JIMMA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

Rainfall-Runoff Modeling Using Hydrologic Engineering Center-Hydrologic Modeling System Models: Case Study of Bilate Watershed, Ethiopia

By: Endale Abebe

A Theses Submitted to School of Graduate Studies of Jimma, Jimma Institute of Technology, in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

February, 2020

Jimma, Ethiopia

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Main Adviser: Dr. Ing. Tamene Adunga (PhD.)

Co-Advisor: Chala Hailu (MSc.)

DECLARATION

I, Endale Abebe Fitamo, declare that this thesis entitled Rainfall-Runoff Modeling Using Hydrologic Engineering Center-Hydrologic Modeling System Model: Case Study of Bilate Watershed, Rift Valley, Ethiopia is my own original work and that it has not been presented and will not be presented to any other university for similar or any other degree award.

Name	Signature	Date

As master's research advisor, we certify that we have read and evaluate this MSc. thesis entitled as Rainfall-Runoff Modeling Using Hydrologic Engineering Center-Hydrologic Modeling System Model: Case Study of Bilate Watershed, Rift Valley, Ethiopia is submitted by Endale Abebe our supervisor-ship as university advisors.

Main advisor name	Signature	Date

Co-advisor name	Signature	Date

ABSTRACT

When the rainfalls on the earth's surface, some portion of it is infiltrated and evaporated, and the remaining portion is changed to surface runoff. The excess surface runoff may result in soil erosion. In Ethiopia, particularly in the study area, the land use land cover management system is poor and the excess surface rainfall causes the erosion of the land surface, overflow of the river on its bank and flooding problems. Flooding have occurred frequently and lead to Migration of people from their place, and properties have been damaged. The general objective of this study is to simulate daily Rainfall-Runoff using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) for Bilate watershed, Rift Valley River Basin, Ethiopia. Bilate watershed is a part of the Abaya Chamo sub basin in the southeast of the Ethiopian Rift Valley and it is located between longitude (37°30'0" to 38°30'0"E and latitude 6°30'0" to 8°30'0"N) and its total area is about 5500km^2. Understanding the complex relationships between rainfall and runoff processes is necessary for the proper estimation of the quantity of runoff generated in a watershed. The input data used were the spatial data, meteorological data and hydrological data. The Bilate watershed was initially delineated and devided into 150 sub basin and then merged into 6 sub basins using the combination of Arc hydro tool version 10.1 and HEC-GeoHMS extension of ArcGIS 10.1. The Curve number was generated using the union of Hydrologic soil group polygon and land use polygon and the Curve number lookup table that links Hydrologic soil code and land use value. The model was simulated for an input daily rainfall and stream flow data of 21 years (1996-2016). The model calibrated and validated using daily rainfall and stream flow recorded data for 14 years (1996 to 2009) and 7 years (2010 to 2016) for calibration and validation respectively at Bilate tena gauging station, at the outlet of the watershed. CN is found to be more sensitive parameter in the Bilate watershed. The objective functions NSE, R^2 and MBE were used to check performance of the model. During calibration the model performance resulted in R^2= 0.8674, NSE = 0.837, MBE=60.35. Also during validation R^2=0.8615 NSE =0.852 values and MBE=56.50. Also the performance ratings for statistics Observations Standard Deviation Ratio (RSR)=0.163 and 0.148 and PBIAS=6.03% and 6.14% for calibration and validation respectively. These values showed that the model performed well during calibration and validations. The hydrologic model was used for determining the peak flow discharge for return periods of 2, 10, 25, 50 and 100 years and the result was found to be 241.8m^3/s, 314.8m^3/s, 651.2m^3/s, 738.01m/s and 1152.1m^3/s respectively in HEC-HMS. Using the Statistical flood frequency analysis, the peak flow discharge of 213.5m^3/s using log Pearson type-III flood frequency analysis for 2-year return periods. For 10, 25, 50 and 100 years return period, 296.32m^3/s, 541.63m^3/s, 652.38m^3/s and 983.125m^3/s using log Pearson type-III flood frequency analysis respectively. The highest peak flow recorded was 1152.1m3/s.

Keywords: *Bilate-watershed, HEC-HMS, Rainfall-runoff, stream flow.*

APPROVAL PAGE

This Thesis work was done under the title "Rainfall-Runoff Modeling using HEC-HMS for Bilate Watershed, Rift valley, Ethiopia" has been approved by the following advisor, co-advisor, examiners, and department chair in the partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering.

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ACKNOWLEDGEMENT

First and for most, I would like to thank my Father, God and for his care, support and endless love during my stay in Jimma Institute of Technology.

My special thanks are given to the Ministry of Water, Irrigation and Electricity, National Meteorological Service Agency and Ethiopian Mapping Agency for providing me the necessary information which is used to accomplish this study.

I wish to express the Ethiopian Road Authority and Hadiya zone Lemo Woreda Water Mining and Energy office for giving full sponsorship during my MSc studying period

My special gratitude goes to my Advisor Tamene Adugna (Dr. Ing) for giving me proper instruction, guidance and advice throughout this research work.

I also wish to express my gratitude to my Co-Advisor Chala Hailu (MSc.) His-constructive comments, untiring help, guidance and practical suggestions inspired me to accomplish this work successfully.

Also I would like to thank to my all friends who have been always encouraging my academic understanding with several ways for the realization of the work, spatially Sewmehone Sisay (MSc) for his progressive support.

My deepest inspiration goes to my wife Kidist Nigussie for moral inspiration and support and being with me to accomplish my academic goals.

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ACRONYMS AND ABBREVIATIONS

a.m.s.l	above mean sea level
DEM	Digital Elevation Model
DMC	Double Mass Curve
ECDF	Empirical Cumulative Distribution Function
EMA	Ethiopian Mapping Agency
GIS	Geographic Information System
Geo-HMS	Geospatial Hydrologic Modeling System
HEC-HMS	Hydrologic Engineering Centers Hydrological Modeling System
IWRM	Integrated Water Resource Management
IDD	International Disaster Database
KW	Kinematic Wave
LPM	Linear Perturbation Model
LULC	Land Use Land Cover
MoWIE	Ministry of Water, Irrigation and Electricity
NMSA	National Meteorological Service Agency
NSE	Nash-Sutcliffe Efficiency
PDM	Probability Distributed Models
RSR	Observations Standard Deviation Ratio
SCS-CN	Soil Conservation Service Curve Number
SLM	Simple Linear Model
SMA	Soil Moisture Accounting
SNNPRS	Southern Nation Nationalities and people’s Regional States
SWAT	Soil and Water Assessment Tools
USDA-NRCS	United States Department of Agriculture, Natural Resources Conservation Service.

1 INTRODUCTION

1.1 Background of Study

Hydrology is the study of the properties of the earth's water, distribution, and effects on the earth's surface and soils, underlying rocks, and atmosphere. Occurrence of rainfall is a natural process which is defined as the amount of precipitation formed in the specific area within some time-interval which expressed in units of millimeters or inches. The precipitated water is measured using rain gauge established in the specific area that serves as point rain fall collector for designed (installed area).

Ethiopia, the water tower of East Africa, is dominated by mountainous topography, the rainfall-runoff processes on the mountainous hilly slopes are the source of the surface water for much watershed of Ethiopian low land (Derib, 2005). Rainfall influences hydrological responses of a watershed, and this in turn influences soil erosion (Grunwald, 2000).

The relationship between rainfall and runoff is essential in a catchment for hydrologic analysis and design. The rainfall will change runoff in term of surface-runoff, interflow and base-flow after it subjected to losses due to evaporation, transpiration, by canopy interception and infiltration. The correlation causes the occurrence of flooding as if it exceeding the capacity of the stream channel which may cause the destruction of nature on the earth surface. Runoff also has negative contribution on the groundwater recharge which is most potable form of water sources.

A balanced ecosystem consisting of soil, water and vegetation is essential for the survival and welfare of human being. However, over-exploitation of natural resources creates disturbances on ecosystems and induces natural hazards. Erosion and sedimentation are major issues in disrupted ecosystems. Gross runoff response as a result of complex interactions between climatologic and physiographic factors usually affects erosion in watersheds. (Rai and Mathur, 2007).

Adequate knowledge of rainfall-runoff processes is vital to estimate the amount of runoff produced within a given catchment. Also knowing the amount of runoff within a given catchment is important for sustainable water resources project planning and management. The activities to estimate runoff volumes and flood peaks can be easily simplified by adopting a modeling concept and by understanding rainfall partitioning and the principal factors triggering runoff (Zhang, 2005).

Hydrological models are tools that describe the physical processes controlling the transformation of precipitation to stream flows. There are different hydrological models designed and applied to simulate the rainfall runoff relationship under different temporal and spatial dimensions. The detailed processes that link the rainfall over the catchment to runoff can be studied by applying physical laws that are reasonably well known. But, the complexity of the boundary conditions (i.e. the physical description of the catchment and the initial conditions and distribution of the variables) makes a solution based on the direct application of the laws of physics impracticable. Moreover, direct application of these laws requires subdividing the catchment into homogenous and isotropic regions (Sileshi., 2010). Hydrological modeling is important for watershed management as hydrology is the driving force behind many processes occurring on the atmosphere.

Rainfall runoff modeling is an important scientific task to simulate daily rainfall of the catchment. Based on the developed model, the performance of the HEC-HMS model in the runoff prediction assessed by comparing the simulation data with the observe data.

1.2 Statement of the Problem

Floods will continue to cause serious economic and environmental losses. It is reported that flood disasters account for about one third of all-natural disasters in terms of their number and the economic losses. Flood and droughts are the world's costliest natural disasters, causing an average $6–$8 billion in global damages annually and collectively affecting more people than any other form of natural disaster (Lampros, 2009).

Now days there are different natural and human-caused factors that increase the total runoff volume and peak discharge of storm runoff events whole over the world. Natural agents like climatic change and weather conditions have direct influence on runoff. Population settlement and their activities is also important factor for runoff fluctuation in watershed (IDD, 2015).

In Ethiopia, particularly the Bilate Watershed, there is no effective land and management practices system. In some part of the watershed especially in Hosanna sloppy catchments there is high flood problem which causes devastation of life and property. Wide agricultural land is inundated by flooding in rain season of Ethiopia. These resulted in the reduction of agricultural productions in the watershed (Getahun, 2017). The areas suffered from serious flooding even in this year 2019 caused damages to houses, various infrastructures as well as cause for loss of human and domestic animals that affects socio economic activities of the concerned watershed.

Hence to overcome these problems Rainfall-runoff and future peak flood determining in the Bilate watersheds is necessary for the effective watershed management strategy.

This study was performed using the Hydrologic Engineering Center Hydrological Modeling System (HEC-HMS) to model the hydrological process of Bilate watershed so as to plan, design and manage rainwater properly. Therefore, knowing the exact characteristic and magnitudes of the rainfall and forecasting the future probably peak flood is critical thing in the river basin for water work design and to take measure for excess flood hazard.

Figure 1. 1 Overflowing of Bilate River

1.3 Objectives

1.3.1 General Objective

The general objective of this study is to apply a hydrological model HEC-HMS technique in order to simulate Rainfall-Runoff for Bilate watershed Rift Valley River Basin, Ethiopia.

1.3.2 Specific objectives

1. To evaluate the performance of HEC-HMS model for Bilate watershed.
2. To model the daily Rainfall-runoff for Bilate watershed.
3. To predict the peak flood comparison for different return period.

1.4 Research Question

1. Is HEC-HMS performed well in rainfall runoff estimation in Bilate watershed?
2. What is the effect daily rainfall on surface runoff?
3. What is the comparison of peak flood discharge of Bilate watershed for different return period?

1.5 Significance of the study

Watershed is an essential resource for the base analysis of appropriate response and development strategies to watershed management of the country in general and at the study area in particular. The modeling of Rainfall runoff is getting a great issue for the future planning and management activities which help the government policymakers, development organizations, and NGOs to formulate the appropriate management policies, design effective evaluation and development programs in the watershed. Besides the detailed documentation of the rainfall runoff, it is also essential to understand the method and the activities undertaken in this process and also the Performance of HEC-HMS model and its sensitive parameters in Bilate Watershed.

For this reason, the Good input at times of planning for future watershed management strategies aimed at foreseeing their future development and impacts, the output rainfall runoff relationship is used as input in the watershed management and has a significant contribution for the future development researches in the Bilate watershed and in rift valley lake basin in general.

2 LITRETURE REVIEWS

2.1 Rainfall-Runoff

Rainfall- runoff correlation is a complex phenomenon to represent in the mathematical form. Rainfall runoff process involves in many parameters either it may be physical features of the catchment or climatological parameter. In the real-world system rainfall runoff process is influenced by each and every physical characteristics of catchment. Surface water is water stored or flowing on the earth's surface and continually interacts with the atmosphere (Praveen Rathod et al, 2015).

Runoff processes operating at any location vary from time to time. Large variations in hydrologic characteristics affect runoff processes that occur across the catchment. Runoff is also the main driver in contaminant transport due to excess or uncontrolled flooding and pesticides from agricultural lands being washed away into waterways during excess rain events. High runoff rates, along with drainage systems cause flooding and erosion that damages vegetation and manmade structures (Huffman & Schwab., 2011).

Saturation excess occurs when the soil becomes fully saturated with water, exceeding the water holding capacity of the soil; when the surplus rainfall can no longer be held in the soil, the water is directed to another location through overland flow (Johnson & Boll, 2003). Infiltration excess occurs when rainfall intensity exceeds the maximum rate that water can infiltrate into the soil, and water must flow over land to a different area (Yang et al, 2015).

The runoff generation at a catchment scale in general or hill slope scale in particular includes two main components: (1) surface runoff, (2) subsurface runoff. There are a number of flow processes within each main component. (Dunne and Rientjes, 2004).

The surface runoff: Flow processes include overland flow, stream flow, and channel flow which is defined as water flow over the land surface based on the differences on gradient. The overland flow is known as infiltration excess (Horton overland flow) or saturation overland flow (Dunne, 1982). The overland flow is observed as sheet flow which then generates the rill flow. A number of the rill flow will contribute or create the stream flow which then converges into channel flow.

Subsurface-runoff: - Subsurface runoff is generated since water discharged from the surface into the subsurface system. The unsaturated subsurface flow mostly is in vertical direction while the perched flow moves in lateral direction. The perched flow is generated where the shallow soil layer has much higher hydraulic conductivity as compared to the lower one.

2.2 Factors Affecting Rainfall-runoff

The factors affecting rainfall runoff are rainfall characteristics such as intensity, duration and distribution, there are a number of site (or catchment) specific factors, which have a direct bearing on the occurrence, and volume of runoff. (Förch, 2007)

2.2.1 Soil type

The significant change between the dry and rainy seasons determines the soil conditions in the tropics, the subtropics as well as in the moderate continental climates. In more developed older soils, this only applies to the heavier minerals which are more resistant to weathering (Grunwald, 2003). The soil typology notation is the same one used in the World Soil Map of the FAO. Within the varying topography of the country, with its diverse geological strata and varying climatic conditions, various soils could develop. Soil types such as Fluvisols and Phaeozem are found in small amounts on the southeastern and eastern catchment borders of Rift valley (FAO, 1998).

2.2.2 Vegetation

The vegetation is essentially dependent on the topography, the climate and the soil. The relief of Ethiopia has a special importance it leads to a vertical differentiation of the climatic zones, which consequently influences the vegetation. Climatic changes in the vegetation are usually slow processes; changes in the landscape caused by humans require a comparatively short time. The natural vegetation in these middle elevations is thus strongly anthropogenically influenced. A growing population pressure and limited available land cause a modification of this landscape, which is difficult to reverse, and the natural vegetation in this zone continues to retreat (Thiemann., 2005).

2.2.3 Land use

Physio graphically the Bilate River basin is a tectonic valley along its length much of the valley is bounded by fault scarps or steep slopes on either side. The floor of the valley is mostly flat plain and appears to be in part a remnant of the depositions floor of ancient large water basin. For the part of the western rift margin which is characterized by chain ridge, hills, deep and wide valleys of small and large streams, and narrow flat lands between the valleys having gentle slopes. It is due to the uplift and subsequent rifting phenomena that created localized and regional fractures and faults, (the rift floor and escarpments are highly faulted. The setup is also caused by erosion, deposition processes, and land use practices (Ayenew et al, 2008).

The land use in the investigation area can only be represented in a highly generalized manner. Perennial crop cultivation in substance takes place on the western grabben shoulder as well as in the northwest of the Bilate River Catchment. Areas which are moderately cultivated are found throughout the catchment. Furthermore, open grassland exists in the region of Lake Boyo and on the eastern flank of the area of investigation. The natural vegetation, for example woods with eucalyptus, various acacia species, juniper trees) as well as shrub land is also found in small areas. (Negasho, 2009).

2.3 Hydrological Model

Hydrologic models are simplified conceptual representations of a part of the hydrologic cycle and they are primarily used for hydrologic prediction and for understanding hydrologic processes (Marye., 2015). There are many existing computer models which are powerful tools that can be utilized to design and estimate the performance of various development activities. The performance of different development proposals can be assessed and compared using a common measurement system. Essentially, models allow the extrapolation from existing systems and knowledge to analyze potential situations. They are only useful to the extent that they accurately model the real world. Unrealistic models, however internally consistent or persuasive they may be, are misleading and risky (Sileshi., 2010).

2.3.1 Types of Hydrological Model

(Xu and Lastoria., 2008) on the basis of process description, the hydrological models can be classified in to three main categories. Lumped, distributed and semi distributed models.

Lumped models: provide a unique output for the whole watershed. They do not provide any information regarding the spatial behavior of the outputs. The whole catchment is assumed to be homogeneous and all potential variations are lumped (averaged) together. Thus, the degree of accuracy of the model is expected to vary with the degree of non-homogeneity of the catchment. Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven., 2000).

Distributed models: In contrast, distributed model approaches capture the system by partitioning the catchment into a number of smaller units. Parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed modeling approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of (often unavailable) data for parameterization in each grid cell. However, the governing physical processes are modeled in detail, and if properly applied, they can provide the highest degree of accuracy (Singh, 1997).

Semi-distributed models: Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin into a number of smaller sub basins. There are two main types of semi-distributed models:

1) kinematic wave theory models (KW models, such as HEC-HMS), and

2) probability distributed models (PD models, such as TOPMODEL). The KW models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (K.J., 1989). In the PD models spatial resolution is accounted for by using probability distributions of input parameters across the basin. (Tensay, 2011).

2.3.2 Selection of Hydrological Model

Thus, the degree of accuracy of the model is expected to vary with the degree of non-homogeneity of the catchment. Sources (Kiesel, 2006)

The main advantage of these models is that their structure is more physically-based than the structure of lumped models, and they are less demanding on input data than fully distributed models (Sintayehu, 2015). HEC-HMS, SWAT, HBV are some examples of semi-distributed models. Finally, the model that has been chosen for now is Semi distributed models. Parameters of semi-distributed (simplified distributed) models are partially allowed to vary in space by dividing the basin in to a number of smaller sub-basins.

There are multiple criteria which can be used for choosing the “right” hydrologic model. These criteria are always project-dependent, since every project has its own specific requirements. Among the various selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik M. Juraj, 2003).

1. Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project such as long-term sequence of flow?)
2. Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?)
3. Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?),
4. Price (Does the investment appear to be worthwhile for the objectives of the project?

In general, the reasons behind for selecting HEC_HMS model for this study are:

1. Physical based model: It is based on readily observed and measured information and it attempts to simulate many hydrological components.
2. The model was applied for land use and land cover change impact assessment in different parts of the world.

3. It is public domain with for free and online access.
4. Its compatibility with ArcGIS interface: for ease of data base management.
5. It’s easy linkage to sensitivity, calibration and uncertainty analysis tools.

2.3.3 Limitation of HEC-HMS Model

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation and simplified flow representation. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite.

2.4 Rainfall Runoff Model:

Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) is open source computer software that helps in simulating the hydrologic cycle (precipitation, evapotranspiration, infiltration, surface runoff and base flow) of a catchment by describing its physical and meteorological properties.

The program uses separate model to represent each component of the runoff process like model to compute runoff volume, model of direct runoff/base flow/ channel flow as well as alternative models to account for the cumulative losses for e.g.: SCS CN loss model. Then, it computes runoff volume by subtracting losses (infiltration, storage, interception, evaporation etc.) from precipitation. HEC-HMS compatible version will be used during for the required project (Brauer, 2016).

This model relates the rainfall data of the catchment to river flows and forecasting future flood using the rainfall-runoff simulated result as input. River flows may be forecasted at specific points along a river to provide warnings at these points or used as input to flood routing models to provide warnings further downstream.

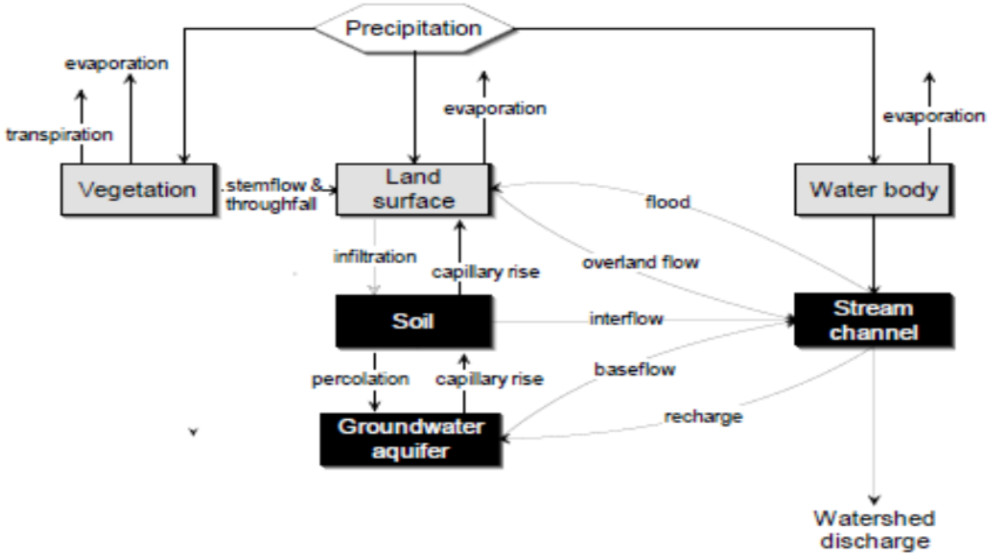


Figure 2. 1 Schematics of Rainfall-runoff processes HEC-HMS (Feldman, 2000)

2.5 Model applied to simulate rainfall-runoff process

2.5.1 HEC-HMS Model Description

HEC-HMS is a semi-distributed conceptual hydrological model which simulates rainfall runoff and the basin (for and geographical information of the basin to get the simulated rainfall-runoff and calibrate and validate streamflow volume. HEC-HMS model setup consists of a basin model, meteorological model, control specifications, and input data.

