.e. rainfall intensity, amount, duration, distribution over the drainage basin, and other meteorological and climatic conditions that affect evapo-transpiration, such as temperature, wind speed, sun shine hours and relative humidity). There are a number of location specific factors which have an immediate effect on the occurrence and quantity of stream flow. The main factors are reviewed below.

2.2.1.1 The Catchment Soil Type

The fundamental functions of soil are as an intermediate that provides a huge number of passageways for runoff. Runoff flow in soil depends on the permanency and size of the pores. The extent of the conduits depends on the degree of aggregation, the size of the soil texture and the arrangements of particles and aggregates. The catchment soil infiltration capacity depends on the porosity of a soil which determines the water storage capacity of the soil and affects the resistance of water to flow into deeper layers. The Porosity of a catchment differs from one soil type to the other. In sandy soils and loose soils the highest infiltration capacities is observed while loamy soils or heavy clay have lesser infiltration capacities. The infiltration capacity of soils depends further more on the moisture content existing in a soil at the commencement of a rainstorm.

2.2.1.2 Catchment Vegetation Type

The amount of precipitation missing to interception storage on the plants depends on the type of plants and their growth stage. Additionally vegetation has the effect the on the infiltration capacity of the soil of the catchment. Solid vegetation in the catchment shields the soil from the precipitation drop effect and minimizes the crusting outcome. In addition, the root systems as well as organic matter in the soil increase the soil porosity thus allowing more water to infiltrate. Vegetation also slows the surface runoff flow predominantly on gentle slopes, giving additional time to evaporate and infiltrate.

2.2.1.3 Slope and Catchment Characteristics

The total volume and peak rate of stream flow increases along with the watershed area. However, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same area. It takes more time for the runoff coming from the most distant part of the watershed to arrive at to the outlet. The volume of runoff per unit of area (runoff efficiency) increases with the diminishing area of the catchment i.e., the bigger the area of the catchment the bigger the time of concentration and the lesser the runoff efficiency. As many studies have shown, the catchments with steep slope plots yield huge amount of runoff than those with catchments of gentle slopes.

2.3 Soil erosion and sediment yield of the catchment

Sediment yield is the quantity of eroded sediment discharged by the stream channel in any selected point over a period of instance, which is the total quantity that stored in to the reservoir located at the downstream boundary of the catchment (Yared Buruk Tedla, 2011). The tones/year is the unit for sediment yield. The specific sediment yield can be described as the yield for every unit of land area (tones/km^2/year). Accurate estimation of it is necessary for planning of reservoirs and manages the sediment yield so that the reservoir can carry out its necessities. Sediment yield can be affected by the slope, geology, climate, drainage density and patterns of human disturbance.

The process of soil erosion includes the removal, movement and subsequent deposition of soils and sediment yield is the detached soil from the soil surface mutually by the precipitation impact and by the shearing force of runoff.

2.3.1 Sediment properties

Sediment is the fragmented substance, mainly created by chemical, physical and organic weathering of rocks from the earth's outer layer with extent from huge boulders to colloidal size fragments and differ in profile from smoothed to sharp.

Once the sediment particles are detached, they are transported either by the wind and/or water or by gravity. In the channel the stream flow erodes the accessible material in the stream bed and/or the banks of the channel until the flow is loaded with as large amount sediment particles as the power of the stream will permit transport. The bed load transport is the transportation of sediment particles by sliding, rolling and saltating and the suspended sediment particles which include the fine silt particles are transported as the suspended load transport.

Sediment transport by the flowing water which is the focus of this study is strongly linked to the surface soil erosion due to the rainfall. The water seeping in to the ground can contribute landslides or surface erosion which may become the main source of sediment from the rivers.

In general the Soil erosion brings sediment transport and then sedimentation which can be described as the continuous cycle of sediment.

The sediment erosion or the sediment yield (in tons per year) depends on the local area: the climatic conditions (rainfall, temperature, wind speed, sunshine hours, and relative humidity), the Soil type, the Land use/land cover and the Watershed surface slope of the catchment.

2.4 Hydrological models description

A hydrological model is the mathematical representation of the flow of water and its constituents on the land surface or subsurface environment. The catchment hydrologic models have been developed for many different reasons and therefore have many diverse forms. But, they are commonly planned to meet up one of the following aims.

1. One objective of watershed modelling is to gain a better understanding of the hydrologic phenomenon functioning in a watershed and how variations in the watershed may affect these phenomenon or in general assessment of the watershed;
2. Another objective of catchment modelling is the generation of synthetic sequences of hydrologic data for facility design;
3. For prediction of flood and estimation of stream flow quantities, flow rates and sediment yield for a given watershed.

Typical hydrologic model inputs are topography, soil characteristics, land cover, land use, meteorological data, and suspended load/pollutants. Model out puts vary from predictions of peak discharges or discharges or total volumes of flood flow (stream flow, subsurface flow/ ground water recharge evapo-transpiration, pollutants), sediment yield to the complete specifications of the distribution of flow over time, either for individual storm events in event models or for continuous sequences of flows in a continuous or sequential models (Chong-yu Xu, 2002).

2.4.1 Hydrological Models of a stream flow and sediment yield

A hydrological model is the simplified representation of a complex process of the real world system which considers the hydrologic cycle and it is the quantitative expression of observing, analyzing or predicting a process by simulating it through the transformation of rainfall to runoff in catchments. The landscape gets affected in a numerous ways while the runoff flows above the land surface and all the way through the stream channels. The bed material caused by the shallow surface flow and steep headwater streams and the eroded surface soil can be passed by the stream flow to lower parts of the watershed. Therefore, erosion and sediment transport need to address as it leads to a number of problems which can be evaluated in conjunction with hydrologic simulation. Also, a good calibrated and validated model can be used for hydrologic prediction and future sediment load estimation.

The most commonly used hydrological modeling tools for watershed analysis and stream flow estimation, are SWAT, HEC-HMS and MIKE-SHE and at the same time they have surface erosion computing component which basically measures erosion due to rainfall or surface runoff by using USLE or MSULE equations. Both SWAT and HEC-HMS have sediment routing component which basically represents sediment erosion and deposition within rivers. HEC-HMS has Soil Moisture Accounting algorithm which is theoretically more applicable for simulating continuous rainfall-runoff processes and also taken as a tool to develop a hydrological and surface erosion and sediment routing model for the study area of Gidabo river basin.

2.4.2 Hydrological model selection

Which model to be used for appropriate modeling of any research depends on;

1. The time scales we are working at;
2. The hydrologic quantity/ the required output of the model we are trying to obtain;
3. The availability of input data do we have for the watershed;
4. The availability and cost of the model.

Model selection determines what questions is need to be answered and what information is required, and in model selection of any project; the simplest method that can provide the answer to our questions, the simplest method that will yield adequate accuracy, a model that fits the problem, the assumptions underlying the model used, are the important questions and items which should be considered first.

For this research Arc-GIS which is used as the platform for generating basin models using the interfacing extension of HEC-GeoHMS and the HEC-HMS model for estimation of stream flow and sediment yield was selected because the HEC-GeoHMS and HEC-HMS are free of charges, easily accessible and have been widely used in many researches and to check the performance HEC-HMS model for the estimation of sediment yield, since it was not used for estimation of sediment yield in Ethiopia until the late time. In general based on the budget allocated to this research, the availability of the required data and the time constraint HEC- HMS model were used for this research.

Regardless of the diverse modeling activities that are experienced in the basin, the HEC-HMS model for estimation of the stream flow and sediment yield was not tested, calibrated and validated in Gidabo river catchment and also the surrounding river catchments. For that reason, the purpose of this research were; to develop the precipitation-runoff model, to assess the stream flow potential of the watershed, to estimate the sediment yield of the river watershed, to calibrate and validate the HEC-HMS model and use the analogous calibrated values for upcoming hydrological studies in the nearby catchments by using HEC-HMS model. .

2.5 Description of HEC-HMS hydrological model

2.5.1 History of HEC-HMS model

The application of rainfall-runoff model HEC-HMS, developed by the hydrologic Engineering Center, is the earliest research and engineering planning model used by a science institution, government organization or engineering corporation. The program is generalized modeling system capable of representing many different watersheds. The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS is a computer program designed to simulate the Precipitation- runoff of dendritic watershed (US Army corps of Engineers, 2013)). Previously, HEC-HMS was paying attention on modeling rainfall-runoff processes but currently starting from the release of HEC-HMS version 4.0 in 2013 the combination of Arc-GIS with HEC Geo-HMS for watershed development and HEC HMS for watershed sediment yield analysis proved to be an effective method for approximating the sediment yield of any given watershed.

HEC-HMS is the semi-distributed deterministic model which means that the parameters of the model are to some extent acceptable to fluctuate in space by separating the sub-basin in to minor sub-basins, physically based model which means the scope of the physical modeling occurrence, movement, distribution and storage of water and their variability are within space and time. HEC-HMS requires the availability of data but less demanding on input data than the distributed models and uses conservation of mass (continuity equation) and conservation of momentum (momentum equation) governing channel flow equations of fundamental physics laws.

Equation of continuity; $$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} - q = 0 \qquad (2.1)$$

Momentum equation; $$\frac{\partial Q}{A\partial t} + \frac{\partial}{A\partial x}\left(\frac{Q^2}{A}\right) = g(S_0 - S_f) - g\frac{\partial h}{\partial x} \qquad (2.2)$$

This shows the local acceleration term, the convective acceleration term, the pressure force term, the gravity force term and the friction force term respectively used in the above equation.

Where q-lateral inflow; Q-discharge in the channel; A-area of flow in the channel; S_o-bed slope; h-depth of flow; g-acceleration due to gravity and S_f-friction slope of channel.

2.5.2 Capabilities of HEC-HMS model

The HEC-HMS model is theoretically semi-distributed and physically based model intended to create rainfall-runoff processes in an extensive range of geographic areas, from diminutive urban and natural catchment runoffs to huge river basin water supplies and runoff hydrology for solving the largest potential range of problems. The HEC-HMS model manipulates split models to characterize every section of the runoff processes, including models that calculate runoff volume, models of base flow, models of direct runoff and model of channel routing. Each one model simulation combines a basin model, meteorological model and control specifications with simulation options to attain results. HEC-HMS is competent of performing both event and continuous hydrologic simulations of catchments'.

HEC-HMS is used in combination with the Arc-GIS and HEC-GeoHMS for the simulation of stream flow and sediment yield of the catchment. Arc-GIS is a computer program used as the platform for generating basin models whereas the HEC-GeoHMS is an interfacing tool used to connect the results of GIS to HEC-HMS model. It is a geospatial hydrology toolkit in Arc-GIS to generate hydrologic inputs that are capable and straightforwardly used with HEC-HMS. It as well allows visualizing the spatial information, export and files catchment physical characteristics from the Digital Elevation Model of the catchment and GIS data, delineate sub basins, perform spatial analyst and streams to create hydrologic parameters and in addition it constructs inputs to hydrologic models and support with information preparation.

The HEC-GeoHMS develops the catchment basin model files, background map files, meteorological model files and grid cell parameter files which can be used by the HEC-HMS to develop a hydrological model. HEC-GeoHMS can also generate tables containing physical characteristics of streams and watersheds. With regards to hydrologic parameter estimation, HEC-GeoHMS contains tools to assist the user in estimating initial values of some hydrologic parameters (US Army corps of Engineers, 2013).

After the processing and generation of out puts of the river catchment using the HEC-Geo HMS, the Hydrologic Modeling System (HEC-HMS) simulates the hydrologic cycle of the precipitation, evapo-transpiration, infiltration, surface runoff and base flow of the watershed by describing its meteorological and physical properties. Its primary functions are quantifying rainfall losses in to the soil (computing rainfall excess), converting excess rainfall in to runoff, computing base flows, routing flows and also estimating sediment yield of the catchment.

2.5.3 Surface Runoff Model in HEC-HMS

Extensive choices of mathematical models for every hydrological component that theoretically correspond to catchment properties are included in the program. The program uses separate model to represent each component of the runoff process like model to compute runoff volume, model direct runoff /base flow/channel flow and also different models to account for the collective losses. Subsequently the HEC-HMS model calculates stream flow volume through subtracting the storage infiltration, interception, evaporation etc. losses from precipitation and HEC-HMS 4.4 was used during this project.

HEC-HMS divides the catchment in to subordinate basins. each one sub-basin is linked through a junction in a channel. HEC-HMS models the direct runoff by implicitly combines the near surface flow and overland flow. It does not include the detailed model of interflow or flow in the ground flow aquifer, instead representing only the combined outflow as base flow. All the models included in the HEC-HMS are deterministic. It uses a separate model to represent every section of the runoff process including; models of direct runoff i.e., overland flow and interflow, models of runoff volume, models of base flow and models of channel flow.

In HEC-HMS model, the hydrological procedure of changing rainfall in to runoff has been represented by four processes: loss, transform, base flow and channel flow. These processes are described in the following section:

2.5.3.1 Computing the runoff volumes or loss method with the HEC-HMS model

This model calculates the runoff amount of the watershed by computing the losses all the way through interception, surface storage, infiltration, evaporation, transpiration and followed by subtracting it from the precipitation at every moment footstep. The HEC-HMS model provides five choices for computing the losses and many of the models are event models which simulate behavior of a hydrologic system during the precipitation event, and to do so, they require specification of all conditions at the start of the event. The other way is a continuous model which is a model that can simulate together the wet and dry weather manners.

In this project, Soil Moisture Accounting (SMA), which is a continuous model, was used in the Gidabo river catchment. Soil moisture accounting (SMA) model is an empirical model in HEC-HMS model which has the performance of long time simulation of hydrologic processes that occurs over time in a watershed. It considers for both dry and wet weather property and it computes water transport and storage all the way through both surface and subsurface layers.

The model simulates the movement of water through and storage of water on; vegetation, the soil surface, in the soil outline, and in the groundwater layers. The flow components incorporated in this model are precipitation, evapo-transpiration and stream flow on the surface, infiltration and percolation in the subsurface layer.

HEC-HMS includes the continuous model that considers both dry and wet weather conditions and this model computes the movement of the runoff through and storage of precipitation on vegetation, in the soil profile, on the soil surface and in the ground water layers. Given the precipitation and potential evapo-transpiration (ET), the model computes basin stream flow, losses due to evapo-transpiration and profound percolation over the whole catchment.

The SMA algorithm is a continuous, semi distributed and empirical loss method available within HEC-HMS simulates flow into, away, and among the storage volumes. It consists of series of different layers for the movement of water within the land based components. This algorithm allows HEC-HMS to compute the rainfall excess, groundwater flow, and deep percolation; and then updates the moisture content within different storages during each time step. The one-dimensional SMA loss model allows the water to flow in only one direction during each time step. This introduces errors in the model at larger spatial scales. Complex behavior of flow due to heterogeneity in landscape and soil properties cannot be well accounted by a one-dimensional hydrologic model. An improvement over this error in HEC-HMS is achieved by including separate storage compartments and semi-distributed modeling capabilities.

The SMA model computes flow in to, out from and among the storage volumes in the type of;

1. **Precipitation:** Precipitation is a gift in to the system storages which initially used as an input to the canopy interception storage. The surplus amount of precipitation is then available for infiltration after the canopy interception storage is filled.
2. **Infiltration:** the infiltration is the water movement which reaches to the soil profile starting from the ground surface and this available water for infiltration in the instant time step comes from precipitation that drops from the canopy interception and the water already in the surface storage space. The amount of infiltration within the time interval is related the amount of water accessible for infiltration, the condition of the soil profile and the highest infiltration rate based on soil texture précised by the model customer.
3. **Percolation:** it is the movement of runoff down from the soil profile, via the groundwater layers, and into a profound aquifer. In the soil moisture accounting model, the percolation rate among the groundwater layer i.e., the two groundwater layers and the soil-profile storage depends on the amount of volume in the supply and getting layers. When the supply layer is nearly filled and the receiving layer is nearly zero, the rate of percolation becomes larger. Conversely, when the in receipt of layer is nearly full, and the source layer is nearly empty, the percolation rate becomes diminish.
4. **Surface runoff and groundwater flow:** the surface runoff is the runoff beyond the infiltration rate which overflows on the surface storage space. This amount of runoff is called direct runoff and this

runoff is computed with the HEC-HMS model. Groundwater flow is the total of the amount of subsurface flow from all groundwater layers at the finishing time period.

5. **Evapotranspiration (ET):** evapo-transpiration is the remaining runoff from the canopy interception, surface depression, and soil profile storages which is exploited as losses. The potential evapo-transpiration amount is fulfilled primarily from canopy interception, and then from the surface interception, and finally from the soil profile. The potential evapo-transpiration within the soil profile is originally fulfilled from the upper zone of and then from the tension zone of the soil moisture accounting. If potential evapo-transpiration is not totally fulfilled from the original storage in a time gap, the unfulfilled potential evapo-transpiration amount is full from the subsequent accessible storage. While evapo-transpiration is from interception storage, surface storage, or the upper zone of the soil profile, real evapo-transpiration is the same as to the potential evapo-transpiration. When potential evapo-transpiration is drained from the tension zone, the actual evapo-transpiration is a proportion of the potential evapo-transpiration.

The precipitation occurring during a storm event is intercepted by vegetation, falls into a water body or on the land surface. The part of precipitation intercepted by vegetation is removed by the process of evapo-transpiration, whereas, the precipitation falling on the land surface is either lost through evaporation and infiltration or gets converted into the overland flow to reach out to stream channels. The remaining small portion of rainfall falling on a water body is lost through evaporation or reaches the main stream channel. The portion of infiltrated precipitation is either discharged comparatively quicker through the interflow or gets percolated down to the groundwater and then reaches the stream channel through the slow process of base flow. Precipitation contributes first to canopy-interception storage.

Precipitation in excess of canopy-interception storage, combined with water already in surface storage, is available for infiltration. If the volume available is greater than the available soil storage, or if the calculated potential infiltration rate is not sufficient to deplete this volume in the determined time step, the excess goes to surface-depression storage. When surface-depression storage is full, any excess is surface runoff. The infiltrated runoff enters soil storage, with the tension zone satisfying initially. The runoff in the soil profile percolates to the primary subsurface layer. Then any remaining water from the groundwater layer one may percolate to the groundwater layer two.

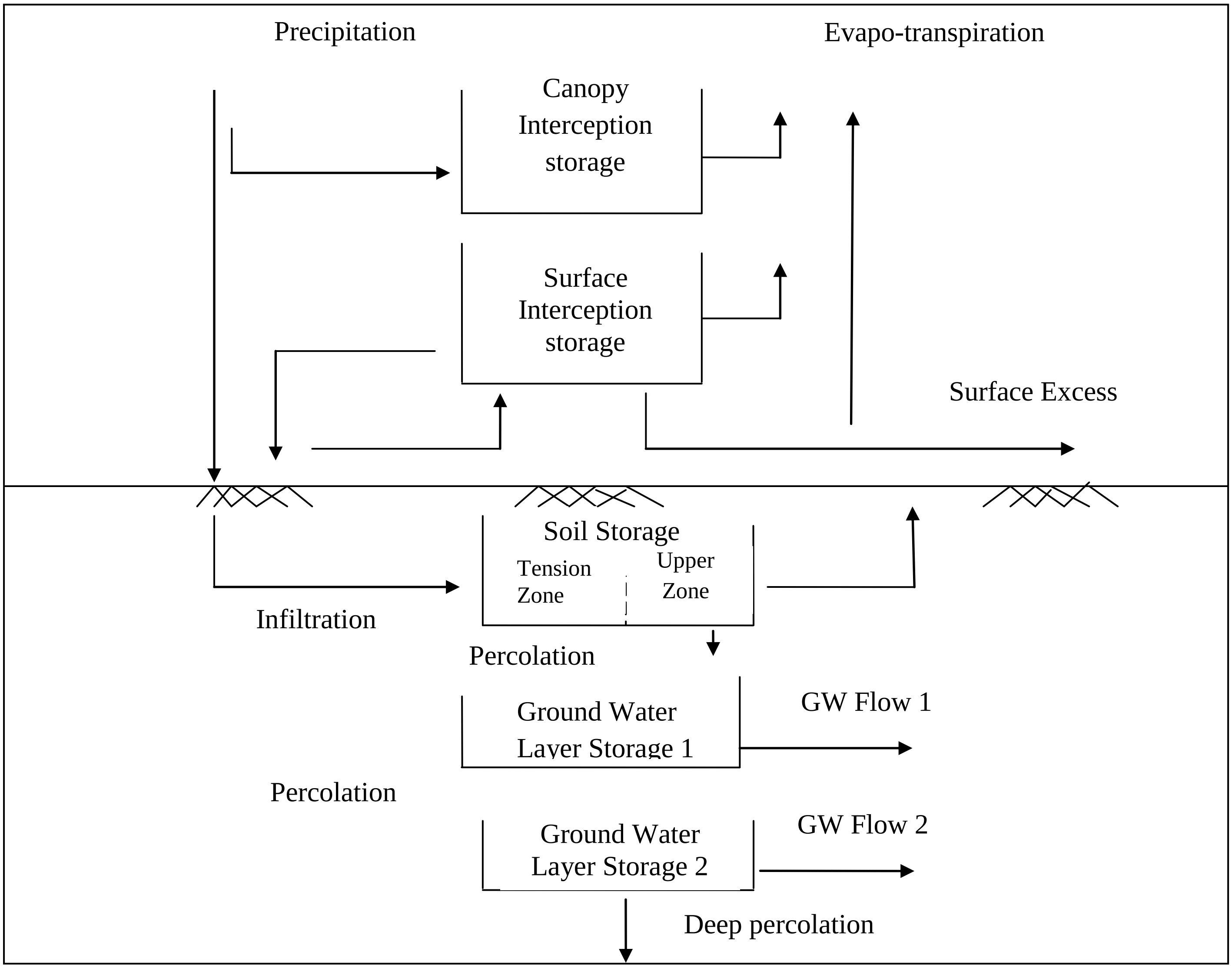


Figure 2. 1 Soil Moisture Accounting losses module from HEC- HMS 4.3 user manual

The Canopy-interception storage shown in the figure above represents the precipitation that is captured on trees, grasses, shrubs and do not arrive at the soil surface.

Precipitation which first fills the canopy storage and after this storage become available for filling other storage volumes is the only inflow in to canopy interception storage layer and the water in this layer is held until it is removed by evaporation.

The Surface-interception storage in the diagram above in figure 2.1 is the total water held in the shallow surface depressions which comes from the precipitation not captured by the canopy interception and in excess of the infiltration rate and finally it is removed by infiltration and evapo-transpiration. Once the volume of the surface interception is exceeded the excess water is added to the surface runoff.

The Soil-Profile storage in the above figure represents the water stored in the top layer of the soil. In this layer the inflow is the infiltration from the surface and the outflow is the percolation to the ground water layer and evapo-transpiration. The upper zone in this layer as shown in the figure above is the section of soil profile that will lose runoff to evapo-transpiration and /or percolation whereas the tension zone (water attached to the soil particles) is the region that will lose runoff to evapo-transpiration only. The Groundwater Storage layer in the soil moisture accounting represents horizontal interflow processes and the losses from subsurface layer are from the groundwater flow or percolation from one layer to the other. The percolation from the ground layer 2 to deep percolation i.e. aquifer flow is not modeled in the SMA.

2.5.3.2 Modelling direct runoff or transform method with the HEC-HMS model

In HEC-HMS different models are used to simulate the development of direct runoff from the excess precipitation on a catchment as alteration of precipitation excess into point runoff. The user-specified, Clark, Mod -Clark, Kinematic Wave, Snyder and the Soil conservation service unit hydrographs are the most common unit hydrographs for the direct runoff computation in HEC- HMS model.

The transform or the Conversion method is an approach for estimating direct runoff at the outlet of catchment from the surplus precipitation falling on it based on the ideology of unit hydrograph. Unit hydrograph is the runoff hydrograph created from excess precipitation of unit depth happening over the catchment for the transformation of excess precipitation to runoff. The principles of the unit hydrograph are;

1. Excess rainfall and runoff formed are directly relative to each other,
2. Excess rainfall is dispersed evenly with respect to time and space over the catchment area and,
3. The runoff formed from the specified excess precipitation is autonomous of time of occurrence and precedent moisture contented.

A unit hydrographs are commonly used to predict peak discharge rates and the pattern of that discharge over time using the runoff produced during the precipitation event. Clark unit hydrograph method routes the incremental runoff from a watershed through a linear reservoir and translates the data into hydrograph ordinates. Clark's method can be applied to a wide range of watershed areas. The input parameters are area, A and time of concentration, tc. These parameters are used to section the watershed along its primary watercourse into subareas containing equal travel times. The translated flows are then routed through storage that is assumed to be at the outflow location and it offers the ability to make adjustments for changes in drainage characteristics without requiring a complete reworking of the problem.

2.5.3.3 Modelling base flow in HEC-HMS model

The sub-surfaces processes estimations of the HEC-HMS model are performed by the base flow method contained in the sub-basin. The most commonly used models in the process of base flow simulation in HEC-HMS model are; bounded recession, constant monthly, linear reservoir, nonlinear Boussinesq and recession method. But for this study, the Recession model is used with the soil moisture accounting model. The recession has the ability to automatically reset after each storm event and consequently used for continuous simulations.

The initial base flow of the sub-basin at the beginning of the simulation must be specified which is estimated from the observed stream flow data of the out let of the catchment. The recession constant in the recession method describes the rate at which the base flow recedes between storm events and is defined as the ratio of the base flow at the current time and to the base flow one day earlier. The base flow resets when the current flow divided by the peak flow falls to the specified value and it is most excellent calibrated with the measures reliable with those used to calibrate the HEC-HMS model.

2.5.3.4 Modelling Channel flow in the HEC-HMS model

Channel flow routing is a process to find out the flow hydrograph at the downstream of a watershed from the known hydrograph at the upstream. When the hydrograph moves from upstream to the downstream, it attenuates or gets delayed. Channel routing accounts for the flow hydrograph as the flood waves passes downstream and this helps for accounting for storages and studying the attenuation of flood peaks.

Channel routing uses a simple finite difference approximation of the continuity formula.

$$(I_{t-1}+I_t)/2+ (O_t - O_{t-1})/2 = (S_t - S_{t-1})/\Delta t \qquad (2.5)$$

Where It_{-1} and I_t are the inflow, O_{t-1} and O_t are the outflow and $St_{-1}$and St, are the storage at time t-1 and t respectively.

There are different routing methods which uses a hydrologic routing methodology as compared to a hydraulic method that uses the complete unsteady flow equations. The Kinematic wave routing, the Lag routing, the Lag and K routing, the Modified puls routing, the Muskingum routing, the Muskingum-cunge routing and the Normal depth routing are the most common routing methodology in the HEC-HMS model.

For sediment yield estimation in the reach, it is necessary to represent the river network like natural channels and for this; Muskingum-cunge model can give a better calibration of sediment load. The Muskingum-Cunge method, which was selected for this study is an advanced use of the Muskingum method when Cunge explained how the coefficients K and X could be related to the hydraulic properties of a simplified prismatic channel. It is based on the combination of the conservation of mass and the diffusion representation of the conservation of momentum (Center, 2018).

The Muskingum-Cunge routing technique is a straightforward approximate technique to estimate the outflow hydrograph at the downstream part of the channel reach from the inflow hydrograph at the upstream part of the channel. It is an easy hydrological runoff routing method used among the numerous models used for runoff routing in streams of natural channels, and it has been comprehensively functional in watercourse engineering practices.

2.5.4 Soil erosion and Sediment yield routing model in HEC-HMS

The land is affected in several ways when the runoff flows over the catchment surface and through river channels. The surface runoff flood erodes the land and carries the soil over land to the rivers and sharp head Water Rivers comprise high stream flow rate which causes to the wearing way of the river bed material. These eroded surface materials and bed soils are transported to the river flow to the reaches of the catchment and the sediment yield is usually collected in the lower reaches where the flow rate becomes lower which results in a number of problems to the reservoirs in the watershed.

In HEC-HMS model, the movement of sediment in the catchment can be incorporated as part of the hydrology of the basin model and this erosion and sediment transport component is an optional component in the basin model and is accessible when the features are activated for the basin model since the component features are deactivated by default so that the data entry tools for sediment are not visible in the program interface (Center, 2018). The sub-basin elements of the incorporated in the HEC-HMS model includes the surface erosion and wash-off where as the erosion, deposition and sediment transport are included in the elements of the reaches of the HEC-HMS model.

According to HEC-HMS 4.3 manual the erosion and sediment transport modeling in HEC-HMS requires a number of properties to be specified which are applied to all elements in the basin model. The transport potential specifies how the sediment carrying capacity of the stream flow will be calculated for non-cohesive soils and many methods are developed for a particular sediment grain-size distribution and environmental conditions.

The erosion of the catchment results from the different physical processes which can be described as; The raindrops, which break apart the top layer of the soil→ erosion of surface soil→ movement of the dislodging soil particles with the overland flow and the total soil erosion is associated to the precipitation rate, slope of the land surface and the surface condition.

2.5.4.1 Soil Erosion method

In this study area, the soil erosion method which estimates the full amount sediment load transported away of the catchment to the outlet used is the Modified Universal Soil Loss technique which is adapted from the original Universal Soil Loss Equation which was based on rainfall intensity. There is small surface runoff and small associated surface erosion with high infiltration and vice versa. The modification to the original USLE equation changed the formulated to calculate the erosion from surface runoff instead of precipitation and other components remain the same.

$$\text{Sediment yield} = 95\times(Q_{sur}\times q_{peak})^{0.56}\ K\times LS\times C\times P \text{ (fps unit)} \quad (2.6)$$

$$\text{Sediment yield} = 11.8\times(Q_{sur}\times q_{peak})^{0.56}\times K\times LS\times C\times P \text{ (metric unit)} \quad (2.7)$$

Where, the sediment yield for a given event is in (tons), $Q_{sur\ is}$ the surface runoff amount (ft^3 or m^3/s), q_{peak} is the peak runoff amount (ft^3 or m^3/s), K is the catchment soil erodibility factor, C is the catchment cover and land management factor, LS is the Topographic factor of the catchment, and P is the Practice factor which are described in detail below and the equation of 2.7 i.e., the metric unit system was used in this research.

1. Erodibility Factor (K): is a function of the catchment soil texture, soil organic matter content, soil structure, and soil permeability which describes the difficulty of eroding the soil ranging from 0.75 for silt and clayey loam soils to 0.05 for unconsolidated loamy sand and it describes the difficulty of the eroding soil.
2. Topographic Factor (LS): it describes the susceptibility of soil erosion due to length and slope ranging from 0.1 for short, flat slopes to 10 for long, steep slopes and long slopes have more erosion than short slopes.

3. Practice Factor (p): it describes the result of specific soil conservation practices which includes strip cropping, contouring, terracing for agricultural practices and silt fence, settling basins and hydro seeding for urban practices and it is usually difficult to establish ranges for it.
4. Cover and Land management Factor (C): it describes the pressure of plant canopy on surface erosion which taken 1 for bare ground (most susceptible to erosion), 0.1 for fully mulched or covered soils and 0.0001 for forest soils with a well developed soil.
5. The threshold in the MUSLE equation is used to set the lower limit of runoff events that cause surface erosion and the flow with a lesser amount of the threshold will not cause surface erosion. The exponent of the MUSLE equation is used to allocate the sediment yield in to a time series sedigraph (Center, 2018).

2.5.4.2 Soil Erosion transport potential method

The sediment transport capability of the runoff can be computed from the runoff parameters and sediment behaviours. If the Sediment transport ability of the runoff is greater than the available sediment in stream flow then, erosion from stream bed occurs and if the sediment transport capacity of the runoff is less than the available sediment in stream flow, deposition to the reach bed is occurred.

