JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE PROGRAME IN HYDRAULIC ENGINEERING

RAINFALL-RUNOFF MODELING USING HEC-HMS HYDROLOGIC MODEL FOR GUDER RIVER WATERSHED, BLUE NILE BASIN, ETHIOPIA

BY: ABDETA GELETO UTA

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES, JIMMA INSTITUTE OF TECHNOLOGY, HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

JANUARY, 2020
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MAIN ADVISOR: Dr.ing. TAMENE ADUGNA(PHD)

CO-ADVISOR: Mr. WANA GEYISA (MSC.)

JANUARY, 2020
JIMMA, ETHIOPIA

DECLARATION

I declare that this thesis work entitled: "(RAINFALL-RUNOFF MODELING USING HEC-HMS HYDROLOGIC MODEL FOR GUDER RIVER WATERSHRD, BLUE NILE, BASIN, ETHIOPIA)" is my original work and has not been presented for a degree in any other university or Which has not been accepted for award of any other academic degree of the university.

Abdeta Geleto	____________________	________________.
Name	Signature	Date

This thesis has been submitted for examination with my approval as university supervisor

Main Advisor: Dr. Ing. Temane Adugna(PhD)

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Co-Advisor : Mr. Wana Geyisa (MSc.)

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Signature	Date

APPROVAL SHEET

This thesis entitled by “RAINFALL-RUNOFF MODELING USING HEC-HMS HYDROLOGIC MODEL FOR GUDER RIVER WATERSHED, BLUE NILE, BASIN ETHIOPIA” Submitted by Abdeta Geleto Uta is approved and accepted as a partial fulfillment of the requirements for the degree of Master of Science in Hydraulic Engineering at Jimma University, Institute of Technology.

Main Advisor: Dr. Ing. Tamane Adugna(PhD)

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As a members of the Examining board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by Abdeta Geleto Uta. We recommend that the thesis has been accepted as a partial fulfillment of the requirements for the degree of Masters of science in hydraulic Engineering.

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ABSTRACT

Rainfall-Runoff modeling is important for a number of hydrologic applications including flood forecasting, water resource planning and management. This study presents the result of a watershed rainfall-runoff modeling for Guder river watershed having area of 6597Km^2 *using Hydrologic Engineering Center-Hydrologic Modeling Systems(HEC-HMS).The watershed runoff is varying spatially and temporally due to manmade factors and natural factors on the watershed. These issue needs efficient water resource planning and management which is based on the accurate information on runoff generated from the watershed. Therefore, the objective of this study was to model rainfall-runoff process of the Guder watershed using HEC-HMS hydrologic model. The input data used for this study were spatial data and hydro-metrological data collected from different sources. The watershed was delineated and its properties were extracted from a 30 m × 30 m Digital Elevation Model (DEM) of the Abbay Basin. The use of Hydrologic Engineering Center-Geospatial Hydrologic modeling System(HEC-GeoHMS) can easily and efficiently create hydrologic inputs that can be used directly for Hydrologic Engineering Center-Hydrologic Modeling Systems(HEC-HMS). To account for the loss, runoff estimation, base flow and flow routing, the Soil Conservation Service Curve Number (SCS-CN), Soil Conservation Service Unit Hydrograph (SCS-UH),Constant monthly varying and Muskingum methods were used respectively. The rainfall runoff simulation was conducted using initial parameter. The initial results showed that there is clear difference between observed and simulated peak flow and total volume. Thereafter, a model calibration with an optimization method and sensitivity analysis was carried out. The sensitivity analysis was conducted to determine the most sensitive parameters that affect the model. The results shows that the model was more sensitive to Muskingum (K) and(X).The data for the period of 1994 to 2003 was used for model calibration, and data from 2004 to 2009 was used for model validation. To check the performance of the model, Nash-Sutcliffe efficiency (NSE),coefficient of determination (*R^2*)and Root Mean Square Error(RMSE) statistical tools were used. The calibration and validation of the model was found good NSE,* R^2 *and RMSE were found to be 0.788,0.900 and13.7m*^{3}*/s for calibration and 0.786, 0.873 and15.5m*^{3}*/s for validation respectively. Therefore, HEC-HMS has performed well in simulating rainfall-runoff for Guder watershed. The daily runoff potential was generated after validation of the model. The daily runoff potential of Guder watershed was generated from 01Jan1987to31Dec2017. The daily maximum and minimum runoff potential of Guder watershed was 245.1m*^{3}*/s and 0m*^{3}*/s respectively. The hydrologic frequency 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 174.7m*^{3}*/s,351.9m*^{3}*/s,525.3m*^{3}*/s,685.3m*^{3}*/s and 879.8m*^{3}*/s respectively. These information will be useful as the input for flood mapping of the study area. The study recommends the land use land cover of the watershed may change from time to time due to different factors. Therefore, the future study should consider the effect of dynamic change in major categories of land use land cover on runoff.*