2.5.2 HEC-GeoHMS

Hydrologic Engineering Center’s Geospatial Hydrologic Modeling System has been developed as a geospatial hydrology tool kit for engineers and hydrologist. The program is an extension of ArcGIS and allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation HEC-GeoHMS provides the connection for translating GIS spatial information into hydrologic models. HEC-HMS accepts the hydrologic inputs as a starting point for hydrologic modeling (Asadi, 2013).

2.6 Fitting a flood Probability Distribution

A probability density function (PDF) is a continuous mathematical expression that determines the probability of a particular event. If a prediction is to be based on a set of hydrologic data, then the distribution that best fits the set of data may be expected to give the best estimates usually an extrapolation of the probability of an event occurring (Asnake, 2018).

2.6.1 Easy Fit Software

Easy Fit is a data analyzer and simulation software which allows to fit probabilistic distributions to given data samples, simulate them, choose the best fitting sample, and implement the results of analysis to take better decisions. This software can be used as a Windows compatible program, and also as an add-on to Excel spread sheets (Pakgohar, 2014).

When a certain distribution is chosen as data distribution, it is expected to fit suitably with data, so we are ready to practically fit those data with the distributions. Data fitting process includes using certain statistical techniques which allow estimate fitness parameters based on sample data.

The distribution fitting software can be very useful in this sense. Clearly this program was using the methods of parameter estimation on the best-known distributions, in order to save time and concentrate on data analysis. Since researchers sometimes want to fit several different kinds of distributions to the data simultaneously, they need to estimate parameters of each distribution separately (Mehrannia, 2014). The Input data fitting software usually the data in any accepted format and distributions which want to fit with them. Fitting choices Output results of the fit would include graphs related to raw input data, distribution or improved fitting parameters, graphs of fitted distribution, additional graphs and tables which help to choosing best fit for the data.

2.6.2 Statistical Theories

The general review of statistical theories and techniques in data fitting and Goodness-of-Fit test field is required to identify probable fit distribution. By having an overview on statistics which relates the graphs in order to show goodness of the data.

2.6.3 Goodness-of-Fit Tests (GOF)

The goodness of fit (GOF) tests measures the compatibility of a random sample with a theoretical probability distribution function. In other words, these tests show how well the distribution selected fits to the data. The results are presented in the form of interactive tables that help to decide which model describes your data in the best way. A couple of goodness-of-fit test have been conducted such as Kolmogorov-Smirnov test, Anderson-Darling test along with the chi-square test at significance level for choosing the best probability distribution (Alem, 2018).

2.7 Previous Study

Studies have been done and are currently being done to investigate different hydrological phenomenon of river basin especially Parametric Land Suitability Assessment for Rain fed Agriculture, water resources assessment, precipitation variability in the Case of Bilate Alaba Sub-watershed, Southern Ethiopia. Most of the available works conducted so far are project-based merely developed to predict flood magnitudes using empirical methods and frequency analysis techniques. In Water Resources Assessment in the Bilate River catchment precipitation Variability, observed rainfall variability and intensity in the catchment follows a semi-humid to semi- arid tropical bimodal distributed precipitation pattern. Accordingly, Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects. The extreme variability of daily and monthly precipitation amounts all over the catchment area essentially limits the exact assessment or even prediction of water resource availability. In addition, the long-term variation of precipitation overlapping with the seasonal variability cannot be predicted accurately as well, to lack of reliable data. (Stefan and Gerd, 2004).

Genene conducted Inter-comparisons of the performance of different rainfall-runoff hydrological models in Abaya-Chamo river basin a case study of Bilate and Kulfo catchments. The study in the sub-basin with the objective of testing different hydrological rainfall runoff models. Two linear models (Simple Linear Model SLM and Linear Perturbation Model LPM) and two conceptual models (Soil Moisture accounting & Routing SMAR Model and HBV Models). are used for the test. Based on performance criteria he has got that the SMAR model performs better in the two catchments. The objective function Nash-Sutcliff Efficiency NSE in the Kulfo and Bilate catchments was 0.4 and 0.63 respectively. (Genene., 2006).

(Tesfaye, 2015) Conducted Ground water potential evaluation based on integrated Gis and Remote sensing techniques, in Bilate River catchment: South Rift Valley of Ethiopia. His concern is to evaluate and delineate Ground water potential zones in the Bilate River catchment using integrated geographic Information system (GIS) and Remote sensing techniques. Thus, four different groundwater potential zones were identified, namely 'high, 'moderate',' low' and 'poor'. The high potential zones correspond to alluvial plains, lacustrine sediments, the fracture valleys, and valley fills, which coincide with the low slope and high lineaments density areas. The eastern portion and valley escarpment of the study area fall under moderate groundwater potential zone. The low zones mainly comprise structural hills and an escarpment which contributes high run-off.

(Abyot, 2008) Conducted the HEC-HMS model performance on Kulfo and Bilate catchments, as his conclusion result shows The Nash-Sutcliffe efficiency was calculated 0.58 for Bilate and 0.28 for Kulfo, and the R^2 is 0.77 and is 0.83 for the Bilate, and for the Kulfo catchments, respectively.

(Ingrid and Gerd, 2007) Conducted water Balance Modeling in the Bilate River catchment and faced difficult to use standardized hydrological models due to limited data both spatially and temporally. The precipitation runoff model NASIM was used to account the necessary water balance parameters, but strong relief and great variability of the precipitation, as well as the influence of evaporation, are not represented adequately by the number of climatic stations. In addition, NASIM does not work on a raster basis at present. Thus they strongly recommended a further use of GIS for the visualization of the simulation results, and more research is required to modify the model and conduct more field work from which initiated to Carrey out further research using GIS in the area.

(Johannes, 2007) the research aimed improving hydrological description of Lake Tana basin and thus contributes towards integrated water Resource management (IWRM).

The study makes the use of remote sensing techniques for hydrologic components of water balance estimation. Satellite derived parameters have been used for evaporation estimation, satellite based rainfall estimates have been validated with recorded data and land cover information has been obtained from moderate resolution optical images Penman-Monteith method for evapotranspiration estimation, HEC-HMS for flood hydrograph (SCS and SWAT curve number) and soil water balance method for runoff estimation were used in the study. The authors presented that major impact of land use/land cover change on runoff estimation in Lake Tana basin need to be carefully identified. The authors concluded the goodness of soil water balance method for un-gauged catchment for runoff estimation in Lake Tana sub basin.

(Arekhi et al, 2011) Conducted Evaluation of HEC-HMS Methods in Surface Runoff Simulation (Case Study: Kan Watershed, Iran), compared the different methods of precipitation loss Constant loss, Initial and constant loss rate, Deficit and Green & Ampt. Objective of this study was to fit the peak flow discharges and total volume of flow in HEC-HMS. The results showed that for two objective functions, Initial and constant loss rate method shown the best results, had less changes percent of simulated to observed discharges in 70% events and Green & Ampt and Initial Dificit and Constant loss rate methods placed in next preferences.

3 MATERIALS AND METHODS

3.1 General Description of the Study Area

The Abaya Chamo sub-basin is located in the southwest of Addis Ababa, between 5-5.8 °N latitude and 37- 38.5 °E longitudes. It forms part of the Main Ethiopian Rift valley, which in turn part of an active rift system of the Great Rift Valley, Ethiopia. The total area of the Abaya Chamo Basin is around 18.599km^2(Bekele, 2001). The Bilate River is the longest river that drains into the Abaya Chamo sub-basin, with a length of about 255 km. It is also the only river which flows into Lake Abaya from the north. The Bilate watershed is located in the northern part of the Abaya Chamo sub-basin.

The Bilate River originate from the north of the Gurage Mountain and flows towards the south in to the Lake Abaya and constitutes about 38% of Lake Abaya basin. Generally, many small streams drain towards Abaya Lake along with Bilate River. Most of its tributaries as well as large volume of water sources are from Gurage, Silte, Hadiya, kambata and Wolyita zone high lands of the catchment.

3.1.1 Location

Bilate watershed covers the area between Gurage high lands to Lake Abaya shore, which includes the portion of Southern Nations Nationalities and People Regional State and South-central Oromia Regional states and the total area coverage is around 5324 square kilometers. It is located between 37°30ˈ0" to 38°30ˈ0"E and 6°30ˈ0" to 8°30ˈ0"N latitudes and longitudes respectively.

The elevation of Bilate watershed ranges between 3337 meter a.m.s.l in the north and 1168 meter in the south with a mean elevation of 2013.4 meters and has a maximum length of about 255km.

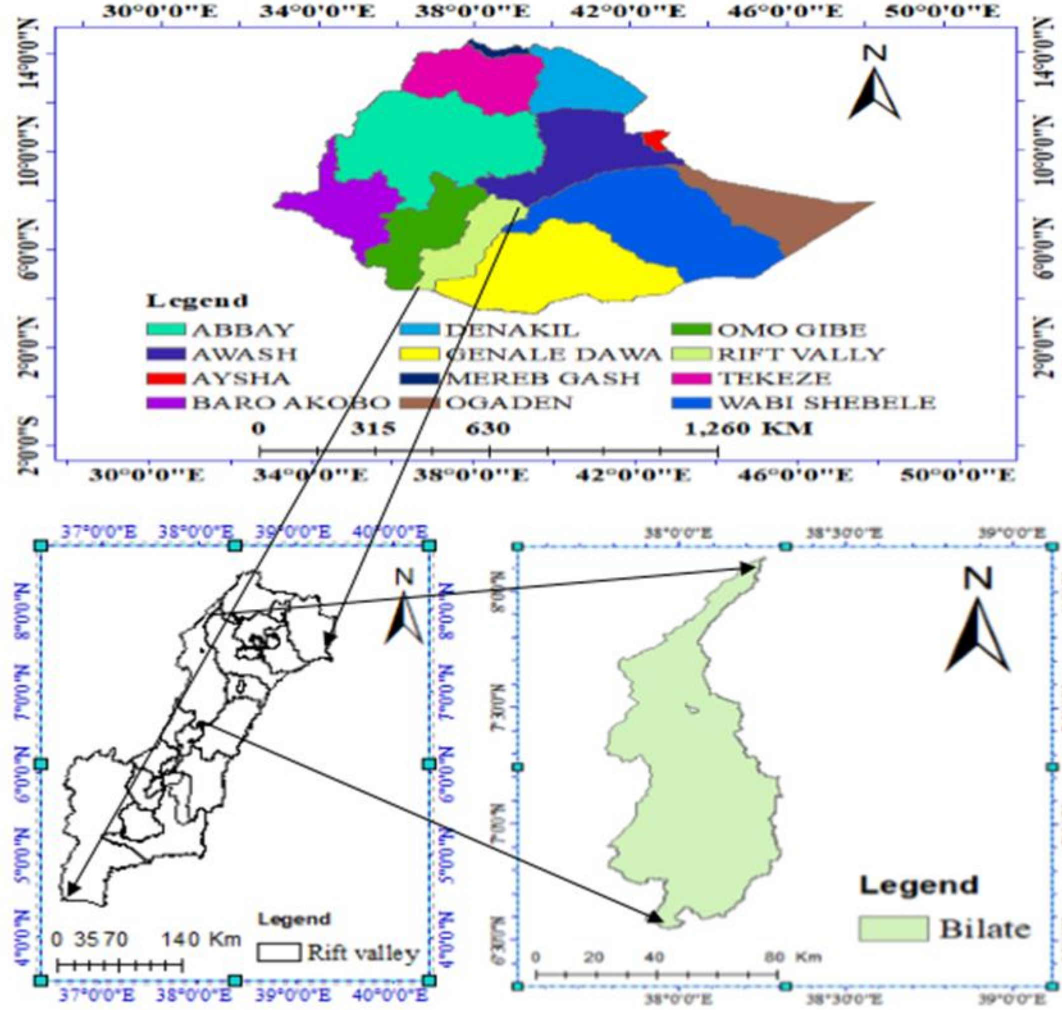


Figure 3. 1 Location Map of the study area

3.1.2 Climate

The climate of the area is humid to sub-humid in the highlands and semi-arid to arid in the rift valley. Precipitation Variability, rainfall variability and intensity in the watershed follows a bimodal distributed precipitation pattern.

This Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects. (Stefan and Gerd, 2004).

3.1.3 Soil and Geology

Soil properties influence the relationship between runoff and infiltration rates which in turn control the degree of permeability. Soil is the principal factor in hydrogeology that determines the water penetrating potential. The commonly observed soil by covering most area includes Polic-Verti-soils and chromic-Luvi-soils which are Silt Clay in texture with a moderate draining condition.

3.1.4 Hydrology

Precipitation and evaporation are the two fundamental phases in the hydrological cycle which involves processes in the atmosphere and at the earth's surface/ atmosphere interface. Precipitation is the primary input of the hydrologic cycle (Warren et al., 2003).

3.2 Materials used

For proper implementation of this study the following equipment's and materials were used for data collection, processing and evaluation and performing simulation properly.

1 Arc View-Arc hydro tools(software): - For delineation of streams to be used as an input for HEC-GeoHMS and they are terrain preprocessing.
2 Easy Fit Software to know best fit flood Probability distribution.
3 HEC-GeoHMS extension Data processing for watershed function and for generation of basin model file. For data processing for Watershed function and for generation of Basin Model file.
4 Arc GIS to classify land use and Hydrologic soil class, give detail division of catchments as we wish to sub divide and to generate CN-for each sub basin.
5 Microsoft EXCEL for data preparation, adjustment and provide data for the software.

3.3 Flow Chart of the Thesis

Hence, to make the data readily available to the model the integration of ArcGIS 10.1 version with its water resource utility extensions namely Arc hydro tool 10.1 and HEC-GeoHMS 10.1 are vital.

The following procedures describe the major steps in starting a project research and taking it through the GIS Extensions, Arc hydro tools and GeoHMS development of a hydrologic Model using DEM. These are:

Terrain Model Pre-Processing is executed by using the Arc hydro extension which contains Data-management, Reconditioning of DEM, build walls, fill sinks, Flow-Direction, Flow-accumulation, stream definition, stream segmentation, Catchment Grid delineation etc.

Hydrologic Processing is carried out by using HecGeohms extension, these includes Basin Processing, Watershed and River Characteristics, Hydrologic Parameters and HMS Model Files and HEC-HMS schematics. The process of generating input data for the basin component and the overall activities of the study is set in the figure 3.2 below.

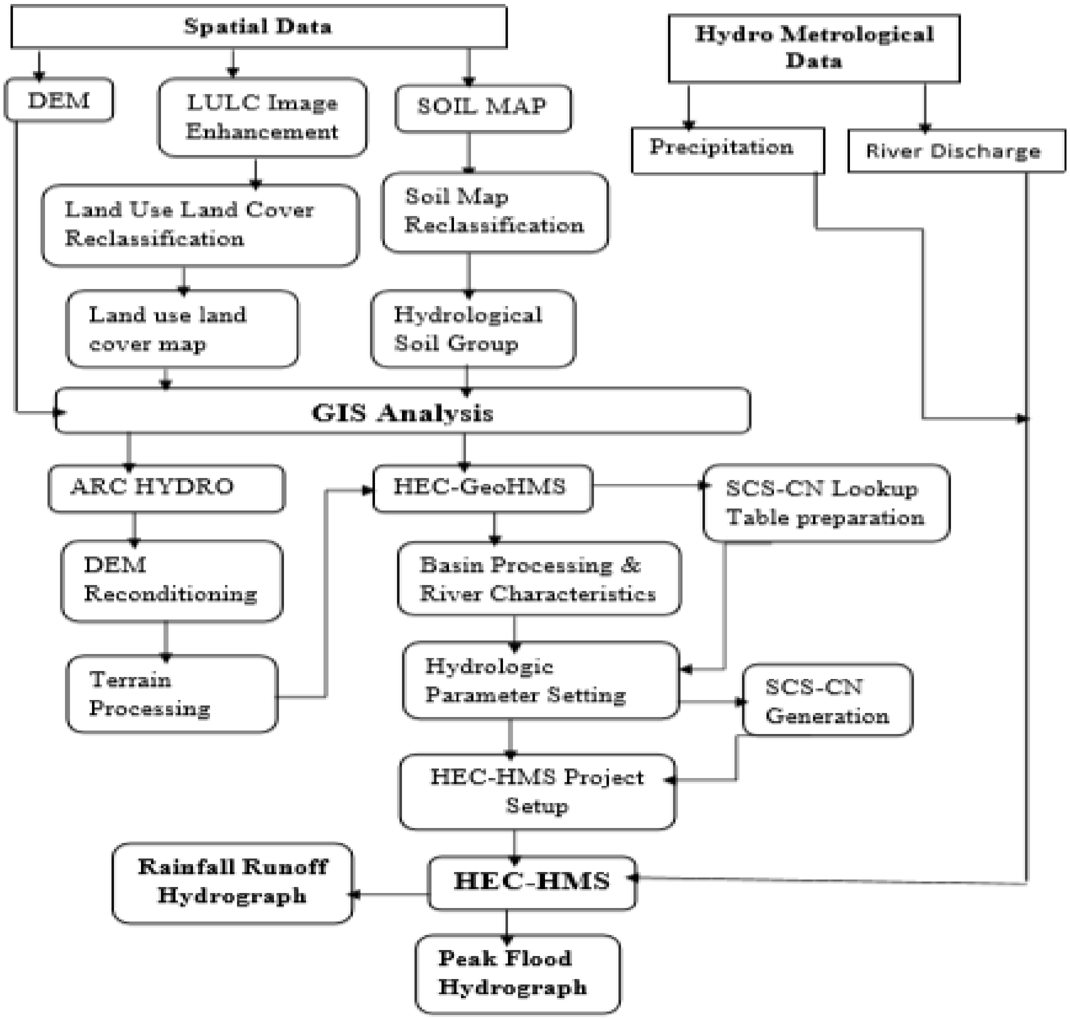


Figure 3. 2 Schematics of Work Flow Diagram

3.4 Data collection and analysis

Input data as an important part of rainfall-runoff modelling can be categorized into hydro meteorological (rainfall and stream flow) and physiographic (digital elevation model, land use/cover and soil type) databases. The HEC-HMS model needs input data to process and generate an output. For this study the HEC-HMS uses the input data such as, the Spatial data (Digital Elevation Model, soil map, land use and land cover), Meteorological data (precipitation) and Hydrological data (stream flow).

Table 3. 1 Data Type and Source

Data types	Data sources
Digital Elevation Model	Website: https://vertex.daac.asf.alaska.edu/
Soil map	Ministry of Water, Irrigation and Electricity (MoWIE)
Land use/land cover	Ministry of Water, Irrigation and Electricity(MoWIE)
Meteorological	National Meteorological Service Agency (NMSA)
Hydrological data	Ministry of Water, Irrigation and Electricity(MoWIE)

3.4.1 Spatial Data

3.4.1.1 Digital Elevation Model (DEM)

Topography was defined by a Digital Elevation Model (DEM). DEM describes the elevation of any point in a given area at a specific spatial resolution. The DEM used for this study was 12.5m x 12.5m resolution.

The watershed ranges from1167 to 3337 meters above sea level. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain. Sub-basin parameters such as slope and the stream network characteristics such as flow direction and flow accumulation were derived from the Digital Elevation Model.

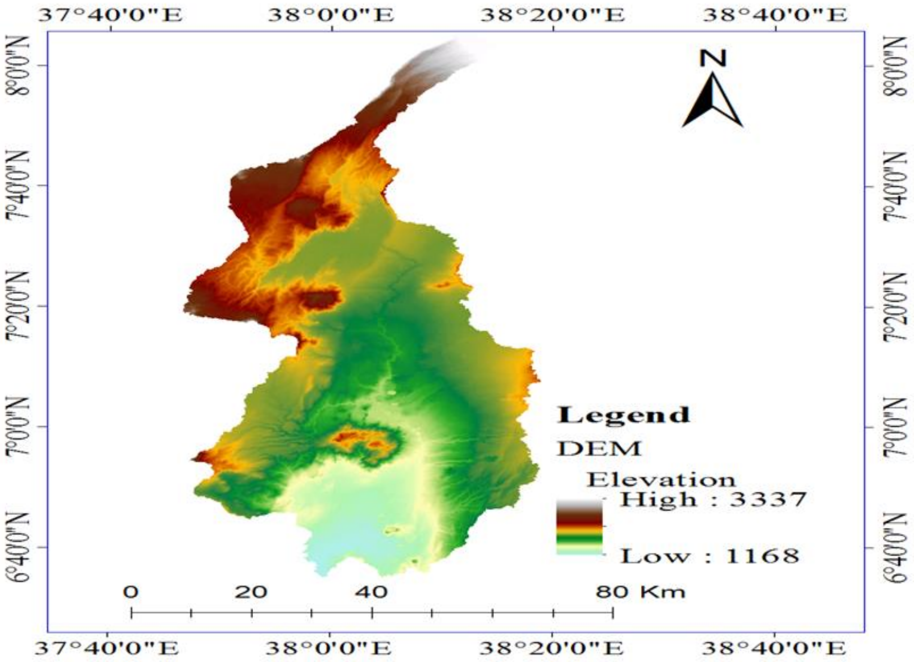


Figure 3. 3 Digital Elevation Model of the watershed

3.4.1.2 Soil Data

The soil resource data of the basin is classified in to different hydrologic soil groups by ArcGIS based on using look up tables. Hydrologic soil groups are group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration. (Modified from USDA-NRCS (1986). These properties are depth to a seasonally high water table, intake rate and permeability after prolonged wetting, and depth to a very slowly permeable layer. Based on this information Hydrological soil group was assigned for each soil type which is later used for computation of Curve Number (CN) to be used in the SCS method of runoff estimation.