The reach bed is represented by the upper layer which represents the top of the stream bed which actively interacts with the flow field and responds quickly to changes in flow rate and the lower layer which represents the underlying substrate of the reach and long term processes and is linked to the upper layer with a simple bed mixing algorithm.

There are different methods available in the HEC-HMS model to estimate the sediment transport potential of the river. But the Engelund Hansen equation has been found as prediction formulae having a high level of accuracy for this study.

The generalized form of Engelund Hansen Equation:

$$G = K\left((0.05*W*V^{2}*h^{1.5}*S^{1.5})/((s-1)^{2}*D*\sqrt{g})\right) \tag{2.8}$$

Where; G is the volumetric sediment transport rate (m3/s), K is the calibration coefficient (1 for standard equation), W is the width of flow (m), V is the water velocity (m/s), h is the runoff depth (m), S is the runoff surface slope (m/m), s is the specific gravity of sediment (dimensionless), and D is the sediment diameter (mm) and g = acceleration due to gravity (m/s2).

2.5.4.3 Sediment routing method

The methods that are available in the HEC-HMS model for sediment yield method for reach includes; Fischer's Dispersion, Linear Reservoir, Uniform Equilibrium and Volume Ratio.

The volume ratio used for this study uses the conceptual approach to associate the transport of sediment to the movement of stream flow in the reach. The sediment from upstream elements is supplemented to the sediment which is previously available in the reach for each time interval, the erosion or the deposition of sediment is computed for every grain size to find out the accessible sediment for routing. The percentage of accessible sediment that leaves the reach in every time gap is supposed to be equivalent to the portion of stream flow that goes out from the reach during that matching interval and the entire grain sizes are transported in the course of the reach at the equivalent velocity, although erosion and deposition are estimated independently for all grain size.

The first bed curve describes the allocation of the bed sediment by means of the grain size at the start of the simulation of the model. Erosion Limit or Deposition Limit is optional. Bed width which is used in calculating the amount of the lower and upper layers of the bed model and it should be typical of the reach. Field survey may provide more accuracy of the model. Bed depth has to be representative of the total depth of the lower and upper layers of the bed. It represents the upper limit depth of integrated over extremely extended time periods. Active bed factor is used to calculate the depth of the upper layer of the bed model. At each time interval, upper layer depth is computed as the d90 of the upper layer, multiplied by the factor (Shammi Haque, 2018).

2.6 Review of HEC-HMS model applications

The HEC-HMS model is the most commonly used catchment model to set up the hydrologic model system and simulate rainfall-runoff process. Use of the hydrologic model as the parameter depending on rainfall characteristics and general ground is regarded as the independent variable to establish the relationship between model parameters, rainfall characteristics and geological factors (Chang, 2009).

Several studies have been conducted using the HEC-HMS model in different regions under different soil and climatic conditions. A continuous soil moisture accounting (SMA) was used in the HEC-HMS model to estimate the stream flow in the vamsadhara river basin in India (Singh, 2015). The effect of climate change and land use changes on sediment load for the Brahmaputra river basin using HEC-HMS was done by (Shammi Haque, 2018).

HEC-HMS model has been also used to simulate rainfall-runoff process for flood forecasting and sediment yield in different regions of the world (Afra Dafe Jaferi, 2016); (Attikora, 2019); (Bennett, 1988); (Barik, june 2017); (D.Roy, 2013); (Jang Pak, 2008); (Iliasse Khaddor, March, 2015), (Z. Yusop, 2007). According to (Pak, Matthew Fleming, Scharffenberg, Gibson, & Brauer, 2015) the HEC-HMS model was evaluated independently through calibration and validation by comparison to SWAT and HSPF models of the same watershed and results indicated that HEC-HMS effectively predicts sediment yield rates for sub-basins, long term aggradations and degradation trends for reaches and sediment trap efficiency rates for reservoirs.

It was also used for watershed management in different parts of Ethiopia. The model was found accurate spatially and temporally predicting watershed response in event and continuous simulations as well as simulating various scenarios in flood forecasting and early warnings.

The HEC-HMS model has grown to be incredibly well-liked and used in several hydrological researches due to its capability in the simulation of runoff both in longtime and short events, its use of familiar methods and its straightforwardness to operate. The HEC-HMS developed Hydrographs either directly or in combination with other software's are used for studies of availability of water, urban drainage, impact of future urbanization , reduction of flood damage, stream flow forecasting, regulation of the floodplain and systems operation. Even though the HEC-HMS model has been experienced and calibrated in a worldwide level, small attempt has been made in the Ethiopian catchments context.

The Gidabo river catchment, which has area coverage of 3245.67 km2, has wide-ranging farming practices and has been badly affected by flood problems and land degradation. As a result, precise estimation of the total amount of stream flow and sediment yield from the continuous rainfall events is seriously essential to put into action the suitable water and soil conservation, flood protection and erosion control measures in time. In spite of the diverse modeling activities that are experienced in the river catchment, the HEC-HMS model was not experienced, calibrated, and validated in the Gidabo River Catchment. For that reason, the aim of this research were: To estimate the stream flow and sediment yield of the watershed; and to calibrate and validate the HEC-HMS model and use the analogous calibrated values for upcoming hydrological studies in related watersheds contained by the basin and the in close proximity of the basin.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 The study area description

3.1.1 The study area Location

The study area Gidabo river catchment is situated in the Rift Valley Lakes Basin found both in the administrative Regions of Southern Nations Nationalities and people's Regional State (SNNPRS) and Oromiya National Regional State, the southern part of Ethiopia. To be more exact, it falls in the Abaya area of Dale region of Sidama zone of SNNPRS (close to Dilla city to east of Abaya Lake) and Borena zone of Oromiya region. The Gidabo River catchment covers a watershed area of about 3245.67 km^2 up to its meeting with the Abaya Lake. The catchment lies in the region involving 6°09' and 7° N Latitude and 37° 50' and 38°38'E Longitude and at a mean elevation of 1190 m a.m.s.l. The Lower component of the river catchment which largely comprises of swamp and delta area is sheltered with elevated grasses. However, the middle part of the river watershed is in use with little and spread grasses and bushes. The upper part of the river catchment is covered with thick bushes and shrubs (MoWE, 2010). The geographic location of the Rift Valley Basin is highlighted in gray in the Ethiopian map belowin figure 3.1.

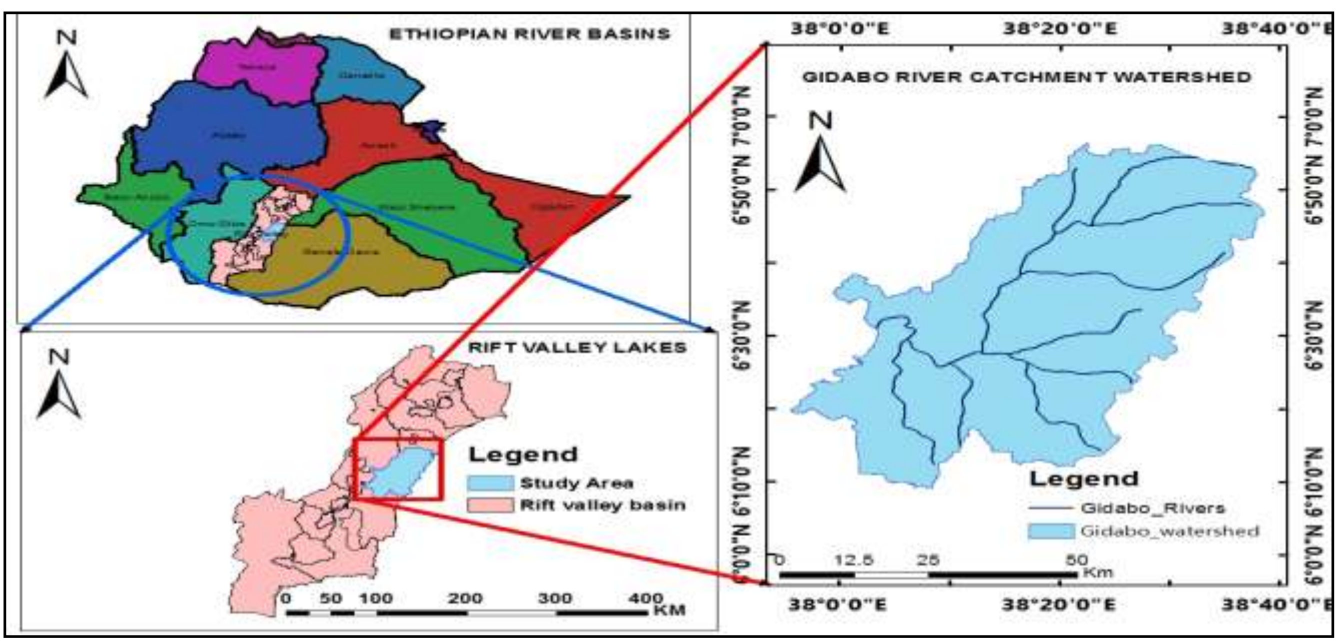


Figure 3. 1 Location map of the study area; Ethiopian river basins, Rift Valley Basin and Gidabo River Catchment

3.1.2 Topography of the study area

The landscape of the river catchment can be broadly grouped in to three categories. These are the huge eastern escarpment of the catchment, the edge of Eastern high terrain and the catchment floor, with huge variety of elevation divergence from 1146 m a.s.l. at Abaya Lake in the west to about 1533 m a.s.l.in the east of north. This huge variety of elevation is coming from the delayed tertiary rifting doings and erosion processes (MoWE, 2010). The floor of the catchment is created by ignimbrites which are poured out with the cracks opened following the creation of the Gidabo catchment and the major physiographic units in the catchment are valleys, undulating plains, steep stream banks and major escarpment at the eastern part of the Gidabo catchment (MoWE, 2010).

3.1.3 The study area climatic condition

The long-established climate classification of Ethiopia is based on the temperature and altitude and the country's climate zones are cold climate at more than 3000 m altitude (Wurch), temperature like climate highland with 2500 to 3000 m altitude (Dega), warm climate with 1500 to 2500 m altitude (Woina Dega), hot and dry type, smaller than 1500m in altitude (Kolla), and hot and hyper arid type climate (Bereha) (NMSA, 2001). The study area falls within the traditional Kola agro-climatic zone, which can be classified as semi-arid climate. The rainfall of the catchment is characterized by the bimodal pattern with the main rainy season in between April to May and from September to October season. These two peaks of rainy season are divided by the comparatively small rainy season in July and august. The average annual rainfall recorded was 1121.05 mm with minimum monthly rainfall of 28.85mm in February and maximum monthly rainfall of 170.53 mm in May.

According to the analysis of the recorded temperature Gidabo river basin stations in this study, the average monthly temperature at the watershed is in the range of 10 c^0 to 30 c^0 and the average daily temperature may reach 36 to 40 c0 with the maximum average temperature of the month of February and March and the minimum temperature on July.

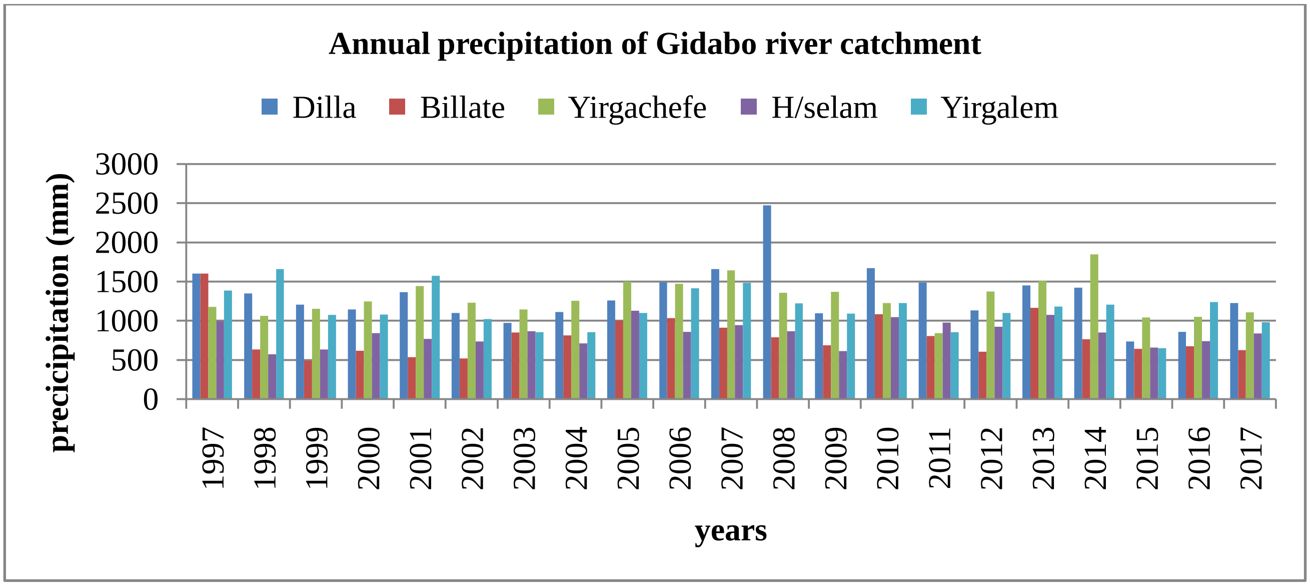


Figure 3. 2 Total yearly precipitation graph of Stations in the region of the GRB (1997-2017).

3.1.4 Soil of the study area

The soils of project area have been delineated into different soil mapping units and the most extensive soils of the project area are Vertisols largely occurring in the bottom of the valley area (MoWE, 2010). Cambisoils which are young and shallow and Luvisols are among the soils found abundantly in the shallow depths of the catchment area profile. They are well developed in the areas where there are clearly marked wet and dry seasons and when leaching is not very high. Elsewhere there are Nithosols (red basaltic soils) which are basically associated with high rainfall and are matured soils with deep profiles. They are also potentially good for farming and other agricultural practices as they are friable and have stable structure; as a result they are the most cultivated soil type. Extensive area of Leptosols which are young, shallow and stony soils that are highly susceptible to erosion and drought and the well drained soils which include Luvisols are mostly located on nearly level to gently undulating slopes of the land (Yared Buruk Tedla, 2011).

3.1.5 Land use / Land cover of the study area

The Gidabo command area land use and land cover are greatly changing due to the high population growth in the basin. The catchment is covered by the land uses of forest, shrub/bush, woodland, grassland, cropland, wet body, unproductive land and settlements with the dominant of the cropland in the catchment (MoWE, 2010).

Forest and woodland area is dominated by different plant species and it is difficult to penetrate in to the unit due to its high vegetation cover. This unit mainly concentrated in southern, eastern part of the project area, which stretches from north west to south east at the middle of the command area and used for seasonal nomadic livestock grazing and browsing and mainly located in central part of the command area.

Wetland/ Water body: this unit is covered permanently by water. The land unit is mainly located in the delta region of Lake Abaya areas. Shrub/bush/ grass land: the unit is covered by grass with scattered shrubs (scrubs) and used mainly for cattle and seasonal nomadic livestock grazing and browsing and mainly located in central part of the command area. Crop land is the main land cover type of the study area which covers more than half of the area.

3.2 Input data for the HEC-HMS model

Input data as an important part of the stream flow and sediment yield estimation in model setup and processing of HEC-HMS model can be categorized in to hydro- meteorological (Stream flow data, daily rainfall data, temperature, relative humidity, sunshine hours, wind speed) and the digital elevation model (DEM), soil type, land use/ land cover or in general the physiographic data bases. The necessary information's to create an HEC-HMS model are elevation, land use/land cover data, soil data hydrograph information and data of the percent impervious area of the catchment. These listed data were used to establish the sub-basin properties and estimations of the hydrologic parameters. The slope and elevation which are crucial information of physiographic characteristics of the watershed was generated from the resolution of 30*30 m DEM of the Gidabo basin which was found from the web for at no cost. The HEC-GeoHMS model which is the interface of the Arc-GIS (geographic information system) were used for additional processes of the digital elevation model data. Landscape pre-processing and watershed processing tools were used to produce the distinguishing parameters of the catchment which are used as input documents for HEC-HMS model.

This study uses Arc-GIS, Geographic Information System (GIS) software, to visualize, analyze, compile, and manipulate spatial information. Arc-GIS have several toolboxes that help the users to perform geospatial analysis. For this study, two external toolbars, i.e., Arc Hydro and Geo-HMS were added to Arc-Map to facilitate hydrologic modeling process. Arc Hydro is used to delineate and characterize streams and watersheds, calculate drainage properties like slope, flow accumulation, stream network, etc. The Geo-HMS toolbar is used to develop SMA parameters automatically and transfer the data to HEC-HMS from a geospatial environment.

The watershed that was examined in this study was Gidabo Watershed, the mouth of which is located in the Main Ethiopian rift, North-east of Lake Abaya. This study utilized the Hydrologic Engineering Center Geospatial Hydrologic Modeling Extension (HEC Geo-HMS) tool kit within Arc-GIS; then applied what was created in ArcGIS with the GeoHMS tool kit and inserted the data into Hydrologic Engineering Center Hydrologic Modeling System (HEC HMS) for hydrologic analysis. HEC HMS has a function called Sediment Erosion Module that calculates the sediment yield of a watershed using the Modified Universal Soil Loss Equation (MUSLE). Other data that need to gathered and processed for the study included the utilization of Arc-GIS alone and the data processed with spreadsheet applications and then inserted into HEC HMS.

3.3 Data collection and analysis

A massive number of data and works are required for the set and process of hydrological model for a river catchment stream flow and sediment yield simulation.

The data that are used in this research work are;

1. The Digital elevation model (DEM) of the catchment,
2. land cover/land use data off the catchment,
3. The meteorological data such as the precipitation, the maximum and minimum temperature, the sun shine hours of the river catchment,
4. The soil data of the catchment,
5. The hydrological data of the river catchment for stream flow calibration and validation,
6. The observed sediment data, also for sediment yield calibration and validation ,
7. The modeling software of the Arc-GIS 10.7, Arc-hydro, Geo-HMS and the HEC-HMS modeling software.

The data required for model development of the HEC-HMS and stepwise procedures for the simulation, modeling and methodologies applied for estimation of stream flow and sediment yield for the study area of this research listed above are discussed in detail in the following pages of this chapter.

3.3.1 Digital Elevation Model

Digital Elevation Model (DEM) data of 90m resolution has been collected from the Ministry of Water, Irrigation and Energy of Ethiopia. DEM represents the topographic feature of the study area. In general the DEMs of the catchment are used to characterize; the surface of the watershed, Slope, altitude, delineate drainage system, catchment boundary (watershed), sub-catchments, stream network, Quantify catchment variables, Soil moisture and Flow time in the catchment.

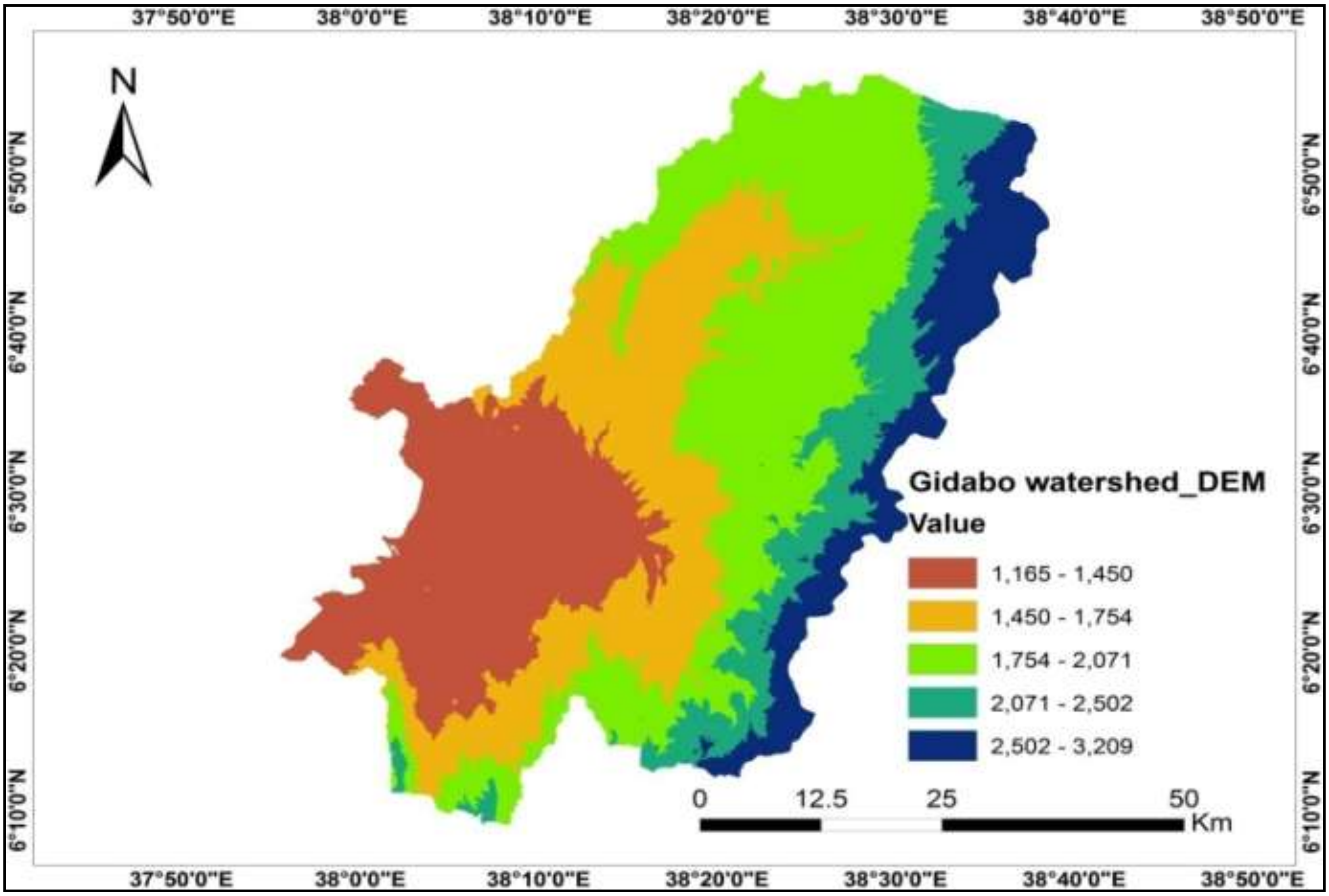


Figure 3. 3 Digital Elevation Model (DEM) of the Gidabo River Basin (GRB)

3.3.2 The catchment Soil data

One of the contributing factors in determining the amount of runoff and sediment yield in the HEC-HMS hydrological model is the soil data of the catchment. The soil data is used to determine the stream or catchment characteristics and hydrologic parameters estimations. The soils of the Gidabo river watershed mostly varies from clayey loam soils, which have created on their parental bedrocks according to their texture and sandy alluvial deposits of transported soils of the river runoff (Yared Buruk Tedla, 2011). The soil types of the Gidabo river catchment of this study area in general can be shown in the figure 3.4 and table 3.1 below.

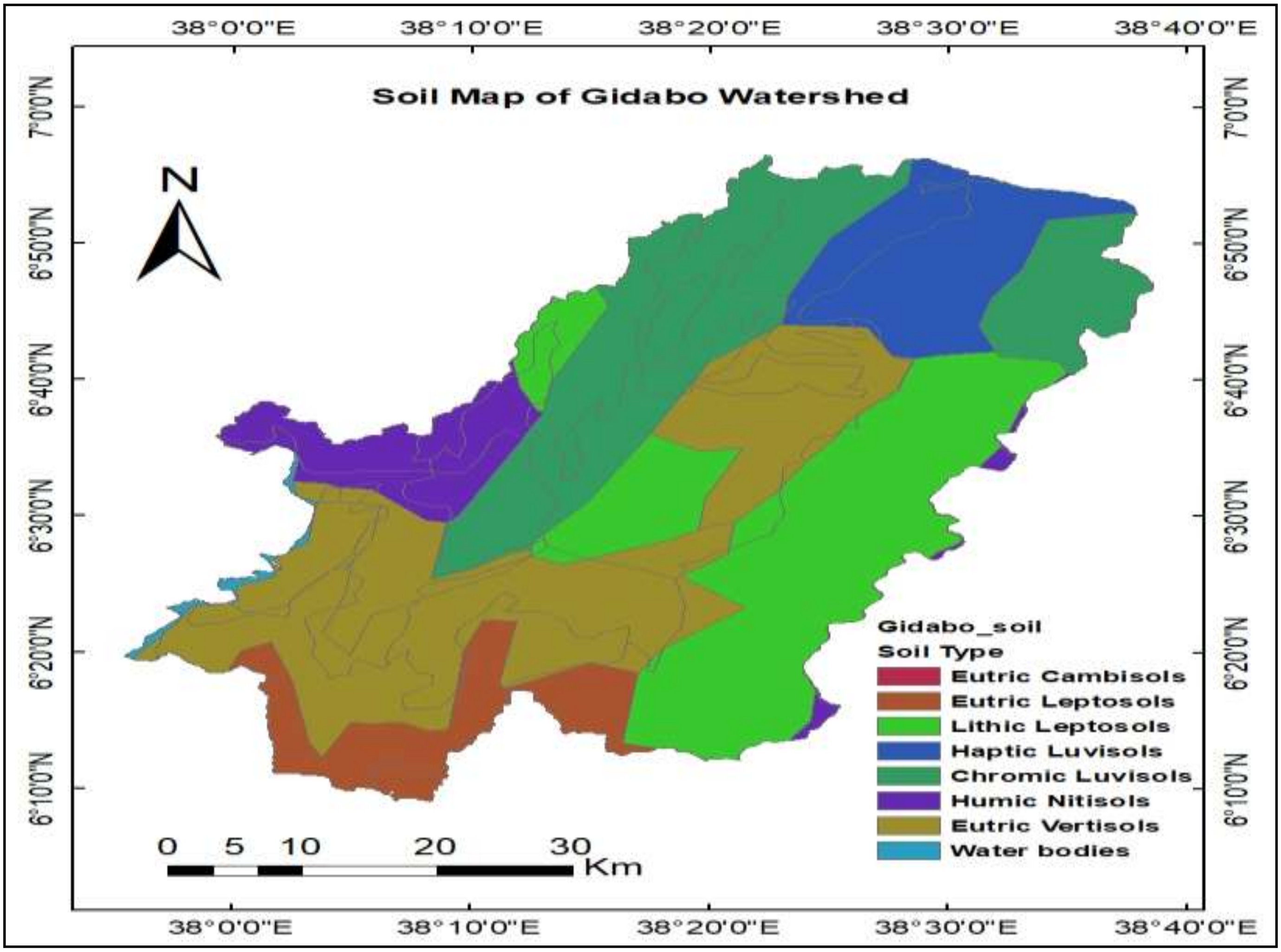


Figure 3. 4 Soil map of Gidabo River Basin (GRB)

The soil map of Gidabo River in this study is taken from MOWIE which is similar to FAO/UNESCO legend for the Soil Map of the World 1974 is used to indicate the dominant soil unit in each cell. It refers to the soil characteristics of the Digital Soil Map of Gidabo river watershed. Dominant soil types for Gidabo river catchment are shown in Table 3.1

Table 3. 1 Soil types of Gidabo River Catchment

Soil Group Name	Symbol	Soil group	Soil type	Area (km2)	Percent area coverage
Eutric Cambisols	CMe	D	Clay	0.02	6.16193E-06
Eutric Leptosols	LPe	A	Sandy loam	233.0087	0.071789128
Lithic Leptosols	LPq	A	Sandy loam	794.4295	0.244760822

Haptic Luvisols	Lvh	B	Loam	354.5687	0.109241319
Chromic Luvisols	Lvx	B	Loam	673.4703	0.207493735
Humic Nitisols	NTu	B	Loam	228.599	0.070430515
Eutric Vertisols	VRe	D	Clay	925.678	0.285198004
Water bodies	WR	D	Clay	35.964	0.011080377

3.3.3 Land use/ Land cover data

In the Gidabo River catchment, the land use and land cover which is correlated with the amount of canopy and surface storage/loss and is the most important factor that affects the surface runoff, erosion and the actual evapo-transpiration, is changing rapidly due to the high population growth in the watershed.

The Land use/Land cover map of the study area of Gidabo river catchment, which is collected from MoWIE is shown in Figure 3.5 below.

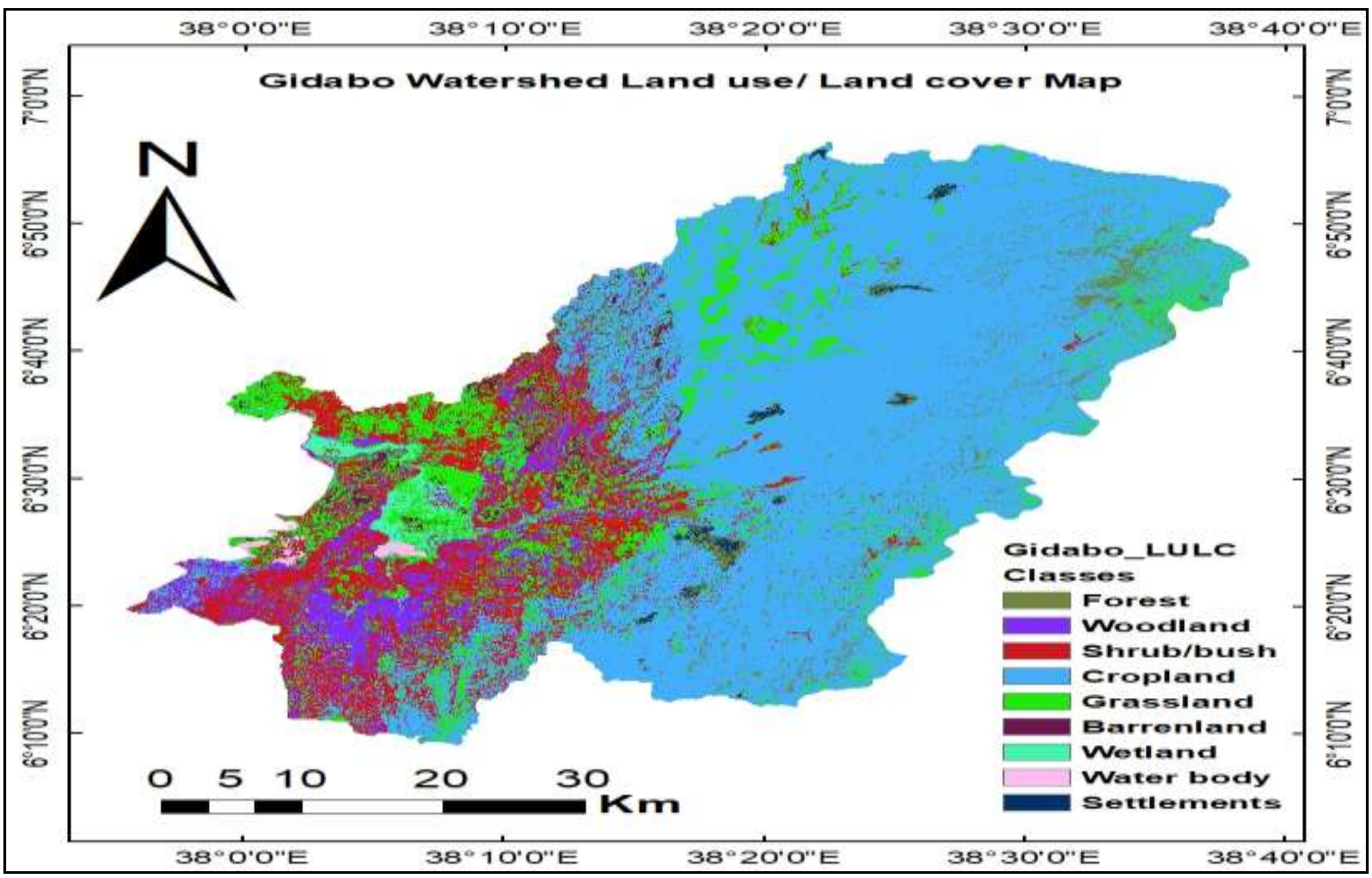


Figure 3. 5 Gidabo river catchment Land use/ Land cover map

The crop land is the dominant land use types in the study area of Gidabo river catchment as shown in the figure 3.5 above.