Keywords*: GIS, Guder, HEC-GeoHMS, HEC-HMS, Rainfall-Runoff modeling*

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CMS	Catchment Modeling System
CN	Curve Number
DEM	Digital Elevation Map
EMA	Ethiopia Mapping Agency
ERA	Ethiopian road authority
ESRI	Environmental System Research Institute
FAO	Food and Agricultural Organization
GIS	Geographical Information System
HEC-GeoHMS	Hydrologic Engineering Center - Geospatial Hydrologic Modeling System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling System
HSG	Hydrological Soil Group
IDF	Intensity duration frequency
Lu/Lc	Land use/land cover
MoWIE	Ministry of water, Irrigation and Electricity
NMSA	National Metrological Service Agency
NRCS	Natural Resource Conservation Service
NSE	Nash Sutcliffe efficiency
Pct	percent
R^2	Coefficient of determination
RMSE	Root mean square Error
SCS- CN	Soil conservation service - curve number
SMA	Soil moisture accounting
SRTM	Suttele Rader Topography Mission
UH	Unit Hydrograph
USACE	United State Army Corps of Engineers
USGS	United State Geological Survey
WMO	World Meteorological Organization

1 INTRODUCTION

1.1 Background

Water resources are essential renewable resources that are the basis for existence and development of a society. Proper utilization of these resources requires assessment and management of the quantity and quality of the water resources both temporally and spatially (Mohamed et al., 2018). Water crises caused by shortage, flood and diminishing water quality, among others, are increasing in all parts of the world. The growth of population demands for increased domestic water supply and at the same time, results with a higher consumption of water due to expansion in agriculture and industry. Mismanagement and lack of knowledge about existing water resource and the changing climatic condition have consequence of an imbalance of supply and demand of water (KUNDZEWICZ, 1997).

The most important objects of complex management of catchment water are numerous large multi user storages capturing the basin inflow for the purpose of water supply to urban areas or irrigation for agricultural areas, flood protection, recreation or generation of electricity. As fresh and clean water is becoming scarcer and water pollution by human being grows, a better distribution of demand coming from a growing number of water consumers is becoming imperative (Simic et al., 2009). According to Diviac *et al*. (2009) Shows that In order to create the highest possible power of the hydropower plants and achieve the best possible water management, it is necessary to know or to evaluate basin water circulation at daily, weekly, monthly or annual level.

The surface water, in the form of lake and river discharge (runoff) is predominately obtained from rainfall after being generated by the rainfall runoff processes. In order to make decisions for planning, design and control of water resource systems, long runoff series are required. The latter are not often available with reasonable length. On the other hand, for flood control and reservoir regulation, future flows shall be forecasted with rainfall-runoff models. A number of rainfall-runoff model exist for generation of flow forecasting and other purposes (Mohamed et al., 2018).

A rainfall-runoff model is a mathematical model describing the relation between rainfall and runoff a catchment area, drainage basin or watershed. More precisely, it produces the surface runoff hydrograph as a response to a rainfall hydrograph as an input. Establishing a Rainfall-runoff relationship is the central focus of hydrological modeling, from its simple form of unit hydrographs to rather complex models based on fully dynamic flow equations (Niravkumark et al., 2015).

Numerous methods have been developed by different researchers to simulate the rainfall runoff process. Although a variety of rainfall-runoff models are available, selection of a suitable rainfall runoff model for a given watershed is essential to ensure efficient planning and management of watershed. In order to estimate runoff from rainfall events, loss rate or infiltration parameters have to be calculated (Yener et al., 2012).