The hydrologic group designation for any soil type can be either A, B, C, or D, where the runoff potential increases from A to D. Major soil types for the Bilate watershed and their designation hydrologic group is listed in table at annexes of this paper. annexes (TableA-2)

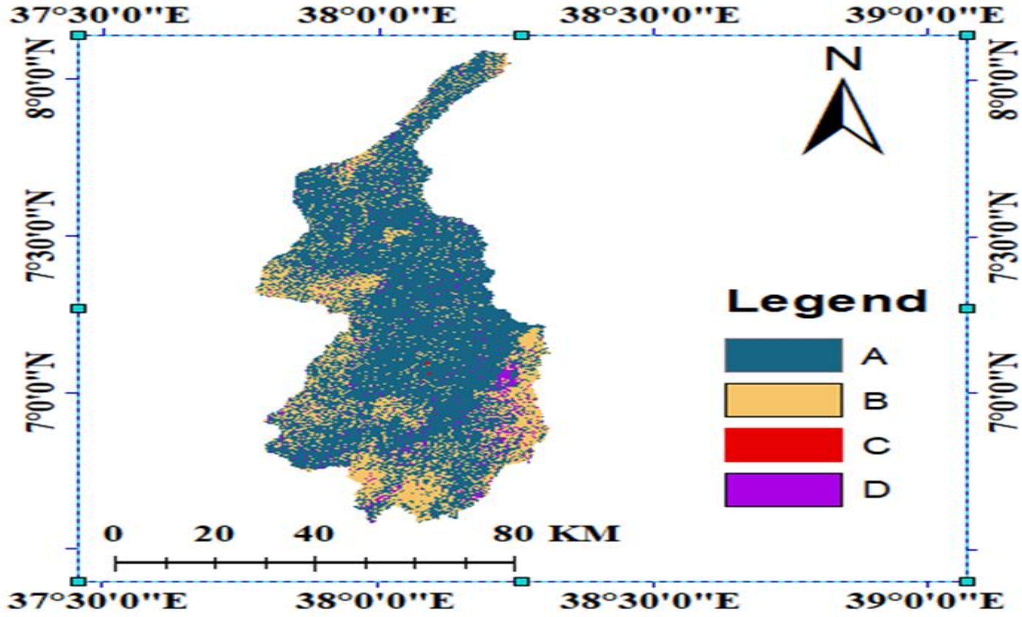


Figure 3. 4 Hydrological soil group for the watershed

3.4.1.3 Land use

The commonly observed land use and land cover is riparian wood and bush land, pastoral grazing and scattered seasonal cultivation. Regarding the recent land use, land management and conservation attempt, there are some gulley rehabilitation works practiced near Alaba kulito and few areas of the watershed by plantation and by constructing runoff controlling strips. (Tessema, 2005).

Spatial distribution and specific land use parameters were required for modeling Rainfall runoff. Land use change is one of the major reasons for variations in the hydrological parameters of a watershed. Since the basin is an agricultural catchment there is dynamic land use/cover change. With the information derived from remotely sensed data and conventional data stored in a GIS, land cover change and its impacts was identified. Hence the accurate identification of land use and land cover information has a major impact on the runoff estimation; therefore, reclassification is needed based on scientific methods. Finally, the reclassified land use and land cover maps were produced by reclassification tools in ArcGIS.

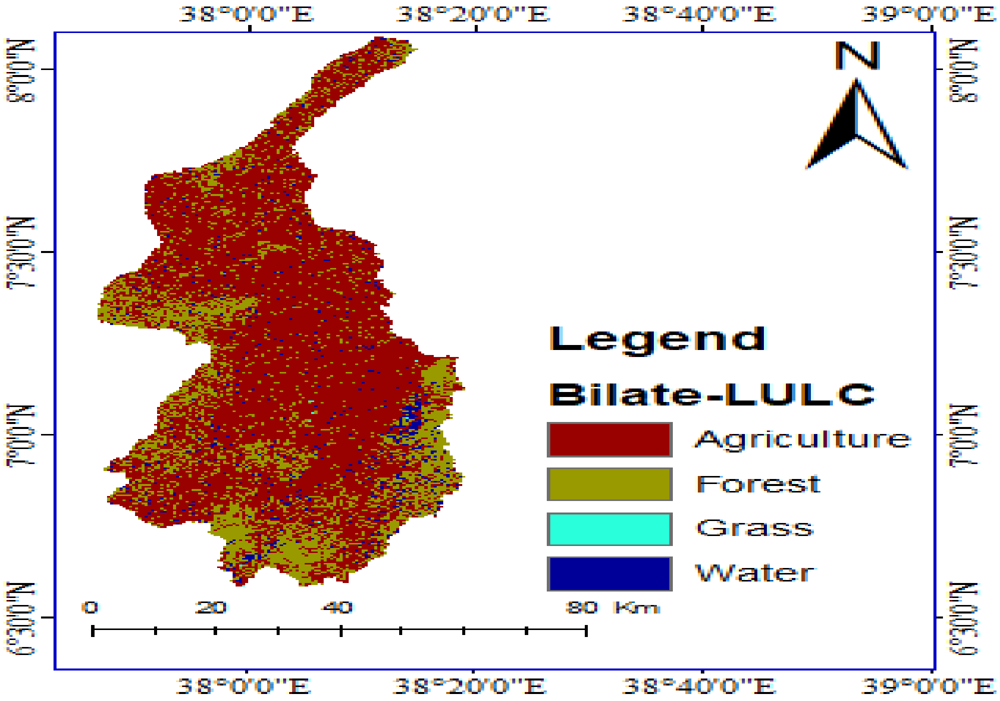


Figure 3. 5 Reclassed land use and land cover

3.4.2 Meteorological Data

The input weather data used in this study was daily rainfall recorded at rain gage stations. Those are Wulbareg, Hosanna, Alaba-kulito, Angacha, Bodity-school and Bilate-Tena.

Table 3. 2 Meteorological Stations and location

Stations	Data-period(Year)	Longitude (Degree)	Latitude (Degree)
Alaba-kulito	1996-2016	38.094	7.311
Angacha	1996-2016	37.857	7.341
Bilate-Tena	1996-2016	38.083	6.817
Bodity-school	1996-2016	37.955	6.954
Hosanna	1996-2016	37.759	6.702
Wulbareg	1996-2016	38.120	7.736

3.4.2.1 Filling missing data

Measured precipitation data are important to many problems in hydrologic analysis and design. For gauges that require periodic observation, the failure of the observer to make the necessary visit to the gauge may result in missing data. Vandalism of recording gauges is the problem that results in incomplete data records, and instrument failure because of mechanical or electrical malfunctioning can result in missing data. Any such causes of instrument failure reduce the length and information content of the weather data record. Which may result from changes in observation procedures, changes in exposure of the gauge, changes in land use that make it unreasonable to maintain the gauge at the old location leads in missing data. (Vent Te chow., 1998).

There are number of methods for estimating missing data such as, Arithmetic average method, normal ratio method, quadrant method, and inverse distance, weighting method and regression methods. The most common method used to estimate missing rainfall data is Normal Ratio method (Chow and Mays., 1988). This method is used because of if any surrounding gauges have the normal annual precipitation exceeding 10% of the considered gauges. The Normal ratio methods are expressed by the following relationship:

$$\mathrm{Px} = \frac{Nx}{N}\left(\frac{P1}{N1} + \frac{P2}{N2} + \cdots + \frac{Pn}{Nn}\right) \qquad 3.1$$

Where, P_x =Missing value of precipitation to be computed. N_x is average annual value of rainfall for the station. N_1, N…N_n are average annual value of rainfall for the neighboring station, P_1, P_2...P_n are the Rainfall of neighboring station during missing period and N= Number of stations used in the computation.

Table 3. 3 Stations and filled missing data record

Stations	Data length	Missed%	Remark
Alaba kulito	1996-2016	25.75	Filled by Normal ratio method
Angacha	1996-2016	16.06	Filled by Normal ratio method
BilateTena	1996-2016	11.56	Filled by Normal ratio method
Bodily school	1996-2016	23.3	Filled by Normal ratio method
Hosanna	1996-2016	12.36	Filled by Normal ratio method
Wulbareg	1996-2016	10.91	Filled by Normal ratio method

The percentage of missed data resulting from lack of appropriate records, shifting of station location and processing for each station and data type are shown in table (3.3).

3.4.2.2 Data consistency checking

Thus after filling the missing daily weather data, their consistence is checked by using double mass curve method. A consistent record is one where the characteristics of the record have not changed with time (Yang., 2015).

Double Mass Curve analysis is the method that used to check consistency in a gauge record. The method for checking consistency of a hydrological or meteorological record is considered to be an essential tool for taking it for analysis purposes. It is determined by plotting the cumulative values of observed time series of station for which consistency need to be checked on y-coordinate versus cumulative value of observed time series of group of stations on x-axis.

The station affected by trend or a break in slope of the curve indicates that conditions have changed that location. The data series, which is inconsistency, was adjusted to consistent values by proportionality. Therefore, the stations are adjusted for consistency by using the equation:

$$So=\Delta Yo/\Delta Xo \qquad 3.2$$

Where, so: is the slope of section, Yo: is the change in the cumulative catchment for gauge Y between the end point of the section 0, Xo: is the change in the cumulative catchment for the sum of the regional gages between the endpoints of sections 0.

A sample of double mass curve for hosanna station is given on figure 3.6 below the remaining’s are shown under the Annexes B.

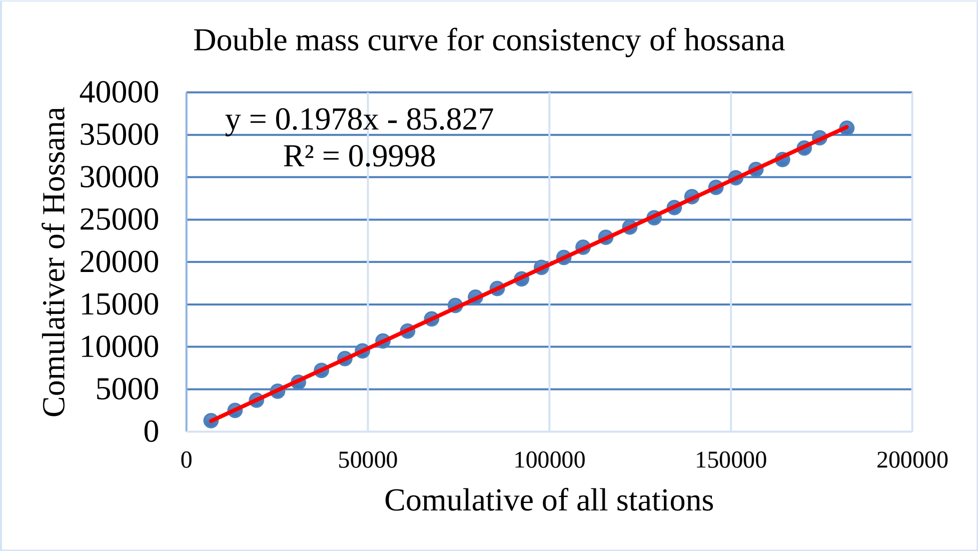


Figure 3. 6 DMC for Consistency Check for Hosanna station

3.4.2.3 Estimation of Mean Rainfall

A Rain gauge represents only point sampling of the areal distribution of a rainfall recorded during daily rainfall which may interfere with the surrounding catchments. In practice, however, hydrological analysis requires knowledge of the Estimation of Mean Rainfall over an area.

Arithmetic average, Isohyet and Thiessen polygon methods are in use to convert the point rainfall values at various stations in to an average value over a catchment. Thiessen polygon method is the most commonly used method for calculating areal precipitation. The advantage of this method is that it is easy to understand, allows for the uneven distribution of rain gages stations. (Allen & de gaetano., 2005). For this study, Thiessen polygon method is used. Mean monthly rainfalls from the available familiar six stations for a 21-year period (1996–2016) in the catchment area were employed. The method gives weight to point data in proportion to space between stations.

In a drainage basin rain catch at one station may be different from that of a second station in the same basin. An average value of these rain catches is worked out, so as to get an idea of average precipitation on the entire basin. In this method adjacent stations are joined by straight lines, thus dividing the entire area in to a series of triangles. It is assumed that the entire area within any polygon near to the rainfall station that is included in the polygon than to any other rainfall station. The rainfall recorded at that station is, therefore, assigned to that polygon.

Figure (3.7) below shows Thiessen polygon of Bilate watershed used as weight of station studies with in that polygon.

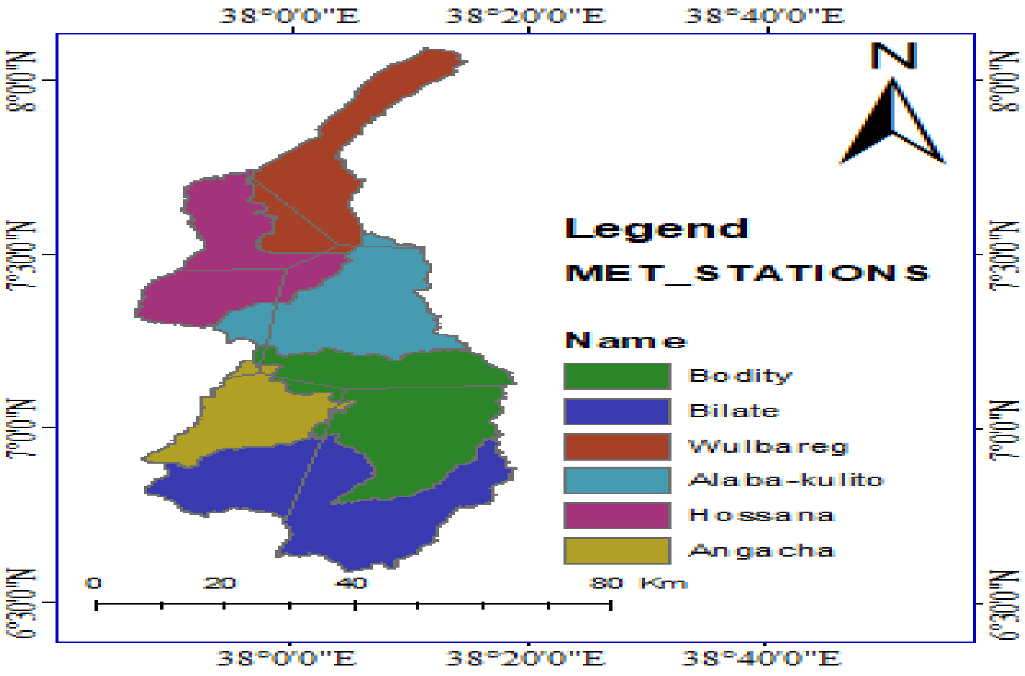


Figure 3. 7 Thiessen polygon for Bilate watershed

To determine mean areal rainfall, amount of rainfall at each station multiplied by area of its polygon and the sum of those products is divided by total area of the catchment. Each polygon area is assumed to be influenced by the rain gauge station inside it, i.e., if P_1, P_2, P_3 ... Pn are the rainfalls at the individual stations, and A_1, A_2, A_3 ... An are the areas of the polygon surrounding these stations, (influence areas) respectively, the average depth of rainfall for the entire basin is given by.

$$\mathrm{Pavg} = \frac{\mathrm{P1A1+P2A2\ldots+PNAN}}{\mathrm{AT}} = \frac{\sum \mathrm{AiPi}}{\mathrm{AT}} \qquad 3.3$$

Where, P_{avg} is the areal average rainfall, A_T is the total area of the basin.

Table 3. 4 The rain gage stations and their area coverage

Stations	Areas		Mean annual rainfall In mm
	Km²	%(Percentages)	
Alaba kulito (W780)	800.99	25.75	33906.60
Angacha (W690)	500.79	16.06	37377.51
Bilate Tena (W1030)	359.79	11.56	46875.28
Bodity school (W1020)	725.07	23.3	38487.96
Hosanna (W800)	384.53	12.36	30367.28
Wulbareg (W690)	339.419	10.91	38016.42

3.4.3 Streamflow Data

Daily river discharge values for Bilate watershed, recorded a Bilate Tena gauging station which is found at the downstream of Bilate watershed were obtained from the hydrology department of the Ministry of Water, Irrigation and Electricity Ethiopia (MoWIE). This discharge data was used for model calibration and validation. The station has discharge data from 1996 to 2016, there is some missing data and the missing data if filled using multiple regression of XLSTAT 2018.

3.5 Best Fit flood probability distribution

In order to describe the amount of maximum yearly observed data, it was necessary to identify the distributions, which best fit to the data. In this study, around seven continuous probability distribution with Normal, Lognormal, Log-Pearson type III, Gamma, Weibull, Inverse Gaussian and Generalized Extreme value distribution are considered to test the goodness of fit, but only three distributions were used for the discharge comparison with the HEC-HMS (Hydrologic Engineering Center-Hydrologic Modeling System) result. The analysis of observed data was prepared with the help of Easy Fit software and Microsoft Excel.

3.5.1 Easy Fit Software

Easy Fit is a data analysis and simulation software which enables us to fit and simulate statistical distributions with sample data, choose the best model, and use the obtained result of analysis to take better decisions. This software can function as a stand-alone windows application or as an add-on for Excel spread sheet.

3.5.2 Excel integration

Easy Fit program is easily integrated in main menu of Excel and allows to implement the analysis and simulation in Excel environment. Easy fit software benefits of more than 650 spread sheets in Excel which can facilitate the calculation tasks. Data analysis graph result is sited on Annexes-D of this paper.

3.5.3 Estimating CN Values for Each Sub Basin

To convert the rainfall data to the runoff data, curve number method or was used. CN map was prepared by integrating the maps of vegetation, hydrologic soil groups and land use in GIS and Arc View 10.1 software. The objective is to use soil and land use data to create a curve number grid using HEC-GeoHMS (ArcGIS 10.1 version).

The land use land cover data of the basin, along with the soil information obtained has been used while producing the polygon runoff curve number for the entire sub-basin. Later the CN values were summarized to a single mean value for each sub basin using the spatial analysis tools.

Preparation of the land use for CN Grid: - The Bilate land use originally has 16 different land use land cover classes. This was reclassified to similar characteristics and reduces the number of land use classes and to make the task easier. The majority of cells represent Agricultural/cultivated followed by grassland, forestland, and then water body. So it's necessary to reclassify Bilate land use to represent these four major classes by using ArcGIS. Annexes A (Table A-3)

Preparing Soil data for CN Grid: - Soil Conservation Service Curve Number is a method used to account for estimation runoff potential across the watershed. It describes the surfaces potential for generating runoff as a function of the soil type and land use present across the surface. The Soil Conservation Service Curve Number (SCS CN) method is an efficient and widely used method for determining the direct runoff (effective rainfall) from a storm event for flood disaster assessment (rainfall-runoff modeling). The CN can be estimated based on the hydrologic soil group (HSG), land use/cover, and hydrologic Soil group (Chow 1998)

Merging of Soil-Land Use Data The result of union features inherit attributes from both feature class polygons that are used as input as parameters for curve number generation.

Creating CN Look-up table

By considering the average value for recommended hydrologic soil groups with land use value for the normal condition, and the CN lookup table is prepared in order to generate the curve number of the watershed. In determination of CN the hydrologic soil classification is adopted based on infiltration. Columns A, B, C and D store curve numbers for corresponding soil groups for each land use category (Value).

Table 3. 5 CN lookup table for CN Generation

No	Description	Hydrologic soil groups			
		A	B	C	D
1	Agricultural/ cultivated	67	76	83	86
2	Forest	35	60	76	82
3	Grass	45	65	75	80
4	Water	98	98	98	98

Creating CN Grid: -Finally, by Having hydro DEM, the Land use-soil polygon (union) that have land use and Hydrological soil class category to generate curve number for the watershed. The results of the curve number per Sub basin are shown below on figure 3.8.

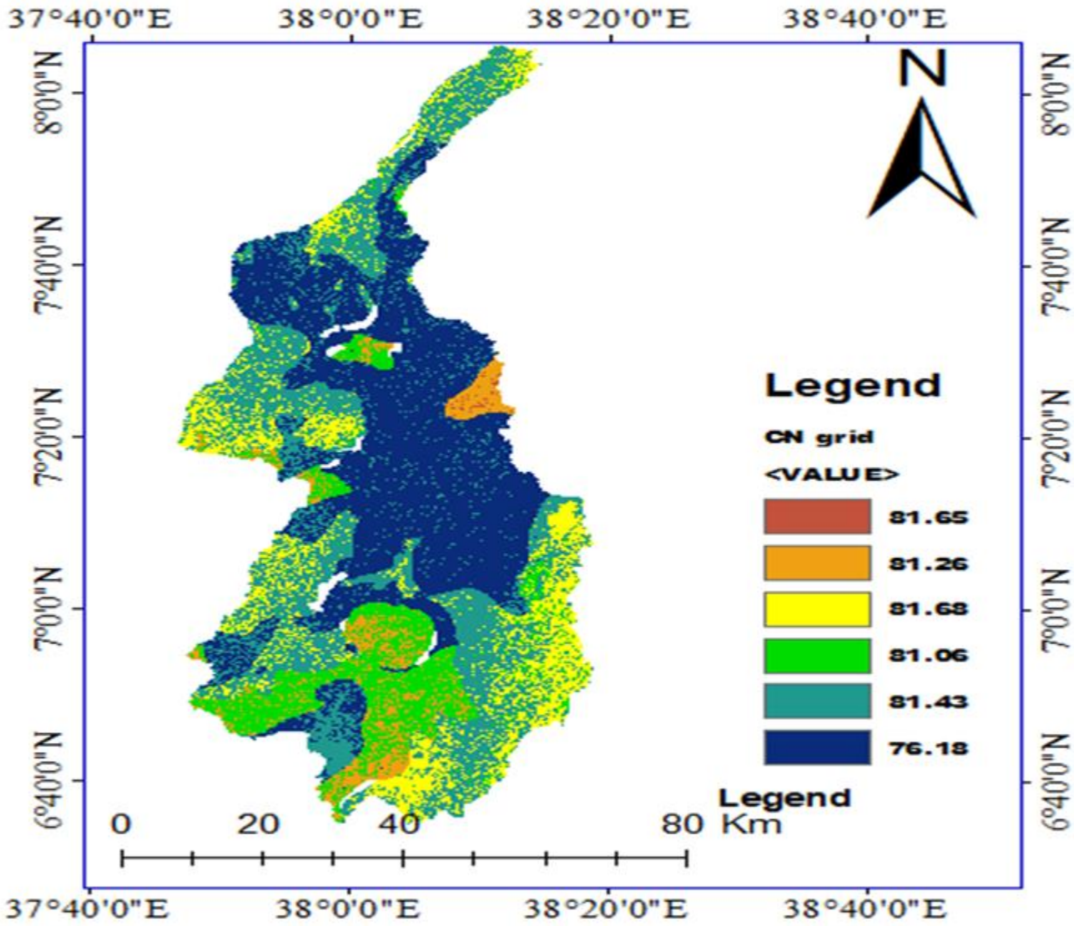


Figure 3. 8 CN-value for the LULC and soil type polygon

3.6 HEC-GeoHMS

HEC-GeoHMS is capable to generate the watershed's boundary, and acts as an interface between ArcGIS and HEC-HMS software (USA., 2010)

3.6.1 HEC-GeoHMS model setup

HEC-GeoHMS is a set of ArcGIS tools specifically designed to process geospatial data and create input for the HEC-HMS. HEC-GeoHMS provides the connection for translating GIS spatial information in to model files for HEC-HMS. HEC-GeoHMS operates on DEM to derive sub-basin delineation and to prepare a number of hydrologic units. In this study it is intended to derive parameters like: Curve Number, Basin Lag time, and Time of concentration and initial abstraction and sub basin area determination.

3.6.2 Terrain Processing Using Arc Hydro and Hec-GeoHMS

The processing of DEM to the delineation of the watersheds is referred to as terrain pre-processing (www.hec.usace.army.mil).

In this study, Arc Hydro (tools version that works with Arc-GIS 10.1) to process a DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. The main steps undertaken by terrain pre-processing are:-DEM reconditioning, Fill sinks, Flow direction, Flow accumulation, Stream definition, Stream segmentation, Catchment grid delineation, Catchment polygon processing, Drainage line processing, Drainage point processing, longest flow path for the catchment and Slope determination.