3.3.4 Meteorological Data Collection and Analysis

The continuous HEC-HMS model requires the daily values of the precipitation and evapo-transpiration for the simulation of the runoff. The daily evapo-transpiration data used in this study is estimated from the collected maximum temperature, minimum temperature, and sunshine hours. The meteorological data have been collected from the National meteorological Agency of Ethiopia (NMAE). The location of meteorological stations in and around the Gidabo river catchment is shown in Figure 3.1 below.

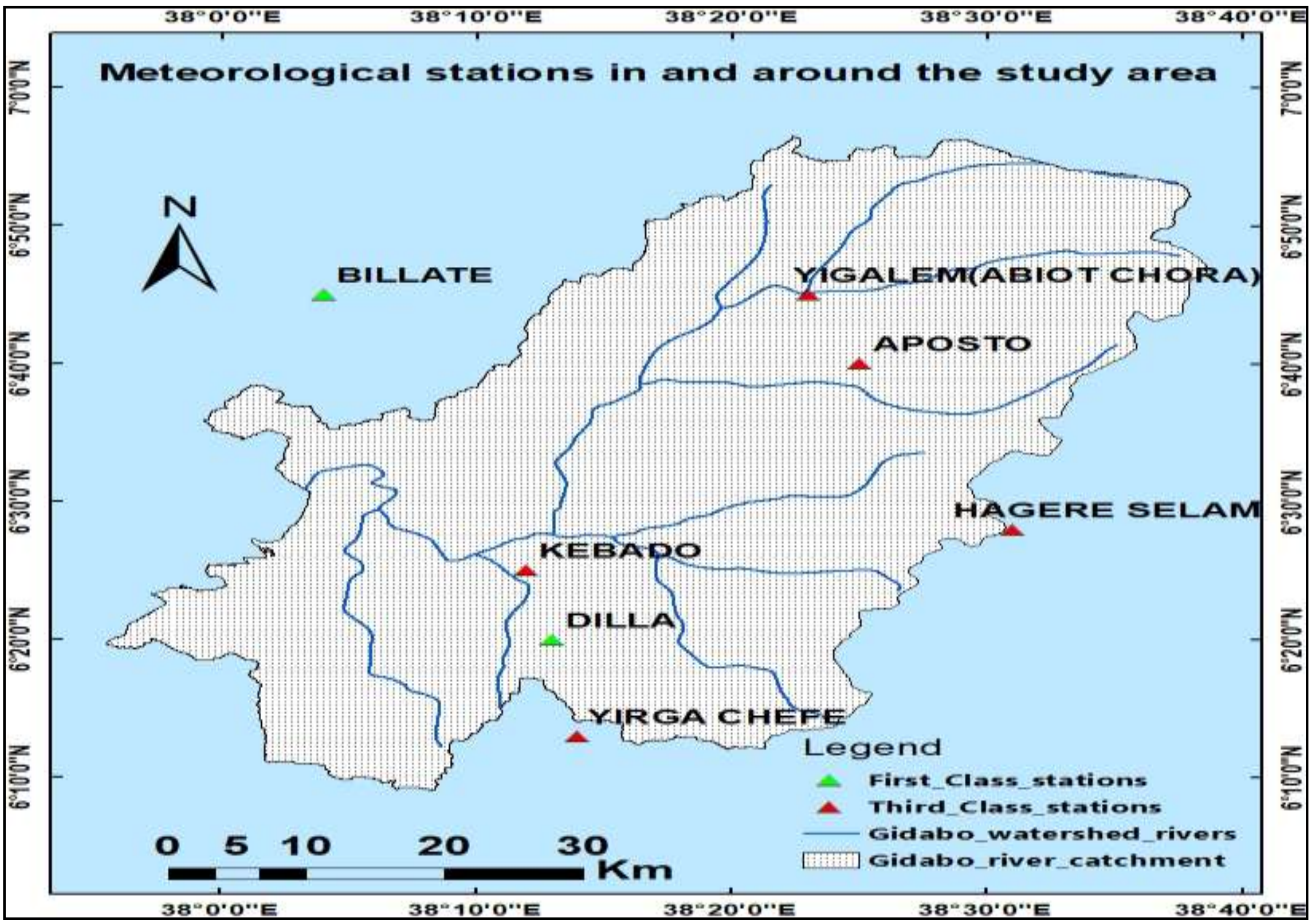


Figure 3. 6 Meteorological stations in and around the study area

3.3.4.1 Precipitation data analysis

Precipitation input data is one of the basic input requirements for HEC-HMS model. The precipitation statistics for the chosen stations in the Gidabo river catchment area have diverse degree of omitted values with Dilla and Billate stations of small missing values. These missing values of the stations are filled with the inverse distance weighting method.

Table 3. 2 key meteorological stations located in and around the study area

No.	Name of station	Latitude	Longitude	Elevations(m)	Data series	Class
1	Dilla	6.333	38.217	1579	1997-2017	1
2	Hagere Selam	6.467	38.517	2841	1997-2017	3
3	Billate	6.75	38.067	1361	1997-2017	1
4	Kebado	6.43333	38.3333	1807	1997-2017	4
5	Yirga Alem	6.75	38.383	1786	1997-2017	3
6	Yirga Chefe	6.217	38.233	1856	1997-2017	3
7	Aposto	6.735833	38.37222	1762	1997-2017	4

The Kebado and Aposto stations stated above in table 3.2 are used only for calculation of missing precipitation data only (not used for model input data) for this study area. The meteorological data gathering of this study ranges from 1997 to 2017 years. The bimodal pattern with the highest rainfall during April, May and October is the characterization of Gidabo river catchment precipitation stations as shown in figure 3.5 below.

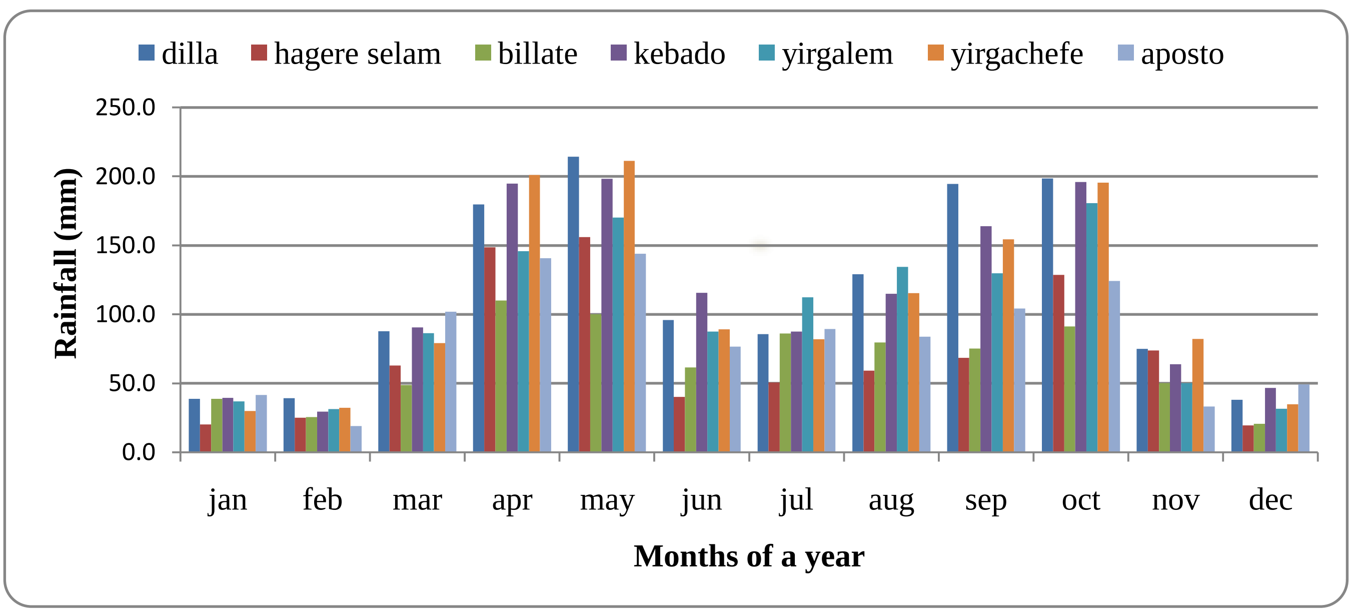


Figure 3. 7 Gidabo River Catchment stations mean monthly precipitation (mm) graph (1997-2017)

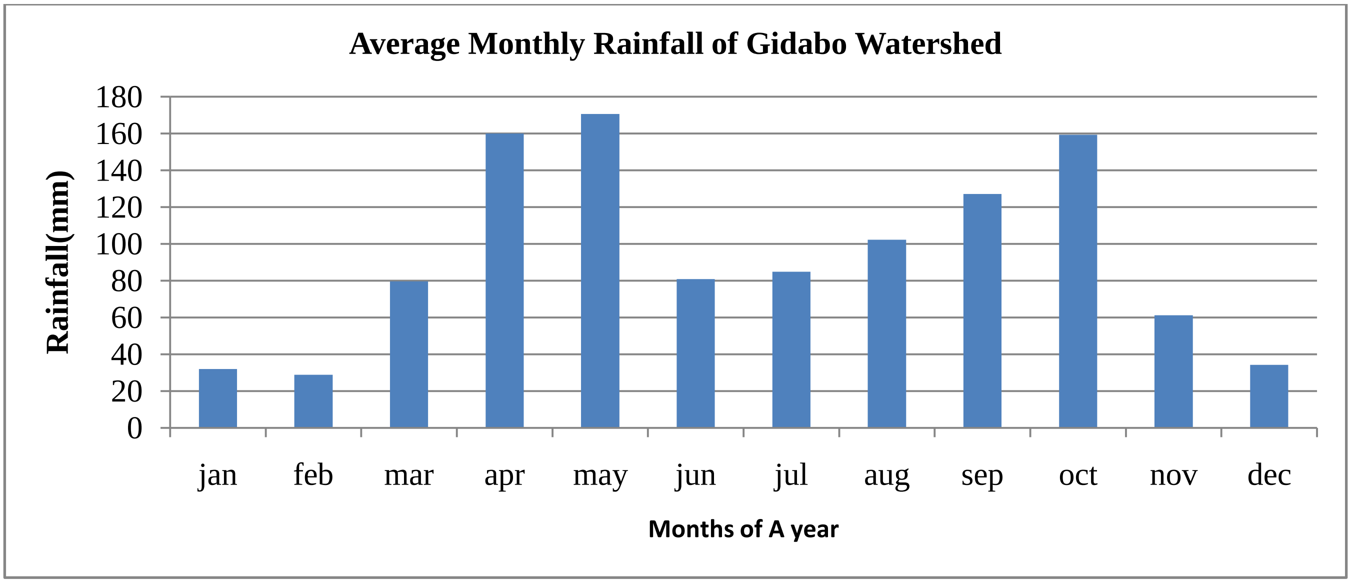


Figure 3. 8 Gidabo River Catchment extended term mean monthly precipitation (mm) graph (1997-2017)

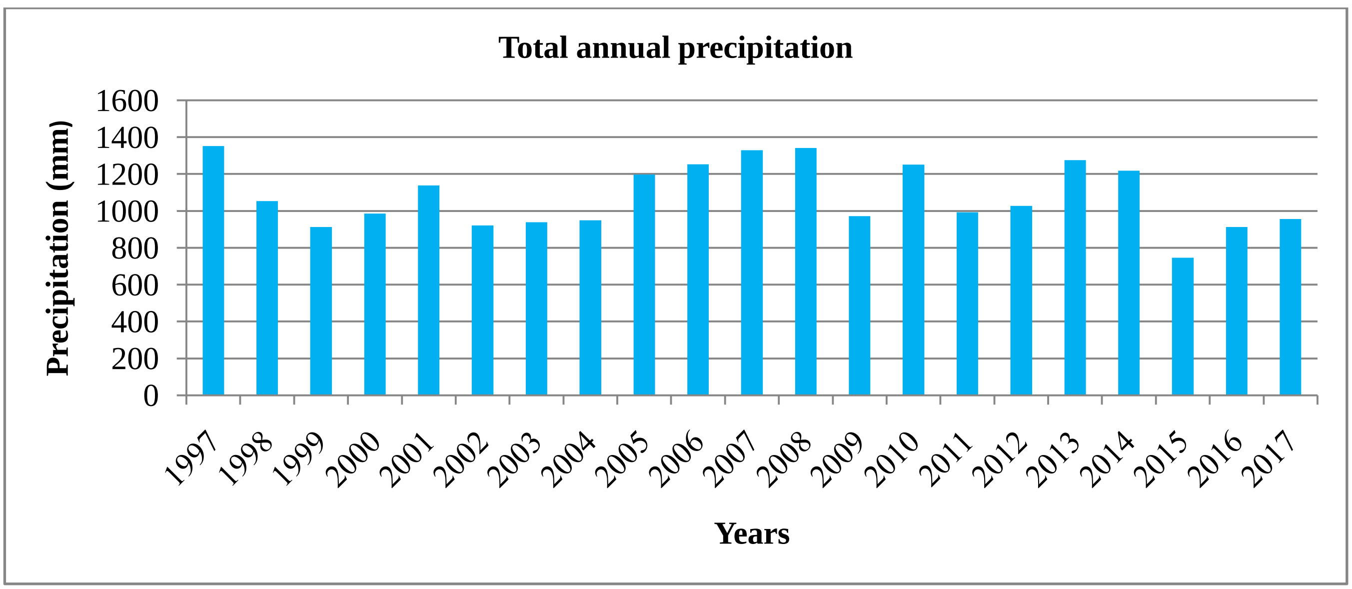


Figure 3. 9 Gidabo River Catchment extended term total annual precipitation (mm) graph (1997-2017)

From figure 3.9 above the years 1997, 2007, 2008 and 2013 are the wettest years and the years 1999,2002,2003, 2004, 2015 and 2016 are relatively the driest years in the period from 1997-2017. This diagram is constructed from the average annual precipitation of the five meteorological stations of Gidabo river catchment used in this thesis research.

The Dilla and Bilate stations have sunshine hour records from 1997 to 2017, which is the same length of years as their precipitation data recorded and the rest have only precipitation and temperature data. This is very important to use as input to the HEC- HMS model as it requires the same length of year for precipitation, temperature and sun shine hour data.

3.3.4.2 Temperature data analysis

The average minimum temperature varies from 11.38 ^{0}C in Jan to 13.63 ^{0}C in May and the maximum temperature ranges from 25.12 ^{0}C in July to 29.54 ^{0}C in March. Air temperature regulates the growth and development of many plants by regulating the rate of biochemical processes. The growth of many crops ceases below a critical temperature of 5^{0}C or above 35^{0}C adversely affecting the yield. The monthly mean temperature for maximum and minimum are given in Table 3.3.

Table 3. 3 Gidabo River catchment maximum and minimum mean monthly temperature

Tmax	28.66	29.03	29.54	27.99	26.48	25.82	25.12	25.56	26.0	26.23	27.2	28.08
Tmin	11.38	11.61	12.88	13.61	13.43	13.64	13.43	13.14	13.06	12.92	12.01	11.63
Months	Janua.	Febru.	March	April	May	June	Jully	Aug.	Sept.	Octo.	Nov.	Dece.

Where; Tmax and Tmin are the average monthly maximum and minimum temperatures respectively. The maximum and minimum average monthly temperature of the Gidabo river catchment of five meteorological stations is shown in the figure 3.8 & figure 3.9 below respectively.

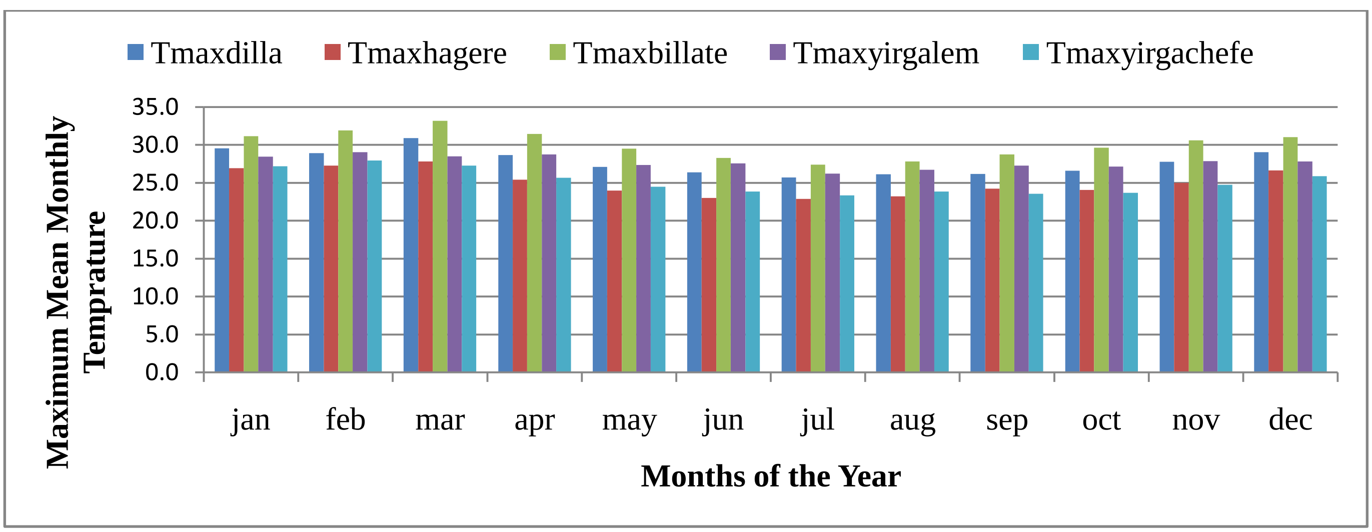


Figure 3. 10 Graph of average monthly maximum temperature of GRB stations

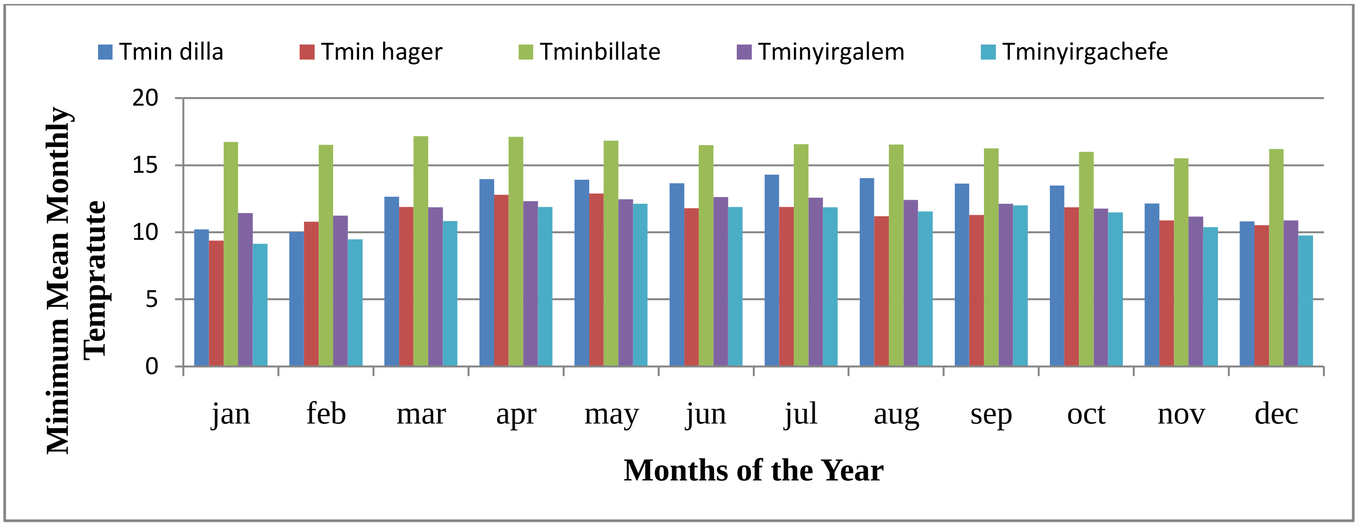


Figure 3. 11 Graph of average monthly minimum temperature of GRB stations

3.3.4.3 Sunshine Hour data analysis

The mean monthly sunshine hours in project area of Gidabo river catchment varies from 5.06 hours /day in July to 8.08 hours/day in Febrauary. The mean monthly sunshine hour is given in Table 3.4 shown below.

Table 3. 4 Mean monthly sunshine hour of the Gidabo River Catchment

Sunshine(hrs)	7.98	8.08	7.34	6.72	6.65	5.96	5.06	5.37	5.74	6.27	7.44	7.83
Months	Jan.	Febru.	March	April	May	June	July	Augu.	Sept.	Octb.	Nove.	Dece.

3.3.4.4 Evapo- Transpiration (ETo) data analysis

Evapo-transpiration (ET) is the combination of two separate processes of Water losses by direct evaporation from soil and plant surfaces, and Transpiration, in which water moves from the soil through plants to leaves where it is vaporized and diffuses through the stomata to the ambient air. Accurate estimation of the potential evapo-transpiration (ETo) is essential for the estimation of the runoff in the watershed and for planning, design and operation of irrigation systems. There are many empirical methods for estimating ETo that require many weather data which are not readily available, but some of the methods require only air temperature for ETo estimation.

The most widely accepted methodology for ETo estimation from daily meteorological data is the Penman-Monteith method, and it has been proposed as the standard model for validating other formulations and estimating ETo because it can be determined unambiguously, providing consistent values in all regions and climates. The main drawback of the Penman-Monteith method and other evaporation estimating methods such as PriestleyTaylor methodology is that it requires weather or climate data (solar radiation or sunshine duration, air temperature, humidity, and wind speed) that are often unavailable (Quej & Moratiel, Feb,2019). But these data are commonly lacking or of questionable quality in developing countries like Ethiopia and particularly in this project area.

In such situations, temperature based evapo-transpiration (TET) methods such as Hargreaves method and Thornthwaite methods are particularly useful. Air temperature is one of the most widely recorded meteorological parameters. Therefore, TET methods temperature databases are critically important for ET estimation in the study area of Gidabo River catchment based on the available data and in this study the Thornthwaite method along with Willmott method is used for the estimation of evapo-transpiration. Thornthwaite (1948) propose the potential evapo-transpiration (reference evapo-transpiration, $ET_{M,}$ mm per month) for a standard month of 30 days, each day with 12h of photoperiod (the time that the plant or animal is exposed to light in 24 hour duration), was calculated as:

$$ET_M = 16(10*(T/I))^a, \; 0\,^oC \le T \le 26\,^oC \quad (3.1)$$

$$ETo = ET_M\,(N/12)*(dm/30) \quad (3.2)$$

$$I = \sum_{i=0}^{12} (0.2T)^{\wedge}1.514 \quad (3.3)$$

$$a = 6.75\times 10^{-7}I^3 - 7.71\times10^{-5}I^2 + 1.7912\times10^{-2}I + 0.49239 \quad (3.4)$$

Where ET_M is the gross monthly in mm mon $^{-1}$; dm is the number of days in the month; ETo the potential evapo-transpiration in mm mon $^{-1}$ **;** I is a thermal index imposed by the local normal temperature; a is the exponent of Equation (3.1) given by Equation (3.4) and T is the monthly mean temperature in ^oC.

For temperature above 26 ^oC, instead of the original Thornthwaite (1948), willmott al. (1985) represented ET_M by the following equation:

$$ET_M = -415.85 + 32.24T - 0.43T^2, \; T > 26\,^oC \quad (3.5)$$

In order to convert the estimation from the standard monthly (ETM, mm per month) to a daily time scale (ETD, mm per day) the following correction factor (C) was used:

$$C = N/360 \tag{3.6}$$

Where; N is the photoperiod or sunshine hour (h) for a given day.

Finally Latitude or Northing adjustment factor used in the Thornthwaite formula is multiplied by the un adjusted ET_M in order to find the adjusted ET_M. The daily evapo-transpiration values are entered manually in the HEC- HMS model with a coefficient value of 0.7 to compute the actual evapo-transpiration.

Table 3. 5 Monthly evapo-transpiration Adjustment factors in the Thornthwaite formula

Latitude	Monthly Evapo-transpiration latitude adjustment factors of Thorthwaite equation										
0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
10	1	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
15	0.97	0.91	1.03	1.04	1.11	1.08	1.12	1.08	1.02	1.01	0.95	0.97
20	0.95	0.9	1.03	1.65	1.13	1.11	1.14	1.11	1.02	1	0.93	0.94
25	0.93	0.89	1.03	1.06	1.15	1.14	1.17	1.12	1.02	0.99	0.91	0.91
30	0.9	0.87	1.03	1.08	1.18	1.17	1.2	1.14	1.03	0.98	0.89	0.88
40	0.84	0.83	1.03	1.11	1.24	1.25	1.27	1.18	1.04	0.96	0.83	0.81
Months	Jan.	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.

Table 3. 6 Interpolated adjustment factors for use in the Thornthwaite's formula for evapo-transpiration calculation

Station	Latitude	Interpolated latitude adjustment factors of Thornthwaite's evapo-transpiration											
	0	1.04	0.94	1.04	1.01	1.04	1.01	1.04	1.04	1.01	1.04	1.01	1.04
Yirgalem	6.82	1.01	0.92	1.03	1.02	1.07	1.04	1.07	1.06	1.02	1.03	0.99	1.01
Y/chefe	6.15	1.02	0.92	1.03	1.02	1.06	1.04	1.06	1.06	1.02	1.03	0.99	1.01
Billate	6.82	1.01	0.92	1.03	1.02	1.07	1.04	1.07	1.06	1.02	1.03	0.99	1.01
H/selam	6.47	1.01	0.92	1.03	1.02	1.07	1.04	1.07	1.06	1.02	1.03	0.99	1.01
Dilla	6.37	1.01	0.92	1.03	1.02	1.07	1.04	1.07	1.06	1.02	1.03	0.99	1.01
	10	1	0.91	1.03	1.03	1.08	1.06	1.08	1.07	1.02	1.02	0.98	0.99
	Months	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.

After following all the above mentioned procedures the monthly estimated adjusted evapo-transpiration (ETo) varies from 30.97July mm in to 59.31 mm in March. The daily (ETo) values ranges from 1 mm in July to 1.93 mm in February as shown below in Table 3.7.

Table 3. 7 The Mean monthly and daily Evapo-transpiration of the Gidabo river catchment

Monthly ETo	39.3	34.9	35.3	30.78	31.95	27.03	23.34	25	26.2	29.86	34.8	37.95
Daily ETo	1.27	1.25	1.14	1.03	1.03	0.9	0.75	0.81	0.87	0.96	1.16	1.224
Months	Janu.	Febr.	Mar.	April	May	June	July	Aug.	Sept.	Octo.	Nov.	Dece.

3.3.4.5 Meteorological data quality analysis

A, Filling of the meteorological missing data

All the meteorological stations do not have fulfilled data; a few meteorological stations may have little gap in the report due to the instrumental error, failure of the instrument to record the data, lack of record observers or observer error during data recording. Since the outcome of data analysis depends on the quality completeness (with no missing values) of the data, it is often necessary to fill or estimate the missing data before data usage. The missing meteorological stations were estimated from the nearby well data recording stations by using different filling missed data methods.

There are many different methods used to fill the missing meteorological data such as; the arithmetic mean method, normal ratio method, the inverse distance weighting method and the regression methods. Arithmetic mean technique is used to fill up the omitted data when the normal yearly rainfall is less or equal to 10% of the station which information are being collected.

When the normal yearly rainfall whichever index station unlike from that of rainfall station greater than 10% the normal ratio technique can be used. In the absence of the normal yearly rainfall for the station, inverse distance weighing technique is used to fill up the absent meteorological data (Mengistie Abate Beyene, 2017). To evaluate the appropriateness of the diverse techniques for filling in absent data, the good recorded data is detached from the stations and used for validation of the methods. Then the appropriateness of the techniques used for filling the absent data was assessed using mean absolute error (MAE).

For this study by using the above mentioned way the multiple regressions and inverse distance weighing method provides successful estimation of the missing meteorological data, which are supported by the results published in the literatures. The Inverse distance weighting method (IDWM): is the most commonly used method for estimating the missing data. This weighting distance method for estimating the missing value of an observation, which uses the observed values at other stations, is determined by

$$Wo = \sum_{i=0}^{n}(Wi/D^2i) / \sum_{i=0}^{n}(1/D^2i) \quad (3.7)$$

Where Wo is the estimated value of the missing data, Di is the distance between the station with the missing data and the ith nearest weather station (Mohammad-Taghi Sattari, 2016).

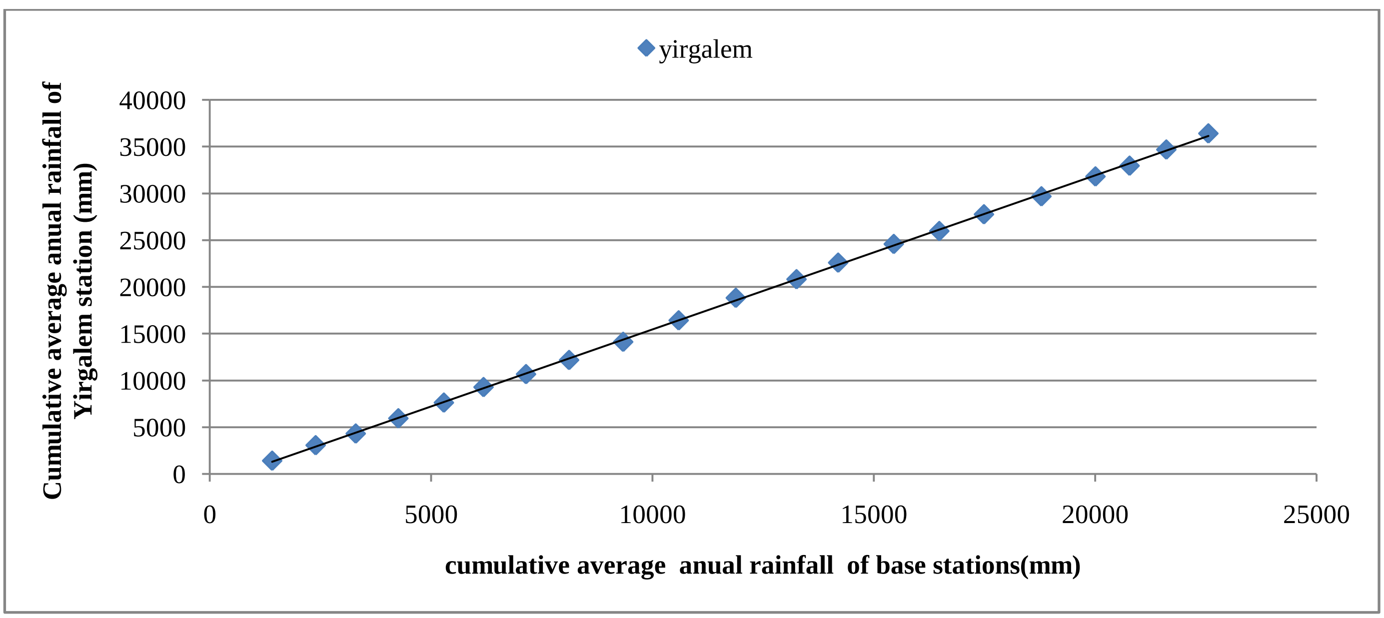
Multiple linear regressions**:** is the statistical method for estimating the relationship between a dependent variable and two or more independent, or predictor, variables. It identifies the best weighted combination of independent variables to predict the dependent variable. This data Wo is estimated using the equation

$$Wo = a_0 + \sum_{i=1}^{n}(a_{iWi}) \quad (3.8)$$

Where a_i, $a_1 \ldots a_n$ are the regression coefficients.