The hydrological modeling which is generally used as utility in various areas of water resource development in assessing the available resources, in studying the impact of human interference in an area such as land use change, deforestation and other hydraulic structure such as dams and reservoirs is very essential (Morada, 1999). Among hydrological modeling tools, rainfall-runoff models are becoming an increasingly indispensable tool in flood studies and operational flood forecasting for integrated catchment planning and flood emergency management (Tan et al., 2005).

The Upper Blue Nile (Abbay River Basin) is critically important to Ethiopia, in view of the combination of large population, huge development potential and massive natural resource. The large population growth in Ethiopia will increase the demand for natural resources, mainly water among each region. Ethiopia is also under great pressure on economic expansion, deforestation, urbanization (Fikru et al., 2018). Guder River watershed is the thematic area of this study, which is one of the major sub-basins of Abbay river basin in Ethiopia with a total catchment area of 6597 km^2. It has massive economic significance for the development of the country. Therefore, proper utilization of this resource requires assessment, integrated catchment planning and management which in turn demands development of rainfall-runoff relationship.

Now the target of this study is to undertake rainfall-runoff modeling by using HEC-HMS Hydrologic model to establish a relationship between the rainfall-runoff for selected Guder watershed.

1.2 Statement of the Problem

Water resources play a important role in the economic development of the developing countries with plentiful of water resources like Ethiopia. The region's explosive population growth and resulting new demand on limited water resource require efficient management of existing water resources and building new facilities to meet the challenge. For successful management and planning water resources, a thorough understanding of the hydrological processes of the basin is crucial (Shimelis, 2017).

Abbay basin is one of the largest basin in Ethiopia which covers an area of 199,000km^2 has a large volume of water resource and a source of life for several peoples living in the basin. The rapidly increasing population, deforestation, over cultivation, overgrazing, and unpredicted flood events are the major problem in the basin. It has been seriously affected by land degradation and flood problems (Merrey & Gebreselassie, 2011). The Guder river watershed is one of the sub-basin of this basin which is faced by land degradation to promote losses of soil fertility in most of watersheds due to runoff (Nadew et al., 2018). This happens because of lack of effective land and water resource management practices. This land degradation also affects basin hydrology and water resources availability in the watershed. Modeling the hydrology of watersheds is required for effective water resource management strategy. Watershed runoff must be predicted to carry out any water & land resource management activities in the same. Because it is very rare case that the records of historical flow, stage or precipitation satisfies the information needed, in addition the study of the hydrologic dynamics of climate change and land use change requires the use of hydrological modeling.

Rainfall-runoff models are useful tools where data are scarce and resources are under development. It is possible to generate runoff discharges from rainfall and other meteorological data where river flow data is not available (Beven, 2012). Hence Rainfall-runoff modeling is essential for effective rainwater management strategy in watershed.

This study is using the Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model to understand the Rainfall- Runoff process of Guder river watershed so as to plan, design, manage rainfall and runoff properly.

1.3 Objective

1.3.1 General objectives

The general objective of this study is to model the Rainfall-Runoff process for Guder river watershed by using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model.

1.3.2 Specific objectives

1. To evaluate the performance of HEC-HMS model in runoff simulation of Guder watershed.
2. To estimate the runoff potential of Guder Watershed.
3. To estimate peak discharge for different return period using HEC-HMS.

1.4 Research Questions

1. What is the performance of HEC-HMS model in Runoff simulation of Guder watershed?
2. How much is the runoff potential of Guder watershed?
3. What is the peak discharge for different return period?

1.5 Significance of the study

The main reason for the modeling of rainfall-runoff process of hydrology is a result of the limitation of the hydrological measurement techniques. Understanding the dominant characteristics of watershed is essential indicator for resource base analysis and development of effective and appropriate response strategies for watershed management of the country in general and at the study area in particular. This study will provide a good input at times of planning for future watershed management strategies aimed at foreseeing their future development and impacts.

Proper water resource planning, management and protection under changing conditions requires the use of rainfall-runoff models that can simulates flow regimes under different scenarios and seasons. The evaluation of HEC-HMS model performance is used for future stream flow forecasting under climatic change by the model.