3.6.3 Terrain Analysis

Steps following terrain analysis were as follows

Terrain Pre-processing: Terrain preprocessing marks the first step in developing an HEC-GeoHMS project. It is used to pre-process the raw DEM for further analysis. Which include the following main steps.

DEM Reconditioning: The DEM reconditioning, also referred to as burning the DEM with the stream is done to raise the elevation of the cells that surround the stream. This is done to ensure that all the water that falls on the basin is captured by the stream and the stream follows the same path as in a topographic map.

Fill sinks: - The DEM data include pits or ponds that should be removed before being used in hydrological modeling. These are cells where water would accumulate when drainage patterns are being extracted. Pits are a sign of errors in the DEM arising from interpolation. These pits were removed by an algorithm known as fill sink.

Filling the depressions allows water to flow across the landscape. This assumption is valid when a large storm event fills up the small depressions and any incremental amount of water that flows into the depression will displace the same amount of water from the depression filling. (Annexes A Figure A-2)

Flow Direction: - Flow direction map was computed by calculating the steepest slope and by encoding into each cell the eight possible flow directions towards the surrounding cells. (Annexes A Figure A-3)

Flow accumulation: The flow accumulation, generated by addressing each cell of the DEM that determines the number of upstream cells draining to a given cell. It contains the accumulated number of cells upstream of a cell, for each cell in the input grid and Can be calculated by multiplying the flow accumulation value by the grid cell area. (Annexes A Figure A-4)

Stream definition: - This threshold is defined either as a number of cells or as a drainage area in square kilometers or classifies all cells with a flow accumulation greater than the user-defined threshold as cells belonging to the stream network. The smaller the threshold chosen, the greater the number of sub basins delineated.

Stream Segmentation: Flow direction and accumulation maps were used to delineate the stream network. The generated stream network has a dendritic shape of third order. The Stream Segmentation function creates a grid of stream segments that have a unique identification.

Catchment Grid Delineation: delineates a sub basin for every stream segment. This depends on the generated flow direction and accumulation map. Furthermore, it also depends on a user-specified number known as threshold. This threshold determines the minimum number of pixels within each delineated sub-basin.

Longest flow path: function allows generating a cost path line from the inlet of the drainage point to the outlet point of a sub basin traveling through a cost surface that has minimum values toward the center and maximum values at the boundary of sub basin. Longest Flow Path of the watershed leads all draining tributary stream networks towards the same outlet. (Annexes A Figure A-5)

Catchment polygon processing: process of converting catchment grid into a catchment polygon. The adjacent cells in the grid that have the same grid code are combined into a single area, whose boundary is vectorized, so that at the end of the process there is just one polygon per sub-catchment.

Drainage Line Processing: Drainage Line Processing function converts the Stream Link grid into a drainage line class. Each line in the feature class carries the identifier of the catchment in which it resides. Figure 3.13 shows the Drainage line of the Bilate watershed. (Annexes A Figure A-6)

3.6.4 Computation of Hydrologic Parameters of the watershed

The watershed parameters calculated by HEC-GeoHMS are the watershed lag-time and the watershed average initial abstractions are obtained. Other parameters such as slope of the area of sub basin and time of concentration are also calculated and stored in the sub watershed attribute table. Annexes E

3.7 THE HEC-HMS

HEC-HMS is developed by Natural Resources Conservation Service (NRCS) of the United States Department of Agriculture (USDA) is one of the most popular methods for estimating the volume and peak rates of surface runoff (Davis, 2010).

The HEC-HMS is a conceptual model in which the process during simulation cannot be observed. It gives the final output from the given input. The surface runoff calculations were performed using SCS Unit hydrograph method which requires Lag time for implementation. Sub-basin element conceptually represents infiltration, surface runoff, and subsurface processes interacting together.

Therefore, HEC-HMS is designed to simulate the precipitation-runoff processes of watershed systems and the peak flood occurrences time. The calibrated model was used for runoff generation for different frequency of the different return period. In this study the Gage weighted method was used selected and specified by Thiessen polygon method. The spatial-temporal precipitation distribution was accomplished by the gauge weight method. The Thiessen polygon technique was used to determine the gauge weights.

3.7.1 HEC-HMS Model Setup

HEC-HMS Model consists four main model components: Basin model, Meteorological model, Control specifications, and input data (time series, paired data, and gridded data).

The Basin Model contains a schematic consisting of any combination of the six objects (sub-basin, reach, junction, source, sink and reservoir) and stores information about the properties and connectivity of the objects in the schematic.

The meteorological component is the first computational element by means of which precipitation input is spatially and temporally distributed over the river basin.

Control specifications are one of the main components of a project, and principally used to control simulation runs. They control when a simulation starts and stops, and what time interval is used in the simulation. The data input to HEC-HMS is possible through two ways. The first and simplest method is manual data input. Here the time series data is copied from Excel or any compatible format and pasted in HEC-HMS time series table for any time series data (either precipitation or discharge). The second and relatively complex is accompanied by saving the data in HEC-DSS and retrieving from it during analysis. For this study manual data input method is used because this method is simple one.

Finally, the input data component stores parameters and boundary conditions for the basin and meteorological models within assigned gages and control specifications.

The HEC-HMS applied for the Bilate watershed was done by sub-dividing the watershed in to six sub-watersheds.

3.7.1.1 Loss determination

The term loss refers to the amount of rainfall infiltrated into the soil. HEC-HMS uses the most common methods for calculating losses such as initial and constant loss rate, Soil Conservation Service Curve number and SMA. For this study the SCS Curve number loss method was chosen because it has been used for long term simulations and also it is best fit model that has been used successfully in many studies (Ouerdachi, 2018). Easy to set up and use, and not too much demanding in terms of data. The actual infiltration calculations are performed by a loss method contained within the sub-basin. All of the possible loss methods in HEC-HMS conserve mass. That is, the sum of infiltration and precipitation left on the surface was always be equal to total incoming precipitation. Thus, effective rainfall was generated from the catchment loss and total rainfall on it.

The model approach used to determine the runoff volume was the SCS-CN method. With this method, the precipitation excess is a function of cumulative precipitation, soil type, land use/cover and antecedent moisture. Considering the initial loss and the potential maximum retention, the precipitation excess can be calculated; the maximum retention and the basin characteristics are related through the curve number. The standard SCS curve number method is based on the following relationship between rainfall depth P, and runoff depth, Q (USDA, 1986; Schulze *et al.*, 1992):

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad 3.4$$

For P>0.2S otherwise Q=0

$S = \frac{25400}{\mathrm{CN}} - 254$ (mm)

Ia $= 0.2S$ Q is the surface runoff (mm), P is the precipitation (mm), S is the soil retention (mm), Ia is the initial abstraction (mm), and CN is the curve number.

To obtain volumes, P and Q (in millimeters) must be multiplied by the basin area. The potential maximum retention (S) represents an upper limit for the amount of water that can enter the basin through surface storage, infiltration, and other hydrologic losses. For convenience, S is expressed in terms of a CN, which is a dimensionless basin parameter ranging from 0 to 100. A CN of 100 represents a limit condition for a perfectly impermeable basin with zero retention, where all the rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the basin trapping all the rainfall with no runoff regardless of the rainfall amount.

3.7.1.2 Transform method

The transform prediction models in HEC-HMS simulate the process of the direct runoff of excess precipitation on the watershed, and they transform the precipitation excess in point runoff. In this study, the Soil Conservation Service Unit Hydrograph model was chosen to transform excess precipitation into runoff. It is a parametric model based on the average Unit Hydrograph (UH) derived from gauged rainfall and runoff data of a large number of small agricultural watersheds throughout the United States. The SCS proposed the Unit Hydrograph (UH) model, and it is included in the HEC-HMS program. The lag time (Tlag) is the only input for this method. It is the time from the center of mass of excess rainfall to the hydrograph peak and is calculated for each watershed based on the time of concentration Tc, as:

$$T_{lag} = 0.6T_c \qquad 3.5$$

where Tlag and Tc are in minute.

Methods for estimating time of concentration: - Two primary methods of computing time of concentration were developed by the Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service (SCS)).

A. Watershed lag Method

B. Velocity Method

But for this study SCS method taking watershed lag method

A. Watershed lag method

The Lag routing method only represents the transformation of flood waves. It is best suited to short stream segment with predictable travel time that doesn't vary with depth of flow. The parameter is the lag time is in minutes. Inflow to the reach is delayed in time by an amount equal to the specified lag, and then becomes outflow. The lag time for flood transformation in stream need to be determined through calibration.

The SCS method for watershed lag was developed by (Mockus and Simas, 1996). It spans a broad set of conditions ranging from heavily forested watersheds with steep channels and a high percent of runoff resulting from subsurface flow, to meadows providing a high surface runoff, to smooth land surfaces and large paved areas.

$$\mathrm{L} = \frac{\mathrm{L}^{0.8}(\mathrm{S}+1)^{0.7}}{1900\mathrm{Y}^{0.5}} \qquad 3.6$$

Applying equation L=0.6Tc, yields:

$$\mathrm{Tc} = \frac{\mathrm{L}^{0.8}(\mathrm{S}+1)^{0.7}}{1140\mathrm{Y}^{0.5}} \qquad 3.7$$

Where: L-lag, (hour), Tc is the time of concentration, (hour), L is flow length, (ft)

Y is the average watershed slope percent (%) is used in the lag method; S is maximum potential retention, in

$$\mathrm{S} = \frac{1000}{\mathrm{CN}} - 10 \qquad 3.8$$

Where: - CN is the curve number factor

Where: CN must be greater than or equal to 50 and less than or equal 95.

3.7.1.3 Routing method

As the flood runoff travels through the channel reach, it becomes attenuated due to channel storage effects. The routing models available in HEC-HMS account for this attenuation. The Muskingum method, which was developed by McCarthy is a popular lumped flow routing technique which was selected for this study (McCarthy, 1938).

The Muskingum routing method is a simple approximate method to calculate the outflow hydrograph at the downstream end of the channel reach from the inflow hydrograph at the upstream end. Among many models used for flood routing in rivers, it is a straightforward hydrological flood routing technique used in natural channels and it has been extensively applied in river engineering practice since its introduction in the 1930s (Tewolde & ., 2006). In this model calibration, two parameters are needed; travel time (K) of the flood wave through routing reach; and dimensionless weight (X) which corresponds to the attenuation of the flood wave as it moves through the reach. The routing parameters in the models are usually derived through calibration using measured discharge hydrographs.

$$S = \mathrm{K}\,[\mathrm{XI} + (1 - \mathrm{X})\,\mathrm{Q}] \tag{3.9}$$

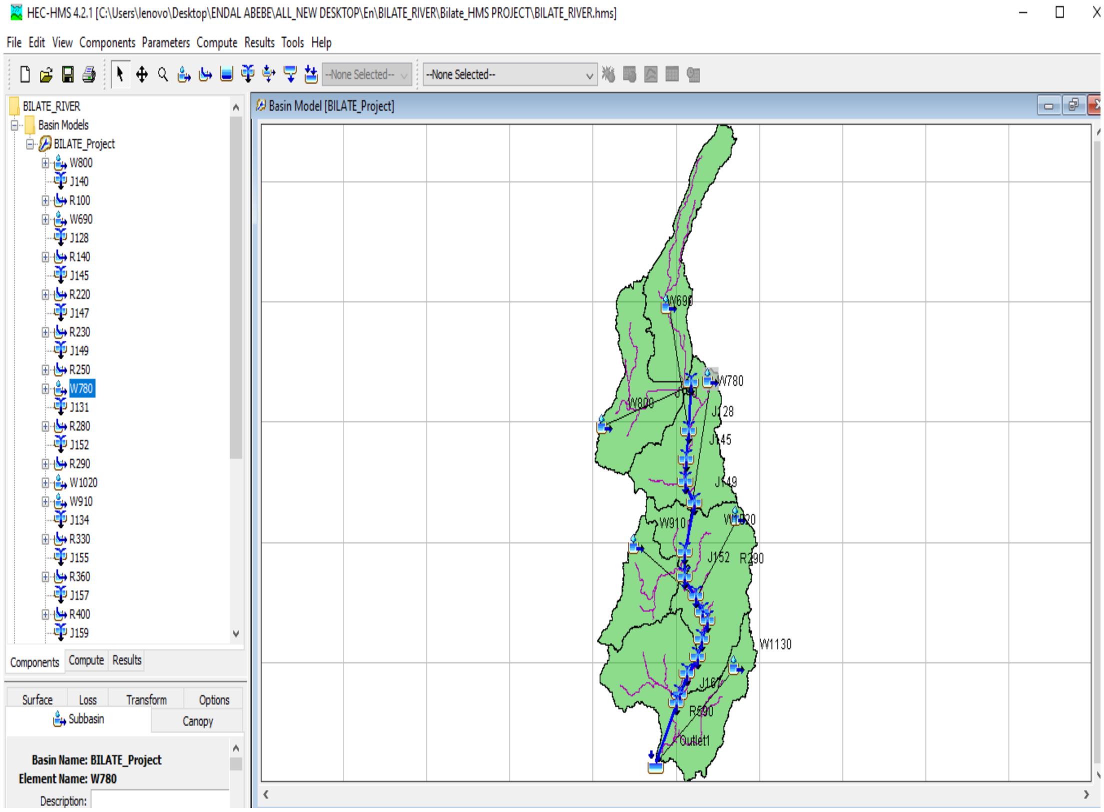
in which the prism storage in the reach is KQ, where K is a proportionality coefficient, and the volume of the wedge storage is equal to KX (I − Q), where X is a weighting factor having a range of $0 \leq X \leq 0.5$.

3.7.1.4 Topologic Analysis and Preparation of HEC-HMS Basin File

Establishing the topology of the hydrologic system consists of determining the element located downstream of each element. Since the HEC-HMS hydrologic schematic allows only one downstream element, no ambiguity is introduced in this process.

A background map file also readable by HEC-HMS is used to graphically represent sub-basins and reaches. Also leads to ease of identification of hydrologic elements. This basin file, when opened with HEC-HMS, generates a topologically correct schematic network of hydrologic elements and displays it in the HEC-HMS - Schematic window together with the background map.

A general basin model for this case consisting of sub-basin1(W690), sub-basin2(W800), and sub-basin3(W780), sub-basin4(W910), sub-basin5(W1020) and sub-basin6(W1130) were set up in HECHMS generated with ArcGIS for the study area.



Basin Name: BILATE_Project
Element Name: W780
Description:

Figure 3. 9 Bilate watershed model in HEC-HMS window

In addition to the one stream flow station at out let element was used in the basin model to relate the simulated flow to the historical observed total flow of the total sub-basins. In this particular study for the respective sub basins, simulation was done with (SCS Curve number) method, SCS Unit Hydrograph, Muskingum model constants (K and X Coefficient) and Monthly constant base flow condition. Here six uniformly distributed stations are used to represent the catchment. The stations are selected according to their relative position (distribution) to each sub-basin, data availability and the area they cover with respect to others.

3.7.1.5 User-Specified Gage Weighting

The sub-watershed precipitation time series are calculated as the weighted average of gage precipitation time series. Given a set of points that represent gages for which precipitation time series are known, then Thiessen polygons are used to establish the area of influence of each precipitation gage. Thiessen polygons are constructed by drawing perpendiculars at the midpoints of the segments that connect the gages, so that all points within a polygon are closer to the polygon gage than to any other gage.

By intersecting the Thiessen with the sub-basin polygons, a new set of smaller polygons is defined in such a way that each new polygon is related to one Thiessen polygon and one sub-basin polygon. The ratio of the area of a new polygon to the area of its corresponding sub-basin polygon represents the weight of the gage for the sub-basin. The sub-basin information consists of the sub-basin name or identification code, and the name of each gage with its corresponding weight. To do these Thiessen polygons, three data sets are defined: - Sub-basin polygons, Annual Precipitation and the Coordinate point of the stations.

The HEC-HMS model provides a variety of options for simulating precipitation-runoff processes.

Table 3. 6 Thiessen polygon weights for each sub-watershed

Sub-basin	Rain-gage stations						
	Percentages of each weight contribution to watershed						
	W690	W800	W780	W910	W1020	W1130	Total
W690	0.78	0.41	0.1	-	-	-	1.00
W800	0.21	0.47	-	0.02	-	-	1.00
W780	0.01	0.11	0.87	0.01	0.33	-	1.00
W910	-	0.01	0.03	0.94	0.01	-	1.00
W1020	-	-	-	0.03	0.62	0.64	1.00
W1130	-	-	-	-	0.4	0.36	1.00

3.8 Modeling by frequency storm method

With the input from HEC-GeoHMS and some edition from the main HEC-HMS, the model was simulated for rainfall intensity of 2, 10, 25, 50, and 100-year return periods. The frequency intensity values are found from the Ethiopian Roads Authority drainage manual (ERA, 2013) from the Annexes A.

Table 3. 7 IDF table for the study area based on (ERA Drainage Design Manual, 2013).

D(hr)	Rainfall depth with different return period(hr)				
	2	10	25	50	100
1	80.05	84.64	88.88	97.82	106.82
2	93.91	99.30	104.27	114.76	125.32
3	100.51	106.28	111.59	122.82	134.13
6	109.82	116.12	121.93	134.20	146.54
12	117.50	124.24	130.45	143.58	156.79
24(One day)	124.34	131.47	138.04	151.93	165.91

3.9 Model Performance criteria

There are several parameters which affect a complex hydrological modeling. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in description of both the elements and processes present in the system are some of the reasons. Therefore, optimizing internal parameters of a model is an important task in order to achieve a well representative hydrological model. This kind of technique is called model calibration which is usually supported by sensitivity analysis.

The performance of a model must be evaluated on the extent of its accuracy, consistency and adaptability (Abushandi, 2013). A forecast efficiency criterion was therefore necessary to judge the performance of the model. Assessing performance of a hydrologic model requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations. For the Model simulation has to be evaluated using efficiency criteria such as coefficient of determination (R^2) and [Nash Sutcliff Efficiency (NSE), 1970]. The R^2 coefficient and NSE simulation efficiency measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. The range of values for R^2 is 1.0 (best) to 0.0. The statistical index of modeling efficiency (NSE) values range from 1.0 (best) to negative infinity. To do these its required to accomplish sensitivity analysis.

3.10 Sensitivity Analysis

Sensitivity analysis is a method to determine which parameters of the model have the greatest impact on the model objective function results. There are five parameters (curve number, Muskingum constants (x and K), surface type, canopy type and lag-time).

Sensitivity analysis was carried out for these 5 parameters. These parameters evaluated of the event model that were subject to the sensitivity analysis. Sensitivity analysis helps to determine the sensitivity of parameters by comparing the output variance due to input variability. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameters that shows higher sensitivity to the output due to the input variability. Therefore, the number of influential parameters that can be involved for calibration will be less in number. It also evaluates the model capacity and helps to understand the behavior of the system being modeled. Sensitivity analysis was performed to determine the influence a set of parameters on predicting total flow.

Finally, the sensitivity analyses were run for the main Bilate catchment gauging station. In the analysis, the sensitive parameters of the stream flow of the basin were identified. The parameters, which resulted from the analysis, were ranked according to the magnitudes of response variable sensitivity to each of the model parameters, which divide high and low sensitivities.

The method used to determine the dominant hydrological parameters and to reduce the number of model parameters which will be used in calibration. However, parameters that had been not evaluated during sensitivity analysis have to be modified during calibration so that the simulated flow model parameters fit that of the observed stream flow parameters. Modifying parameters other than those identified during sensitivity analysis was carried out with investigating the type of error which occurs in simulated variables.

Therefore, sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model calibration, but also for model validation and reduction of uncertainty (Lenhart,et al, 2002).

3.11 Model Performance Evaluation

The Model performance was evaluated for both calibration and validation in different ways including coefficient of determination (R^2) and the Nash-Sutcliffe efficiency (ENS), Mass Balance Error (MBE), Mean Absolute Error (MAE), Root Mean Squared Error (RMSE) and RMSE-observations standard deviation ratio (RSR), are used to assess the hydrological modeling performance.

1. By visually inspecting and comparing the calculated and observed hydrograph
2. Coefficient of correlation (R^2)

$$\mathrm{R}^2 = \frac{\sum\left(\mathrm{Qobs}-\overline{\mathrm{Q\dot{o}bs}}\right)^2 - \sum(\mathrm{QSim}-(\overline{\mathrm{Qsim})2}}{\sum(\mathrm{Qobs}-\overline{\mathrm{QObs})}^2} \qquad 3.10$$

Where: - Q_{obs} is the observed discharge, Q_{sim} is simulated discharge, $_{\mathrm{Obs}}$ is mean of observed discharge, Sim is mean of simulated discharge. The R2 (Eq. 3.10) records as a ratio the proportion of the total statistical variance in the observed dataset that can be explained by the model. It varies from 0 (poor model) to 1 (perfect model). (Gupta et al, 1999)

R^2 is indicates how the simulated data correlates to the observed values of data.

3. Nash-Sutcliffe efficiencies (ENS)

An efficiency of ENS=1 corresponds to a perfect match of modeled is charge to the observed data. An efficiency of ENS=0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero. ($-\infty<\mathrm{ENS}<0$) occurs when the observed mean is a better predictor than the model. The closer the model efficiency is to 1, the more accurate the model.

4. Mass Balance error (MBE)

$$\mathrm{MBE}=\frac{\sum(\mathrm{Qobs}-\mathrm{Qsim})^2}{\sum(\mathrm{Qobs})} * 100 \qquad 3.11$$

The Mass balance error can vary between ∞ and -∞. The model performs best when the value of zero is attained. This M.B.E tells how much direct runoff moved to the out let.

5. The RMSE computes on squared differences the mean magnitude of the error between the observed and modeled values, in which the largest deviations contribute the most. Zero indicates a perfect fit between the simulated and observed data.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Qobs - Qsim)^2} \qquad 3.12$$

6. The RSR is calculated as the ratio of the RMSE and the standard deviation of measured data. It varies from 0 to ∞, in which the lower the RSR value the better, the hydrological model performance (Moriasi et al, 2007).

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Qobs-Qsim)^2}}{\sqrt{\sum_{i=1}^{n}(Qobs-\overline{Qobs})^2}} = 1 - ENS \qquad 3.13$$

Where, $\bar{Q}_{\mathrm{obs}}$ is the mean of observed data.

7. The PBIAS evaluates the average tendency of the simulated values to be higher or lower than those observed. The ideal value of PBIAS is 0; positive values indicate a model bias toward underestimation; and negative values indicate a bias toward overestimation.

$$PBIAS = \left[\frac{\sum_{i=1}^{n}(Qobs-Qsim)}{\sum_{i=1}^{n}(Qobs)}\right] \qquad 3.14$$

The general model evaluation guidelines for systematic quantification of accuracy in watershed simulations were created based on RSR, NSE and PBIAS performance ratings. (Dawson, 2007).