B, Checking the meteorological stations data consistency

The rainfall time series data may show jumps and trends which is known as inconsistency or non homogeneity which is the alteration in amount of systematic error related with the collected information. The information that are used for hydrological calculations should be reliable and homogenous (Meshesha, 2017). In this study the meteorological data was checked for inconsistency by using the double mass curve before it is used for further analysis and the data quality control was done visual inspection.



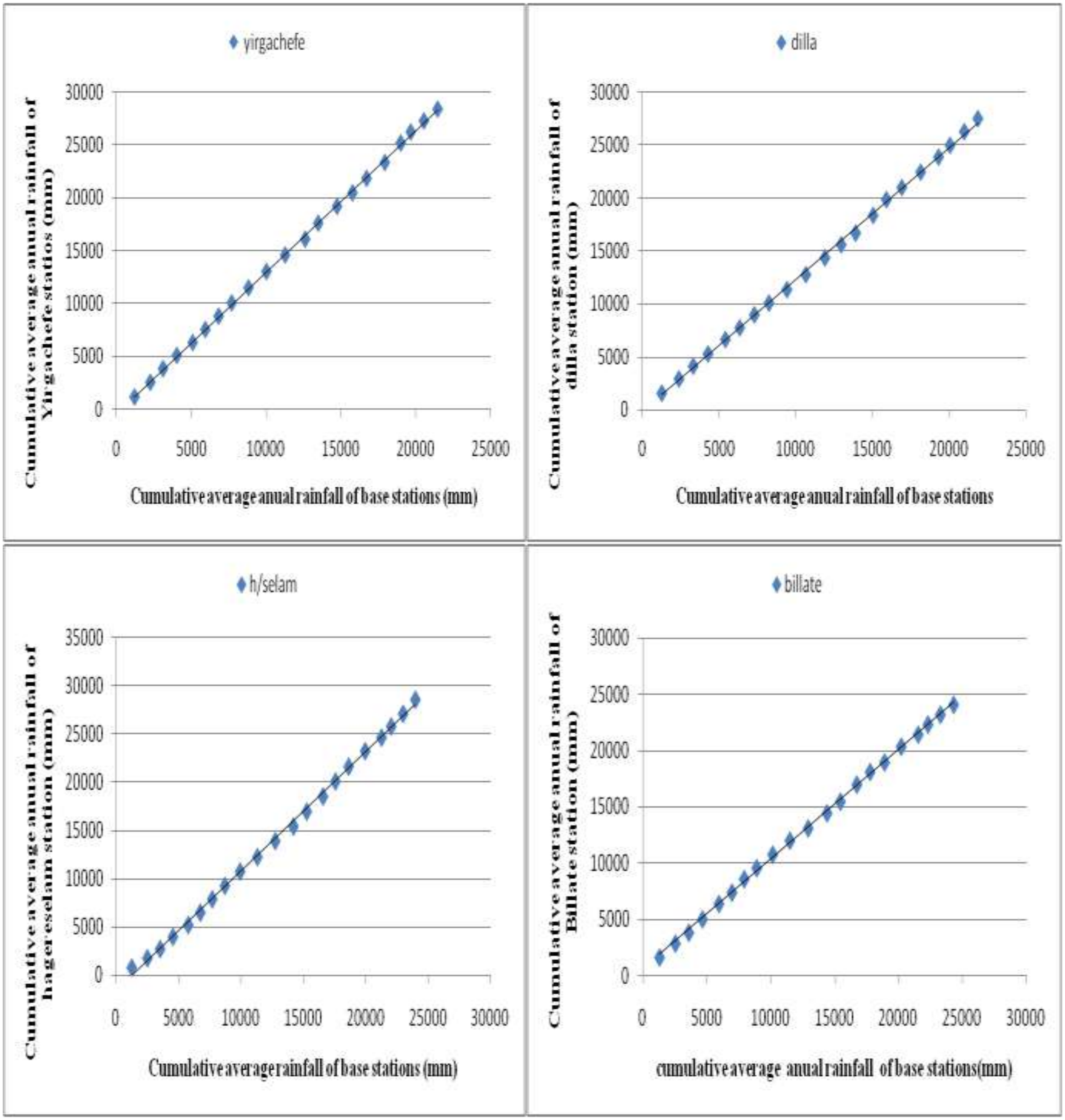


Figure 3. 9 Double mass curves of meteorological stations in the Gidabo river catchment

The procedure for the double mass curve inconsistency test is that the accumulated rainfall at the gauge station whose record is in question is plotted as ordinate versus the accumulated average rainfall of the nearby stations whose rainfall are reliable. When break point is noted in the graph, the doubt station data may be adjusted to the previous slope value if the reason for doing so is convincing.

$$PcA = PA*K \tag{3.9}$$

Where PcA is the corrected precipitation ant any time t at station A, PA is the original recorded precipitation at any time t at station A and K = Gradient after change / Gradient before change

C, Testing the meteorological data for outlier

Outliers are the data points that make tracks significantly from the style of the remaining collected data. The retention or deletion of these outliers can considerably affect the amount of the statistical parameters computed from the data (Ven Te Chow, 1988). Procedures for the treating outliers necessitate judgement concerning both hydrologic and mathematical considerations. According to Ven Te Chow, tests for bigger outliers are measured early if the station bias or skew is bigger than +0.4 by using;

$$y_L = y_{mean}+K_n s_y \tag{3.10}$$

But for the station bias or skew is smaller than -0.4, tests for small outliers are measured early by using;

$$y_L = y_{mean} - K_n s_y. \tag{3.11}$$

Where, y_{mean} the mean of the log transformed flow values, s_y is the standard deviation and Kn is the coefficient factor for outlier test but when the station bias is among ±0.4, tests for both low and high outliers be supposed to be applied prior to removing any outlier from the data set.

Table 3. 8 Outlier test Kn values taken from (Ven Te Chow, 1988).

Sample Size, n.	Frequency factor Kn
10	2.036
11	2.088
12	2.134

Then the maximum flow can be found by using;

$$Q_T = (10)^{y_L}. \tag{3.12}$$

The coefficient of bias or skewness, C_w can be estimated using;

$$C_w = WC_s + (1-W)\, C_m \tag{3.13}$$

Where W is the weighting factor, Cs is the coefficient of skewness computed from the sample data, and Cm is the map skewness, which is readied from the map.

$$W = \frac{V(Cm)}{V(Cs)+V(Cm)} \tag{3.14}$$

V(Cm) can be derived from the regression by relating the skew to physiographical and meteorological characteristics of the basins or from the map of skew (Ven Te Chow, 1988), for African take 0.35. V(Cs) is the function of the record length in years, 10 years for this study area and population skew which can be described as;

$$V(Cs) = 10^{A-Blog\,10(\frac{n}{10})} \tag{3.15}$$

Where;

A = -0.33+0.08|Cs|, if |Cs| ≤ 0.90 (3.16)

A =-0.52+0.03|Cs|, if |Cs| > 0.90 (3.17)

B = 0.94-0.26|Cs, |if |Cs| ≤ 1.50 (3.18)

B = 0.55 |if |Cs| > 1.50 (3.19)

In which |Cs| is the absolute value of the station skew, used as an estimate of population skew.

$$Cs = \frac{n\sum_{i=0}^{n}(\mathrm{Yi}-Ymean)^3}{(n-1)(n-2)\mathrm{Sy}^3} \tag{3.20}$$

The rainfall data used in this research were tested for outliers using the above mentioned procedure.

3.3.4.6 Estimation of areal rainfall

The accuracy in estimation of runoff and flood depends on the methods used for areal rainfall approximation. Since the rainfall is certainly not evenly distributed over the region of the watershed due to the topographic unevenness of the catchment areas, it is preferable to have many rainfall gauging stations as possible to estimate the area rainfalls which represents the real rainfalls over the catchment. But due to the budget constraints, inaccessibility of certain areas or lack of available staff, it is not possible to install rainfall stations in as many locations as we want.

There are many areal rainfall estimation techniques from point rainfall over the catchment. Selection of method needs decision in concern of nature and quality of the data, use, significance and required accuracy of the outcome.

The arithmetic mean method, Thiessen polygon method and the isohyetal method are the most commonly used method in estimating the areal rainfall from point rainfall measurements. The arithmetic mean method assumes that each rain gauge has equal weight where as the isohyetal method the isohyets are drawn between the gauges over a contour base map taking into account exposure and orientation of both gauges and the catchment surface. The rainfall calculation is based on finding the average rainfall between each pair of isohyets, and the area between them in the watershed. The Thiessen polygon method which is used for this study involves assigning the relative weights to the gauges according to the area they cover in computing the areal rainfall. This technique assumes the rainfall is the same at any point over the watershed of the same area of the thiessen polygon region. According to this method the areal rainfall over the catchment (Pt) is computed as;

$$Pt = \sum_{i=1}^{n} TiPi \tag{3.21}$$

Where Pi is the observed rainfall at the centroid of the ith polygon, and the weighting factor Ti is given as

$$Ti = Ai/A_T \tag{3.22}$$

Where A_T is the total area of the catchment, and Ai is the area defined by the intersection of the Thiessen polygon and the basin boundary. This technique is not suitable for use in mountainous regions which have effect on precipitation amount since it assumes that the precipitation varies linearly between the stations.

3.3.5 Hydrological data analysis

3.3.5.1 Stream flow data analysis

Monthly or Daily stream flow data is also used for the HEC-HMS model simulated result for the calibration and validation purpose. The stream flow data have been collected from the Ministry of water resources, irrigation and energy, Hydrology and Water Quality Directorate. Depending on the Availability of the stream flow data in the catchment, four stations namely Gidabo near Aposto, Bedessa near Dilla, Gidabo near Measso and Kolla near Aleta wondo were selected and collected from 1997-2006 for 10 years record period (See Table 3.9). Based on the extent of calibration and validation, the collected stream flow data was arranged as per the requirement of the HEC-HMS model. Flow data was used for model calibration from 1997-2002 and validation from 2003-2006. Any error in the calculation may be a reason for a problem in the model calibration and validation since the effectiveness of the model at the stage of calibration and validation depends on the correctness of the computation.

Table 3. 9 Stream flow and sediment stations and locations

Stations	X(meter)	Y(meter)	Latitude	Longitude	Data series
Bedessa	422584	705568	6.38	38.3	1997-2006
Aletawondo	433677	733189	6.63	38.4	1997-2006
Aposto	431850	746088	6.75	38.38	1997-2006
measso	437336	711077	6.43	38.43	1997-2006

The study area of the Gidabo river catchment hydrological stations location is shown in the figure below 3.10.

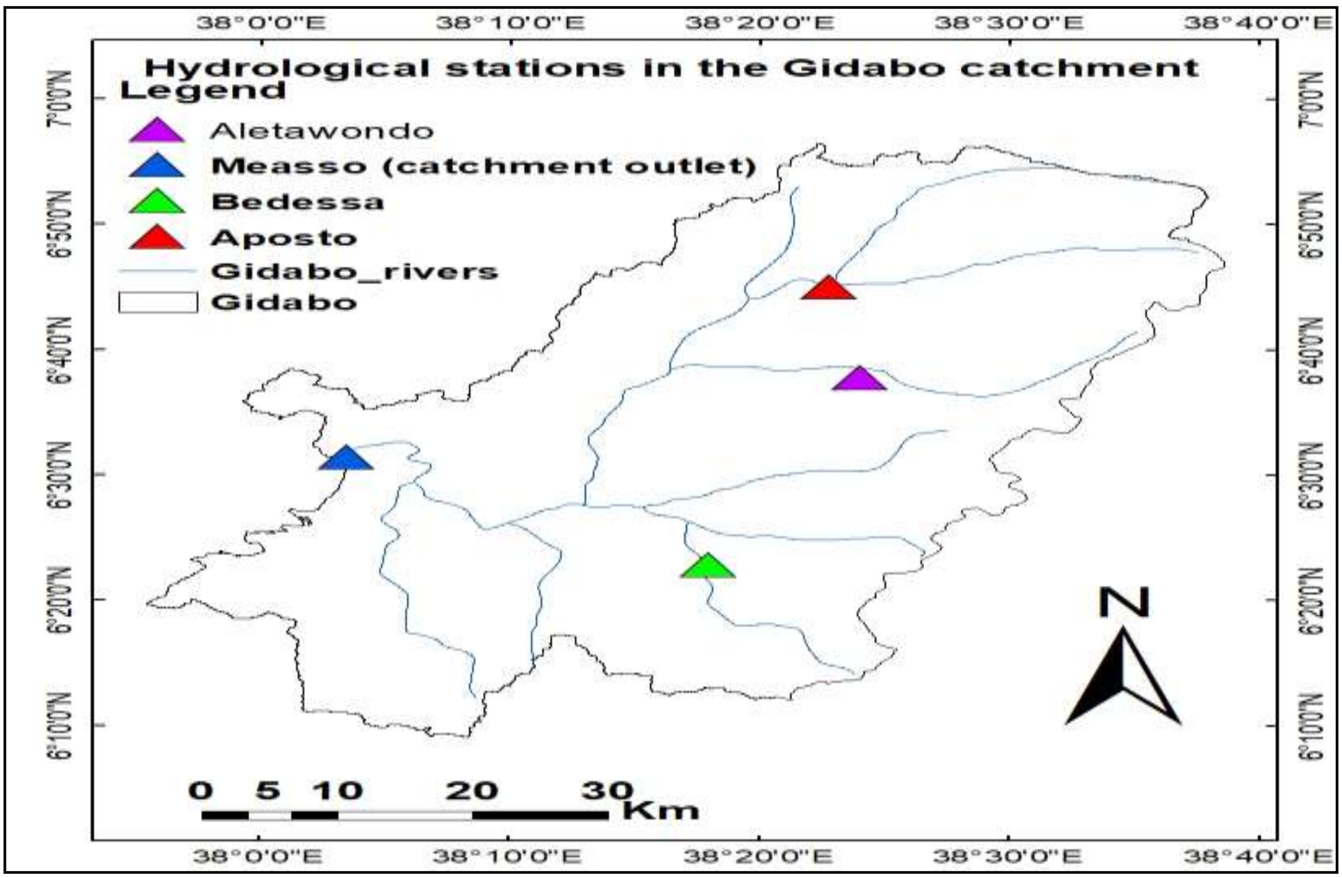


Figure 3. 10 Hydrological stations location of the Gidabo river catchment

The mean monthly stream flow of the Gidabo river catchment of the four hydrological stations located around the catchment from 1997 to 2006 is shown in figure 3.12 below.

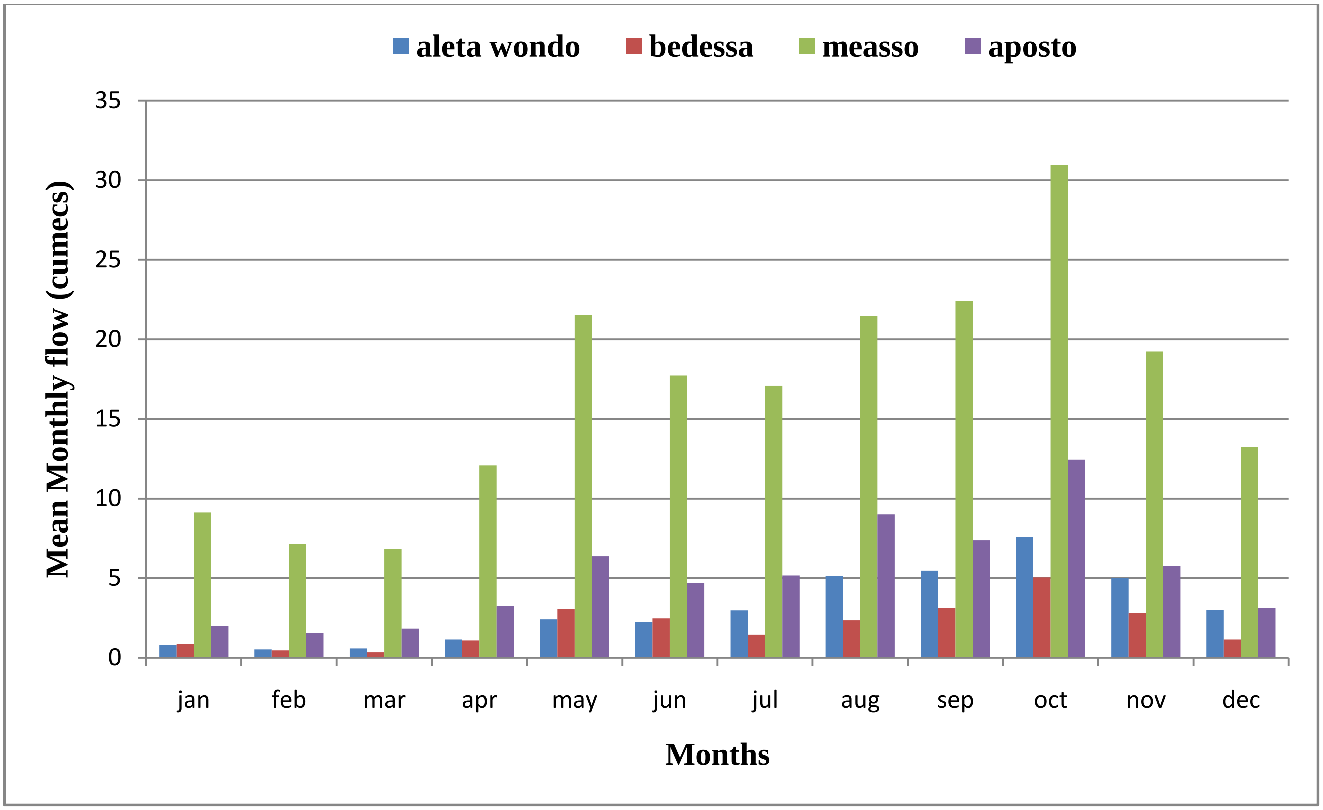


Figure 3. 11 Mean monthly stream flow data of the four hydrological stations in the Gidabo watershed

3.3.5.2 Sediment data analysis

Estimation of sediment yield is important in water resource studies for the design of reservoirs, designing water treatment plant and evaluating the potential sedimentation of reservoirs lakes and ponds. If adequate and reliable records of flow and sediment data are available, various methods could be employed for the estimation of sediment loads in the river catchment. For this study area sediment analysis, the collected sediment data from the MoWIE does not include the data of all the days of months of the years used in this study but rather it is simply the sample taken within different years in different seasons. Due to the absence of complete and long period sediment data, the flow sediment rating curve method is used for good approximation of the sediment loads in the study area watershed and is selected because it is best estimator in cases where sediment data or stream flow data is scattered and/or short periods (MoWE, 2010).

In the flow duration-sediment rating curve method, the sediment rating curve is developed from the available sediment data that has got a simultaneously measured flow data then, by combining the two; the daily sediment yield is obtained. Then the sediment load per day is obtained and then the annual sediment load or the sediment load of any desired duration could be calculated.

The three Gauging stations for the measurement of stream flow and suspended sediment yield sampling was made at the Gidabo near Aleta Wondo, Gidabo near Aposto and Bedessa near Dilla stations. The suspended sediment data for the Meassso (station at the outlet of the watershed) was estimated using area ratio method since the area around Measso has nearly similar catchment characteristics with other listed above stations. As a result, it was mandatory to build up correlation between the suspended sediment load and stream flow for the collected data to get the on a daily basis sediment concentration which is recognized as the sediment-discharge rating curve. The Suspended sediment load computation in this study was completed with the help of the sediment-rating curve which is formed by the stream flow and suspended sediment.

$$Qs = aQ^{b} \qquad (3.23)$$

Where Qs is the sediment load (ton/day, Q is the stream flow discharge (m^3/s), a and b are the coefficients found by the regression analysis. To work on this formula, the sediment load the exchange of the measured sample suspended sediment load from unit of mg/l to unit of ton/day with the exchange formula is needed as expressed by equation 3.13 below.

$$Qs \text{ (metric tons/day)} = 0.0864\ C mg/l * Q \text{ (in m3/s)} \qquad (3.24)$$

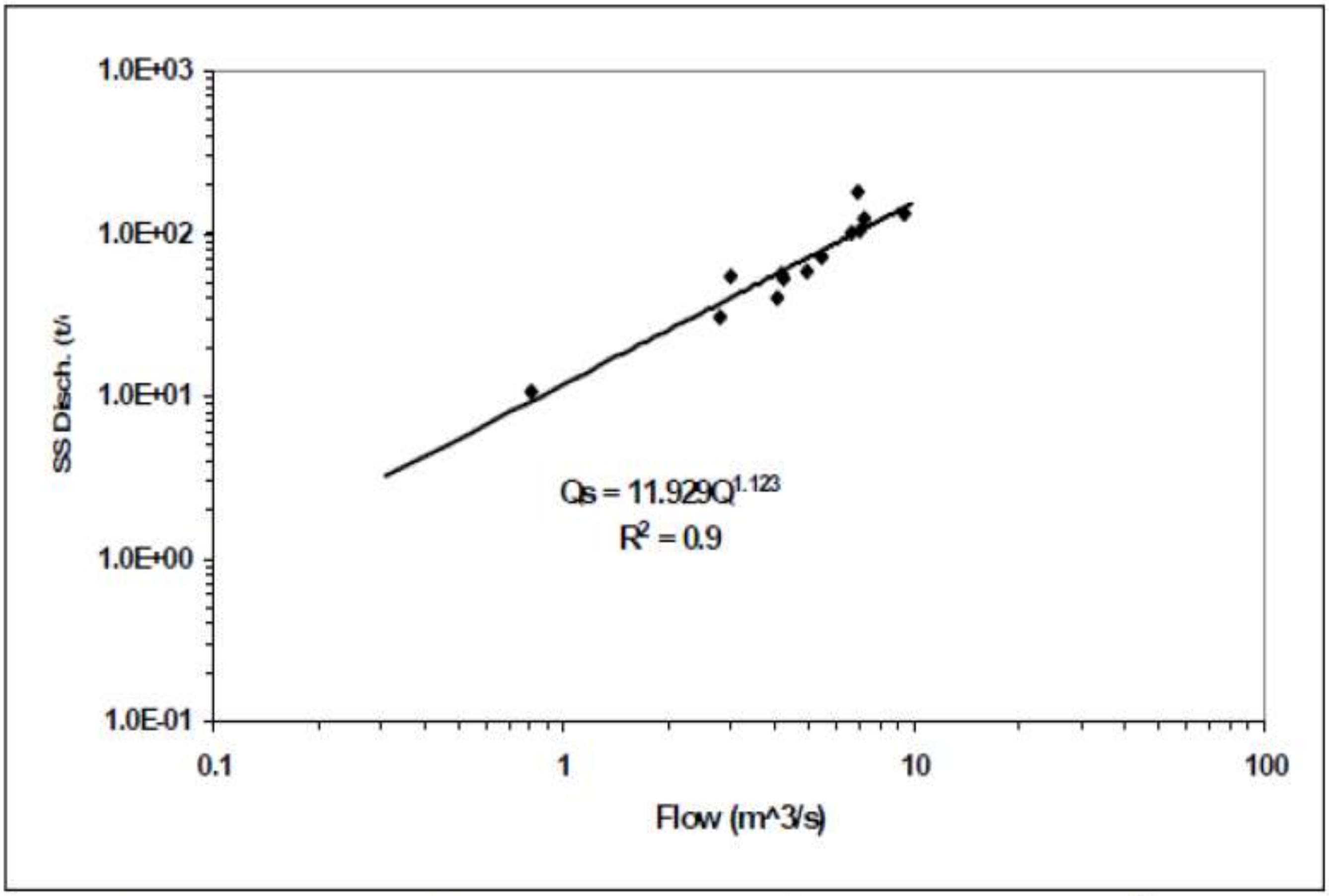
Where:- Qs = the total sediment discharge in tons per day.

Cmg/l = the flux averaged total sediment concentration in mg/l;

Q = the daily mean water discharge in m3/s

The suspended sediment load data obtainable for GRB at Aposto station simultaneously with the measured stream flow is only (1996-2005) for Bedessa and (1994-2005) for Aletawondo with merely very a small amount of data every year. Furthermore, the data do not cover up the complete collection of stream flows; it is covering only low and medium flows. But in the absence of any other data, this data is utilized for the rating curve. The bed load sediment of the river is most probably assumed to be 5% to 25% of the suspended sediment load and for this project the bed sediment load of the river of Gidabo is taken as 10% of the suspended sediment load of the river.

For this research the sediment rating curve of Aposto station taken from the design manual of Gidabo irrigation project of MoWIE and the area ratio technique was used for creating a formula for computation of sediment load at the watershed outlet (un-gauged station) with the help of the total sediment load at gauged Aposto station for the reason that the watershed properties are approximately similar at the Gidabo River Catchment outlet (Measso station).



Where: Q_s is sediment discharge in tons/day and Q is the discharge in m^3/s

Figure 3. 12 Sediment rating curve of Gidsabo watershed at Aposto retrieved from the feasibility the study and design of Gidabo irrigation project volume-III hydrological study section.

Historically, sediment rates in the un gagged catchments have been estimated using a variety of techniques, but the most common and the earliest technique for estimating the daily sediment yield in the un gagged catchment is the watershed area ratio method. The area ratio technique is used to estimate flow and sediment yield in the un gagged catchments when a nearby gagged sub-basin is present for use as a reference. The method estimates the flow and sediment at the un gagged location by multiplying the measured sediment at the nearby reference gage by area ratio of the un gagged to gagged watersheds (chris C. Gianfagna, 19 september 2015).

$$Qs\ un\ gagged = Qs\ gagged \times Area\ of\ un\ gagged / Area\ of\ gagged \qquad (3.25)$$

The major assumption of this method is the sediment yield increases with the watershed area. The other methods for estimating un gagged sediment data includes the empirical regression models, use of flow duration curves and the models developed from the rainfall runoff relationships (chris C. Gianfagna, 19 september 2015).

The choice of gagged station in this method has been determined by geographic closeness to the un gagged watershed i.e. the closest sediment gage. In the other way several reference gages could be used in order to smooth out any timing-related issues between the un gagged and reference locations.

3.4 Methods applied for estimating stream flow and sediment yield using HEC-HMS model

The following steps have been done for the setup and processing of the surface runoff and sediment yield model for estimating the present and future load at the Gidabo river basin (GRB).

1. Secondary data and information collection of the river basin,
2. Filling of the missing data and quality checking of the collected data,
3. Preparing DEM and delineating the watershed of the basin or creating basin model:
4. Processing of necessary input data,
5. Development of the HEC-HMS stream flow model using HEC –GeoHMS,
6. Developing Hydrological and surface erosion model parameters,
7. Editing HEC-HMS stream flow model inputs and simulation,
8. Stream flow model calibration and validation and evaluation of the performance of the model,
9. Development and simulation of sediment model,
10. Sediment routing model calibration and validation. It includes MUSLE factors estimation and selection of calculation methods.

After the DEM and the stream flow lines were gathered and everything fit within the watershed, the process of preprocessing the data for implementation inside a Geo-HMS could precede. This process is essentially watershed delineation and created a series of raster maps that follow a particular order. It is important to ensure that each step is followed and it is in proper order.

The first step was to execute a DEM reconditioning to refine the input terrain data which involved the original DEM as well as the flow lines of the watershed. This function allows for a better spatial referencing with respect to the DEM low points, valleys and existing in flow lines. Following this procedure, HEC-GeoHMS preprocessed the digital elevation model to obtain drainage network and sub-basins of the watershed. The next function was to fill the sinks within the reconditioned DEM. This essentially created a depression less DEM that helps to mitigate problems that will arise during future watershed delineation and analysis.

The flow directions function is the next step which essentially determined the aspect of the topography to determine which direction water will flow. The function only required the fill raster. The next phase was determining the flow accumulation, essentially where water would accumulate during a storm event. As reason would follow the flow accumulation map highlighted the areas of the rivers and streams locations and continue to help better define the streams and topography of the DEM. Next phase was stream segmentation, this essentially created segment of the linked streams that was from the flow accumulation map.

The next raster file was the stream segmentation linkage function, which took all the stream segments and linked them together to create streams throughout the watershed. Following this phase we now have an accurate approximation of the streams with respect to the DEM. The next phase was to create catchment polygons throughout the DEM. These would essentially be the predecessors of the future sub basins in the HMS map. The function essentially breaks up the watershed and creates a shape file within Geo-HMS database for implementation of attribute tables and other relevant data. Breaking the watershed into sub basins allows for better watershed analysis for particular regions within the watershed. After the catchment polygons were created a process of refining the catchment polygons, and then drainage lines attachment and finally adjoinment of the catchment polygons with respect to the drainage lines could be determined for final shape file.

The HEC-HMS project was produced after terrain preprocessing. Initially the project point must be defined at the downstream ending of the catchment based on which the model setup delineated the research project area. The resulting project area for the Gidabo river catchment was 3245.67 km^2. After the delineation, the rivers and sub basins were merged based on stream junctions, batch points which represented the discharge stations were imported and delineated. For every river and sub basins the physical properties were calculated based on the distinguished digital elevation model which includes river length and slope, the slope of the basin, centroid of the basin, the basin longest flow path, the basin longest flow path centroid and basin centroid elevation,.

Afterwards the basin processing step, developing hydrological parameters proceeds by using the soil use data, land use data, slope of the catchment and the stream flow data for each sub-basin. As illustrated in figure 3.14 below, the methodology flowchart of the research shows the general framework that has been used for the stream flow and sediment yield assessment in this study. The historical climate data have been collected from National Meteorological Agency of Ethiopia.

The historical stream flow, soil, land use/land cover and other related ArcGIS data have been collected from ministry of water resources, irrigation and energy. The historical stream flow and sediment data has been used for the model calibration and validation of stream flow and sediment yield. The study area was delineated from DEM in ArcGIS interface where all the land use/land cover, soil and land slope data are clipped successfully to it. The precipitation and stream flow data have been analyzed by double mass curve for consistency and checked for the outlier.

The Methodology used for estimation of stream flow and sediment yield using HEC-HMS model in the Gidabo river basin in this thesis research can be described in a chart as shown in the figure 3.14 below.