Table 3. 8 RSR, NSE and PBIAS general performance ratings for recommended statistics.

Performance Rating	RSR	NSE	PBIAS
Very good	$0.00 \le RSR \le 0.50$	$0.75 < NSE \le 1.00$	$PBIAS < \pm 10$
Good	$0.50 < RSR \le 0.60$	$0.65 < NSE \le 0.75$	$\pm 10 \le PBIAS < \pm 15$
Satisfactory	$0.60 < RSR \le 0.70$	$0.50 < NSE \le 0.65$	$\pm 15 \le PBIAS < \pm 25$
Unsatisfactory	$RSR > 0.70$	$NSE \le 0.50$	$PBIAS \ge \pm 25$

3.12 Model Calibration and Validation

HEC-HMS allows the user to calibrate the model to the best-fit condition by selecting various objective functions to provide the best calibration results (HEC, 2005). Calibration procedure undertaken involved combination of automated calibration provided by the software and manual calibration. (USACE, 2000).

The objective function used was the simulated absolute error. This objective function gave greater weight to large errors and lesser weight to small errors, in addition of giving greater overall weight to error near the peak discharge. The optimization procedure required the use of a search method for minimizing an objective function and finding optimal parameters. The search method used for this calibration was the univariate gradient method. This method is evaluated and adjusted one parameter at a time while holding all other parameters constant. The search method estimates the optimal parameters but do not indicates which parameters had the greatest impact on the solution (Kathol *et al.*, 2003).

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations. Once a model was developed and simulated for the initial parameter estimates, it was calibrated against known discharge runoff rates measured at the gaging station during selected time events. For this study the available hydro-climatic records of six meteorological stations and one stream flow gage stations were analyzed for selection of calibration and verification data for the HEC-HMS model. The calibration was done using daily data for the time period Jan 01, 1996 to Dec 31, 2009.

The process was completed manually by repeated adjusting the parameters, computing, and inspecting the goodness of fit between the computed and observed hydrographs by using the iterative calibration procedure called optimization.

Model performance in calibration and validation periods may not be similar. After calibration, the models were validated using 7-years data Jan 01, 2010 to Dec 31, 2016.

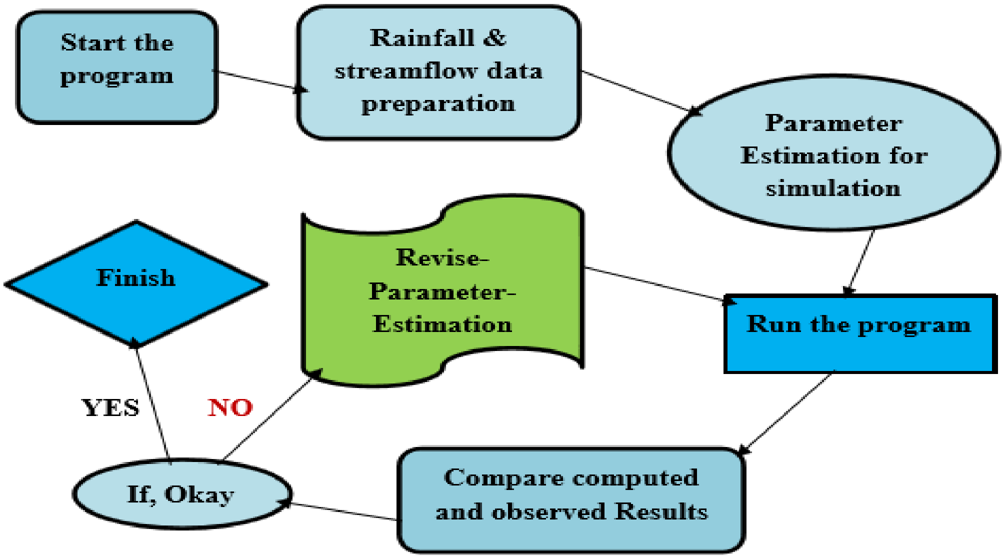


Figure 3. 10 Schematic of Calibration Procedure

4 RESULTS AND DISCUSSION

4.1 Rainfall runoff Model

The HEC-HMS was simulating the daily input rainfall and stream flow data of 21-years' (1996 – 2016) for the Bilate watershed. It was adopted six distinctive sub basin model configurations in the HEC-HMS desktop in order to represent the watershed under this study. In which: the sub basins are represented by a reservoir with an inlet and an outlet; lines represent the channels, with arrows indicating the flow direction; and a reservoir with two inlets and an outlet represents the junction of different elements. Based on the qualitative analysis of the simulated (Q_{sim}) and observed (Q_{obs}) hydrographs generated for the calibration and validation period it can be noted that the calculated hydrographs and the peak flow magnitudes respectively, also the overall fit of the model is very good, indicating the model represents the hydrological processes in the watershed efficiently. It can also be noted the modeled hydrographs overlap each other, showing no significant change, thus demonstrating that different levels of spatial discretization did not interfere in the watershed's outlet flow.

The HEC-HMS hydrological model has been calibrated manually and automatically to optimize the best possible option of fit. The SCS loss, SCS unit hydrograph transform, and the monthly constant base flow method was used for this study. The calibration and validation performance of the HEC-HMS 4.2.1 is carried out by comparing of the daily simulated runoff with the observed stream flow at the out let of the catchments. To assess the performance of the model predictability of representing the hydrological simulation of the reality of the basin the Three basic statistical hydrological model performance check used. The ENs (Nash Sutcliffe efficiency), R^2 (Relation coefficient) and MBE (Mass Balance Error).

4.1.1 Hydrological modeling of catchments

A semi-distributed HEC-HMS hydrological modeling technique applied for Bilate river watershed. The catchments are classified into sub basins and each sub basin parameters manually adjusted by trial and error method and automatically optimized to get the best fit. The table 4.1 shows the sensitive parameters by their order of sensitivity.

Table 4. 1 Parameters for calibration based on sensitivity order.

Parameters	Minimum	Maximum	Fitted value	Rank order
Curve number factor Scale factor	0.8	1.3	1.0172	1
Muskingum x	0.01	0.5	0.2	2
Muskingum k	1	150	5	3

4.1.2 Model Calibration

Model calibration involves adjustments of model parameter values and comparison of predicted output to the measured data. Model calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is performed by carefully selecting values for the model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions (HEC, 2006)**.**

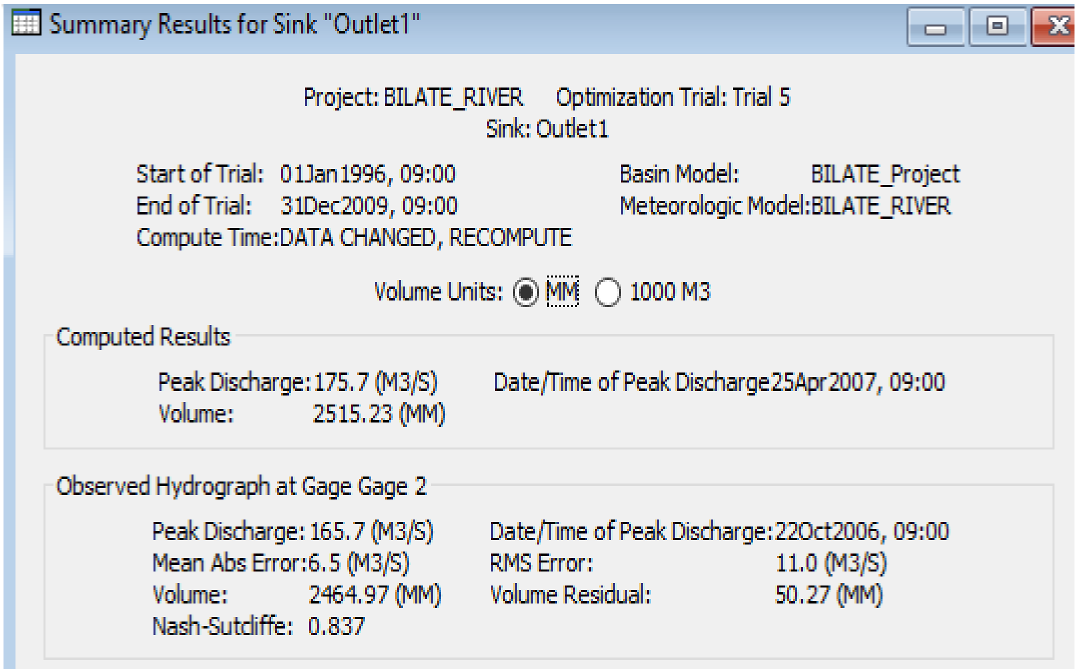
There are manual and automatic or both calibration systems for the distributed hydrologic model. Manual calibration is the trial and error process of model parameter adjustment. After the parameter adjustment, simulated and observed watershed behavior is compared to visualize the match between them. Automatic calibration, on the other hand, uses a mathematical search algorithm that seeks to minimize differences between selected features of modeled and observed behaviors by systematic trial iterations in the values of the model parameter. The quantitative measure of the fit of modeled behavior to the observed (objective function) is calculated after parameter iteration.

In this study, to assess the model performance, 3 objective functions were used during the calibration and validation periods. These are coefficient of determination (R^2), the Nash Sutcliffe efficiency coefficient (NSE) and the Mass Balance Error (MBE). These functions are an implicit measure of comparison of the magnitudes of the peaks stream flow, volumes and times of peak of the two hydrographs.

Therefore, automated calibration in conjunction with manual calibration was used to determine a practical range of the parameter values preserving the hydrograph shape and minimum error in volume and peak flows. The calibration from (1996-2009) period used. Optimization of the parameter values was carried out within the allowable ranges recommended by the US Army corps of Engineers Hydrologic Engineering Center**.** (Feldman, 2000)**.**

After several iterations, the objective function NSE of 0.837 and the coefficient of determination R^2 value of 0.8674 indicates the model performance during calibration was very good (figure 4.1). In addition, the Mass Balance Error (MBE) result in 60.5 and also by visually inspecting and comparing the calculated and observed hydrograph shows very good.

The scatter plot of the values of the measured and the simulated daily stream flow data have also shown very good linear correlation between the two data sets. (Figure 4.2).



Summary Results for Sink "Outlet1"

Project: BILATE_RIVER Optimization Trial: Trial 5
Sink: Outlet1

Start of Trial: 01Jan1996, 09:00
End of Trial: 31Dec2009, 09:00
Compute Time: DATA CHANGED, RECOMPUTE
Basin Model: BILATE_Project
Meteorologic Model: BILATE_RIVER

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 175.7 (M3/S)
Volume: 2515.23 (MM)
Date/Time of Peak Discharge 25Apr2007, 09:00

Observed Hydrograph at Gage Gage 2

Peak Discharge: 165.7 (M3/S)
Mean Abs Error: 6.5 (M3/S)
Volume: 2464.97 (MM)
Nash-Sutcliffe: 0.837
Date/Time of Peak Discharge: 22Oct2006, 09:00
RMS Error: 11.0 (M3/S)
Volume Residual: 50.27 (MM)

Figure 4. 1 The simulated and observed stream flow after calibration

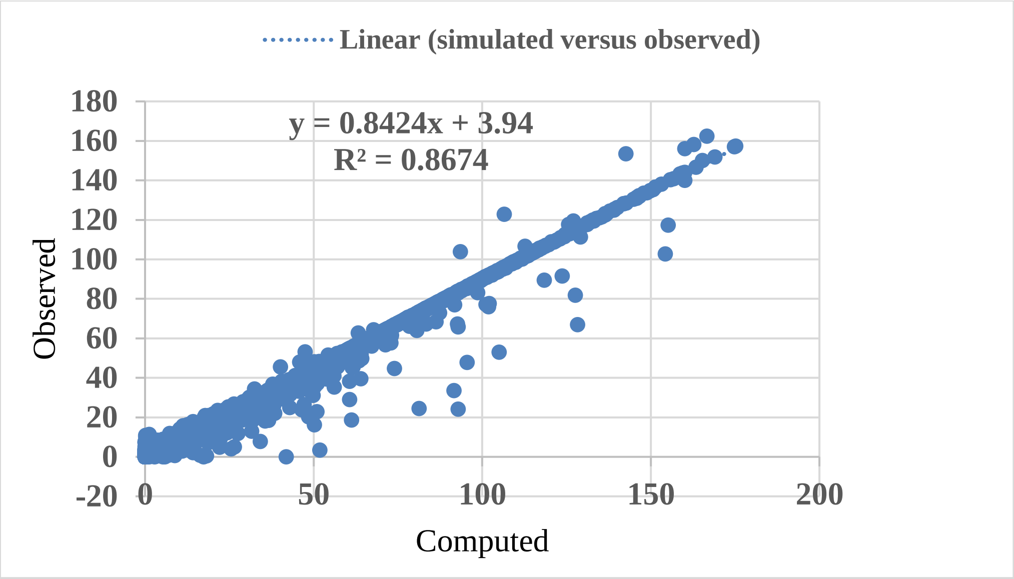


Figure 4. 2 The scatter plot of stream flow hydrographs after calibration.

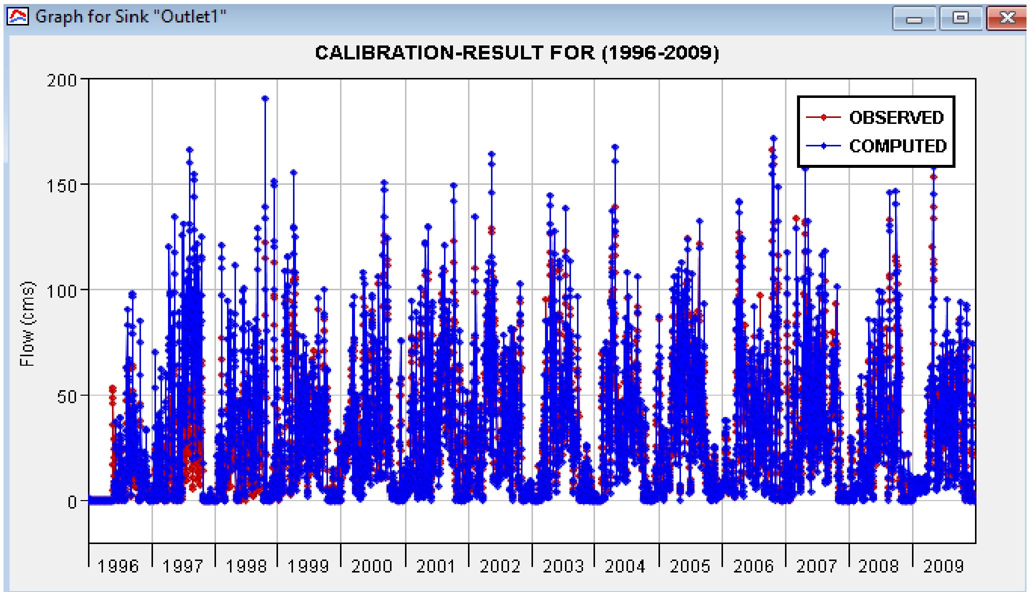


Figure 4. 3 Calibration of Daily Flow Hydrographs(1996-2009).

Table 4. 2 The objective function values of the model calibration.

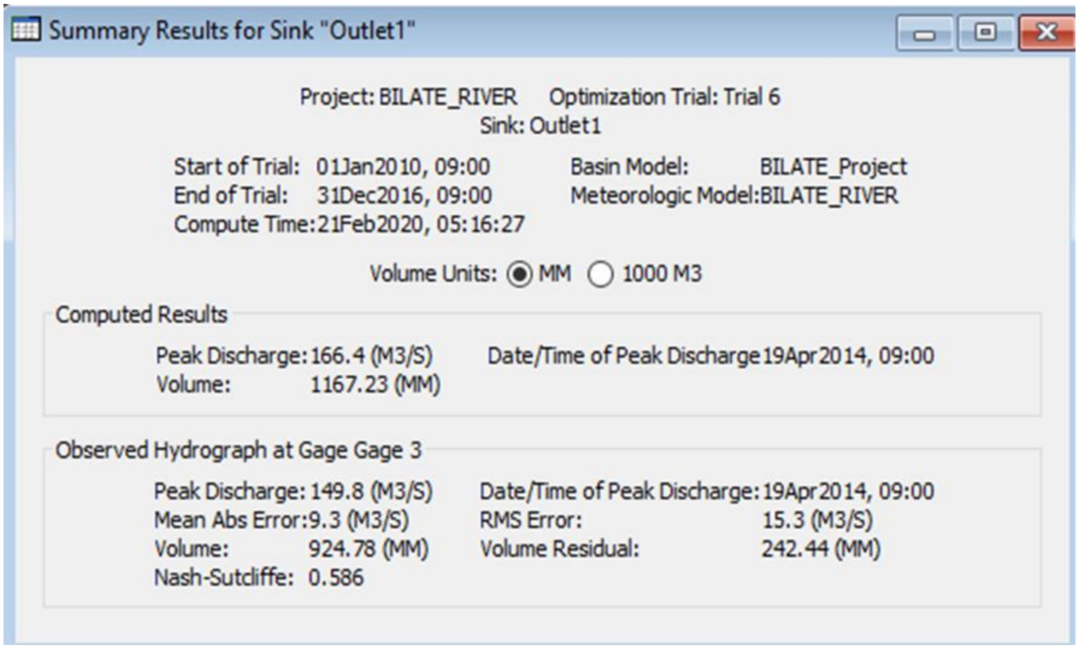
Objective functions	Values
Nash_sucliffe efficiency	0.837
Correlation coefficient (R^2)	0.8674
Mass balance error	60.35
RMS Error(m^3/s)	11.0

4.1.3 Model Validation

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Procedurally, validation follows similar steps like calibration predicted and measured values are compared to determine if the objective function is met. But, measured data sets of watersheds for validation should be different from the one used for model calibration and also there is no model adjustment made during validation.

For the model validation the observed daily stream flow data recorded at the outlet of the catchment from 2010 to 2016 were used. The validation result showed that the coefficient of determinations (R^2), the Nash-Sutcliffe Efficiency (NSE) and the mass balance are 0.7383, 0.586 and 11.10 respectively and also by visually inspecting and comparing the calculated and observed hydrograph shows very good match. these values and hydrographs shows that there is a very good relation between observed and simulate stream flow.

The scatters plot of the values of the measured and the simulated daily stream flows data has also shown a fair linear correlation between the two datasets. The trend and the magnitude of the two data set values are shown in figure 4.5.



Summary Results for Sink "Outlet1"

Project: BILATE_RIVER   Optimization Trial: Trial 6
Sink: Outlet1

Start of Trial: 01Jan2010, 09:00   Basin Model: BILATE_Project
End of Trial: 31Dec2016, 09:00   Meteorologic Model: BILATE_RIVER
Compute Time: 21Feb2020, 05:16:27

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 166.4 (M3/S)   Date/Time of Peak Discharge 19Apr2014, 09:00
Volume: 1167.23 (MM)

Observed Hydrograph at Gage Gage 3

Peak Discharge: 149.8 (M3/S)   Date/Time of Peak Discharge: 19Apr2014, 09:00
Mean Abs Error: 9.3 (M3/S)   RMS Error: 15.3 (M3/S)
Volume: 924.78 (MM)   Volume Residual: 242.44 (MM)
Nash-Sutcliffe: 0.586

Figure 4. 4 The simulated and observed stream flow after validation

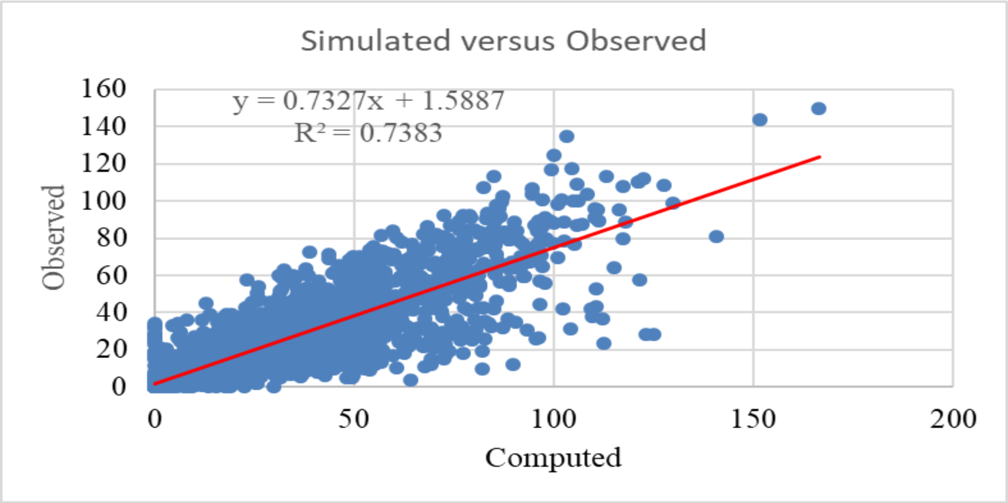


Figure 4. 5 The Scatter plot of stream flow hydrograph after validation.

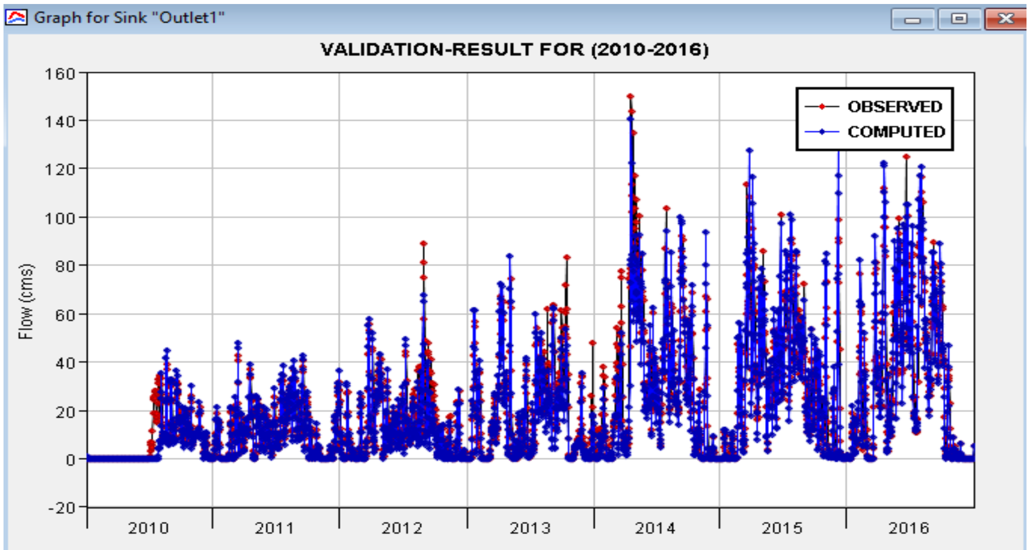


Figure 4. 6 Validation of Daily Flow Hydrographs (2010-2016).

Table 4. 3 The objective function result of the model validation

Objective function	**Values**
Nash_sucliffe efficiency	0.586
Coefficient determination (R^2)	0.7383
Mass balance error (%)	11.10
RMS error (m^3/s)	15.3

The Mode Calibration and Validation results showed good agreement between observed and Simulated rainfall and stream flow and was with acceptable range, coefficient of determination(R^2) is 0.8674 for Calibration and 0.7383 for Validation and Nash-Sutcliffe efficiency(NSE) (0.837 for Calibration and 0.586 for Validation also the MBE (11.10).

4.2 Model performance

For the Bilate watershed the efficiency evaluation criteria parameters almost resemble each other. The Nash Sutcliffe efficiency (NSE), coefficient of determination ($R^{2)}$ and the mass balance error has the value of 0.837, 0.8674 and 60.35 for calibration and 0.586, 0.7383 and 11.10 for validation and also the observed discharge overestimates the simulated discharge during validation.

Based on the critical values the result obtained concludes that the model performed well. In general, the model performance assessment indicated a very good correlation between the daily observed and simulated flows, therefore the model performed well for the Bilate watershed.

Table 4. 4 Calibration and validation summary values of HEC-HMS objective function.

Performance factor	During calibration	During validation
Nash_sucliffe efficiency	0.837	0.586
Correlation coefficient (R^2)	0.8674	0.7383
Mass balance error (%)	60.35	11.10
RMS error (m^3/s)	11.0	15.3

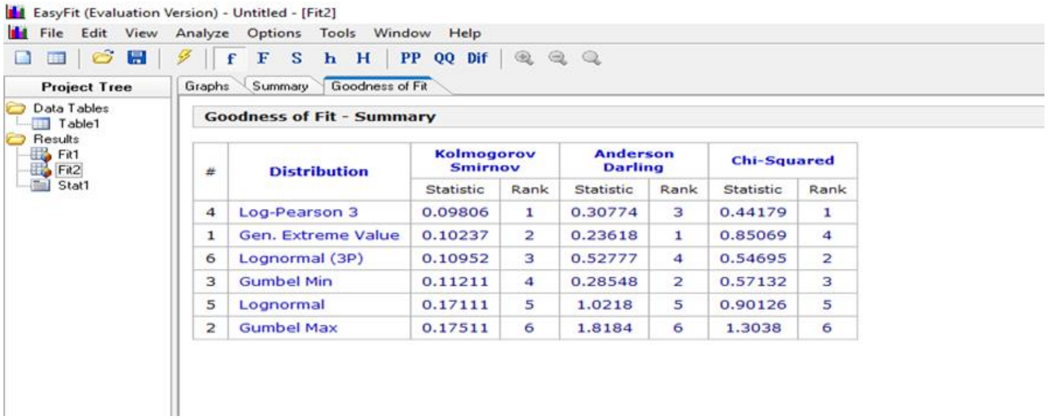
From the calibration and validation result it’s visible that both the observed and simulated stream flow values were relatively close to each other, and also by visually inspection and comparing the computed and observed hydrograph shows very good relation. Therefore, the Concept of the Modeling of Rainfall runoff for the Bilate watershed was successfully performed well. Again all the performance evaluation criteria proof the simulation under the recommended ranges that leads the objective of modeling.

Table 4. 5 Evaluation parameters for Model simulation.

No	Performance evaluators	During calibration	During validation	Remarks
1	NSE	0.837	0.586	Very good
2	RSR	0.163	0.148	Very good
3	R2	0.8674	0.7383	Very good
4	PBIAS	6.03	6.14	Very good
5	RMSE	11.0	15.3	Very good
6	MAE	6.5	9.3	Very good

4.3 Best fit flood probability distribution

The test statistics for Kolmogorov-Smirnov test (D), Anderson-Darling Test (A^2) and Chi-square test (x^2) for yearly discharge data were computed for six probability distributions. The probability distribution having the first rank along with their test statistic is presented by Easy fit software in Figure 4.7



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
4	Log-Pearson 3	0.09806	1	0.30774	3	0.44179	1
1	Gen. Extreme Value	0.10237	2	0.23618	1	0.85069	4
6	Lognormal (3P)	0.10952	3	0.52777	4	0.54695	2
3	Gumbel Min	0.11211	4	0.28548	2	0.57132	3
5	Lognormal	0.17111	5	1.0218	5	0.90126	5
2	Gumbel Max	0.17511	6	1.8184	6	1.3038	6

Figure 4. 7 Goodness of Fit (GOF) Statistics Comparison interface

Comparing the process of fitting for six kinds of distribution. Since Goodness-of-Fit statistics are in form of distance between data and fitted distributions, clearly the distribution with minimum statistics value has been best fitted with data. Based on this fact, Easy Fit were attribute a ranking number to each distribution.

Using Kolmogorov-Smirnov test (D) the statistical value of Log Pearson type three distribution provides good fit to the yearly maximum discharge data at the outlet. Using Anderson-Darling Test (A^2) it was observed that Generalized Extreme Value distribution. Finally using the Chi-squared test (x^2) has been applied to test the Goodness of Fit it has been shown that the Log Pearson type three distribution best fit at the outlet.

Comparing three goodness-of-fit tests it has been observed that the Log Pearson type three distributions provides a good fit for selected discharge at the outlet. Additionally, distributions are sorted based on results from Kolmogorov-Smirnov test (D) statistics, and the best fitted distribution Log Pearson type three distributions governs with minimum statistical values.

4.4 Output of HEC-HMS by Frequency Storm

The minimum peak flow for the Bilate watershed is occurred for 2-year return period for 24-hour duration and the maximum obtained with 100-year frequency storm for the same duration. The value being 241.8 m^3/s and 1152.1 m^3/s for 2-year and 100-year frequency respectively the graph for the 2-year and 100-year return period is shown below on figure 4.8 and 4.9 whereas the remaining's for 10-years, 25-years, and 50-years listed under Annexes D.

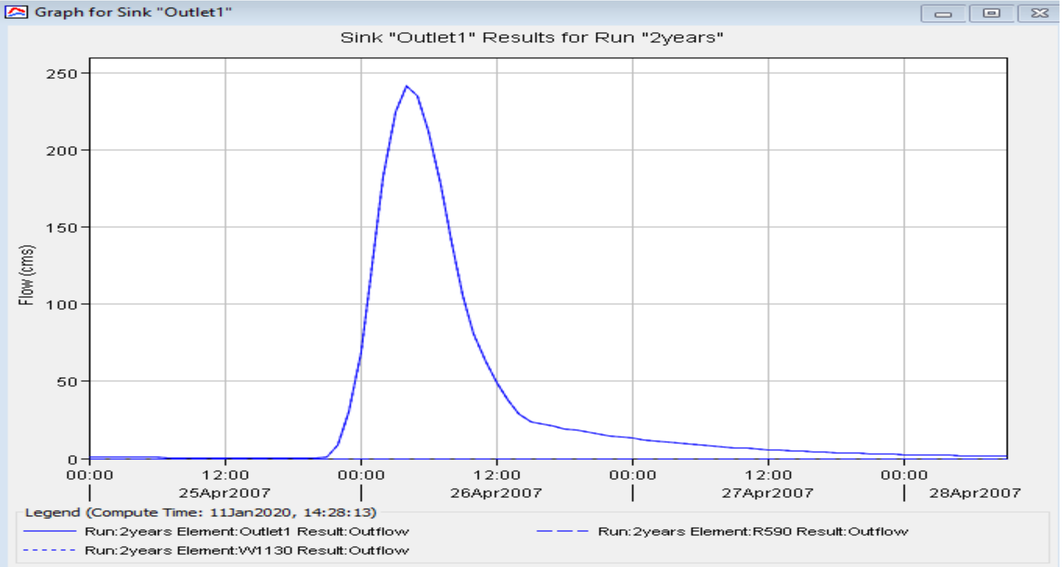


Figure 4. 8 The two year HEC-HMS Frequency Storm Flow for Bilate watershed

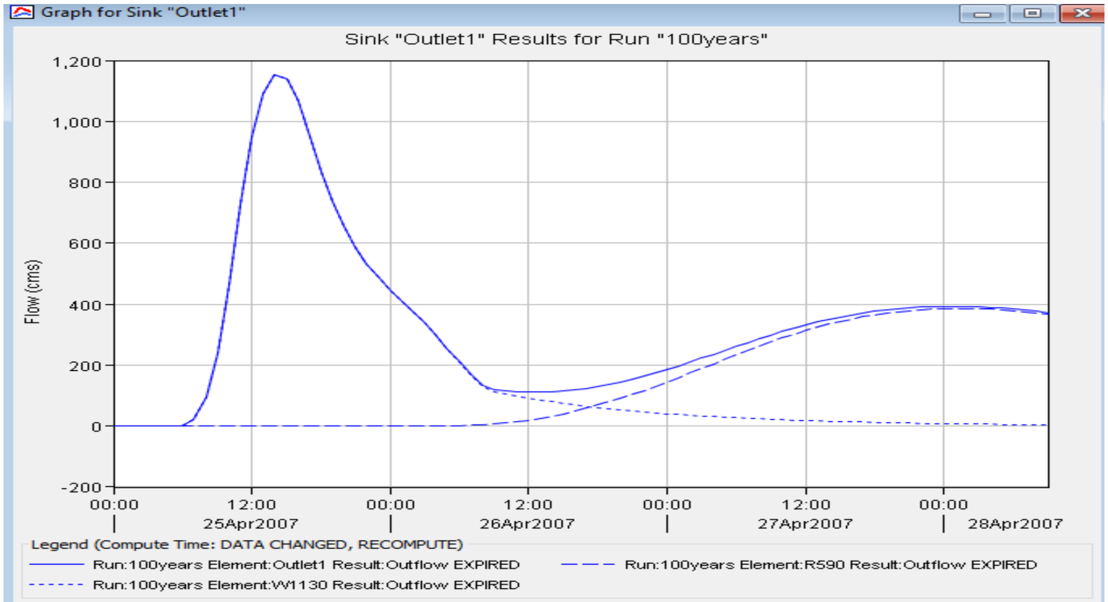


Figure 4. 9 100-year HEC-HMS Frequency Storm Flow for Bilate watershed

Using the parameters obtained from the daily basis the model results peak flows for different return period, the output peak stream flow from the HEC-HMS provides from the daily basis of rainfall depth of 24-hour the model predicts peak flows for the return periods of 2, 10, 25, 50 and 100-years and the flow values were analyzed. Figure (4.10)

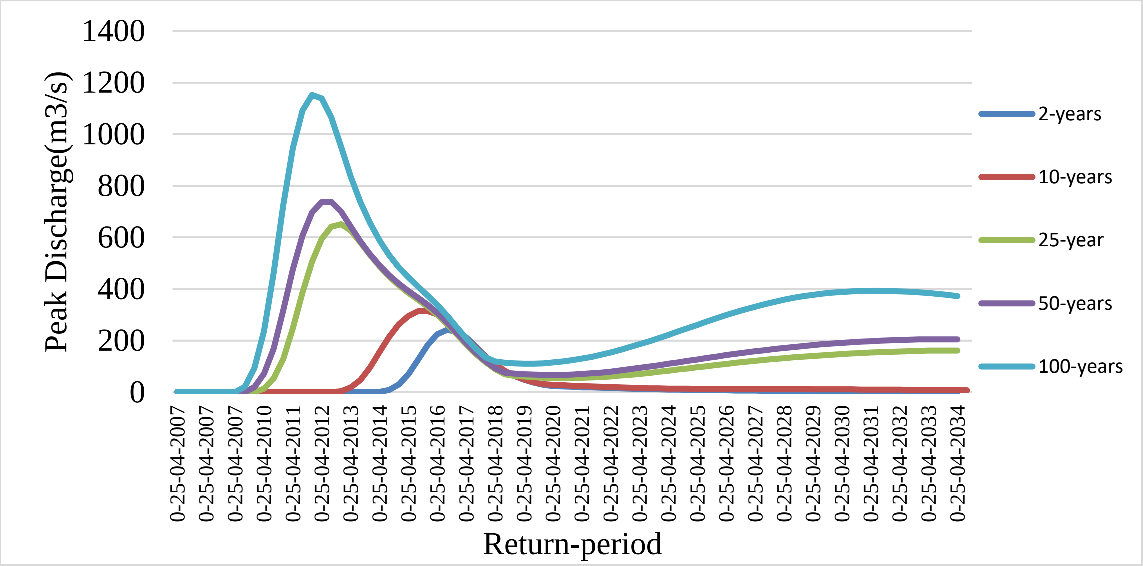


Figure 4. 10 Analysis of Peak Flood By HEC-HMS.

Finally, The HEC-HMS model result was compared with the frequency analysis results. They are selected using software called Easy Fit Software for selection of methods. According to the output the following four popular methods are selected.

Table 4. 6 Flow Comparison (frequency analysis and the HEC-HMS)

No	Return period(years)	Peak Flow(m3/s)			
		HEC-HMS	Easy fit		
		HEC-HMS	Log Pearson Type-3	General extreme value I	Lognormal
1	2	241.8	213.52	145.32	101.23
2	10	314.8	296.32	252.32	169.43
3	25	651.2	541.63	421.78	285.96
4	50	738.01	652.38	600.02	458.20
5	100	1152.1	983.85	821.63	600.03

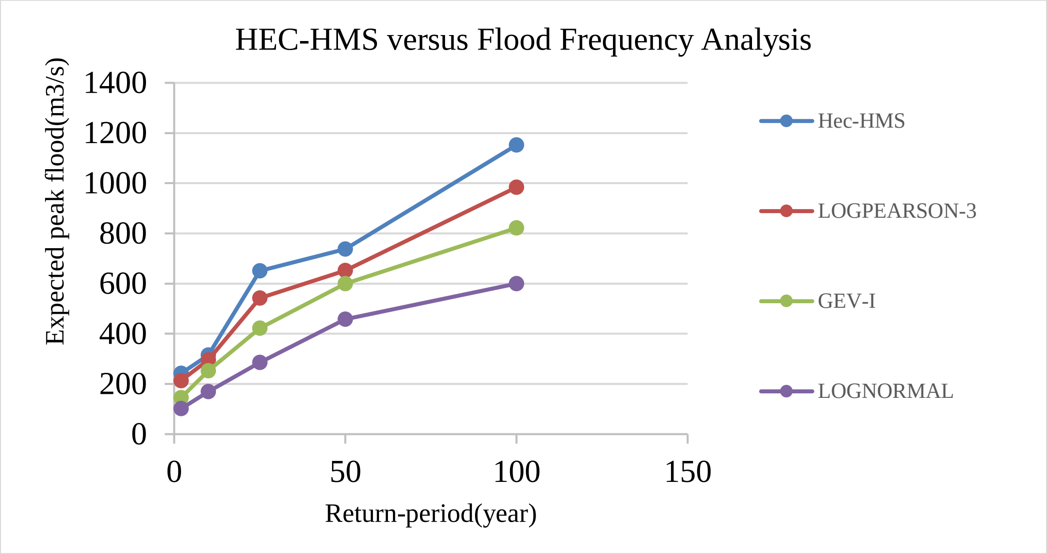


Figure 4. 11 HEC-HMS and flood frequency methods comparison analysis

In the table 4.5 and figure 4.11 the frequency discharge value derived using log Pearson type-III value method show high similarity to the HEC-HMS. The other two are somewhat far apart than the result of the HEC-HMS.

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The physically based, semi distributed Model HEC-HMS was successfully used to simulate Rainfall-runoff in Bilate watershed.

The sensitivity analysis parameters using HEC-HMS Simulation run has pointed out five most important parameters that control the rainfall-runoff simulation over the studied watershed and three most sensitive parameters are examined.

The ability of HEC-HMS to adequately simulate Rainfall and stream flow was evaluated through sensitivity analysis, model calibration and validation. The performance evaluation indicators, a coefficient of determination (R^2) and Nash-Sutcliffe model efficiencies (NSE) during both the calibration and validation periods of stream flow was with the acceptable limits, i.e. $R^2 > 0.6$, NSE > 0.5. This show that HEC-HMS model performed well in Rainfall-runoff Modelling and predicting flood forecasting for the study watershed. Goodness-of-Fit tests can be used to compare fitted distributions, select a model, and determine how good the distribution was fitted to the data. Easy Fit software generates reciprocal reports which facilitate achieving a general perspective over fitted distributions as well as evaluating the level of goodness fit for certain models at various significance levels. It is proficient for further analysis of the hydrological Models in Bilate watershed. It can also be further extended to similar watersheds in the country, particularly in the Rift Valley Basin of Ethiopia. The models slightly over predict stream flow during validation.

Finally, the methodologies developed in this research can also be applied in other ungauged catchments and regions with similar characteristics. We suggest further studies in the study catchment to generate more detailed information for modelling work by reviewing the efficiency of meteorological and hydrometric measurements (poor in quantity and quality during this study) in order to establish the optimal number of stations and their adequate distribution in the catchment.

5.2 Recommendation

Considering its good performance, the HEC-HMS model can be reliably applied to future works that aim to study the drainage capacity of the Bilate River Basin, in order to subsidize public policy proposals for land use and occupation that aim to prevent flooding issues like those that the watershed faces today.

Mitigation measure is recommended for prevention of Runoff and flooding problems. so it’s recommended to do further research on watershed management.

Abaya Chamo Basin is found at the outlet of this catchment, Bilate River is mainly flow to this Basin, that may carry out soils from the upstream or Bilate catchment due to uncontrolled flooding during rainy season. Therefore, the influence of Rainfall needs further study for this watershed and controlling measure is necessary for the downstream farmers unless the future flooding may harm the downstream communities.

It is difficult to recover once the natural land is affected. So, managing the resource and wise use is preferable. Therefore, the government and every stake holder would give attention to the environment and create awareness to the end user of the land, particularly to the farmers who lives in the downstream.

In this watershed still, plantation Greening is necessary and unless and otherwise surface runoff will be increased and may leads to flooding problems in the future.

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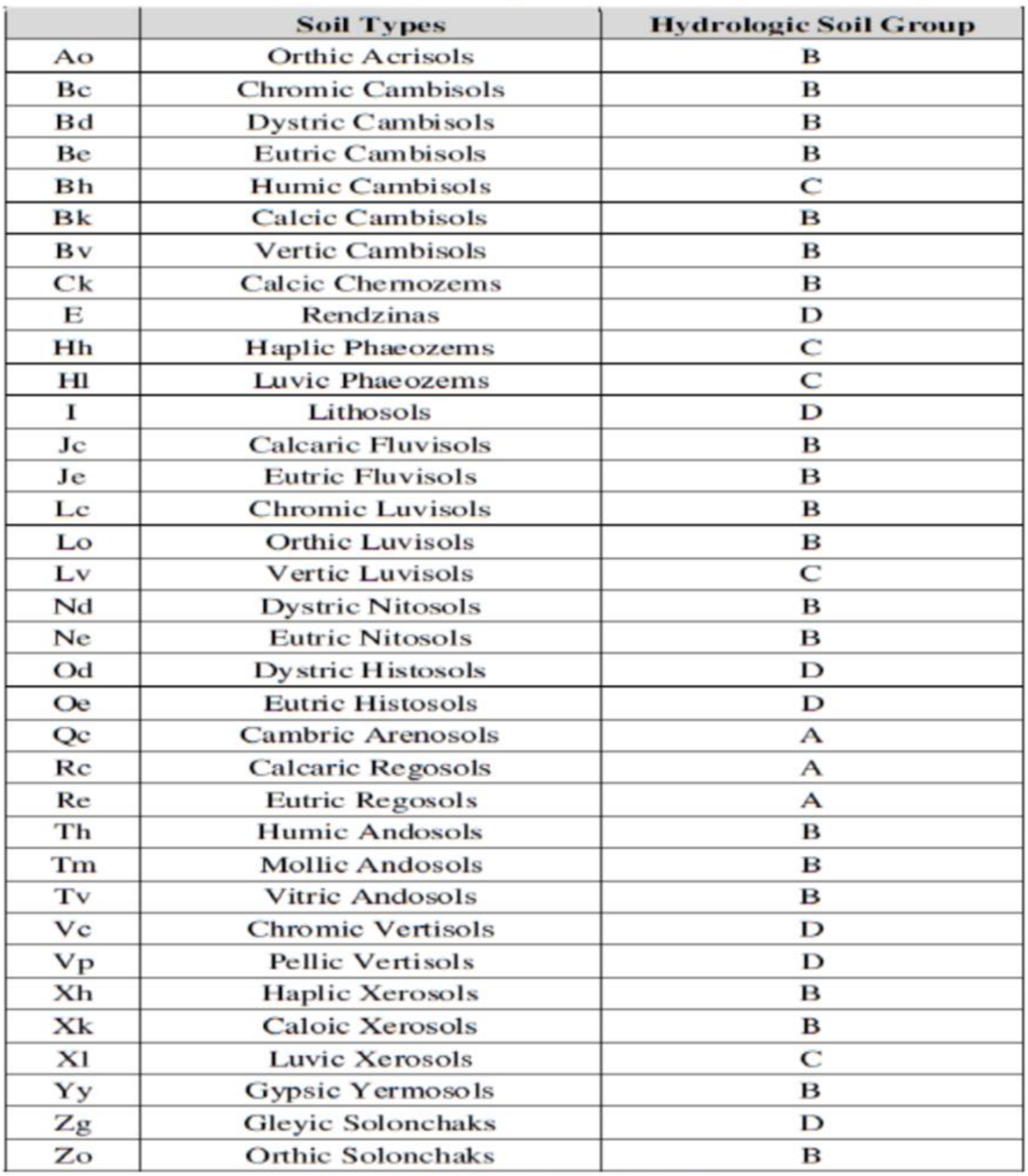
ANNEXES

Annexes A Typical Hydrologic Soils Groups for Ethiopia**,** Land covers of Bilate watershed Terrain processing.



	Soil Types	Hydrologic Soil Group
Ao	Orthic Acrisols	B
Bc	Chromic Cambisols	B
Bd	Dystric Cambisols	B
Be	Eutric Cambisols	B
Bh	Humic Cambisols	C
Bk	Calcic Cambisols	B
Bv	Vertic Cambisols	B
Ck	Calcic Chernozems	B
E	Rendzinas	D
Hh	Haplic Phaeozems	C
Hl	Luvic Phaeozems	C
I	Lithosols	D
Jc	Calcaric Fluvisols	B
Je	Eutric Fluvisols	B
Lc	Chromic Luvisols	B
Lo	Orthic Luvisols	B
Lv	Vertic Luvisols	C
Nd	Dystric Nitosols	B
Ne	Eutric Nitosols	B
Od	Dystric Histosols	D
Oe	Eutric Histosols	D
Qc	Cambric Arenosols	A
Rc	Calcaric Regosols	A
Re	Eutric Regosols	A
Th	Humic Andosols	B
Tm	Mollic Andosols	B
Tv	Vitric Andosols	B
Vc	Chromic Vertisols	D
Vp	Pellic Vertisols	D
Xh	Haplic Xerosols	B
Xk	Caloic Xerosols	B
Xl	Luvic Xerosols	C
Yy	Gypsic Yermosols	B
Zg	Gleyic Solonchaks	D
Zo	Orthic Solonchaks	B

(Source: Ministry of Agriculture)

Figure A-1 Typical Hydrologic Soils Groups for Ethiopia

Table A-1 Runoff Curve number for selected land use and Hydrologic Soil Group.