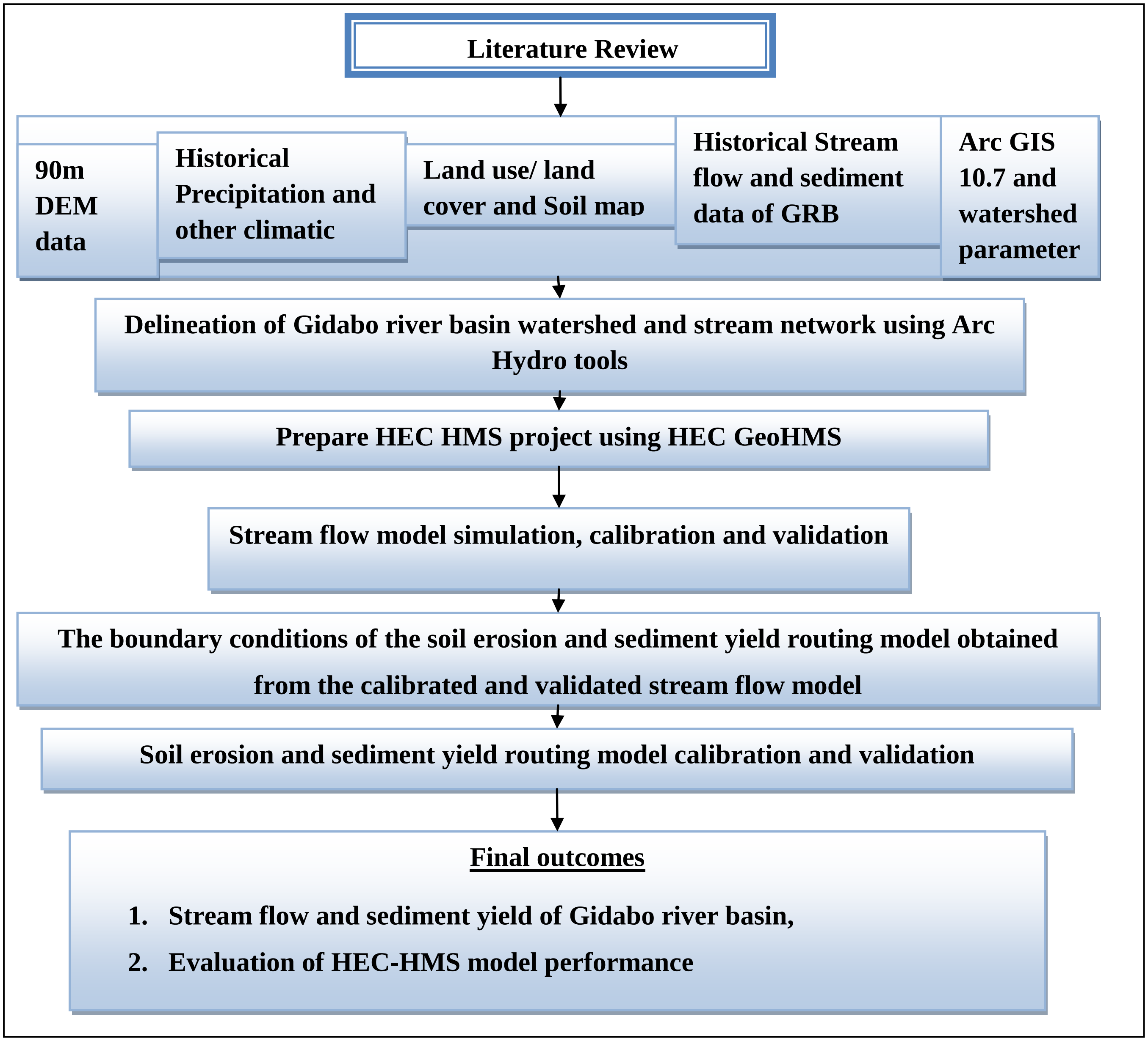


Figure 3. 13 Methodology for estimation of stream flow and sediment yield using HEC-HMS model in the Gidabo river basin.

3.5 HEC-HMS Model Development

3.5.1 Catchment and stream network delineation

Before the HEC-HMS, catchment boundary and streams delineation is necessary for the management of the study area as a watershed using GIS and HEC Geo-HMS. Catchment delineation which is the first step of any hydrologic modeling to get basic watershed properties like catchment area, slope, flow length and stream network for the study area which was performed using Arc hydro tools and the output files from the terrain preprocessing are used to generate input documents for HEC-HMS models by using the HEC's Geospatial Hydrologic Modeling Extension; HEC-Geo-HMS.

3.5.2 HEC-HMS Model Application

The following five components: basin model, meteorological, time series data and control specification and the paired data components are created when the HEC-HMS is opened. The basin component is formed based on the background map which holds the delineated catchment sub basins resulting from the GIS tools. The meteorological section contains the pragmatic rainfall and potential evapo-transpiration data divisions in the sub basins. The control specification element of the HEC-HMS model controls the simulation time and the time gap to be used in the simulation. The time series data section of the HEC-HMS model contains the precipitation, discharge, and sediment load and evapo-transpiration gages and the paired data component contains functions and graphs of different data of the catchment.

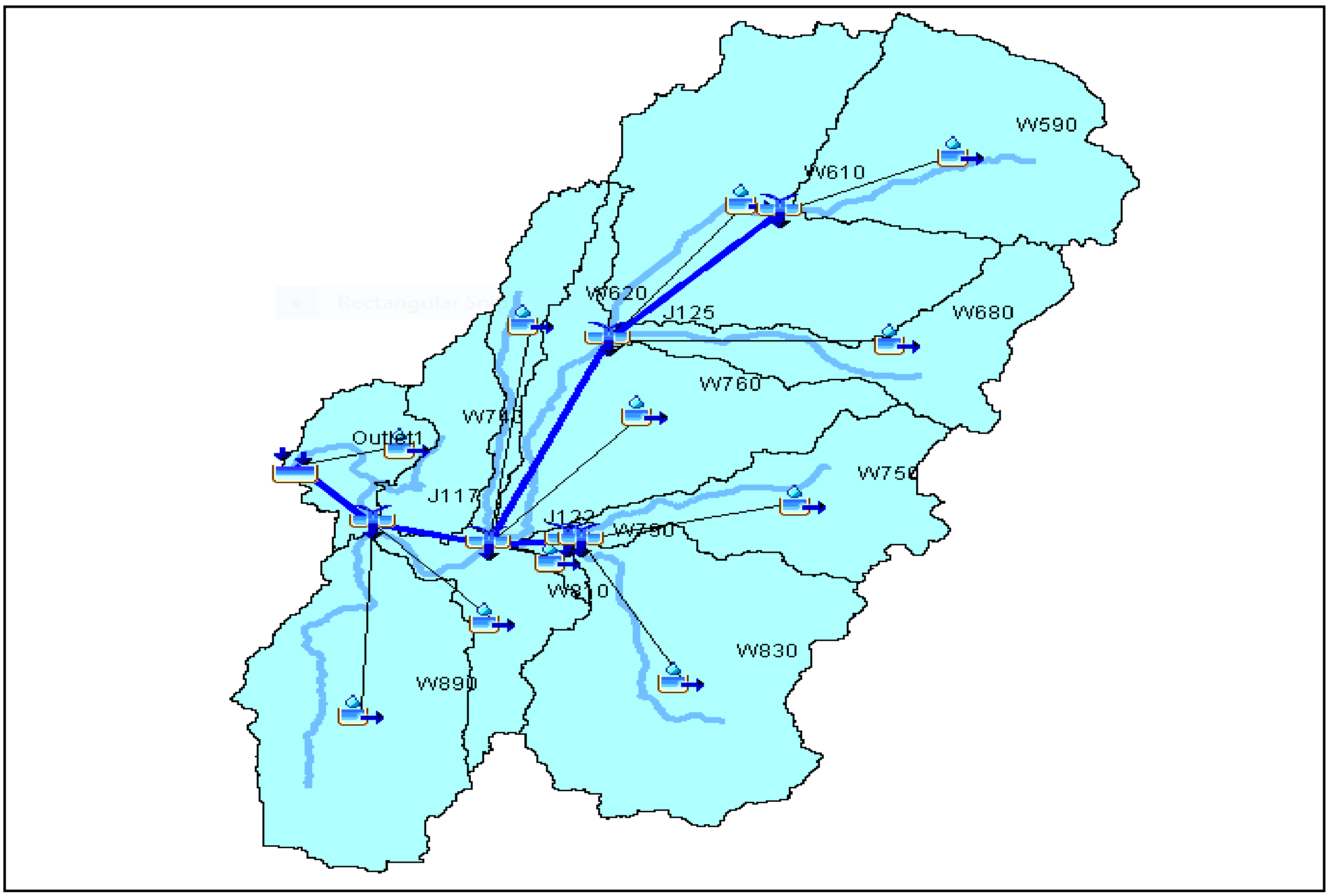


Figure 3. 14 Schematic of the Gidabo watershed model showing sub-basins and river created by HEC-HMS model with the naming of the sub-basins, reaches and junctions begins with W, R and J respectively.

The model of the study area of Gidabo watershed created by the HEC-HMS contains eleven sub basins, six reaches and six junctions as shown above in figure3.16.

3.5.3 Processing Input Data used in the HEC-HMS model

3.5.3.1 Determination of Gage weight factors

It is necessary to use the interpolation techniques to accomplish precise computation of the spatial delivery of the precipitation to the catchments. From the many techniques used the thiessen polygon is one techniques of interpolation which considers the values of un-sampled places are equivalent to the value of the nearby sampled location. The thiessen polygons are formed by subdividing the lines unifying the adjacent neighbor locations, sketching bisectors perpendicularly through these lines, and subsequently using these bisectors to bring together polygon boundary (Shammi Haque, 2018).

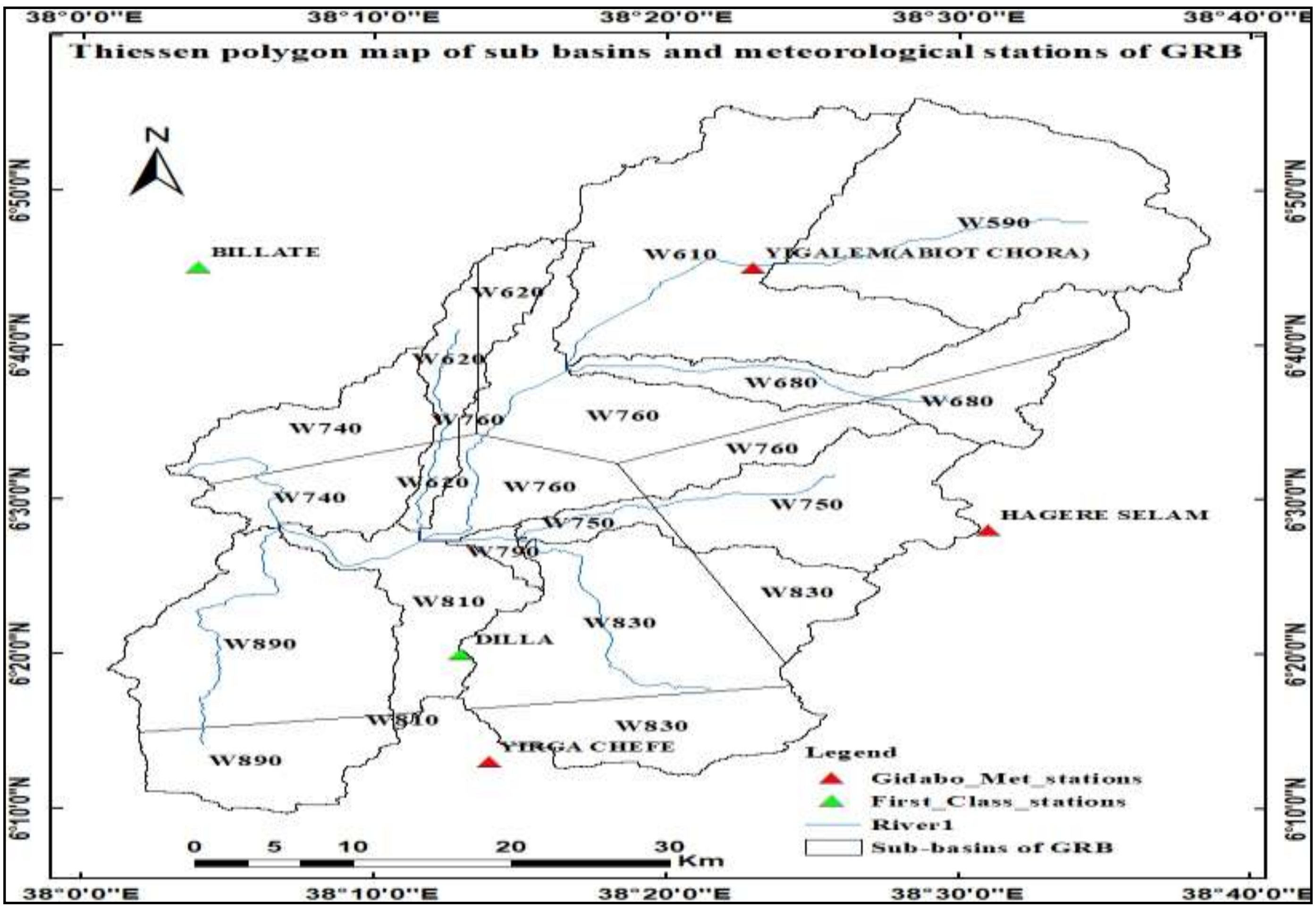


Figure 3. 15 Intersection of thiessen polygons of meteorological stations with the sub basins of Gidabo River Basin

For manipulating the average precipitation over an area of a watershed in thiessen polygon method weight ratio factor, which is described as the ratio of area of a thiessen polygon to the area of its analogous catchment sub-basin polygon as shown in the equation 3.26 below.

$$Wij = Aij/Sij \tag{3.26}$$

Where Wij is the weight ratio factor of gauge i for watershed j, Aij = is the area of the polygon created by the joint of thiessen polygon of gage i with the sub basin j. Sj = area of watershed j.

Table 3. 10 Estimated percent weight factors for sub basins and the meteorological stations of Gidabo catchment

Sub basin	Station	Sub basin area(km^2)	Polygon area (km^2)	Percent weight factor of station for sub basin (%)
W680	Hagereselam	220.952	69.853	31.61
W680	Yirgalem	220.952	151.1	68.39
W760	Hagereselam	372.948	79.89	21.42
W760	Yirgalem	372.948	188.06	50.43
W760	Billate	372.948	3.76	1.01
W760	Dilla	372.948	101.244	27.15
W620	Yirgalem	115.879	46.944	40.51
W620	Billate	115.879	47.794	41.24
W620	Dilla	115.879	21.14	18.24
W810	Yirgachefe	146.95	1.886	1.28
W810	Dilla	146.95	145.064	98.72
W590	Yirgalem	454.621	454.62	100
W790	Dilla	17.05	17.05	100
W740	Billate	219.494	122.409	55.77
W740	Dilla	219.494	97.085	44.23
W750	Dilla	249.885	30.955	12.39
W750	Hagereselam	249.885	218.93	87.61
W610	Yirgalem	488.835	488.835	100

W830	Hagereselam	522.928	79.783	15.26
W830	Yirgachefe	522.928	149.176	28.53
W830	Dilla	522.928	293.968	56.22
W890	Yirgachefe	436.28	132.55	30.38
W890	Dilla	436.282	303.734	69.62

3.5.3.2 Estimating the Impervious Area

The impervious surface is the percentage of land that is covered with impervious materials and any material covering the ground that prevents the infiltration of water in to the soil and the ground moisture cannot escape in to the atmosphere can be grouped as the impervious surface which results in increased surface flow. Impervious surface area for the catchment was defined by using the GIS with the help of the Land use /Land cover map.

The impervious surface have great impact on the watershed water quality and sediment yield, since the increase in the impervious surface results in the lowering of the ground water which leads water shortage. The impervious surface increase the runoff which in turn leads to the increase in flooding events and the rise in acquisition of sediment which imposes sever risks to the personal property and human life in the community living in the area.

HEC-HMS model needs the percentage of impervious area for each sub basin. Considering artificial surfaces area for each sub-basin of Gidabo river basin, percentage of the impervious area for each sub basin has been estimated with the values ranging from 0 to 3% for each sub-basin.

Table 3. 11 impervious percentages of different land use (Rick Guthrie, 2001)

Land use type	Percent impervious (%)
Forest	1
Wetlands/ water body	0
Grass lands	3
Agriculture	3
Rural residential	8
Roads	90
Urban human settlement	80

The percentages of impervious surfaces of each Gidabo river catchment sub-basin is calculated by multiplying the values of the above table 3.11 for each land use type and the percentage of area of each land use of the sub-basin and the percentages of impervious of each sub-basin are shown below in table 3.12.

Table 3. 12 Percent impervious and C factor (Center, 2018) of Different Land use/ Land covers for sub basins in Gidabo River Catchment

Sub basins	Land use	Sub basins area	Land use Area	Percent Impervious	Average percent impervious	C factor
W830	Grassland		38.16	3		0.1
	Settlement	522.93	9.41	8		0
	Cropland		432.43	3	3.0	0.1
	Barren land		7.5	3		1
	Forest		35.12	1		0.0001
W610	Crop land		268.76	3		0.1
	Grassland	488.84	219.98	3	3	0.1
W590	Crop land		441.02	3		0.1
	Barren land	454.46	3.57	3	3	1
	Grassland		9.87	3		0.1
W680	Crop land	220.95	206.8	3	3	0.1
	grassland		13.97	3		0.1
W750	Crop land		222.64	3		0.1
	shrub	249.89	10.41	3	2.9	0.1
	Settlement		0.947	8		0
	Forest		15.72	1		0.0001
W760	Crop land		185.86	3		0.1
	Wetland	372.95	3.84	0	2.6	0
	Forest		62.66	1		0.0001
	Shrub/bush		120.59	3		0.1
W810	Crop land		3.55	3		0.1
	Wetland	146.95	14.68	0	1.0	0

	Woodland		128.68	1		0.0001
W890	Crop land Wet Woodland Barren land	436.28	14.87 44.01 256.68 120.5	3 0 1 3	1.5	0.1 0 0.0001 1
W620	Grass land Wetland Forest	115.88	60.52 0.626 54.68	3 0 1	2.0	0.1 0 0.0001
W740	Grass land Wetland Forest	219.49	1.38 41.39 176.7	3 0 1	1	0.1 0 0.0001
W790	Wetland Forest	17.05	0.92 16.13	0 1	1	0 0.0001

3.5.3.3 Estimating soil moisture accounting (SMA) loss parameters

The canopy in the SMA is a constituent of the sub-basin which is anticipated to signify the existence of plants in the area and the parameters are taken from the land use/ land cover map grids with the following steps.

1. First, clip the land cover raster to the project boundaries. Open the attribute table of the land cover raster. Note that the Value field contains Land Cover Database Classes. Create a new field of type Double and name it Canopy_int. Use the canopy interception values as shown in the Table 3.13 below.
2. create the canopy interception raster by selecting Grid _Code for value filled every bit of the rainfall is stored in the canopy pending the canopy storage space is becoming full. After the canopy is filled the excess rainfall drops on the surface of the soil following the passing of the precipitation through the canopy. The canopy values and surface soil storage were found from the examination of the digital elevation model and Land Use maps of the catchment.

Table 3. 13 Values of canopy interception (A.Ahbari, 2017)

Vegetation type	Interception of canopy (mm)
Grasses and Deciduous Trees	2.032
General vegetation	1.270
Trees and Coniferous Trees	2.540

In the HEC-HMS settings there is specified surface technique which is used to represent the depression of the ground surface where runoff is stored following the fillings of the pores in the soil to the soil's field capacity. The excess surface runoff subsequently stored in the depression storage in anticipation of the runoff starts to happen as component of the rainfall flowing profoundly into the sub surface water zone. While the rainfall velocity better than the infiltration rate of the soil and the storage in the depressions is occupied, the runoff starts to flow.

Table 3. 14 Surface Depression Storage values (Bennett, 1988)

Surface description	Surface Storage	Slope
Steep, Smooth Slopes	1.02	>30
Moderate to Gentle Slopes	6.35-12.70	5-30
Flat, Furrowed Land	50.8	0-5
Impervious paved areas	3.18-6.35	NA

The saturation hydrologic conductivity of layer one is considered to be the maximum soil infiltration rate (mm/hr). The maximum soil percolation rate and Groundwater 1 maximum percolation is found by multiplying the corresponding component percent average of soils coverage in the sub-basin by the saturated hydraulic conductivity of the soil types.

Table 3. 15 Soil texture and properties (Rawls, 1982)

Soil Texture	Saturated hydraulic conductivity (mm/hr)	Porosity, cm^3/cm^3	Field capacity
Sandy	210	0.437	5
Loamy sand	61.1	0.437	22
Sandy loam	25.9	0.453	18
Loam	13.2	0.463	30
Silt loam	6.8	0.501	31
Sandy clay loam	4.3	0.398	27
Clay loam	2.3	0.464	36
Silty clay loam	1.5	0.471	33
Sandy clay	1.2	0.43	20
Silty clay	0.9	0.479	37
Clay	0.6	0.475	42

The maximum soil profile storage is found by multiplying the average percent weight of the depth from the soil surface to the bottom of the layer with the representative soil porosity.

The tension storage was determined from the soil map based on soil texture values by multiplying the representative field capacity with the representative depth from the soil surface to the bottom of the layer and the percolation velocity of soil and the subsurface water level (GW1) percolation velocity was taken as the average of all sub basins soil texture hydraulic conductivity.

Field capacity is the amount of water remaining in the soil a few days after having been wetted and after free drainage has ceased. Different soils have different field capacity and 100% field capacity is the point that the soil holds maximum water. The volumetric soil moisture content remaining at field capacity is about 3 to 25% for sandy soils, 35 to 40% for loam soils, and 40 to 55% for clay soils.

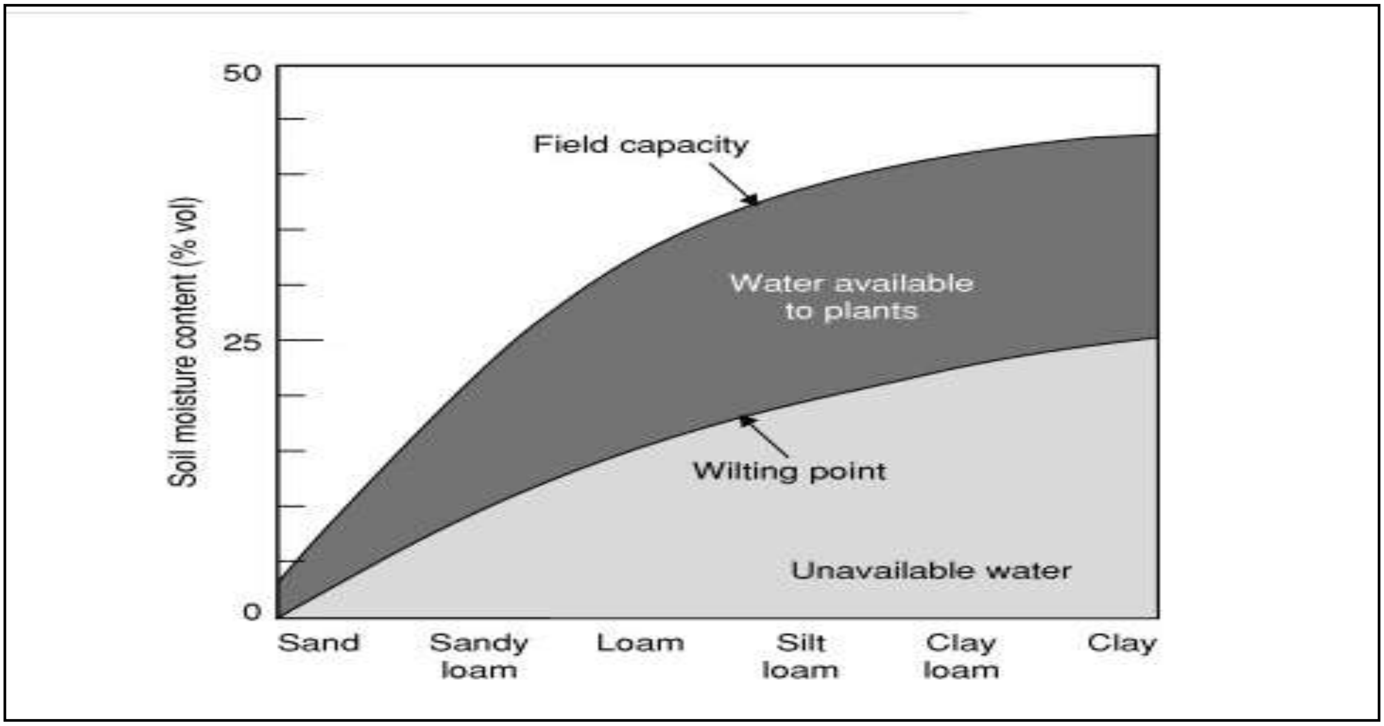


Figure 3. 16 Field capacity of Different soil types (Shirsat, 2005).

The storage coefficients and depths of the GW1and GW2 were determined based on the stream flow recession analysis of the time series stream flow data where as the percolation rate of GW2 were obtained during calibration process by taking the saturated hydraulic conductivity of soils in the sub-basin as the initial parameter for the simulation.

The representative field capacity of soils which is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased. This usually takes place 2–3 days after rain or irrigation in pervious soils of uniform structure and textures with the higher the percentage of silt and clay sized particles, the higher the water holding capacity. All of these are used as an input for soil moisture accounting (SMA) model in HEC-HMS. The following Table 3.16 shows the saturated hydraulic conductivity (cm/hr), the porosity (used for calculating soil storage) and the soil erodibility, K factor discussed later in this chapter, of different soil texture in the Gidabo river catchment used in the HEC-HMS model as an input parameter.

Table 3. 16 Gidabo river catchment soil properties and texture

Sub basins Area (km^2)	Soils code	Soils Name	Percentage (%)	Slope (%)	Texture	Saturated Hydraulic conductivity (cm/hr)	Porosity (cm^3/cm^3)	K(ton/ hectare)
W590 (454.62)	LVh	Haptic Luvisols	67.41	8.21	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	0.842		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	30.63		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	1.09		Sandy loam	2.59	0.453	0.24
W610 (488.84)	LVh	Haptic Luvisols	6.52	14.57	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	24.66		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	65.33		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	3.56		Sandy loam	2.59	0.453	0.24
W620 (115.88)	NTu	Humic Nitisols	9.55	20.98	Loam	1.32	0.463	0.42
	LVx	Chromic Luvisols	67.95		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	22.5		Sandy loam	2.59	0.453	0.24
W680 (220.95)	NTu	Humic Nitisols	33.05	9.68	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	25.61		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	14.72		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	26.55		Sandy loam	2.59	0.453	0.24
W740 (219.49	NTu	Humic Nitisols	64.49	10.52	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	20.85		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	14.66		Clay	0.06	0.475	0.2
W750 (249.88)	NTu	Humic Nitisols	0.56	13.26	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	78.88		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	20.46		Sandy loam	2.59	0.453	0.24
W760 (372.95)	NTu	Humic Nitisols	12.7		loam	1.32	0.63	0.42
	VRe	Eutric Vertisols	23.58	20.61	Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	39.68		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	24.03		Sandy loam	2.59	0.453	0.24
W790 (17.05)	NTu	Humic Nitisols	30.7		loam	1.32	0.563	0.42
	VRe	Eutric Vertisols	48.103	23.85	Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	0.132		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	21.07		Sandy loam	2.59	0.453	0.24

W810 (146.95)	LPe	Eutric Leptosols	15.63	21.86	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	72.07		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	11.85		Clay	0.06	0.475	0.2
	Lpq	Lithic Leptosols	0.42		Sandy loam	2.59	0.453	0.24
W830 (522.93)	LPe	Eutric Leptosols	11.92	13.07	Loam	1.32	0.463	0.42
	VRe	Eutric Vertisols	28.46		Clay	0.06	0.475	0.2
	NTu	Humic Nitisols	30.07		Loam	1.32	0.463	0.42
	Lpq	Lithic Leptosols	29.5		Sandy loam	2.59	0.453	0.24
W890 (436.28)	LPe	Eutric Letposols	20.09	10.36	Sandy loam	2.59	0.453	0.24
	VRe	Eutric Vertisols	66.97		Clay	0.06	0.475	0.2
	LVx	Chromic Luvisols	0.09		Clay	0.06	0.475	0.2
	NTu	Humic Nitisols	12.8		loam	1.32	0.463	0.42

3.5.3.4 HEC-HMS SMA Parameters estimated from stream flow data

For this study area, the daily stream flow data storms occurring in different months and years which are fairly isolated and the stream flow hydrograph is allowed to return to normal for a pair of days before runoff from the next storm is visible. Stream flows consist of from three different sources: stream channels (surface flow), surface soil (interflow) and ground flow (base flow). So the breakup of the stream flow hydrograph in to its various components is necessary for soil moisture accounting in HEC-HMS model.

After creating of the hydrograph of the stream flow data, the tail end of the receding limb represents the time when ground water is the only source contributing to the stream flow when the surface runoff and interflow have stopped.

From the tail end of the receding limb the line is projected to the time of the peak flow, maintaining the slope of that tail-end portion and connects the line to the point at which the hydrograph begins to rise as a result of runoff. Now subtract the ground flow from the stream flow and plot the result on the same graph and then the line represents the contribution to the stream flow from surface runoff and inter flow. Using the same method as is used to create the groundwater line, the inter flow is created which represents GW1. In the runoff and interflow hydrograph portion, the receding limb with the gentle or shallowest slope is selected.

In the soil moisture accounting (SMA) loss method, ground water 1 (GW1) represents the interflow and Groundwater 2 (GW2) represents groundwater or base flow.

The groundwater 1 storage (mm), and the ground water 1 storage coefficient (hr), ground 2 storage (mm),and the ground water 2 storage coefficient (hr) initial value parameters are calculated based on the daily discharge at the out let of the basin as follows (A.Ahbari, 2017):

1. Identify all the hydrograph events using the daily discharge
2. For each event extend the decreasing discharge part having the slowest slope, until the time of the event

The recession curve can be described as:

$$Kr = Qt/Qo \tag{3.27}$$

Where Qo is the initial stream flow, Qt is the stream flow at the certain time t, Kr is a recession constant less than 1 and the storage coefficient, ɑ can be found by using the equation,

$$\text{Storage coefficient} = -1/\ln Kr. \tag{3.28}$$

The recession coefficient =1/ɑ, using the same section of the stream flow hydrograph, finally the ground 2 storage depth for each is calculated as;

$$St = -Qt/Ln(Kr) \tag{3.29}$$

Finally, following the same procedures as above and by using runoff and interflow graph, the Ground water 1 recession coefficient and storage depths can be estimated (Holberg, June 2014).

3.5.3.5 HEC-HMS Base flow Parameters estimation

For this study area the recession model is used for the estimation of base flow. The recession constant in this method describes the rate at which the base flow recedes between storm events and it can also be defined as the ratio of base flow at the current time to the base flow of the former day. Ratio to peak flow determines how to reset the base flow during storm event (Center, 2018). The recession method of base flow estimation is used conjunction with the soil moisture accounting (SMA) loss method.

3.5.3.6 HEC-HMS Channel flow Parameters estimation

The routing models compute the downstream hydrograph from the known boundary condition of upstream hydrograph by solving the momentum and continuity equations. For this study area Muskingum-cunge routing is used and all the parameters except the manning roughness coefficient are found from field measurements.

The Muskingum-cunge model is based up on the combination of the continuity equation and momentum equation as;

$$\frac{\partial Q}{\partial t} + c\frac{\partial Q}{\partial x} = cql + \mu\frac{\partial^2 Q}{\partial x^2} \quad (3.30)$$

Where; c is the wave celerity, μ is the hydraulic diffusivity and ql is the lateral inflow.

$$\boldsymbol{c} = \frac{\mathbf{dQ}}{\mathbf{dA}} \quad (3.31)$$

$$\text{And } \boldsymbol{\mu} = \frac{\mathbf{Q}}{\mathbf{2BSo}} \quad (3.32)$$

Where; B is the top width of the surface and So the top surface slope.

A finite difference approximation of the partial derivatives, combined with equation 3.30 results

$$O_t = C_1 I_{t-1} + C_2 I_t + C_3 O_{t-1} + C_4(q_l \Delta x) \quad (3.33)$$

$$\text{Where, } C1 = \frac{\frac{\Delta t}{K}+2x}{\frac{\Delta t}{K}+2(1-x)},\ C2 = \frac{\frac{\Delta t}{K}-2x}{\frac{\Delta t}{K}+2(1-x)},\ C3 = \frac{2(1-x)-\frac{\Delta t}{x}}{\frac{\Delta t}{K}+2(1-x)} \text{ and } C4 = \frac{2(\frac{\Delta t}{K})}{\frac{\Delta t}{K}+2(1-x)} \quad (3.34)$$

Cunge's derivation resulted in the following values for the parameters K and X;

$$K = \Delta x/c \quad (3.35)$$

$$X = ½(1-(Q/(cBSo\Delta x))) \quad (3.36)$$

Where; K is the travel time of peak through the reach (hr) and X is the weight on inflow versus outflow ($0 \leq X \leq 0.5$), X=0 for reservoir, X=0.0-0.3 for natural channels.

$$\Delta x = c\Delta t \text{ and } \Delta x < 1/2(c\Delta t + Q_o/(BS_o c) \quad (3.37)$$

Where, Q_o is the reference flow computed from the inflow hydrograph using equation (3.14) below.

$$Q_o = Q_B + 1/2(Q_{peak} - Q_{B)} \quad (3.38)$$

Here, Q_{peak} is the inflow peak and Q_B is the base flow.