			Hydrologic soil Groups			
S/N	Land use	Description	A	B	C	D
1	Agricultural/ cultivated	With conservation treatment	72	81	88	91
		Without conservation treatment	62	71	78	81
2	Forest	With Thin stand poor cover no	45	66	77	83
		With Good cover	25	55	70	77
3	Grass	Good condition	49	61	74	80
		Fair condition	39	69	79	84
4	Water	Impervious water surface	100	100	100	100

Table A-2 Major soil types for the Bilate watershed

Major soils	Areas(km)	In%	By Texture	Draining condition	HSG
Pellic vertisols	969.7	21.27	Silty clay	Moderately-well drained	C
Eutric fluvisols	210.52	4.61	Silty clay	Highest-runoff potential	C
Chromic vertisols	517	11.34	Sandy loam	Moderately-well drained & moderate infiltration	B
Orthic solonckacs	1589.05	34.86	loam	Moderately fine to fine drained.	C
Carcaric xerosols	35	1.71	Sandy clay	Moderately fine to fine drained.	C
Calcaric flubisols	191.48	4.2	Sandy clay	Moderately fine drained. Slow infiltration	C
Chromic luvisols	266.87	5.85	Clay	Moderately-well drained & moderate infiltration	B
Dystric nitisols	199.72	4.38	Clay	Low drainage condition & high runoff potential	D
Eutric nitosols	292.03	6.40	Clay	Low drainage condition & high runoff potential	D
Eutric regosols	179.23	3.93	Clay	High drained condition.	C
Luvic phaenzomes	63.916	1.40	Fine Sand	Highly drained high infiltration	A

Table A-3 Reclassified Land use land cover for Bilate watershed

Original NLCD classification		Revised classification (reclassification)	
Number	Description	Number	Description
1	Perennial crops	1	Agricultural land
2	Annual crops		
5	Bare soil		
11	Settlement		
13	Lava field		
0	Moderate forest	2	Forest
3	Wood land		
8	Sparse forest		
12	Open shrubs		
9	Wet land	3	Water
10	Salt pan		
15	waterbody		
4	Open grass	4	Grass
6	Closed grass		
7	Dense grass		
14	Closed shrub		

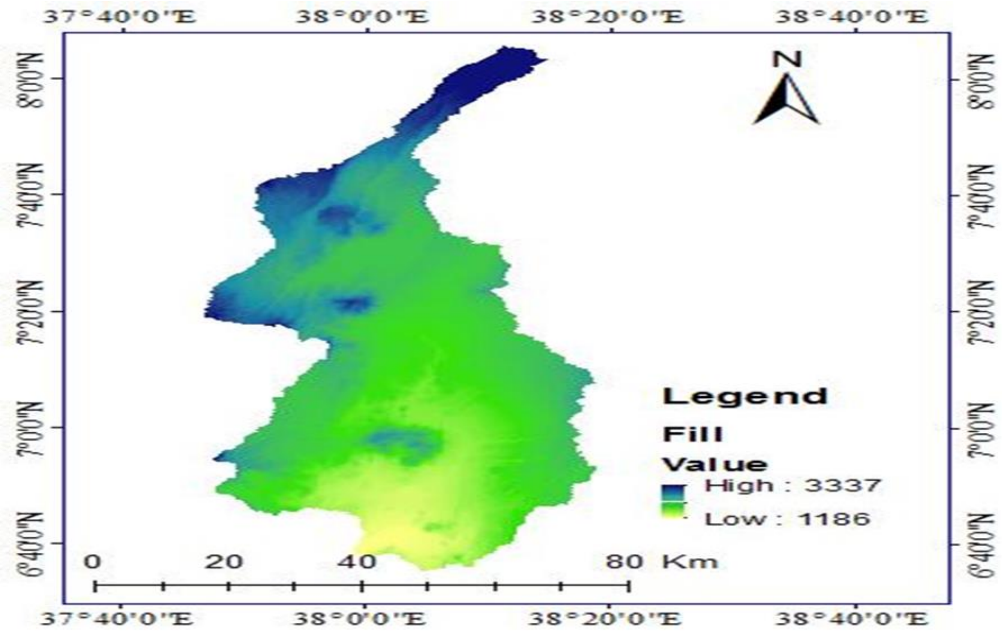


Figure A-2 Fill sink grid map.

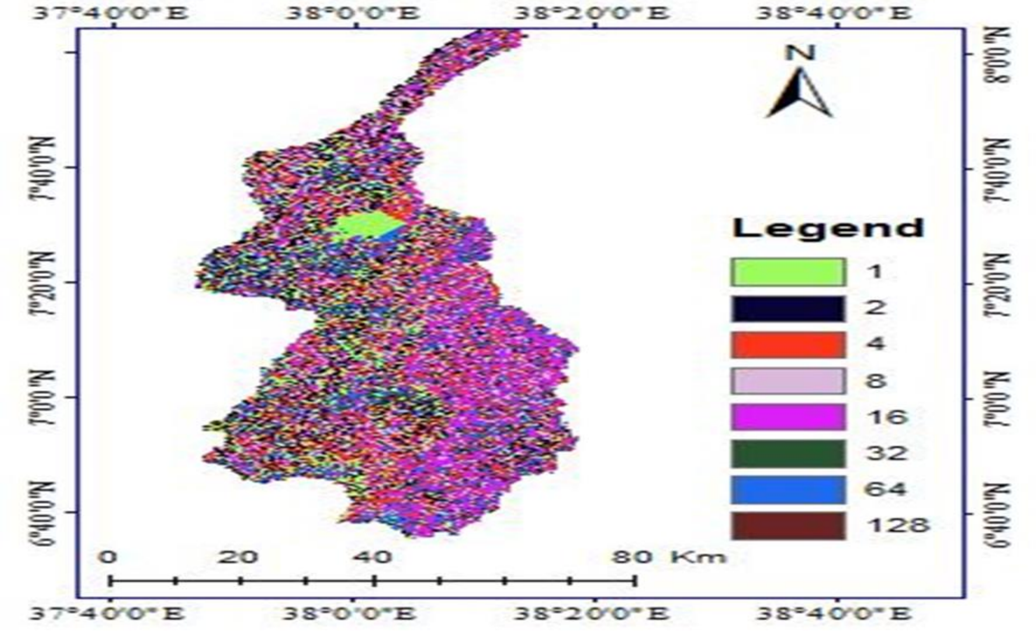


Figure A-3 Flow direction grid

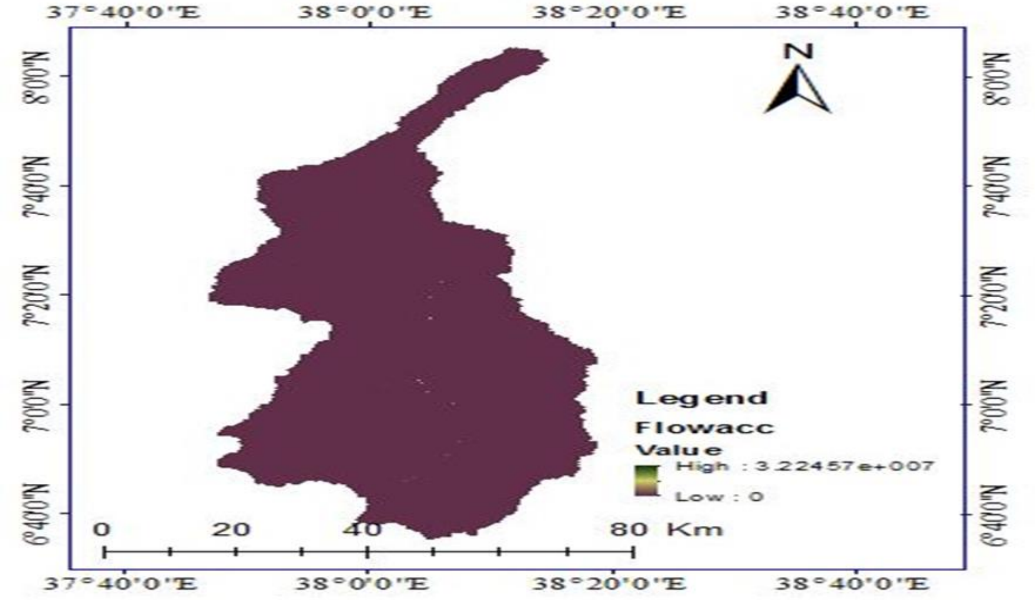


Figure A-4 Flow accumulation grid

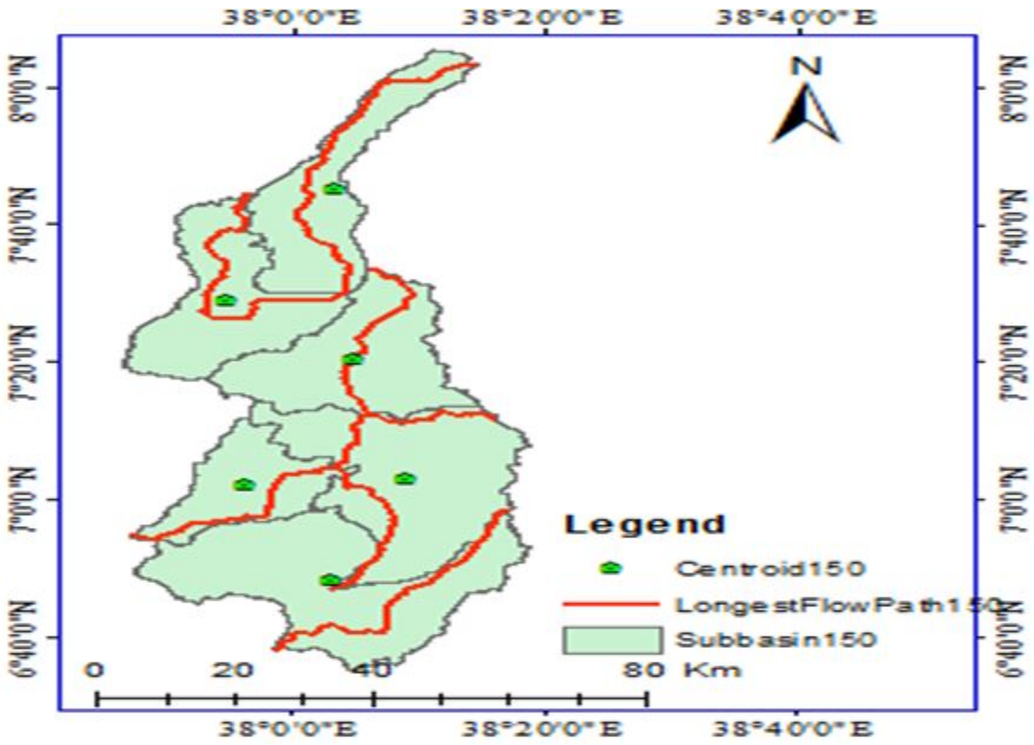


Figure A-5 Longest Flow Path of the watershed

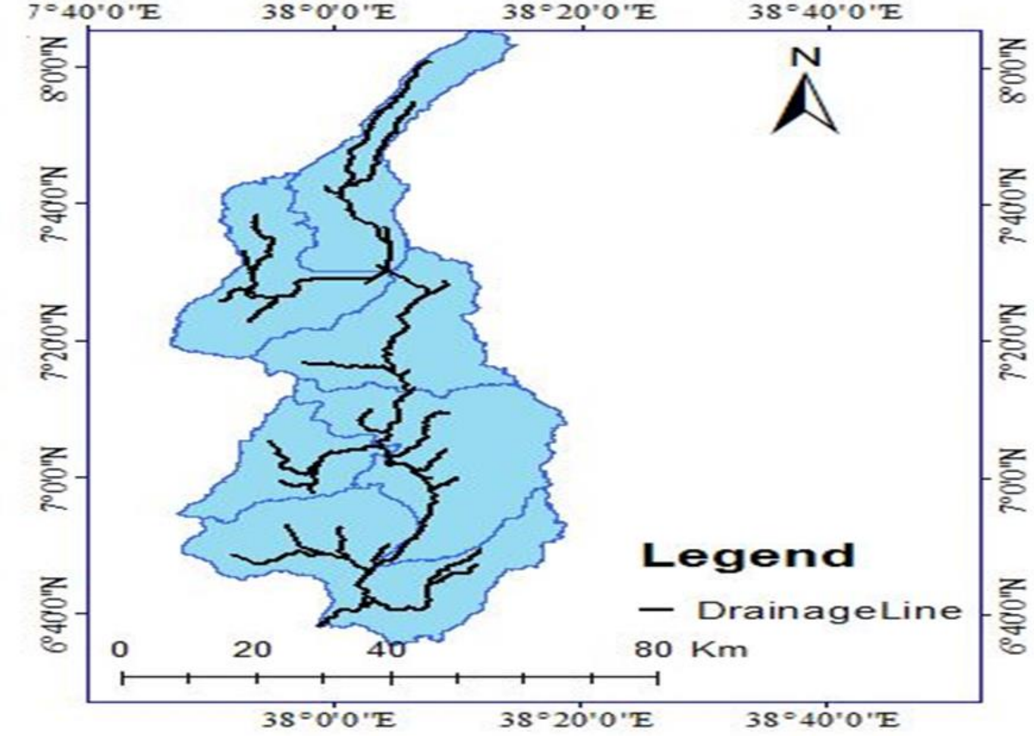


Figure A-6 Drainage line map of the watershed

Annexes B DMC for Consistency of Rainfall Data

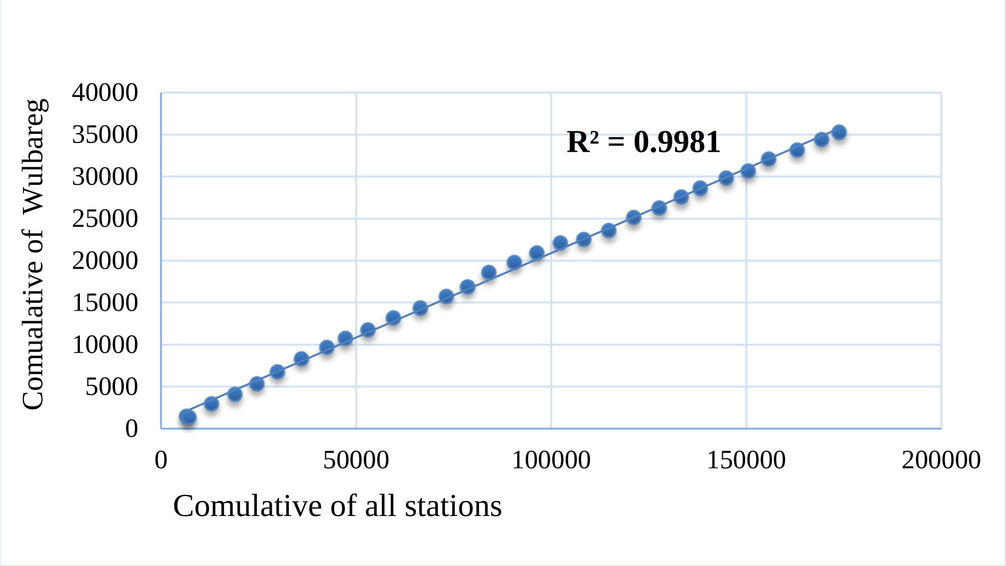


Figure B-1 Double Mass Curve for consistency of Wulbareg station

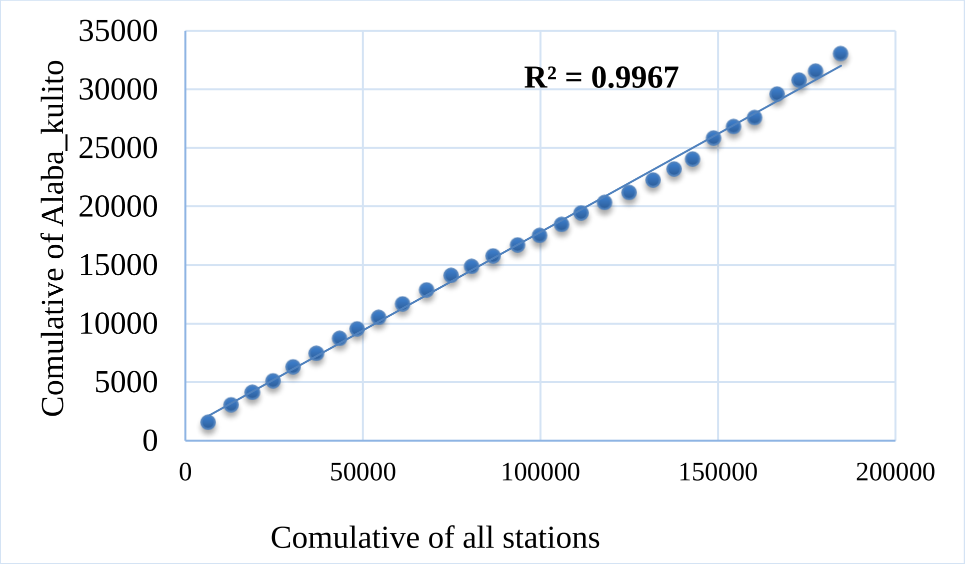


Figure B-2 Double Mass Curve for consistency of Alaba-kulito station

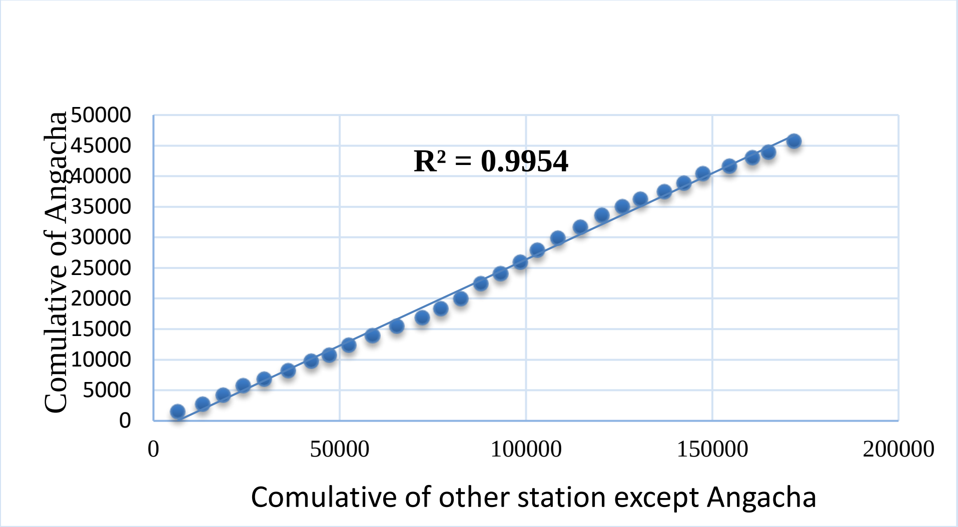


Figure B-3 Double Mass Curve for consistency of Angacha station

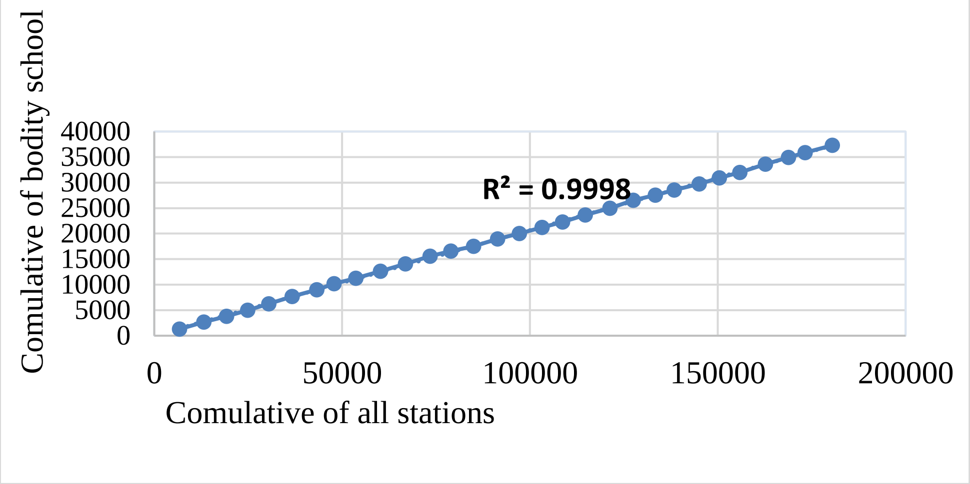


Figure B-4 Double Mass Curve for consistency of Bodity-school station

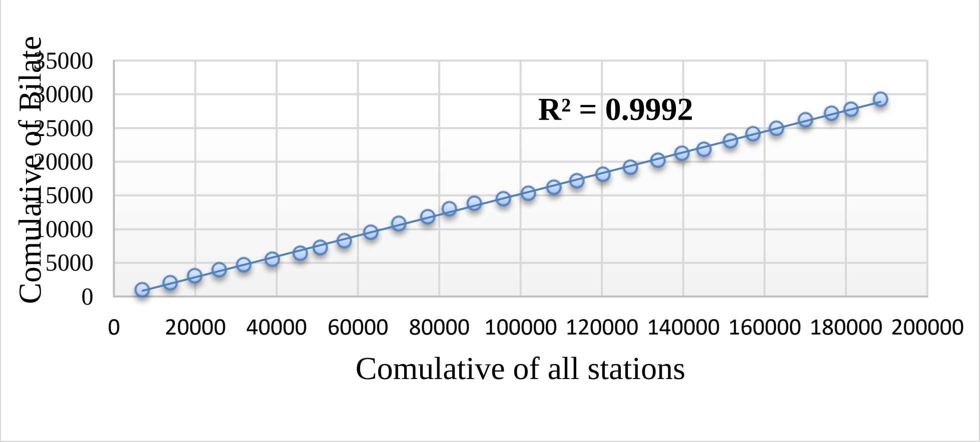
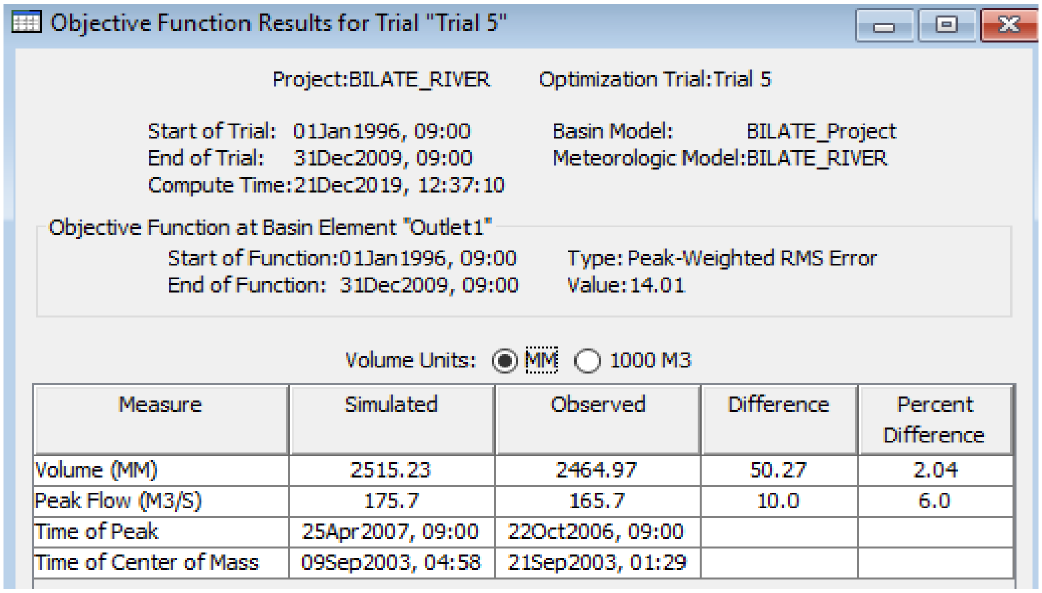


Figure B-5 Double Mass Curve for consistency of Bilate station

Annexes C HEC-HMS OUTPUT



Objective Function Results for Trial "Trial 5"

Project:BILATE_RIVER Optimization Trial:Trial 5

Start of Trial: 01Jan1996, 09:00
End of Trial: 31Dec2009, 09:00
Compute Time:21Dec2019, 12:37:10

Basin Model: BILATE_Project
Meteorologic Model:BILATE_RIVER

Objective Function at Basin Element "Outlet1"

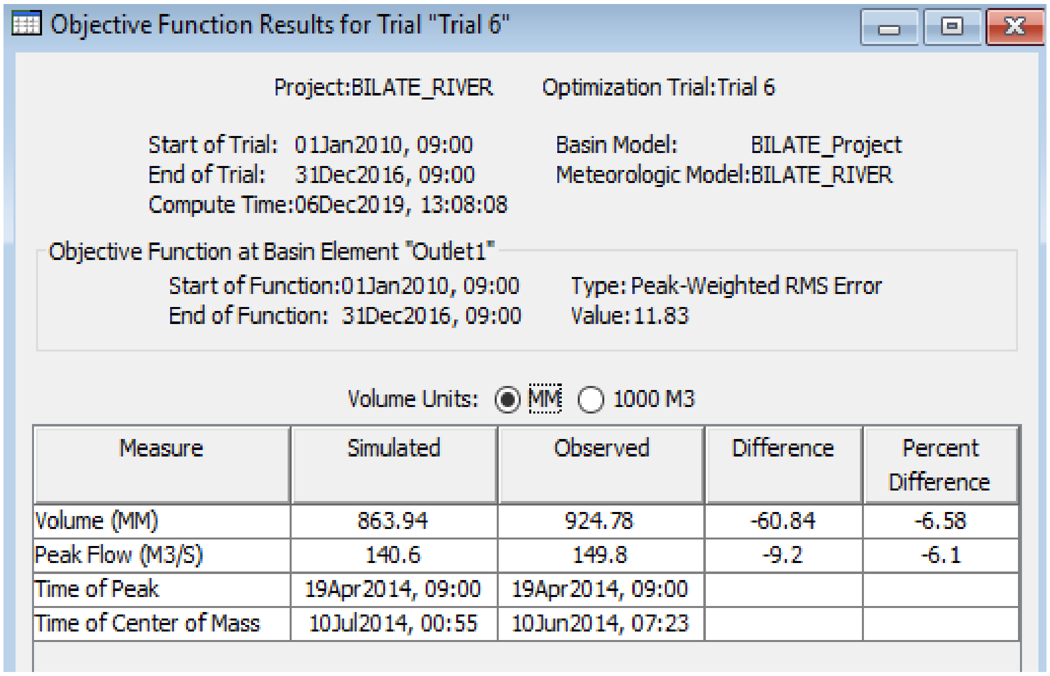
Start of Function:01Jan1996, 09:00
End of Function: 31Dec2009, 09:00

Type: Peak-Weighted RMS Error
Value: 14.01

Volume Units: ● MM ○ 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	2515.23	2464.97	50.27	2.04
Peak Flow (M3/S)	175.7	165.7	10.0	6.0
Time of Peak	25Apr2007, 09:00	22Oct2006, 09:00		
Time of Center of Mass	09Sep2003, 04:58	21Sep2003, 01:29		

Figure C-1 Objective function summary result after calibration



Objective Function Results for Trial "Trial 6"

Project:BILATE_RIVER Optimization Trial:Trial 6

Start of Trial: 01Jan2010, 09:00
End of Trial: 31Dec2016, 09:00
Compute Time:06Dec2019, 13:08:08

Basin Model: BILATE_Project
Meteorologic Model:BILATE_RIVER

Objective Function at Basin Element "Outlet1"

Start of Function:01Jan2010, 09:00
End of Function: 31Dec2016, 09:00

Type: Peak-Weighted RMS Error
Value: 11.83

Volume Units: ● MM ○ 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	863.94	924.78	-60.84	-6.58
Peak Flow (M3/S)	140.6	149.8	-9.2	-6.1
Time of Peak	19Apr2014, 09:00	19Apr2014, 09:00		
Time of Center of Mass	10Jul2014, 00:55	10Jun2014, 07:23		

Figure C-2 Objective function summary result after validation

Table C-1 Calibration and validation output summary

Measure	During calibration		During validation	
	Computed	Observed	Computed	Observed
Volume (m^3)	2515.23	2464.23	1167.23	924.78
Peak flow(m^3/s)	175.7	165.7	166.4	149.8
Time of peak	22April,2007 @09:00	22Oct,2006 @9:00	19April,2014 @9:00	19April,2014 @9:00
Time of Center of mass	09Sept,2003 @4:58	21sep,2003 @01:29	10Jul,2014 @00:55	10Jun,2014 @07:23
Mean absolute error(m^3)	…	6.5	…	9.3
RMS Error(m^3)	…	11	…	15.3
Nash Sutcliffe efficiency	…	0.837	…	0.586
Coefficient of determination (R2)	…	0.8674	…	0.7383
MBE	60.35		11.10	

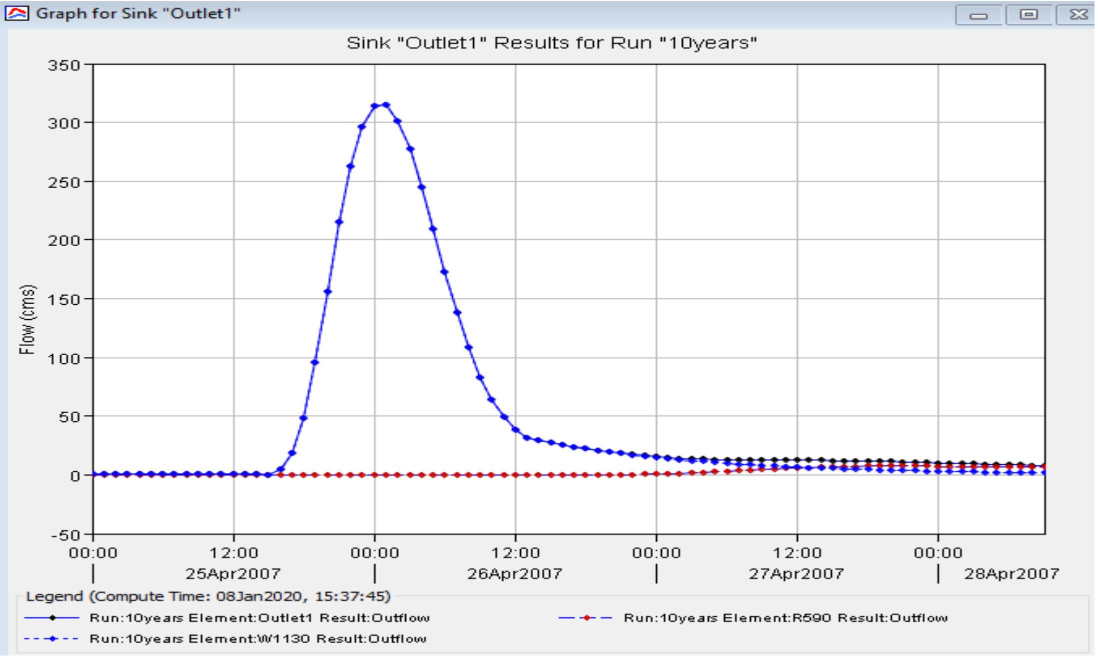


Figure C-3 The 10- years return period peak flood.

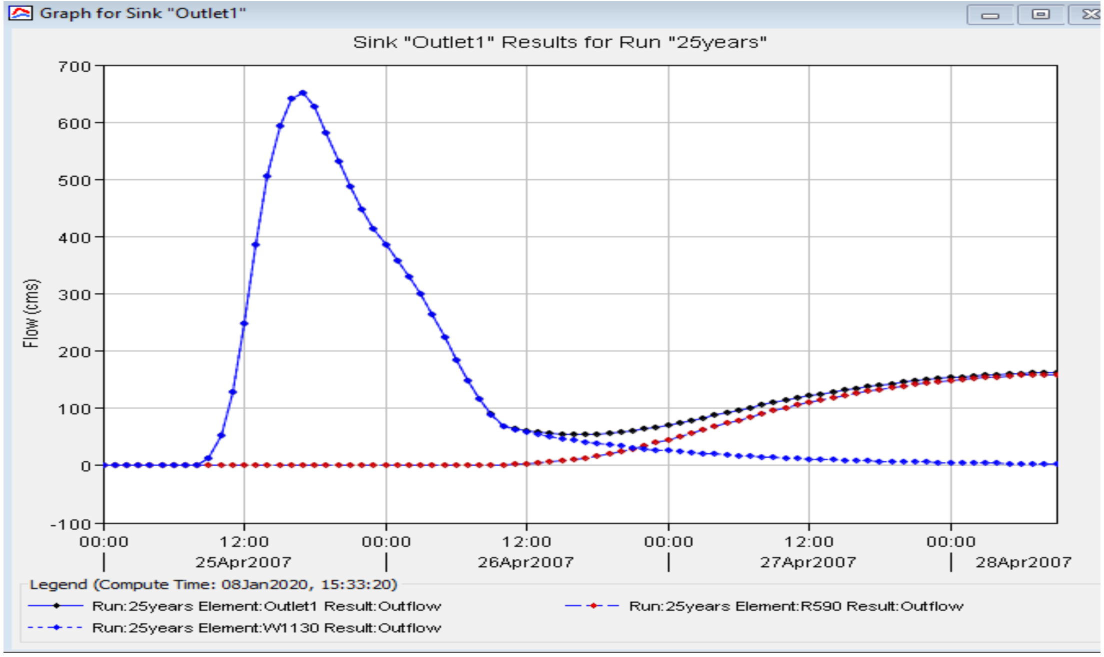


Figure C-4 The 25- years return period peak flood.

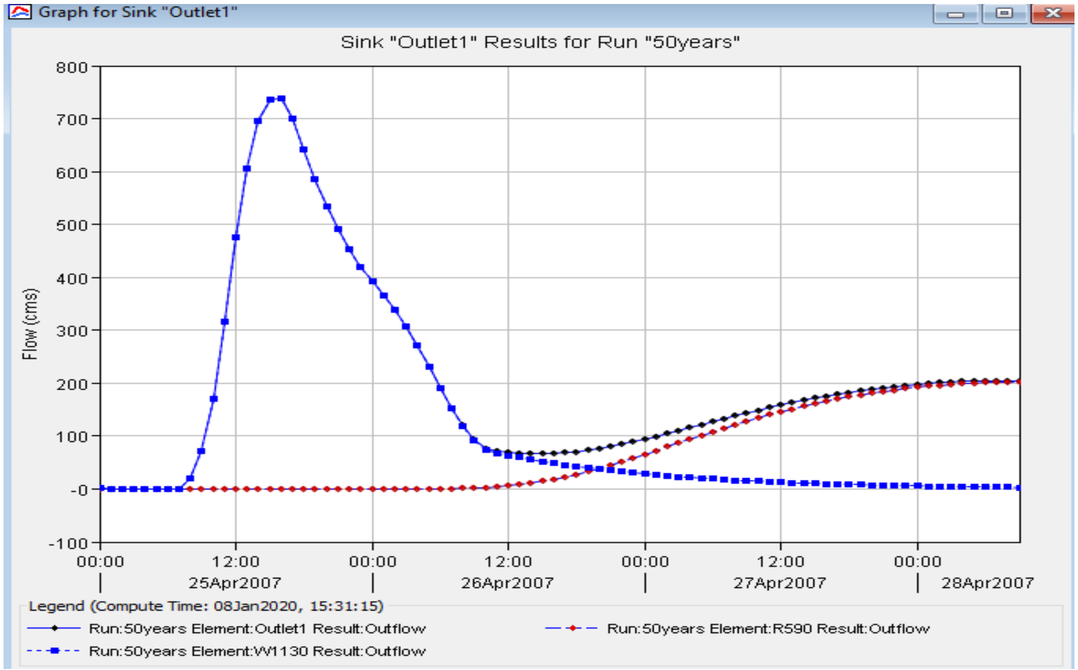


Figure C-5 The 50-years return period peak flood.

Annexes: D Easy fit analyzation Result

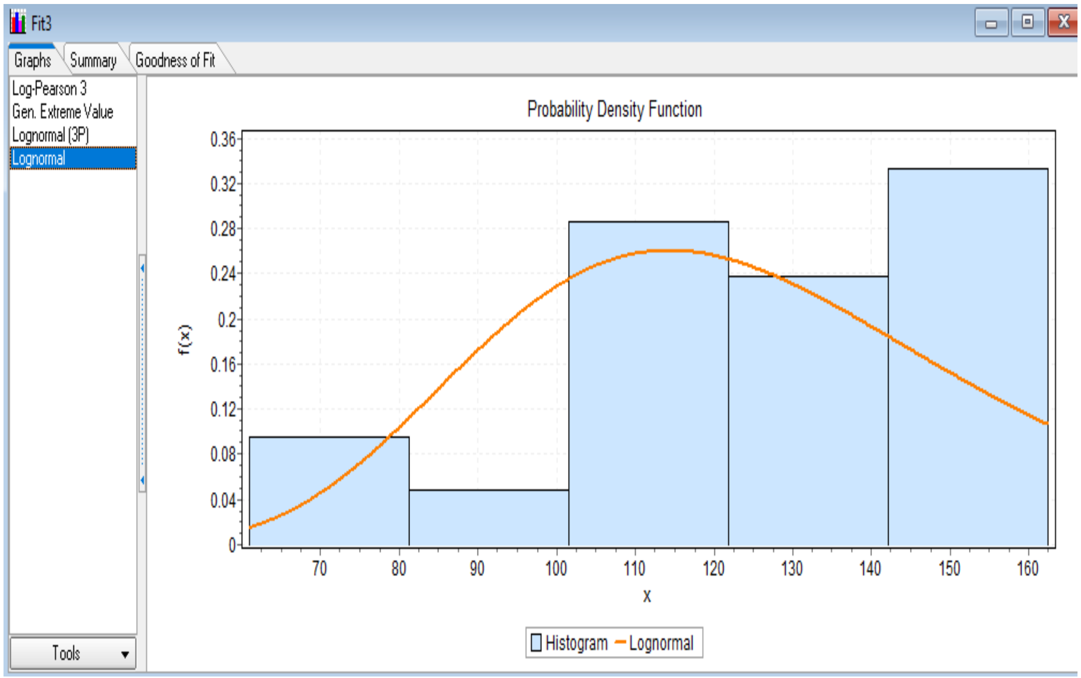


Figure D-1 Probability density Function for Log-Normal Distribution

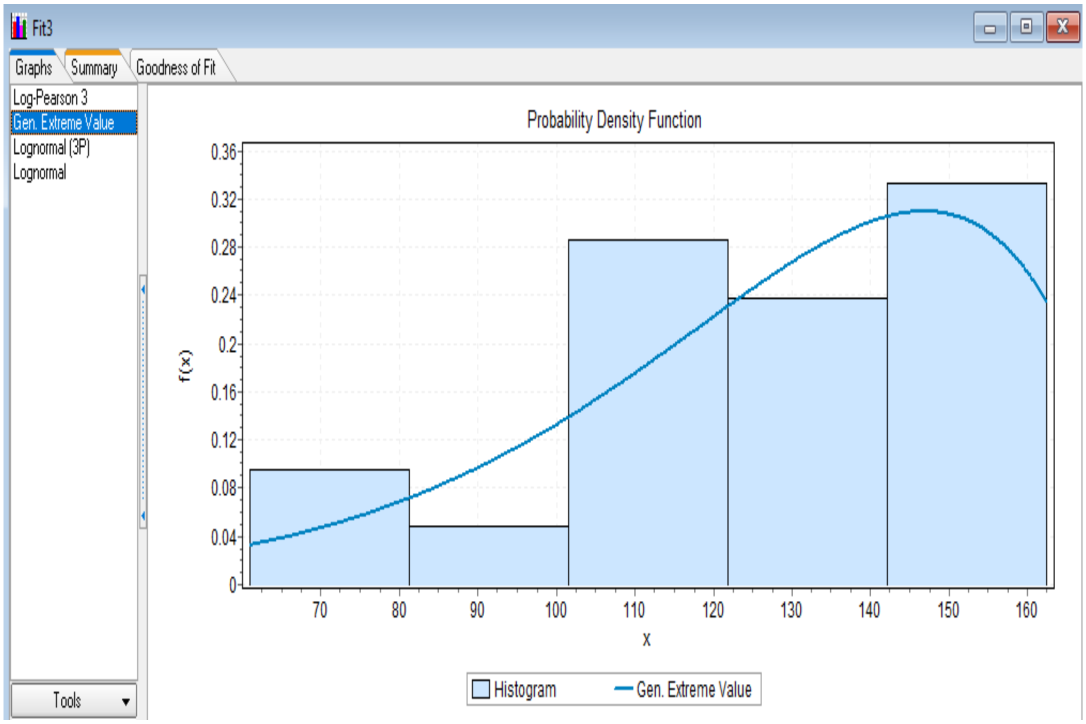


Figure D-2 Probability density Function for General Extreme Value-I Distribution

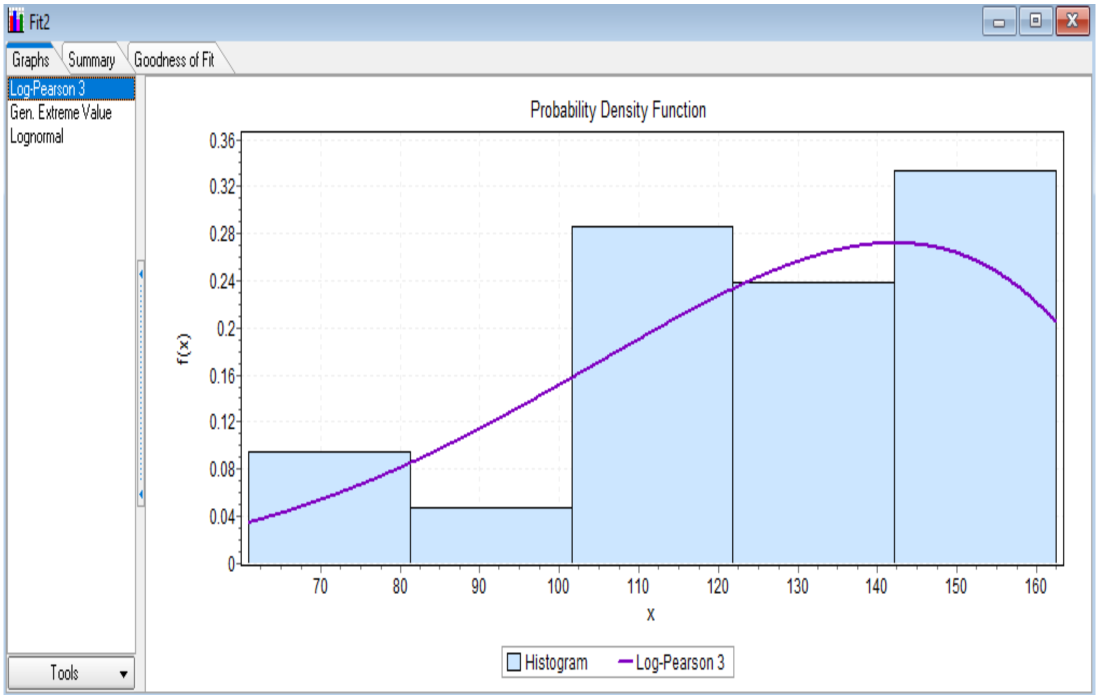


Figure D-3 Probability Density Function for Log-Pearson Distribution

Annexes E Catchment characteristics for each sub basin

Table E-1 Bilate watershed characteristics for each sub-basin

Component	Parameter	Units	Magnitudes(values)
Sub Basin-1	CN	Dimensionless	82
	S(Retention)	in(mm)	55.756
	Ia	Mm	11.151
	Im	%	0
	Area	Km²	715.28
	Lag time	Min	685
	Tc(time of concentration)	min	1141
	Watershed average slope	%	4.29
Sub Basin-2	CN	Dimensionless	81
	S(Retention)	in(mm)	59.58
	Ia	Mm	11.916
	Im	%	0
	Area	Km²	749.08
	Lag time	Min	437
	Tc(time of concentration)	min	728.33
	Watershed average slope	%	13.83
Sub Basin-3	CN	Dimensionless	81
	S(Retention)	in(mm)	59.58
	Ia	Mm	11.916
	Im	%	0
	Area	Km²	799.04
	Lag time	Min	670
	Tc(time of concentration)	min	1116.67
	Watershed average slope	%	20.91
Sub Basin-4	CN	Dimensionless	82
	S(Retention)	in(mm)	55.756
	Ia	Mm	11.157
	Im	%	0
	Area	Km²	468.71
	Lag time	Min	343
	Tc(time of concentration)	min	571.67
	Watershed average slope	%	36.02
Sub Basin-5	CN	Dimensionless	76
	S(Retention)	in(mm)	80.21
	Ia	Mm	16.042
	Im	%	0
	Area	Km²	1115.46
	Lag time	Min	495
	Tc(time of concentration)	min	825
	Watershed average slope	%	34.69

Sub Basin-6	CN	Dimensionless	84
	S(Retention)	in(mm)	48.38
	Ia	Mm	9.676
	Im	%	0
	Area	Km²	1191.37
	Lag time	Min	35
	Tc(time of concentration)	min	59
	Watershed average slope	%	49.73