3.5.3.7 Direct runoff Parameters estimation

This model simulates the direct runoff excess precipitation on a watershed or it is the change of precipitation excess in to point runoff. The basin outflow obtained from one unit of direct runoff produced consistently over the area of the drainage at a uniform precipitation rate during a known period of rainfall period.

The Clark unit hydrograph which was used in this study area is a synthetic unit hydrograph, which means that the user is not required to develop a unit hydrograph through the analysis of past observed hydrographs.

According to Clark the travel time (Tt), which is the time it takes water to travel from one location to another in the watershed, is the component of time of concentration (Tc), which is the time for the runoff to travel from the most distant point of the watershed to the point of interest with in the watershed and is the maximum travel time in the sub basin. Tc, which influences the shape and peak of the runoff hydrograph, is computed by summing all the travel times.

$$Tc = T_{t1}+T_{t2}+\ldots T_{tm} \tag{3.39}$$

Travel time is the ratio of flow length to flow velocity:

$$Tt = \frac{L}{3600V} \tag{3.40}$$

Where; Tt = travel time, (hr), L = flow length, (m), V= flow velocity, (m/s) and 3600 = conversion factor from seconds to hour.

According to the HEC-HMS 4.3 manual, the ratio of storage coefficient, R and time of concentration, Tc (R /(R+Tc) tends to be fairly constant for the watershed. For this study area assuming the constant to be 0.65, then the storage coefficient R is;

$$R = (13/7)Tc \tag{3.41}$$

The average velocity estimation for the computation of travel time for this research is taken from the graph of urban hydrology for small watersheds, TR-55 (Agriculture, June,1986).

3.5.3.8 Estimation of the Erodibility Factor (K)

In this research as described in chapter two, the modified universal soil loss (MUSLE) equation found in the HEC-HMS model was used to estimate the sediment yield. The modified universal soil loss (MUSLE) equation can be described as;

$$\text{Sediment yield} = 11.8 \times (Q_{sur} \times q_{peak})^{0.56} \times K \times LS \times C \times P \text{ (metric unit)} \tag{3.42}$$

(The symbols Q_{sur} , q_{peak} , K,LS,C and P are described in chapter two).

The erodibility factor (K) in the MUSLE equation (3.42) above is used to describe the susceptibility to detachment and transport of soil particles under the amount and rate of runoff for specific rainfall measured under standard plot. The soil erodibility factor, K is the function of the soil configuration, texture, permeability and organic matter content ranging high for clayey loam and silty soils to low for the unconsolidated loamy sand and it describes the difficulty of eroding soil or it is the measure of the soils resistance to the erosive powers of the rainfall and runoff energy and also calculates the inherent erosion.

Table 3. 17 Soil Erodibility factor, K factor data ((David, 1988) and

(Robert P. Stone & Don Hilborn, October 2015)

Texture Class	K Factor (tone/hectare)
Clay	0.13-0.26
Clay loam	0.22-0.50
loam	0.19-0.63
Sandy clay	0.09-0.20
Sandy loam	0.23-0.30
Silt loam	0.30-0.60
Silt clay	0.19-0.27

3.5.3.9 Estimation of the topographic factor (LS)

The combined slope length and slope angle (LS-factor) has the highest influence on the modified soil loss equation. L and S factor are usually considered together to combine the effect of slope steepness and the impact of slope length respectively, which basically reflects the terrain on a given site and describes the effect of topography on soil erosion. In this study, the approach developed by the Moore and Burch (1985) is used to compute the LS factor.

Moore and Burch (1985) equation:

$$LS = (\text{Slope Length}/22.13)^{0.4} \times (0.01745\text{Sin}\Theta/0.0896)^{1.4} \times 1.4 \quad (3.30)$$

Where Slope Length is flow accumulation ×cell resolution of the DEM (for this study area 90m resolution is used) and Ɵ is slope in degree.

For the calculation of LS factor using DEM in Arc Map the following steps should be done:

1. Calculate fill sinks,
2. Calculate flow direction using Fill sinks data as an input,
3. Calculate flow accumulation using flow direction data as an input,
4. Calculate the slope of watershed in degree using DEM as the input layer and finally,
5. Write the LS factor formula in Arc map to calculate raster data.

3.5.3.10 Estimating land cover and management factor (C)

The land cover and management feature defines the power of the plant canopy on erosion of surface soil. For bare ground C factor is 1indicating the land is susceptible to erosion, for fully mulched or covered soils, C is 0.1 and for forest soils with well developed soil under a dense tree canopy is 0.0001 (Center, 2018). The initial parameter values of the land cover and management factor (C) for this research are shown in table 3.12 above.

3.5.3.11 Estimating of the threshold

Threshold is the lower flow or runoff that can cause surface soil erosion. Runoff less than the threshold value will not cause erosion of soil and as a result will no sediment yield. The threshold parameters for this research were estimated from the calibration process.

3.5.3.12 Estimating of the soil practice factor

The soil support practice factor accounts for the managing practices which reduces the wearing away potential of run off by their pressure on drainage patterns,, runoff velocity, runoff concentration and hydraulic forces exerted by the runoff on the soil surface

It describes the effect of the specific soil conservation practices, the best management practices, which includes the agricultural practices of terracing, strip cropping, contouring and the urban practices of the silt fence, settling basins and hydro seeding. The values of the soil practice factor decreases by adopting these preservation practices as they diminish the runoff rate and volume of the catchment and support the deposition of sediment on the mount slope surface.

For this study area the practice factor of sub-basins were estimated using the contouring and slope relationship given in table 3.18 below.

Table 3. 18 Support practice factor according to the cultivation method and slope

(Shammi Haque, 2018)

Slope (%)	Contouring
0.0-7.0	0.55
7.0-11.3	0.60
11.3-17.6	0.80
17.6-26.8	0.90
26.8>	1.00

And the exponent used in the MUSLE equation which is used to distribute the sediment load in to the time series sedigraph is fixed in the calibration process in this research.

3.5.4 Development of Stream flow model using HEC-HMS

3.5.4.1 Initial Model Simulation

A basin input file is developed at the end of the process in HEC-GeoHMS. Map is converted to the HEC-HMS model Units. HEC-HMS schematic tool creates a GIS representation of the hydrologic system using a schematic network with basin elements and their connectivity.

Two shape files: one for river and one for sub basin are created in the project folder. HEC-HMS legends and coordinates are added. Coordinate tools add geographic coordinates to features in HMS Link and HMS Node feature classes. This is useful for exporting the schematic to other models or programs without losing the geospatial information. The project is created through create HMS project. This function copies all the project specific files that have created (.map and .met) to a specified directory and creates (Shammi Haque, 2018).

Subsequently to the formation of the project in the HEC-HMS model, every bit of the crucial corrected meteorological data and hydrological data are incorporated in the model and characterization of the methods used and the preliminary values of the parameters in the sub basins were worked out.

For this study, the soil moisture accounting algorithm was selected for modelling the loss based on the continuous time scale while the Clark unit hydrograph method for direct runoff computation, the recession method for base flow computation and Muskingum-cunge for reach routing method.

The initial parameters for the SMA model as discussed in earlier chapters were estimated for the soil data, land use data and topography of the area. The parameters in the Clark UH i.e. time of concentration is obtained from the GIS processing of the basin while the storage coefficient was evaluated by calibration. The Muskingum-cunge parameters were taken from field data recordings and the recession method used for base flow computation parameters were found as earlier described.

Table 3. 19 Estimated values of selected parameters in HEC-HMS used in this research

Parameter	value
Manning's roughness coefficient	0.04-0.05
Effective river width	4.2 m-6.0 m
Length	1123.675 m -26647.0389 m
Slope	0.0226m/m-0.089 m/m
Surface storage	0.7255 mm-11.862 mm
Maximum infiltration rate	2.3mm/hr-11.5 mm/hr

3.5.4.2 Calibration and validation of stream flow model

Before considering the outputs of a hydrological model as reliable results it needs to be calibrated and validated using the observed data of stream flow. Since HEC-HMS is all about the correct and physically–based parameterization of the catchment, it is necessary to estimate the correct parameter values by using the process of calibration. Calibration is the process whereby the selected parameters and variables of the models are adjusted to make the model output match inspected data for the assessment of the integrity of the model and to bring to a close whether the model is capable to calculate and present credible outputs.

Calibration is the estimation and modification of model parameters and constants to improve the conformity amid the model output data and the recorded data set.

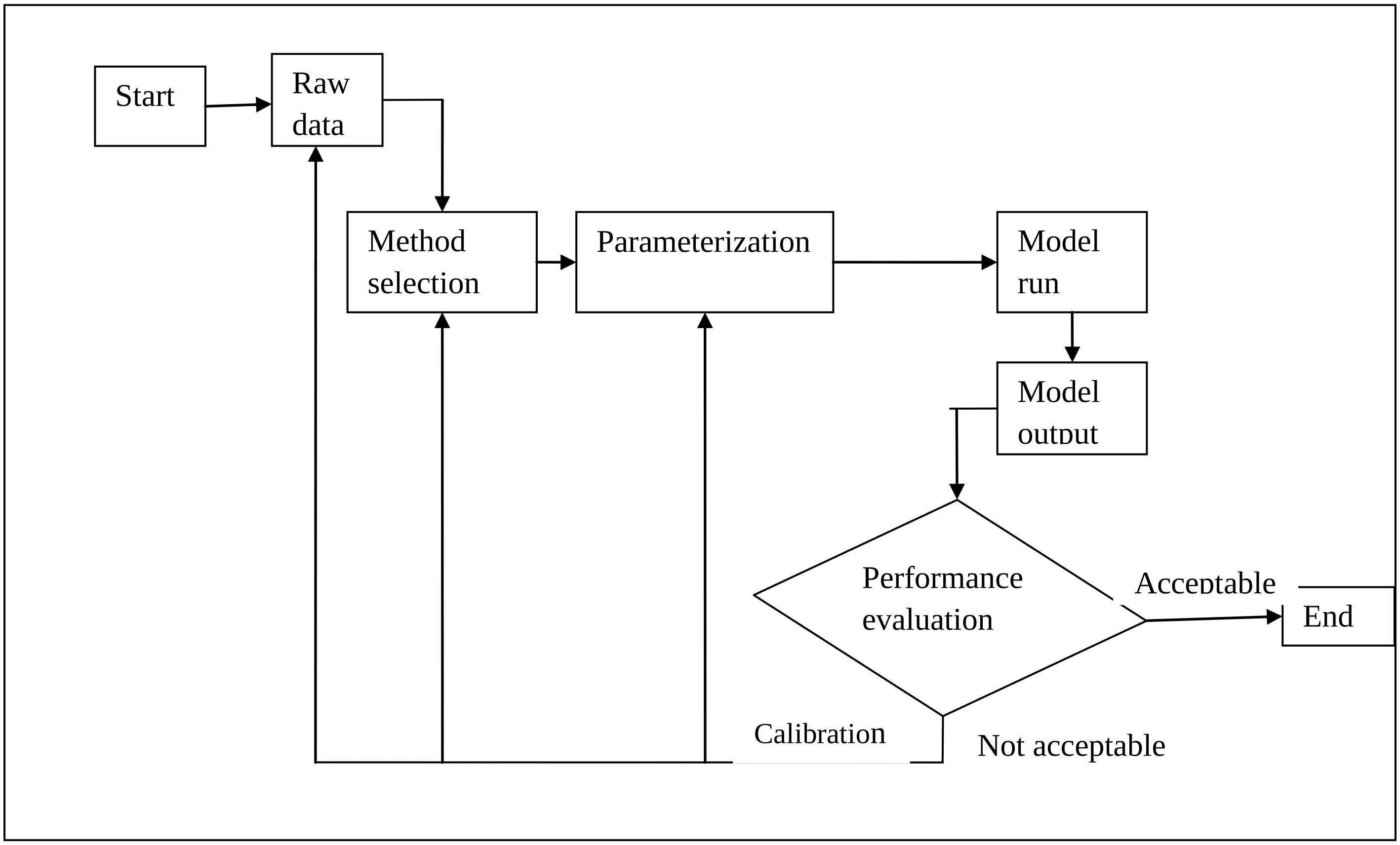


Figure 3. 19 Calibration process in the HEC-HMS modeling

As shown in the Figure 3.19 above, during calibration of the HEC-HMS modeling system in this study;

1. The data sources put in to consideration i.e. if the raw data is the source of any discrepancies between the simulation and observation since bad meteorological data is frequently the source of bad model performance.
2. While modeling methods are initially selected during model setup, calibration reveals that alternate modeling's methods perform better by questioning are the selected modeling methods properly modeling the system?
3. Parameter adjustment is the fine modification portion where parameters are adjusted to improve the model outputs by considering the physically reasonable range of parameters, error bounds on parameter estimations and sensitivity of parameters and by questioning which parameters can be adjusted and how much can a parameter be adjusted? The parameters were first calibrated using automatic calibration

methods available in the HEC-HMS model and manual calibration was conducted as well to adjust the parameters.

Nnumerous parameters in hydrological models can be found from physical parameters (i.e., parameters that can be physically measurable from the properties of watershed such as land use/land cover data, topography and soil type) and process parameters (i.e., parameters represent properties which are not directly measurable). So, the main purpose is to obtain an economical and reproducible method of identifying a parameter set for a particular catchment under particular conditions, which gives the best possible fit between the simulated and observed discharge for a particular calibration i.e. the calibrated parameter set aims at minimizing the difference between simulated and observed discharge. This process is considered to be necessary because there may be uncertainties in the model input and because of that, models give only simplified representations of the catchment's physical processes.

For this study, the model was calibrated with both manual manually and auto-calibration with the optimization trials available in the HEC-HMS model for optimizing the initial estimates of the model parameters.

3.5.4.3 Stream Flow Model Performance Evaluation

Model evaluation can be achieved by analysing the goodness of fit of efficiency index and the criteria for model evaluation used in this study were listed below.

1, the Nash-Sutcliffe efficiency (NSE): determines the comparative degree of the outstanding variance compared with the observed data disagreement. NSE shows how well the scheme of measured data as compared to the simulated data of 1:1 line fitness (Shammi Haque, 2018).

$$NSE = 1 - [\ \sum_{i=1}^{n}(Y_{iobs} - Y_{sim})2\ )\ /\ \sum_{i=1}^{n}(Y_{iobs} - Y_{meanobs})2\ )] \qquad (3.31)$$

Where;

Y_{iobs} is the ith evaluated observed data component;

Y_{isim} is the ith evaluated simulated data component;

$Y_{meanobs}$ is the evaluated mean measured data;

And n is the total number of observations.

2**,** Coefficient of determination (R^2):

$$R^2 = \left\{\frac{\sum_{i=1}^{n}(Y_{iobs} - Y_{meanobs})(Y_{isim} - Y_{meansim})}{\sqrt{(\sum_{i=0}^{n}(Y_{iobs} - Y_{meanobs})2)}\sqrt{(\sum_{i=0}^{n}(Y_{isim} - Y_{me\ ansim})2)}}\right\}^2 \quad (3.32)$$

Table 3. 20 General performance ratings for recommended statistics for calibration and validation process according to (Moriasi, 2007).

No.	Rating of performance	NSE	R^2
1	Unsatisfactory	≤ 0.5	≤ 0.5
2	Satisfactory	0.5 to 0.65	0.5 to 0.65
3	Good	0.65 to 0.75	0.65 to 0.75
4	Very good	0.75 to unity	0.75 to unity

3.5.5 Development of Soil Erosion and Sediment Yield Routing model using HEC-HMS

The sediment loads triggered by greater transport capability of the stream flow and bank erosion which leads to the changing dynamics of a stream and reservoirs can be estimated using the HEC-HMS model. When the sediment module found in the HEC-HMS basin model is activated, the model can simulate the sediment yield from the given catchment. But the soil erosion and sediment yield routing in HEC-HMS requires a calibrated and validated precipitation- stream flow model, soil data, land use data and sediment grain sizes of the river catchment for the estimation of the parameters of the modified universal soil loss equation (MUSLE) equation, the erosion method used in this study.

The length, width, shape, longitudinal and side slope and the manning's roughness coefficient of the river catchment are the necessary data's required for the sediment routing of the reaches of the watershed and since the sediment routing in the model is capable of only using the muskingum-cunge and kinematic wave methods, which require direct river cross-sections of the catchment, out of the other methods used of routing. All this data is used in the progress, calibration and validation of erosion of surface soil and modelling of sediment yield estimation.

For the calibration and validation of the sediment yield obtained from the HEC-HMS model, the observed sediment data is required at the outlet of the catchment (Measso) station; and for this study area, the observed sediment data was found by using the area ratio method of the Aposto station sediment data, which is found near to the outlet of the catchment (Measso) station.

The sediment rating curve (sediment discharge relationship), which were used to generate the observed sediment yield for the station of Aposto was retrieved from the feasibility study and design of Gidabo irrigation project volume-III, ministry of water irrigation and energy of Ethiopia.

Table 3. 21 Values for developing the surface erosion and sediment yield routing model used in this research

Parameter	Value	Source
Erodibility factor	0.20925-0.348684	Soil map of the catchment
Practice factor	0.6-0.9	(Shammi Haque, 2018)
Threshold	1	Calibration
Topographic factor	0.1766-3.786	Slope and length of the catchment
Cover and management factor	0.0000946-0.2797	Land use map of the catchment
Specific gravity (sediment grain)	2.65	(US Army corps of Engineers, 2013)
Clay Density	480.55 kg/m^3	(US Army corps of Engineers, 2013)
Silt Density	1041.2 kg/m^3	(US Army corps of Engineers, 2013)
Sand and Gravel Density	1489.7 kg/m^3	(US Army corps of Engineers, 2013)

The parameters of the soil erodibility factor, the practice factor, the cover and management and the topographic factor of the modified soil loss equation (MUSLE) of the HEC-HMS model are calibrated by using both the automatic and manual calibration method by reading the sedigraph of the simulation results, since the result of the HEC-HMS model sediment yield is generated in graphical form.

For this study area the calibration and validation of the sediment yield of this study was done using the monthly time basis and also the yearly sediment yield of the Gidabo river catchment was estimated as shown in the table 4.5 of chapter four of the results and discussion chapter using the parameters mentioned in the table 3.21 above.

CHAPTER FOUR

4. RESULTS AND DISCUSSIONS

The manual and optimization trials calibration of the HEC-HMS parameters was conducted using the observed stream flow data from Measso station for the period 1997 to 2002. The goodness of fit was evaluated using hydrograph and sediment-graph visualization and calculated statistics value of the estimated and observed stream flows and sediment yield. The comparison of the observed the river stream flow to the simulated runoff in this study shows a close agreement between the two. The parameters were optimized to obtain a closer result of the simulated flow to the observed stream flow. The graph in figure 4.2 below shows that the observed flow pattern which is denoted by the black solid line resembled well with that of the simulated outlet stream flow which is represented by the blue solid line.

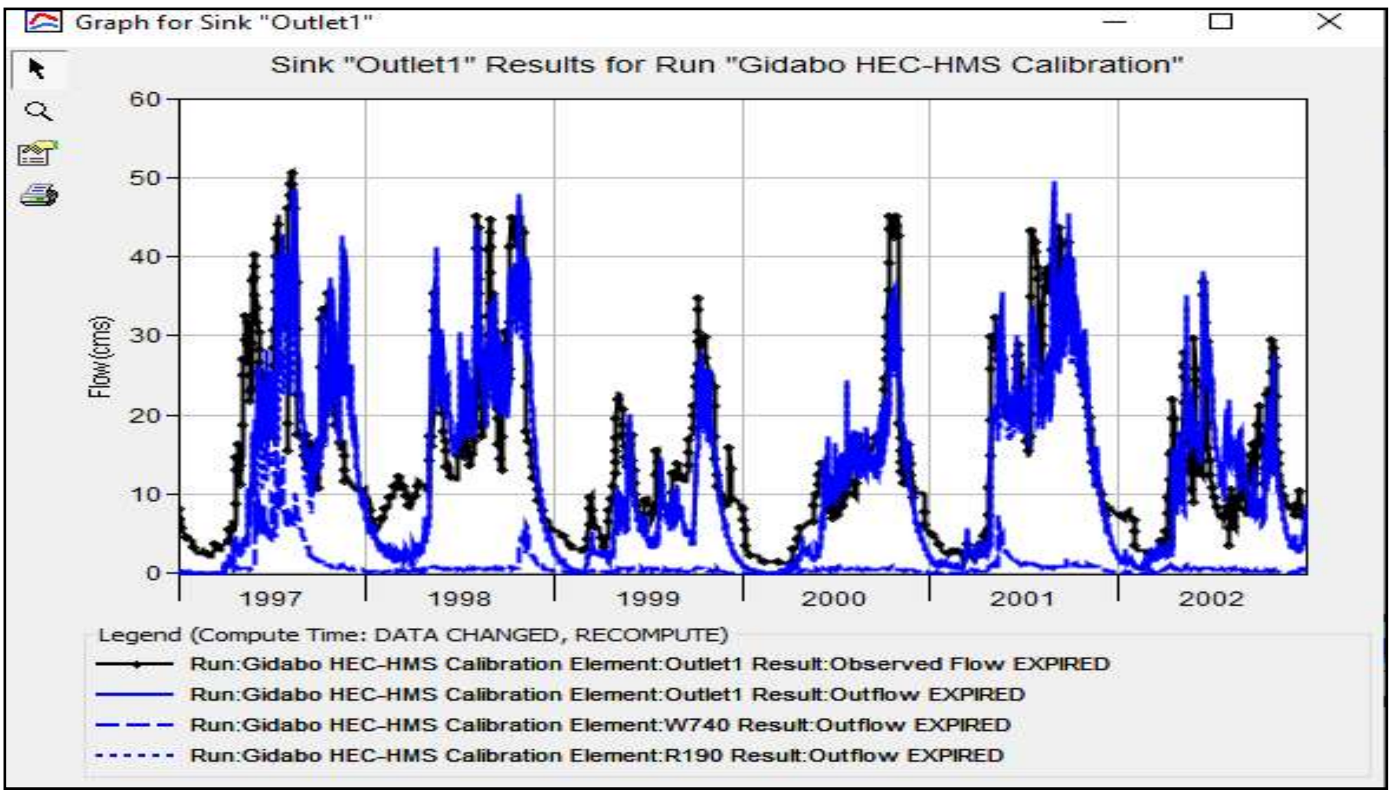


Figure 4. 1observed and simulated stream flow of the Gidabo river basin outlet for the calibrated years (1997 to 2002)

But for the sediment results as shown in figure 4.3 below, the HEC-HMS model does not display both the observed and simulated sediment yield but only displays the simulated sediment in graphical form. The calibration of the sediment yield in the watershed of Gidabo was done on monthly basis with the help of excel by reading the graph and comparing it with the observed sediment at the outlet of the watershed using the auto and manual calibration methods. Based on the performance criteria of table 3.20, the calibration of the sediment shows from good to very good fit of computed sediment yield to observed sediment as shown below in table 4.1.

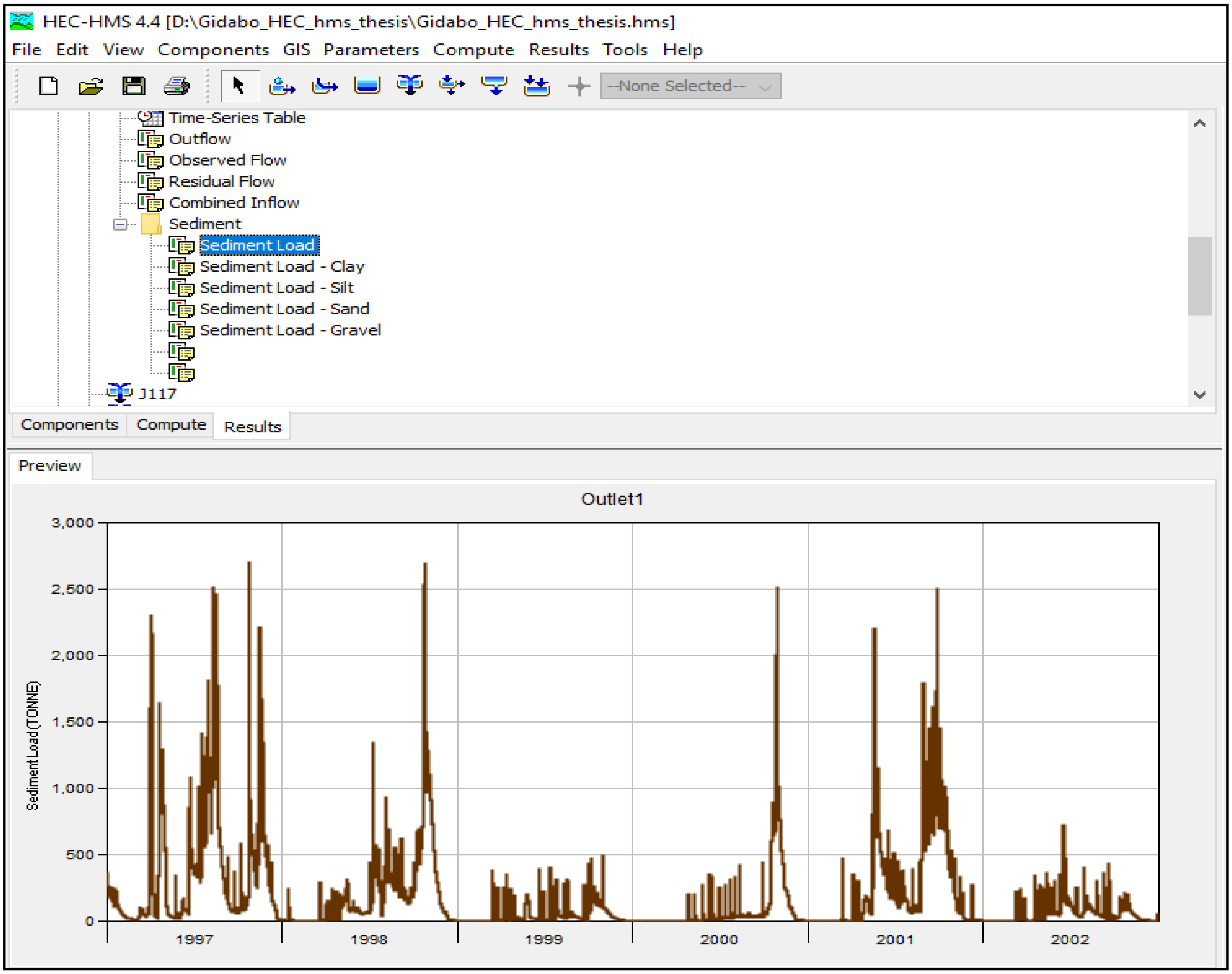


Figure 4. 2 the daily simulated sediment yield for the calibration period of (1997-2002) in Gidabo river catchment.

Model validation involves the operating of the model having the similar input parameters as determined by the calibration procedure. The model was executed for the validation period from 2003 to 2006 with the calibrated parameters to check the ability of the model to accurately calculate the stream flow and sediment yield at the Gidabo watershed, rift valley basin of Ethiopia. Similar to the calibration, the validation comparison of hydrograph and sediment-graph as well as the estimated and observed statistical values of stream flow and sediment yield shows close agreement between the simulated and observed stream flow and sediment yield in terms of the peak value and the rising and recession of the stream flow and sediment yield.

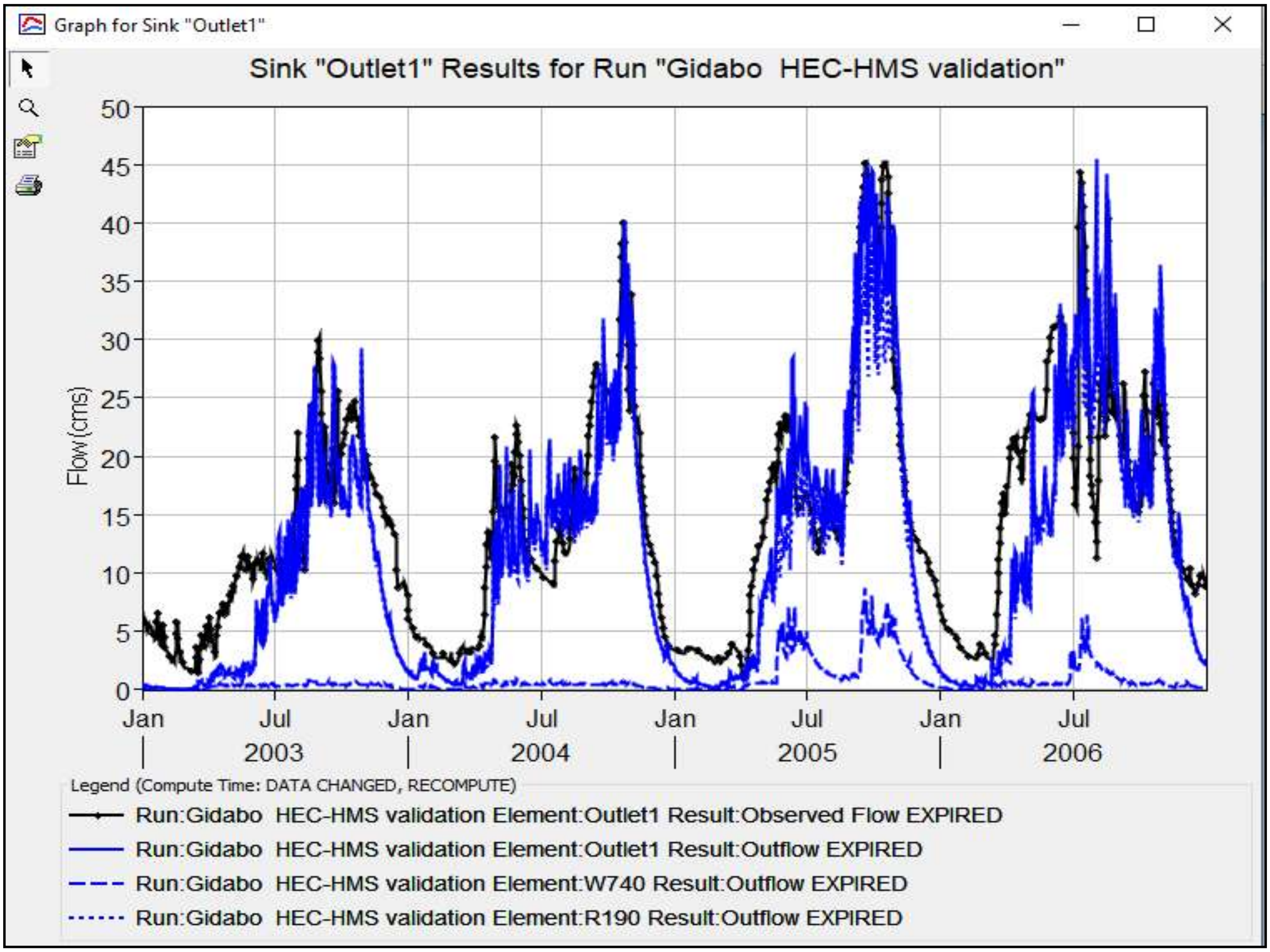


Figure 4. 3 observed and simulated stream flow of the Gidabo river basin outlet for the validated years (2003 to 2006)

The validation of the sediment yield was done in a similar way with the calibration procedures stated above but taking the same parameters of the calibrated sediment in the HEC-HMS model and gives from good to very good of fit between the simulated and observed sediment and the graph of the validated (2003 to 2006) sediment yield of the Gidabo watershed is shown in figure 4.5 below.

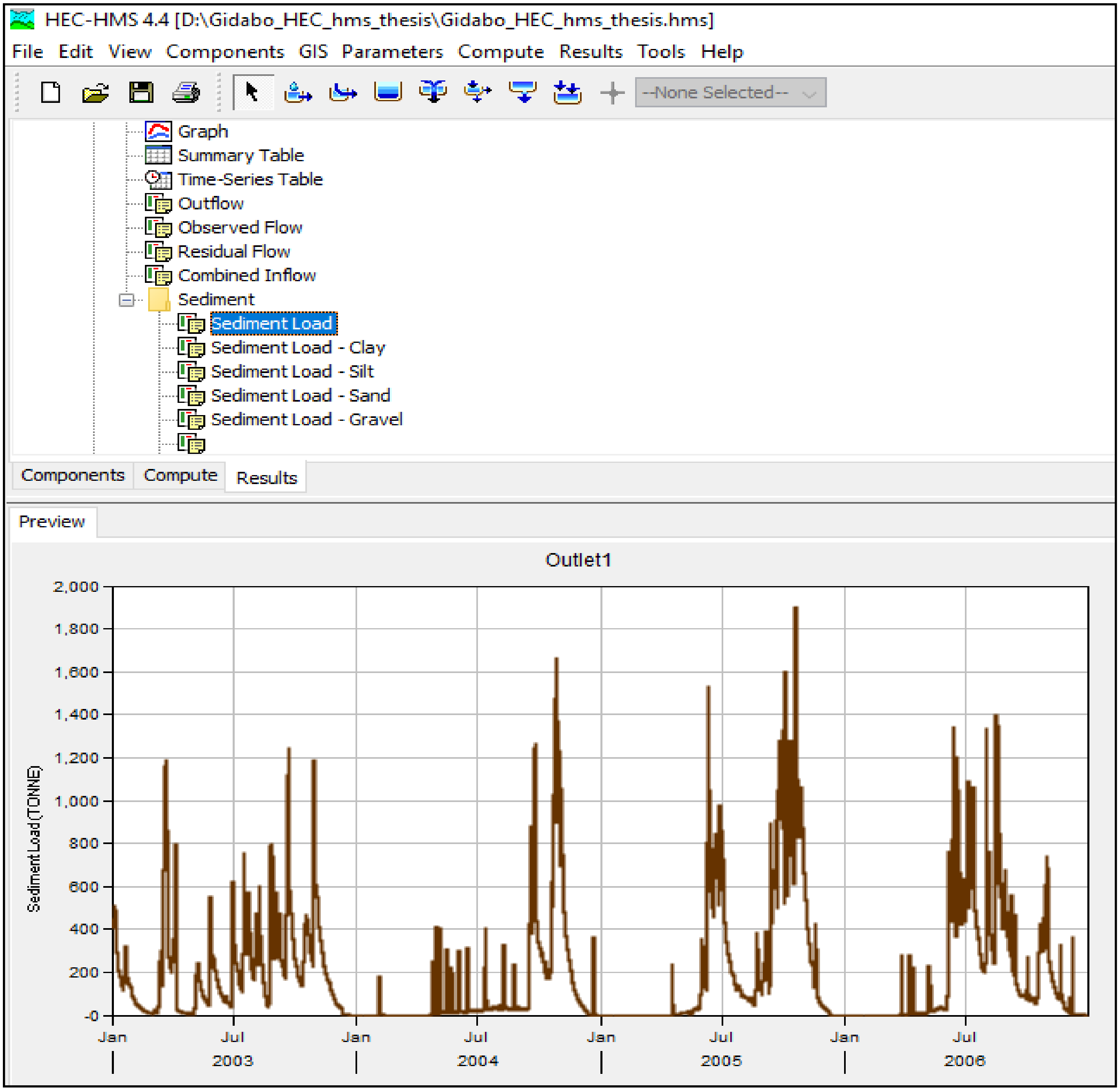


Figure 4. 4 the daily simulated sediment yield for the validation period of (2003-2006) in Gidabo river catchment.

Since the observed stream flow data at the outlet of the Gidabo river catchment is not recorded from the year 2007 until then, the stream flow and sediment yield at the outlet of the catchment is computed from the collected meteorological data of the year from 2007 to 2017 by using the parameters found in the calibration and validation period as shown below in the figure 4.5 and figure 4.6 respectively.

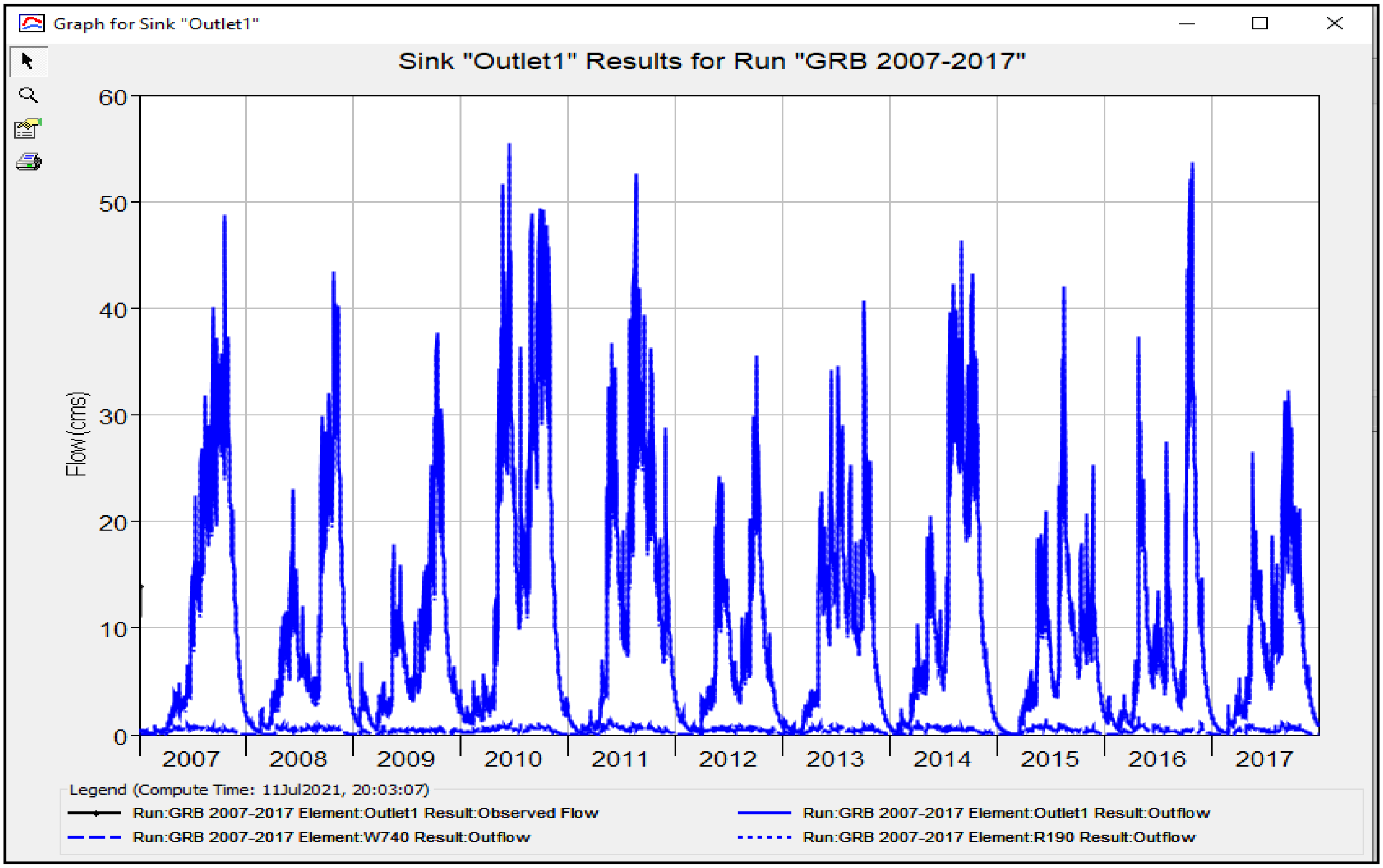


Figure 4. 5 the daily simulated stream flow for the period of (2007-2017) in Gidabo river catchment.

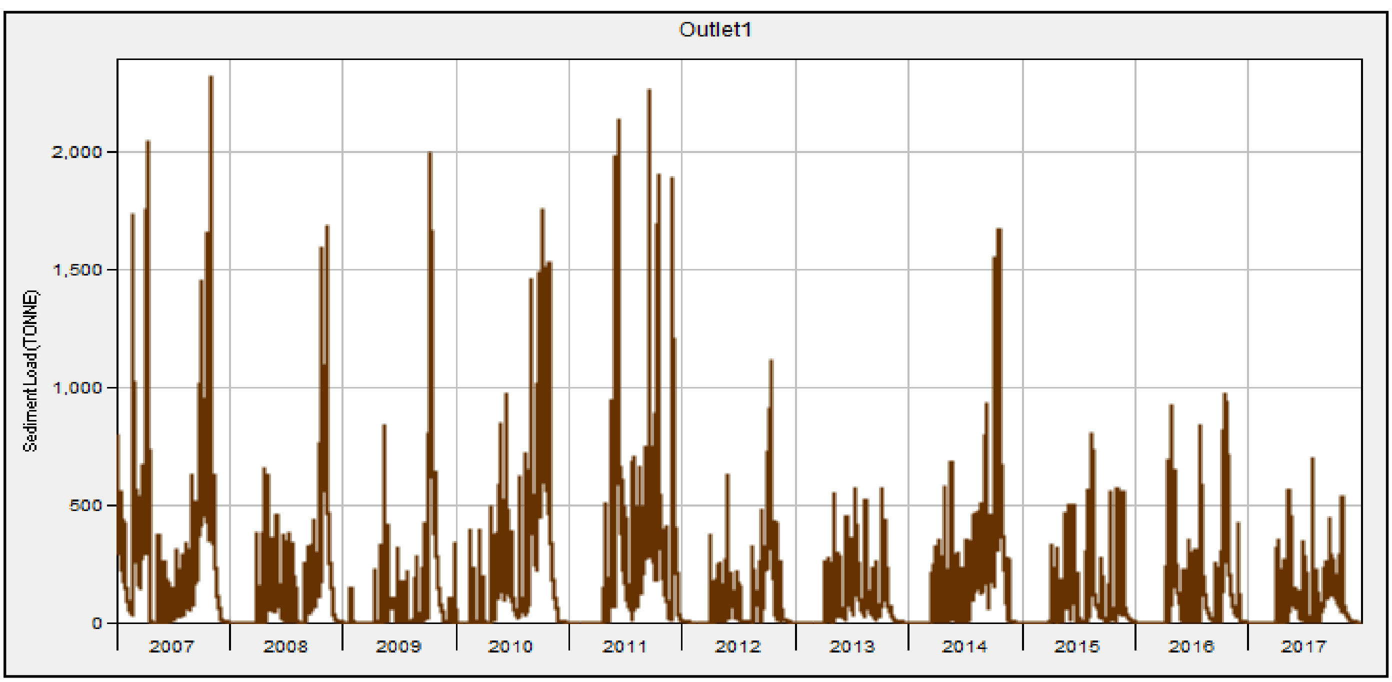


Figure 4. 6 the daily simulated stream flow for the period of (2007-2017) in Gidabo river catchment.

In general the HEC-HMS model performed very well for both stream flow and sediment yield estimation when the whole data period was considered but some discrepancies were displayed for the model runs of individual years which shows the need to parameterize the model according to the varying seasons and thus, seasonal parameterization of the model but out of the scope of this study, might improve the performance of the model.

Table 4. 1 the comparison between the observed and simulated stream flow and sediment yield of HEC-HMS model results of Gidabo river catchment of this study for the calibration and validation period.

Performance criteria		Stream flow		Sediment yield	
		Calibration	Validation	Calibration	Validation
NSE		0.67	0.69	0.67	0.67
R^2		0.72	0.79	0.76	0.8
Mean monthly stream flow in m^3/s	observed	14.35	14.4	-	-
	simulated	11.98	11.81	-	-
Mean monthly sediment in tone	observed	-	-	13,186.30	13,365.72
	simulated	-	-	8,718.97	10,333.89
Volume in mm	observed	840.82	561.54	-	-
	simulated	703.50	461.47	-	-

4.1 Estimation of mean monthly and Annual Stream flow at Gidabo river basin outlet

From the calibrated and validated stream flow of the HEC-HMS model results of the Gidabo river catchment outlet, the mean monthly and average yearly stream flow of the catchment has been estimated as shown in table 4.2 and table 4.3.

Table 4. 2 Average monthly stream flow at the Gidabo watershed outlet from the HEC-HMS model and observed stream flow values

Months	Calibration period (1997 to 2002) (m^3/s)		Validation period (2003 to 2006) (m^3/s)		For the years 2007 to 2017 (m^3/s)	
	Observed stream flow	Simulated stream flow	Observed stream flow	Simulated stream flow	Observed stream flow	Simulated stream flow
January	5.29	1.77	4.56	0.95	-	1.2
February	3.76	0.82	2.98	0.58	-	0.9
March	4.27	1.62	4.08	1.02	-	1.3
April	7.76	3.60	10.47	4.02	-	3.6
May	20.11	14.17	17.40	10.34	-	12.3
June	17.09	16.91	17.91	16.05	-	13.4

July	17.96	18.60	15.82	17.93	-	11.1
August	21.97	20.97	18.61	20.98	-	16.3
September	20.09	17.43	25.74	23.69	-	19.1
October	29.85	24.66	28.24	26.65	-	24.6
November	15.32	17.20	17.27	15.52	-	12.3
December	8.67	6.20	9.41	4.05	-	4.0
Total average monthly stream flow (m^3/s)	14.35	12.00	14.40	11.82	-	10.0

Table 4. 3 Estimated average annual stream flow from HEC-HMS model and observed average annual stream flow at the Gidabo watershed outlet

Years	Calibration period (1997-2002) model and observed stream flow results (m^3/s)	
	Observed stream flow	Simulated stream flow
1997	17.26	14.37
1998	17.43	16.61
1999	11.08	6.62
2000	10.89	8.77
2001	18.38	15.68
2002	11.04	9.95
Total average annual stream flow (m^3/s)	14.35	12.00
Years	Validation period (2003-2006) model and observed stream flow results (m^3/s)	
	Observed stream flow	Simulated stream flow
2003	11.67	7.72
2004	12.94	11.20
2005	15.81	13.87
2006	17.17	14.46
Total average annual stream flow (m^3/s)	14.4	11.81
Years	Computed model stream flow result (m^3/s) (2007-2017)	
	Observed stream flow	Simulated stream flow

2007	-	10.9
2008	-	9.0
2009	-	7.5
2010	-	16.4
2011	-	12.9
2012	-	7.0
2013	-	9.3
2014	-	12.2
2015	-	7.5
2016	-	9.3
2017	-	7.9
Average annual stream flow (m^3/s)	-	10.0

4.2 Estimation of mean monthly and Annual Sediment Load at Gidabo river basin outlet

From the calibrated and validated sediment yield HEC-HMS model results of the Gidabo river catchment outlet, mean monthly and average yearly sediment load of the catchment has been estimated as shown in table 4.4 and table 4.5.

Table 4. 4 Average monthly sediment yield load at the Gidabo watershed outlet from the HEC-HMS model and observed sediment values for the calibrated and validated years and for the years of 2007 to 2017

Months	Calibration period (1997 to 2002) (ton/month)		Validation period (2003 to 2006) (ton/month)		For the years 2007 to 2017 (ton/month)	
	Observed sediment	Simulated sediment yield	Observed sediment	Simulated sediment yield	Observed sediment	Simulated sediment yield
January	4,505.99	2,161.39	4,416.21	2,428.33	-	1,423.18
February	2,936.16	636.67	3,400.65	1,687.92	-	2,279.24
March	3,596.37	4,887.67	5,346.76	4,921.25	-	4,753.33
April	7,070.11	6,216.67	8,684.45	5,675.00	-	9,590.91
May	15,759.45	9,506.67	17,036.97	10,281.67	-	12,357.73
June	13,442.40	11,450.00	18,510.15	15,575.00	-	7,936.36
July	11,932.84	11,125.56	14,908.06	14,260.00	-	9,253.03
August	21,062.43	14,552.78	17,493.75	14,260.00	-	12,287.27
September	18,877.71	11,566.67	21,460.37	17,700.00	-	15,363.64
October	33,298.92	19,908.89	27,754.76	23,456.67	-	23,606.97

November	18,354.30	10,608.33	14,419.73	10,325.00	-	13,022.73
December	7,398.93	2,006.39	6,956.81	3,435.83	-	3,250.30
Total average monthly sediment load (ton/month)	13,186.30	8,718.97	13,365.72	10,333.89	-	9,593.72

Table 4. 5 Estimated average annual sediment yield from HEC-HMS model and observed average annual sediment load at the Gidabo watershed outlet

Years	Calibration period (1997-2002) model and observed sediment results (ton/year)	
	Observed sediment	Simulated sediment yield
1997	270,499.98	205,143.33
1998	190,712.26	113,610.00
1999	92,127.83	52,318.33
2000	152,596.19	55,057.67
2001	156,952.03	153,183.33
2002	86,525.37	48,453.33
Total average annual sediment load (ton/year)	158,235.61	104,627.67
Years	Validation period (2003-2006) model and observed sediment results (ton/year)	
	Observed sediment	Simulated sediment yield
2003	139,942.26	127,940.00
2004	134,117.35	96,421.67
2005	172,904.58	133,016.67
2006	194,590.47	138,648.33
Total average annual sediment load (ton/year)	160,388.67	124,006.67
2007	-	215,413.3
2008	-	107,875.0
2009	-	91,610.0
2010	-	153,726.7
2011	-	174,996.7
2012	-	81,008.3

2013	-	75,608.3
2014	-	124,615.0
2015	-	78,808.3
2016	-	84,738.3
2017	-	77,971.7
Average annual sediment load (in tone)	-	115,124.70

The yearly computed sediment yield (tons per year) of the Gidabo river catchment can be also shown graphically as in the figure below 4.7.

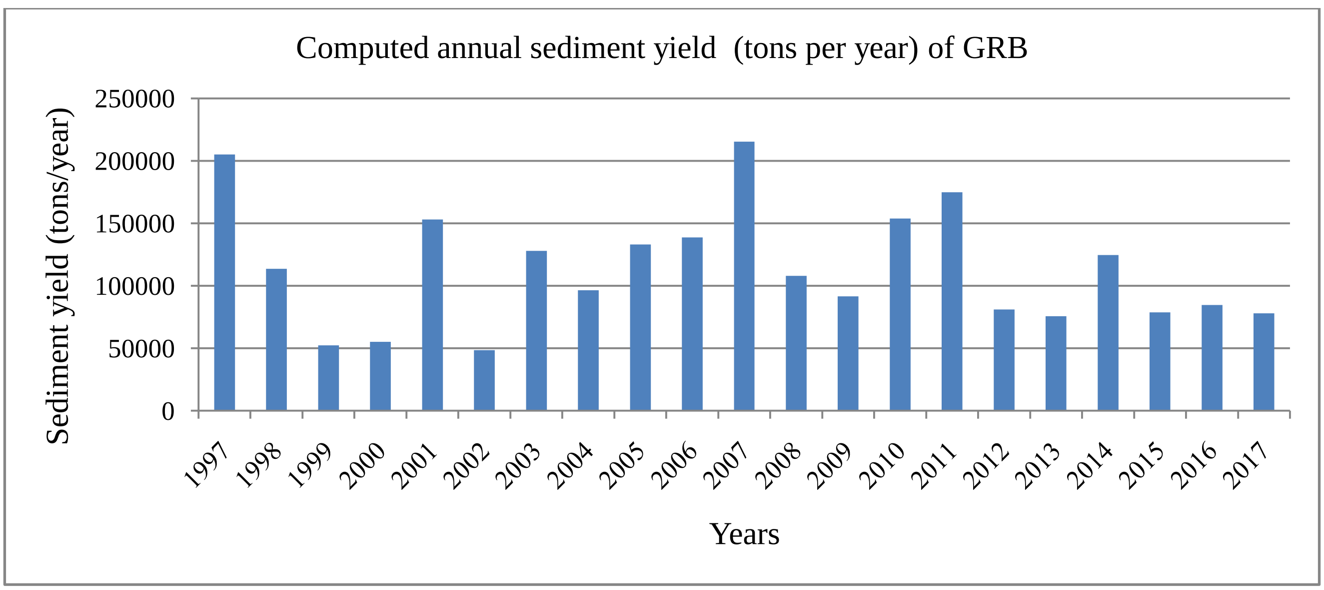


Figure 4. 7 the estimated annual sediment yield (tons per year) of the Gidabo river catchment (1997 to 2017)

4.3 Discussion of the HEC-HMS model results

The HEC-HMS model adopted for the estimation of stream flow and sediment yield of the Gidabo watershed data demanding conceptual model which must be calibrated and validated well for the accurate prediction of runoff and sediment yield and the data involved in the model requires careful observation and field surveys to achieve high level of accuracy but for this study all the data was obtained from secondary sources from various organizations.

Since SMA is a continuous modeling, it requires evapo-transpiration data and it is estimated using the temperature based evapo-transpiration estimation method of Thornthwaite’s method due the un availability of relative humidity, wind speed, etc., data. According to (O. Alkaeed, 2006) Thornthwaite's provides underestimation in arid areas and overestimation in humid areas and hence may affect the study results of this thesis.

In this study observed stream flow data, which is used for the calibration and validation purpose, at the outlet of the catchment was restricted to the year 2006 and the stream flow and sediment yield of the catchment for the years 2007 to 2017 was estimated using the parameters found in the calibration and validation period of 1997 to 2006 and the average annual stream flow and average annual sediment yield of 12.64 m3/s and 114,317.17 tons/year for the calibration and validation period of 1997 to 2006, 10 m3/s and 115,124.7 tons per year for the years 2007 to 2017 and 11.32 m3/s and 114,720.93 tons per year for the years 1997 to 2017 respectively at the outlet of the watershed (Maesso station). Nash-Sutcliffe efficiencies and coefficient of determination of the model indicates well to very good model performances. The modeling in this study was conducted according to daily rainfall and discharge, which is again the maximum limit for the HEC-HMS model and it, is recommended to check the modeling of the Gidabo River basin using the HEC-HMS conceptual model by incorporating hourly rainfall and discharge data.

4.4 Limitations and Uncertainties of the study

In Gidabo river basin, like the other river basins of Ethiopia, there is no gauged sediment data. In this study observed sediment data is estimated using the sediment discharge rating curve and area ratio method of estimating un-gauged station of sediment. The collected data quality and the time period they enclosed has been the major constraint of the paper produced in this research. The precipitation data and stream flow data used in this study in the HEC-HMS hydrologic model were daily basis, and had many gaps in both the precipitation and stream flow data series. The precision of research would be improved considerably if the precipitation and stream flow data sequence were comprehensive.

The SMA method adopted for rainfall runoff modeling in the basin is a data intensive conceptual model and the data used in the model are supposed to come up from vigilant field surveys and meticulous measurements for improved model calibration and truthful stream flow estimation of the catchment. But, measurements and surveys of such type have not been done in the catchment and almost all the data used in this study were obtained from secondary sources and the results produced from such type of data may not be good enough and may perhaps be the causes of incorrect conclusion.

The gauged stations location for gathering of weather and meteorological data was underprivileged. This has come up with plenty of approximations in the meteorological analysis of the study area. The sediment results of the HEC-HMS model is not displayed in tabular form, it is only in graphical form and this has resulted in approximations in the analysis of sediment yield as well.

The observed stream flow of the outlet station (Measso) of the Gidabo river catchment were restricted to the year of 2006 and due to this reason the stream flow and sediment yield of the catchment from the years 2007 to 2017 were estimated using the parameters found in the calibration and validation period and this may result in erroneous computation of stream flow and sediment yield of for the mentioned years of the catchment.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In this research, hydrological model of Gidabo watershed were developed by using the HEC-HMS model for estimation of stream flow and sediment yield of the basin and was successfully calibrated from 1997-2002 and validated from 2003-2006 on the continuous time period. The overall model efficiencies given by Nash-Sutcliffe Efficiency criteria are 0.67 and 0.69 for the stream flow and 0.67 and 0.67 for the sediment yield respectively for the calibration and validation time periods, indicating a good model fit performance. The coefficient of determination (R^2) for the calibration period and for the validation period of stream flow 0.72 and 0.79 and sediment yield was found to be 0.76 and 0.8, respectively, indicating good model fit. Due to the lack of observed stream flow in the outlet of the catchment for the years 2007 to 2017, the HEC-HMS model can be used to model stream flow and sediment yield in the Gidabo River basin from the years 2007up to 2017 by using the parameters found in the calibration and validation period.

Conclusion can be drawn undoubtedly from this research that the research questions in the order they have affirmed in chapter two of this study have been answered comprehensively and the HEC-HMS model simulates the average annual stream flow and average annual sediment yield of 12.64 m3/s and 114,317.17 tons/year for the calibration and validation period of 1997 to 2006, 10 m3/s and 115,124.7 tons per year for the years 2007 to 2017 and 11.32 m3/s and 114,720.93 tons per year for the years 1997 to 2017 respectively at the outlet of the watershed (Maesso station). From the results of this thesis, one can conclude that the HEC-HMS model can estimate well both the stream flow and sediment yield of river catchments.

5.2 Recommendations

Based on the results and the knowledge gained during the study, the following recommendations are made;

1. The model was calibrated and validated at the Gidabo watershed outlet station (Measso) and more calibration and validation point of the model will increase the better representation of the modeling of the Gidabo watershed.
2. The soil moisture accounting parameters can be better estimated by measured data of soil and land use properties and calibration as well as validation of the sediment yield will be better by measured continuous suspended sediment load data the outlet of the GRB.
3. Possible discrepancy of the computed sediment output data is expected as the HEC-HMS displays the results in graphical form and the calibration and validation of the sediment in this study is done by

approximation of the output graphical sediment data in monthly basis and it is better if the model displays the results of sediment in tabular format.

For the good potential sediment reduction; proper terracing of slopes which sets aside for cultivation to reduce the speed at which water flows down the slope thereby reducing the soil erosion, Contour plowing which is plowing the land sideways, forming furrows perpendicular to the angle of the slope which act as blocks, Intercropping which is the practice of growing two or more crops on the same field so that the land is not exposed to erosion, Constructing check dams which are small ditches that are prepared along sloppy areas to reduce the impact of the down slope surface flow, Extending irrigation schemes along the major river basins and their tributaries so that water will be available in proper quantities at the proper times will be the possible actions which depends on the living of the peoples in the region of the watershed.

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APPENDIX A

Appendix A-1; Average monthly precipitation data of stations of the Gidabo catchment

Average monthly precipitation (mm) of selected stations					
	Dilla	Hagereselam	Billate	Yirgalem	Yirgachefe
January	38.7	20.1	38.7	37.0	30.0
February	39.3	25.1	25.5	31.2	32.2
March	87.7	62.8	48.8	86.4	79.2
April	179.6	148.5	110.0	145.7	201.0
May	214.2	155.9	100.1	170.1	211.2
June	95.8	40.2	61.6	87.4	89.1
July	85.7	50.7	86.1	112.4	81.9
August	129.1	59.1	79.7	134.3	115.5
September	194.6	68.5	75.1	129.7	154.4
October	198.4	128.6	91.2	180.6	195.4
November	74.9	73.8	50.2	50.2	82.1
December	38.0	19.5	20.7	31.5	34.8

Appendix A-2 Average annual precipitation (mm) of Gidabo catchment meteorological stations

years	Dilla	H/selam	Billate	Yirgalem	Yirgachefe
1997	1601.6	994.16	1601.6	1386.7	1175.9
1998	1346.9	570.6	632.4	1658.8	1061
1999	1205.5	633.11	492.2	1075.7	1154.3
2000	1145.4	842	616.4	1078.4	1245.7
2001	1366.1	768.1	536.9	1573.9	1444.6
2002	1101.4	734.3	520.6	1020.1	1229.8
2003	974	867.5	851	852.5	1146.3
2004	1112.1	709.6	815.2	855.6	1253.5
2005	1260.5	1129.9	1000.7	1100.8	1498.2
2006	1491	860.3	1032.4	1412.9	1471.6
2007	1660.7	945.7	913.3	1482.2	1644.1
2008	2473.5	868.5	787	1224.1	1356.7
2009	1095.4	612.3	685.7	1090.5	1371
2010	1669.7	1046.3	1082.3	1227.4	1227.4
2011	1488.9	975.6	805.9	853.5	843.5
2012	1132.9	923.8	606	1100.47	1373.88
2013	1449.9	1073	1163.8	1182.31	1506.6
2014	1423.7	849.18	763.8	1204.24	1847.4
2015	736.4	659.8	643.5	650.76	1043.4

2016	857.775	740.9	676	1238.68	1048.59
2017	1224.5	838.9	626.3	978.96	1109.5
Average	**1324.66046**	**840.17**	**1324.6605**	**1154.6903**	**1288.24**

Appendix A-3; Average monthly maximum temperature of stations in the catchment of Gidabo

	Tmax.Dilla	Tmax. H/Selam	Tmax.Billate	Tmax.Yirgalem	Tmax.Yirgachefe
January	29.6	26.9	31.1	28.5	27.2
February	28.9	27.3	31.9	29.1	28.0
March	30.9	27.8	33.2	28.5	27.3
April	28.7	25.4	31.5	28.8	25.6
May	27.1	24.0	29.5	27.4	24.5
June	26.4	23.0	28.3	27.6	23.8
July	25.7	22.9	27.4	26.2	23.3
August	26.1	23.2	27.8	26.7	23.9
September	26.2	24.3	28.7	27.3	23.5
October	26.6	24.1	29.6	27.1	23.7
November	27.8	25.0	30.6	27.9	24.8
December	29.0	26.6	31.0	27.8	25.9

Tmax= maximum Temperature

Appendix A-4; Monthly maximum temperature of Dilla meteorological station in the catchment GRB

Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1997	30.9	32.9	33.3	28.2	27.3	27.4	26.0	27.0	27.6	26.9	27.0	27.7
1998	28.1	28.8	30.8	30.3	28.3	27.6	26.9	26.3	26.1	26.0	28.3	29.9
1999	29.9	33.0	32.0	30.3	26.8	26.8	25.3	26.9	26.2	26.0	29.0	30.1
2000	31.7	33.0	33.9	26.6	23.5	23.4	23.2	23.0	25.5	27.9	29.4	30.5
2001	27.1	28.5	27.4	24.9	24.2	23.6	23.2	24.9	24.2	23.0	26.1	28.6
2002	26.5	28.9	30.3	29.5	27.9	27.0	27.4	27.2	27.2	30.0	29.0	29.6
2003	29.9	33.8	34.7	30.1	28.9	26.8	25.7	26.4	26.8	27.9	28.5	28.3
2004	27.5	29.8	31.4	27.0	28.2	25.9	26.2	26.8	26.7	27.4	28.2	29.2
2005	30.8	32.8	31.1	30.1	26.0	26.2	25.5	26.5	26.5	26.5	28.0	29.9
2006	31.2	30.8	29.6	27.4	27.6	27.3	25.4	26.0	26.7	27.2	27.5	28.1
2007	29.5	31.0	29.4	29.3	26.2	27.1	26.2	25.7	25.6	27.3	28.2	29.1
2008	30.7	30.9	31.7	28.5	26.1	25.9	24.6	25.2	26.3	26.3	27.3	29.2
2009	29.6	30.9	32.3	28.1	27.8	27.3	26.9	27.6	27.2	27.4	29.5	28.2
2010	29.2	29.5	28.5	27.9	26.8	26.4	26.8	25.6	25.9	27.5	29.5	29.9
2011	31.0	9.7	32.0	31.7	27.0	26.0	25.9	25.5	25.5	27.3	26.5	25.6
2012	30.7	31.9	32.4	28.3	27.5	24.8	25.9	26.0	25.4	27.3	28.0	27.1

2013	30.6	32.3	27.8	27.6	26.4	25.4	24.7	25.0	26.2	26.1	27.2	28.6
2014	30.2	30.3	30.7	28.6	27.0	26.7	26.0	25.8	25.1	25.4	27.1	27.8
2015	30.4	31.9	32.0	28.8	27.5	26.6	26.7	28.0	27.5	27.6	28.1	31.2
2016	30.5	31.9	32.3	28.4	27.2	26.2	25.4	27.8	24.9	25.3	25.8	31.8
2017	30.8	31.2	32.2	30.1	27.1	27.3	25.3	25.4	24.9	24.1	26.8	32.2

Appendix A-5; Monthly maximum temperature of H/Selam meteorological station in the catchment GRB

Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1997	26.7	29.5	29.9	23.9	23.9	23.1	22.7	26.1	25.6	23.7	23.7	24.0
1998	24.4	25.2	26.4	24.1	24.9	23.5	21.2	22.7	23.8	24.0	24.4	26.6
1999	27.5	29.0	26.7	26.5	23.7	22.9	21.3	23.6	24.5	23.4	24.9	26.0
2000	28.0	29.5	29.6	26.3	23.3	22.4	22.8	21.8	24.0	23.9	25.1	27.0
2001	26.5	27.7	26.7	24.3	23.5	22.5	22.7	23.9	24.1	23.9	25.6	27.1
2002	26.1	27.8	26.6	24.9	22.8	21.5	22.4	22.4	24.5	22.9	24.5	24.7
2003	25.8	29.0	28.5	24.6	22.1	25.9	23.7	23.4	25.1	26.7	27.2	25.9
2004	27.0	27.9	28.6	24.4	23.5	22.4	23.0	24.0	24.7	24.3	24.0	25.1
2005	26.8	28.5	26.7	25.8	23.1	21.4	20.7	22.2	23.2	22.4	23.5	25.4
2006	27.0	27.5	27.6	24.1	24.0	23.0	22.3	22.6	23.3	23.4	23.8	25.3
2007	26.3	28.4	27.2	26.0	21.9	22.5	21.9	21.7	22.9	23.1	24.1	26.1
2008	27.9	28.4	27.9	24.0	22.9	21.6	21.6	23.0	25.1	23.7	24.2	26.0
2009	26.6	27.9	28.6	23.9	23.4	23.2	22.7	23.6	25.3	24.4	25.7	25.4
2010	27.2	27.3	25.7	25.0	24.0	22.8	24.0	22.1	23.8	24.3	25.6	26.8
2011	28.4	29.2	29.3	28.1	23.9	23.2	23.8	23.0	23.9	25.2	26.6	25.8
2012	28.8	29.8	30.8	27.1	27.5	22.8	22.6	24.3	24.1	24.2	24.0	28.1
2013	28.1	29.7	27.5	26.3	23.4	22.1	24.9	21.9	24.7	23.9	26.9	28.0
2014	27.7	29.4	27.2	24.8	23.7	23.6	25.3	23.8	24.2	27.3	28.9	29.4
2015	28.3	29.4	28.9	25.5	24.1	23.8	23.4	24.8	26.9	25.0	27.9	31.2
2016	27.9	29.4	31.2	26.4	26.2	23.1	23.0	22.8	25.2	25.1	25.4	31.8
2017	28.6	28.5	29.6	27.0	24.4	23.3	23.4	23.4	23.4	23.8	24.1	32.2

Appendix A-6; Monthly maximum temperature of Billate meteorological station in the catchment GRB

Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1997	31.7	33.4	34.3	29.3	29.7	25.8	27.1	29.1	31.2	29.4	28.6	29.8
1998	30.3	30.6	33.1	32.8	29.6	28.9	27.3	26.7	29.2	28.9	31.6	32.0
1999	32.4	34.5	34.8	33.2	29.1	29.1	26.4	28.0	27.2	27.7	31.0	31.6
2000	32.9	34.2	35.0	32.5	28.8	27.9	27.0	27.1	27.3	29.6	31.0	31.9
2001	31.8	33.3	32.3	31.0	29.2	26.9	27.0	27.8	29.2	30.1	31.0	32.2
2002	31.6	33.7	31.9	29.7	28.8	27.3	27.4	26.9	27.1	29.6	28.7	29.3

2003	29.7	31.5	31.6	29.6	28.7	26.8	23.9	26.2	26.6	27.3	28.1	27.8
2004	27.8	28.7	29.3	28.8	29.1	28.2	28.2	28.8	29.7	31.1	32.1	31.9
2005	32.3	34.4	32.8	32.3	27.8	28.0	27.4	28.4	28.3	29.6	30.8	31.5
2006	32.8	33.1	31.5	29.5	29.8	28.6	27.1	27.0	28.8	29.7	30.2	30.8
2007	31.8	33.5	32.8	31.9	26.7	26.7	26.7	26.3	27.6	29.6	30.9	31.8
2008	33.1	33.4	34.6	31.5	29.2	28.8	26.6	27.3	28.8	29.6	29.2	31.2
2009	31.8	33.3	34.7	31.2	30.9	30.0	28.8	29.6	30.7	30.3	32.5	30.8
2010	31.7	31.6	31.1	29.9	28.4	27.5	28.4	27.4	28.3	30.8	31.7	31.6
2011	17.8	34.0	34.1	33.9	29.7	27.8	27.8	27.2	27.8	30.7	30.4	29.4
2012	33.7	34.7	35.7	33.9	30.9	29.4	26.6	27.7	28.5	31.9	32.3	32.8
2013	33.4	35.1	35.7	30.3	28.5	27.6	26.6	26.7	29.1	29.8	30.7	31.8
2014	33.7	33.3	33.5	31.9	30.3	29.0	28.3	28.9	29.0	29.3	30.9	31.2
2015	32.9	34.9	34.9	33.0	30.4	28.6	29.3	30.5	32.0	32.3	32.1	31.2
2016	33.3	34.6	35.2	31.4	29.3	28.3	27.7	28.1	30.2	31.2	31.9	31.8
2017	33.9	35.0	35.0	34.4	30.1	30.0	28.6	28.5	27.9	30.1	31.7	32.2

Appendix A-7; Average monthly minimum temperature of stations catchment of Gidabo

Months	Tmin Dilla	Tmin H/selam	Tmin Billate	TminYirgalem	TminYirgachefe
January	10.2	9.4	16.7	11.4	9.1
February	10.0	10.8	16.5	11.3	9.5
March	12.7	11.9	17.2	11.9	10.8
April	14.0	12.8	17.1	12.3	11.9
May	13.9	12.9	16.8	12.5	12.1
June	13.6	11.8	16.5	12.6	11.9
July	14.3	11.9	16.6	12.6	11.9
August	14.0	11.2	16.5	12.4	11.6
September	13.6	11.3	16.3	12.1	12.0
October	13.5	11.8	15.7	11.1	11.2
November	11.6	10.6	14.8	9.3	10.0
December	10.1	9.8	15.7	9.1	9.1

Tmin= minimum Temperature

Appendix A-8; Monthly minimum temperature of Dilla meteorological station in the catchment GRB

Years	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
1997	11.3	7.0	12.9	13.9	12.4	13.2	14.2	13.9	12.7	14.3	14.4	12.9
1998	13.9	13.5	13.5	15.0	13.6	13.3	15.4	15.3	14.3	14.5	10.0	7.1
1999	8.4	8.1	14.0	13.3	12.2	12.4	13.8	12.2	12.6	13.6	10.0	8.8
2000	6.9	7.2	10.4	13.2	13.2	12.7	13.6	13.9	13.1	12.6	9.6	7.2

2001	11.2	10.2	13.3	13.6	13.5	13.7	14.3	14.9	13.4	13.8	11.3	10.4
2002	10.7	9.5	13.8	13.5	14.0	14.0	13.5	14.0	13.1	13.0	12.3	13.4
2003	10.7	9.7	11.1	13.7	13.2	13.1	13.5	13.2	12.8	12.4	11.4	9.4
2004	11.3	11.3	11.3	14.4	12.9	13.1	13.6	14.5	13.3	12.3	12.7	11.6
2005	10.1	10.5	13.8	14.1	14.9	13.8	13.9	14.2	14.0	13.6	11.4	7.2
2006	9.9	12.3	13.3	14.1	13.6	13.9	14.9	14.1	14.0	14.4	13.1	12.7
2007	12.3	12.3	11.7	14.4	14.8	15.1	14.8	14.1	14.6	12.2	11.9	7.7
2008	9.3	10.2	11.1	13.7	14.1	13.9	15.0	14.4	14.4	13.8	11.5	9.2
2009	10.4	11.2	12.5	14.3	14.2	13.2	13.6	13.8	14.2	14.1	11.3	13.5
2010	11.3	14.8	14.4	15.0	15.7	14.7	15.7	15.4	14.7	13.9	11.1	9.6
2011	10.0	0.8	12.9	13.8	15.4	15.2	14.7	14.8	14.7	13.0	13.8	13.4
2012	8.2	8.3	10.8	14.2	13.9	14.5	14.7	14.7	14.4	13.3	12.8	8.8
2013	10.4	10.6	13.0	13.1	14.3	13.6	14.5	13.9	14.1	14.0	12.9	10.6
2014	10.5	12.9	13.0	13.1	14.3	13.6	14.5	13.9	11.6	12.0	10.2	8.3
2015	8.1	9.9	12.3	13.5	14.4	14.5	14.0	13.1	13.1	13.7	10.4	11.4
2016	13.3	11.6	13.5	16.1	15.0	14.0	15.8	10.8	10.9	12.0	13.9	18.2
2017	5.8	11.1	13.0	13.7	14.9	14.0	15.4	14.8	14.6	15.5	13.7	16.3

Appendix A-9; Monthly minimum temperature of H/Selam meteorological station in the catchment GRB

Years	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	9.7	9.4	10.5	11.8	13.2	13.0	12.7	10.8	12.7	13.0	13.6	13.3
1998	12.9	10.9	12.2	11.6	12.8	11.9	10.5	10.5	5.3	6.3	5.3	4.4
1999	7.8	11.1	12.5	13.7	13.2	12.9	12.1	12.0	12.1	12.8	10.6	10.1
2000	9.7	11.3	12.4	13.2	13.2	12.2	11.4	11.6	12.7	12.0	10.7	9.3
2001	8.7	11.3	11.6	12.5	12.5	12.2	11.8	11.8	12.3	12.5	10.4	10.3
2002	10.4	10.0	12.2	13.1	12.8	12.3	11.9	11.8	12.3	13.0	10.9	12.0
2003	10.0	11.2	12.1	12.1	11.7	12.8	13.1	10.5	9.7	12.2	11.6	8.3
2004	10.8	11.1	12.5	13.7	13.3	12.1	11.4	12.1	12.1	11.5	11.7	10.4
2005	9.5	10.7	12.0	12.3	11.7	10.7	9.7	9.4	9.7	10.3	8.2	7.6
2006	11.4	13.4	13.7	13.9	13.8	12.6	12.3	12.1	12.1	13.8	13.0	12.6
2007	11.7	13.0	13.0	15.2	12.5	13.8	12.5	13.1	13.6	12.9	11.6	9.5
2008	11.0	11.1	11.5	13.9	13.6	12.6	12.7	12.8	13.6	13.6	11.6	10.3
2009	11.3	13.2	13.7	14.5	13.5	12.5	11.9	12.2	12.9	13.7	12.1	13.1
2010	12.0	14.4	14.2	14.5	14.8	13.5	14.8	12.7	13.0	13.4	8.8	9.3
2011	10.6	11.5	13.3	14.5	14.5	13.9	13.2	13.0	13.4	13.5	13.5	13.0

2012	8.4	10.5	11.0	13.2	13.9	8.3	8.1	8.4	7.7	8.3	7.1	5.5
2013	5.5	6.4	9.1	10.8	9.1	8.3	13.3	7.5	7.4	8.0	11.2	9.3
2014	5.3	11.1	8.3	8.7	9.2	8.2	12.6	7.8	7.9	11.7	9.9	7.8
2015	3.9	6.7	9.4	9.2	9.6	8.7	8.2	7.1	7.2	9.5	8.4	7.7
2016	7.3	7.3	12.2	10.3	13.7	8.4	8.1	7.4	7.4	9.0	12.1	18.2
2017	3.4	8.1	9.4	12.4	13.9	13.4	13.6	13.2	13.8	14.3	12.1	16.3

Appendix A-10; Monthly minimum temperature of Billate meteorological station in the catchment GRB

Years	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	16.8	17.3	17.5	16.8	16.2	15.8	16.7	16.4	15.6	17.0	16.4	15.2
1998	16.5	16.6	16.4	17.8	18.1	16.9	18.0	17.6	16.6	17.0	14.4	15.9
1999	16.5	16.0	17.0	18.1	16.7	17.3	17.1	16.5	16.6	17.3	15.6	15.7
2000	17.2	17.7	18.0	17.7	16.6	16.5	17.0	17.1	17.1	16.1	16.3	16.0
2001	17.4	16.8	17.5	17.1	17.1	16.5	16.7	16.6	16.0	16.5	14.7	17.0
2002	17.9	16.6	17.5	14.0	13.9	13.6	13.7	13.5	12.4	12.4	11.3	12.6
2003	10.7	10.7	11.8	13.7	13.2	12.7	13.0	12.8	12.9	12.4	13.6	15.6
2004	16.3	16.4	17.3	17.0	16.1	16.0	16.4	16.9	15.9	15.4	15.7	16.2
2005	17.2	18.4	18.2	17.8	16.8	16.9	16.1	16.7	16.0	15.9	15.0	15.8
2006	17.9	17.1	17.3	16.9	16.7	16.4	16.8	16.8	16.6	16.6	15.3	17.2
2007	17.6	18.3	16.3	17.5	16.4	16.8	16.4	16.4	16.7	14.3	15.8	16.5
2008	17.1	18.0	16.8	16.5	16.7	16.8	16.9	16.8	16.6	15.9	15.6	16.5
2009	17.0	17.4	17.5	16.9	16.3	16.5	16.4	17.0	16.8	16.6	16.0	17.9
2010	17.4	18.6	17.6	17.6	18.2	16.9	18.2	17.3	16.5	16.0	15.6	17.0
2011	16.0	16.9	18.6	17.6	17.9	16.9	16.4	16.3	16.9	16.4	16.7	16.1
2012	17.0	16.2	18.3	17.6	17.0	17.6	17.2	16.7	16.4	15.7	16.1	16.8
2013	17.8	18.6	17.2	17.4	16.7	17.2	16.3	16.6	16.0	16.1	15.0	15.6
2014	17.4	18.0	17.2	16.2	17.1	16.4	17.4	17.1	16.9	16.9	15.9	16.3
2015	16.9	17.6	18.0	17.3	18.1	17.5	17.3	17.7	17.6	17.6	17.4	18.2
2016	19.4	19.6	19.1	19.5	18.6	17.4	17.5	17.1	17.2	17.5	17.3	18.2
2017	16.8	17.3	19.2	17.9	18.4	17.9	18.3	18.1	17.8	17.7	16.8	16.3

Appendix A-11; Average monthly sun shine hours of stations of the Gidabo catchment

	Dilla	H/selam	Billate	Yirgalem	Yirgachefe
January	8.2	8.1	7.7	7.9	8.1
February	8.1	7.9	7.9	8.1	8.4
March	7.4	7.2	7.4	7.4	7.3
April	6.5	6.4	7.1	7.1	6.5
May	6.5	6.4	6.7	7.2	6.5

June	5.7	5.5	6.1	6.9	5.6
July	4.4	4.4	6.0	6.1	4.4
August	4.8	4.8	6.1	6.3	4.8
September	5.2	5.2	6.4	6.7	5.2
October	6.0	5.9	6.6	6.8	6.0
November	7.5	7.3	7.3	7.7	7.4
December	8.2	7.9	7.4	7.7	8.1

Appendix A-12; Monthly Sun shine hours of Dilla meteorological station in the catchment of GRB

Years	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	8.3	10.2	8.2	5.6	7.4	6.4	4.0	6.0	6.3	5.3	5.7	8.6
1998	7.0	8.0	7.8	7.8	6.9	6.5	4.6	4.5	5.3	5.3	9.5	10.1
1999	9.5	9.9	8.7	7.1	7.9	7.7	4.5	6.2	6.5	5.2	9.3	10.1
2000	10.1	9.8	9.0	7.2	7.7	7.1	4.5	5.0	4.8	7.5	9.5	10.4
2001	8.9	9.3	6.4	7.2	7.5	6.1	5.4	5.4	6.6	7.1	9.4	9.7
2002	9.2	9.7	7.3	7.9	7.3	6.3	6.5	5.9	6.8	7.3	9.8	8.1
2003	9.0	9.6	8.5	6.8	8.0	7.3	4.2	5.0	6.4	8.7	9.1	9.5
2004	8.5	9.5	8.5	6.3	8.7	6.3	4.9	5.5	5.4	7.6	8.8	9.5
2005	9.2	9.5	8.0	7.8	5.8	6.8	4.8	6.8	5.8	7.1	8.9	10.5
2006	9.2	8.7	7.5	6.6	7.9	6.2	4.8	4.7	4.9	5.9	9.2	8.6
2007	9.1	9.3	8.2	7.0	5.3	5.4	5.3	4.7	5.0	7.8	9.2	10.3
2008	7.3	6.8	5.8	5.7	5.4	4.6	2.7	4.2	4.1	3.8	6.3	8.2
2009	6.7	8.1	7.8	5.4	6.2	6.1	5.3	4.5	4.8	6.0	7.8	4.8
2010	7.4	4.7	4.1	5.3	2.2	4.3	2.2	3.4	3.0	4.5	6.1	3.8
2011	5.4	7.6	5.1	6.7	5.5	2.1	3.9	3.4	3.5	4.5	3.5	3.3
2012	8.7	8.6	8.6	4.8	5.7	3.1	3.1	3.9	3.2	6.0	5.2	5.4
2013	6.4	6.1	3.6	3.9	3.5	2.5	3.3	3.4	4.4	5.4	5.2	9.7
2014	9.0	7.3	7.6	7.2	5.3	5.5	3.4	3.7	4.2	3.1	5.2	7.1
2015	8.4	8.5	8.4	6.5	5.4	4.6	4.5	5.9	6.1	6.2	7.8	7.7
2016	8.2	9.3	8.1	4.3	5.8	4.4	3.9	4.8	4.5	5.0	6.3	8.4
2017	9.4	8.0	8.0	7.5	5.9	5.8	3.2	3.1	5.9	7.6	7.9	7.5

Appendix A-13; Monthly Sun shine hours of Billate meteorological station in the catchment of GRB

Years	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1997	9.2	10.2	9.2	9.6	9.3	9.8	9.6	9.7	10.1	9.8	10.2	9.9
1998	9.9	10.5	9.9	10.3	10.0	10.4	10.0	10.1	10.5	10.2	10.6	10.3
1999	10.4	11.5	10.9	10.9	10.6	10.9	10.6	10.6	10.9	10.5	10.9	10.5
2000	10.5	11.1	10.4	10.7	10.4	10.7	10.4	10.4	10.6	10.2	10.5	10.2

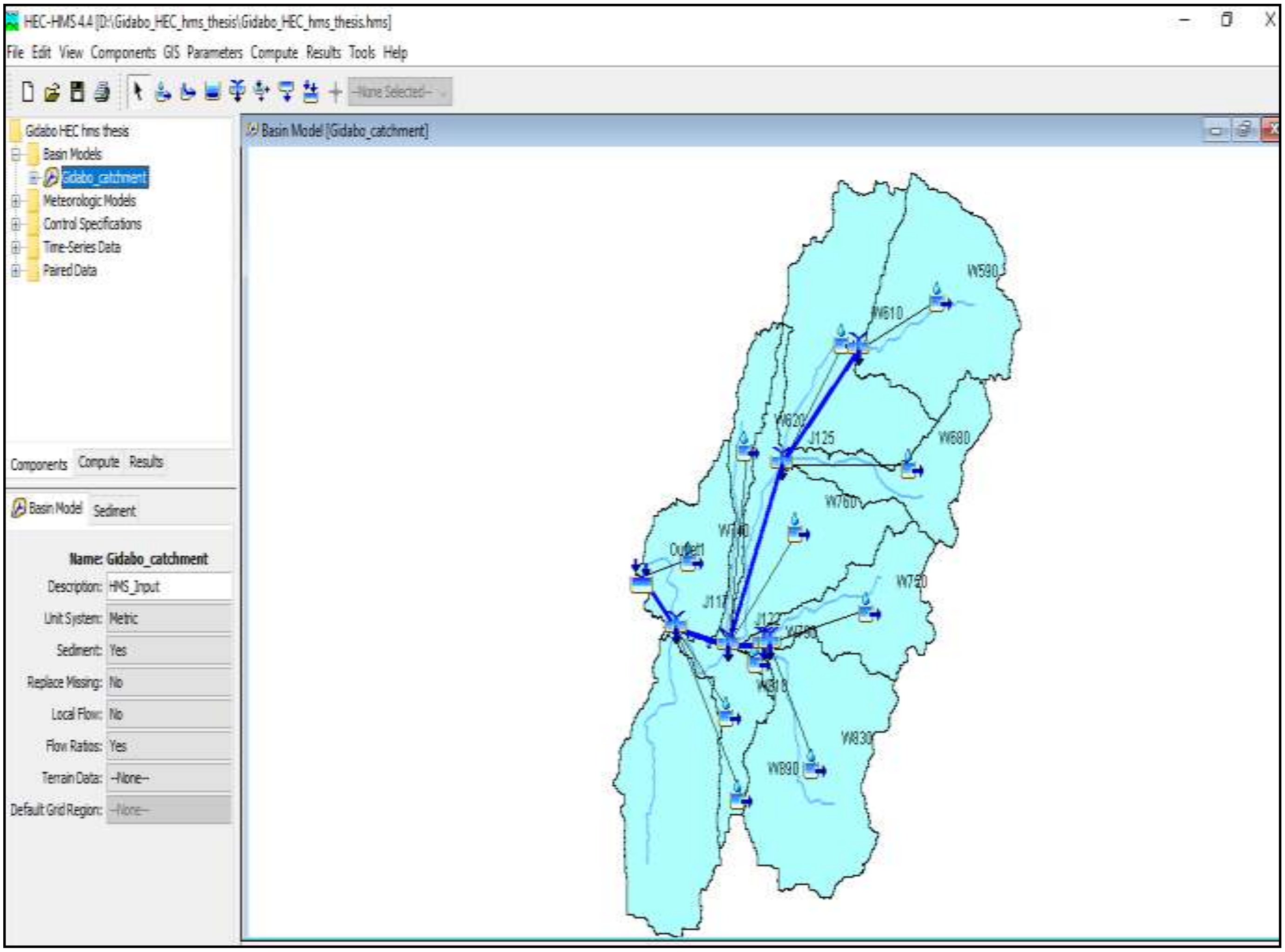
2001	10.1	11.2	10.1	10.4	9.9	10.0	9.5	9.5	9.7	9.3	9.3	8.8
2002	8.8	9.4	8.3	8.4	8.0	8.1	7.5	7.3	7.6	7.1	7.2	6.9
2003	6.8	7.5	6.8	7.1	7.0	7.2	6.8	6.7	6.7	6.2	6.3	6.1
2004	6.1	6.5	5.9	6.1	5.9	6.2	6.0	5.9	6.4	6.3	6.7	6.6
2005	6.7	7.7	7.2	7.4	7.4	7.7	7.5	7.6	7.8	7.5	7.7	7.4
2006	7.4	8.3	7.6	8.1	8.2	8.6	8.5	8.6	9.1	9.0	9.1	8.5
2007	5.6	6.1	6.9	5.4	3.4	2.2	3.4	2.5	3.1	5.9	6.8	8.1
2008	7.3	6.8	5.8	5.7	5.4	4.6	2.7	4.2	4.1	3.8	6.3	8.2
2009	6.7	8.1	7.8	5.4	6.2	6.1	5.3	4.5	4.8	6.0	7.8	4.8
2010	7.4	4.7	4.1	4.2	2.2	1.1	2.2	3.4	3.0	4.5	6.1	3.8
2011	5.4	7.6	5.1	6.7	5.5	2.1	3.9	3.4	3.5	4.5	3.5	3.3
2012	8.7	8.6	7.1	4.0	4.7	3.0	3.1	3.6	3.3	5.8	5.2	5.4
2013	6.4	6.1	3.6	3.9	3.5	1.8	2.7	4.0	4.3	4.7	5.2	7.3
2014	7.5	5.3	6.7	6.0	5.5	4.1	2.8	3.8	4.2	3.1	5.2	7.1
2015	8.8	8.2	7.3	4.4	3.9	1.7	3.1	6.2	6.1	5.0	4.7	4.7
2016	6.4	7.6	6.3	3.7	4.4	2.6	3.4	4.8	4.5	5.0	6.3	8.4
2017	8.6	7.0	7.2	7.1	5.9	5.8	3.2	3.1	5.9	7.6	7.9	7.5

Appendix A-5; the monthly observed stream flow data of Measso station of Gidabo watershed outlet

Years	Monthly stream flow data of Gidabo watershed outlet (Measso) station											
1997	5.23	2.76	3.03	7.51	27.47	24.04	35.66	33.71	14.73	26.71	15.28	10.74
1998	6.95	9.12	10.23	10.74	23.13	13.54	15.71	29.19	22.97	40.20	20.18	7.07
1999	4.70	3.07	5.90	6.69	17.62	9.54	9.82	9.98	14.32	27.55	14.54	9.36
2000	3.55	1.62	1.37	3.71	7.96	11.93	9.65	15.08	16.69	37.03	13.51	8.56
2001	3.89	4.67	2.46	7.28	26.72	22.91	28.88	35.16	39.56	28.20	14.65	8.02
2002	7.28	4.67	2.67	11.32	18.24	20.06	8.22	9.12	12.32	19.72	12.22	8.16
2003	5.24	3.13	2.74	5.76	10.07	10.69	10.85	19.58	20.28	22.85	17.40	13.24
2004	9.37	7.15	6.85	13.58	16.81	15.86	13.54	14.85	25.02	29.31	19.57	6.36
2005	3.38	4.60	3.24	7.09	18.53	19.06	14.69	16.17	38.45	38.94	17.34	10.25
2006	4.87	3.12	7.56	21.41	24.69	29.02	26.93	23.37	19.14	21.43	17.54	14.13
Month	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.

APPENDIX B

Appendix B-1; the schematic of Gidabo watershed with sub-basins, reaches, junction and rivers in HEC-HMS model



Appendix B-2; the monthly estimated stream flow data at the Measso station of the Gidabo catchment

Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	0.2	0.1	0.1	2.4	7.8	20.4	29.9	32.9	14.2	24.0	26.3	14.2
1998	5.0	2.5	2.1	3.7	24.4	19.1	21.4	28.5	25.8	34.4	25.9	6.5
1999	1.7	0.4	2.5	3.1	9.1	7.3	6.2	8.0	5.8	20.2	12.3	3.0
2000	0.6	0.2	0.2	1.7	2.7	10.2	13.4	15.1	14.8	26.5	15.3	4.5
2001	1.4	0.9	2.4	3.8	23.7	21.5	25.5	25.8	34.2	29.2	14.7	5.1
2002	1.8	0.8	2.4	7.0	17.4	22.9	15.3	15.5	9.9	13.7	8.7	4.0
2003	0.3	0.1	0.3	1.5	1.7	6.2	9.8	17.8	19.4	18.6	13.2	3.9
2004	1.7	1.3	1.1	3.8	12.8	13.8	15.2	16.2	20.1	28.0	16.6	3.9
2005	1.0	0.4	0.8	2.7	11.9	20.6	17.0	17.8	36.4	36.7	17.3	3.9

2006	0.8	0.6	1.9	8.1	15.0	23.6	29.6	32.1	18.8	23.4	15.1	4.6
2007	0.3	0.2	0.4	1.4	3.2	5.4	15.5	22.8	28.4	31.1	17.4	4.4
2008	1.0	0.7	1.1	3.8	8.3	11.5	6.4	4.1	16.2	27.3	23.0	4.9
2009	2.3	2.5	1.1	2.8	7.7	8.8	5.1	7.4	14.0	24.9	9.6	3.9
2010	1.8	2.3	2.9	4.5	26.3	31.5	17.6	22.2	34.1	37.6	13.0	3.1
2011	1.0	0.4	0.9	2.3	16.7	19.9	13.7	29.3	27.2	23.0	12.0	9.0
2012	1.9	0.6	0.5	3.0	9.2	13.7	6.5	5.8	16.0	18.9	6.4	2.1
2013	0.8	0.4	1.5	3.3	13.8	16.7	19.9	14.0	11.1	21.3	7.3	1.8
2014	0.4	1.0	2.5	5.7	12.9	8.1	16.3	31.2	26.3	29.0	10.0	2.7
2015	0.5	0.1	0.6	3.2	8.4	12.2	6.2	21.8	10.8	9.2	11.8	5.1
2016	1.8	0.9	1.7	6.9	17.6	7.0	7.9	11.0	3.9	31.3	16.7	4.5
2017	0.9	0.5	1.6	2.7	11.3	12.2	7.5	10.2	21.6	16.9	7.6	2.0

Appendix B-3; the monthly estimated sediment yield output of HEC-HMS model (1997-2017)

		Monthly computed sediment yield in tone of GRB at the catchment outlet										
Years	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1997	7233	1960	4753	14600	18600	23500	27383	35650	15000	40817	31500	7750
1998	3203	1680	2222	2750	4237	2500	12917	19117	11500	45983	16000	2170
1999	155	373	3875	3900	2170	4600	5787	6200	6000	9300	7300	930
2000	155	290	155	1650	5270	5500	5167	7233	6500	45467	4000	2118
2001	155	280	4392	4850	28210	10500	7233	26350	38000	20667	7600	4960
2002	155	140	1292	3550	6303	9500	6200	7233	6500	8783	1750	2067
2003	27900	17733	19427	10600	7595	6300	8060	29708	18500	17877	7800	517
2004	155	4495	155	6100	6510	2100	4960	1240	7500	23767	2350	11728
2005	155	140	155	4100	41953	19500	8267	17308	27000	10333	1600	258
2006	155	140	4288	4600	10850	36000	17050	7957	6000	35650	12000	258
2007	10850	16427	7853	22600	18600	9000	13433	19117	18500	39783	31500	7750
2008	723	1740	4805	8050	6303	6500	6717	8783	12500	33583	16000	2170
2009	1343	373	3307	9600	6717	4500	5683	8267	13000	23767	10300	4753
2010	155	4882	4702	6600	16120	9000	10333	22217	27500	34617	16000	1602
2011	155	280	5425	13000	28210	11500	10850	15500	34000	29967	19600	6510
2012	723	145	5890	4550	9300	4500	6200	8267	14000	19117	6250	2067
2013	1085	607	4443	9000	7492	8000	8783	9042	6500	12710	6500	1447
2014	155	193	5735	9000	10127	8300	10850	14260	22500	28933	11100	3462
2015	155	140	4185	6000	9817	8000	11367	13175	7500	9300	7000	2170
2016	155	145	672	9600	13433	9500	6717	11367	5000	17050	8000	3100
2017	155	140	5270	7500	9817	8500	10850	5167	8000	10850	11000	723