1.6 Scope of the study

The study was covered rainfall-runoff modeling for Guder river watershed by using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) model. The main objective of this is to model rainfall- runoff process of Guder river watershed. Under this determination of rainfall-Runoff relationships, CN grid generation, daily runoff potential estimation, HEC-HMS model performance evaluation, HEC-HMS modeling by frequency storm, comparison of HEC-HMS output with flood distribution methods, identification of the volume and discharge of the catchment were performed to achieve the main objective.

1.7 Thesis Organization

The thesis is organized in Five chapters: Chapter 1 provides brief introduction about rainfall-runoff relationships, about the problem that initialize this study, the objective of the study, the research questions, Significance of the study, scope of the study.

Chapter Two describes the reviewed literature related to the study on the concept of Hydrological processes, System approach in catchment modeling, Hydrological models, Rainfall-Runoff modeling, SCS-curve number methods, Hydrological soil group of Ethiopia, Geographical information system and runoff modeling, Model selection criteria HEC-Geo HMS, HEC-HMS model, flood frequency analysis and rainfall intensity.

Chapter three Describes materials and methodology under this chapter the following topics are discussed:- brief description of the study area, Material and tools used in this study, Flow chart of the thesis work, data collection and Analysis, Input data preparation for HEC-HMS model, Curve number grid input preparation, HEC-HMS model setup, Sensitivity analysis, model calibration and validation and model performance evaluation. Modeling by frequency storm, Best fit flood probability distribution.

Chapter four Results and discussions the main parts of the research study:- terrain processing results, Curve number grid generation, HEC-HMS project generation, model simulations, model calibration, validation result, daily estimation of runoff potential, output of HEC-HMS by using frequency storm and Comparison of HEC-HMS result with selected flood frequency distribution methods.

Finally, in Chapter five presents conclusion and recommendations based on the results of the models. In addition to this References and Annexes are attached at the end.

2 LITERATURE REVIEW

2.1 Hydrological Process

Hydrologic process can be defined as the natural system in which water moves between land, atmosphere and the ocean cyclically. These cycles and the consequences of which now threaten the living existence of the hydrologic process of any typical watershed. Hydrologic cycle is composed of several natural processes which have interactions and they can be represented or simplified using a mathematical model (National Research Council, 1991). The following are the main components of hydrological cycle that have relation with runoff generation are: -precipitation, interception, infiltration, evaporation, transpiration and runoff. The runoff comprises all the surface and shallow subsurface water flows caused by precipitation events. The surface runoff always occurs if more water is applied to the soil than it can absorb by infiltration.

Overland flow can be grouped into three different classes, being distinguished by three physical processes (Morgan, 2005) as cited in (Junker, 2012).The first type is the Hortonian overland flow (named after scientist Robert E. Horton, who made the first detailed studies of this type of runoff), which occurs if the rainfall intensity is higher than the soil infiltration rate. This phenomenon often occurs during heavy rain storms.

The second type of surface runoff occurs if the soil is saturated and as a consequence further uptake of water by soil is not possible. Soil saturation is the result of periods with much rain. After the soil reaches a saturated state, following rainfall events cause runoff. Furthermore, soil properties (depth, particle distribution, texture) have effects on the absolute water storage capacity of the soil. Basically sandy soils usually have a lower storage capacity where up on the soil depth always plays an important role. Logically the absolute capacity decreases due to less soil depth and consequently runoff occurs more often on shallow soils (Morgan, 2005).

The third type of runoff is caused by deposition of silt-sized particles transported by the Hortonian overland flow. These particles can form an impermeable crust that reduces the infiltration rate of the soil dramatically. Subsequent rainfall events then cause surface runoff. Stream flow includes not only overland runoff, but also subsurface runoff. In hydrology stream flow is generated by the three component's surface flow, interflow and groundwater flow. The three components can also be distinguished regarding their time of response to the precipitation events. In this case they are separated into two classes, the fast reacting flows (surface flow, fast interflow and rain directly falling into flowing water) and the slow reacting flows or so called base flows (groundwater flow or slow interflow). Applied to river discharge this means that only during rainfall events and short periods of time right after the events runoff contributes to discharge. In the days after the event the precipitation water actually still contributes to river discharge, but not as direct surface or subsurface flow (runoff) instead as slow interflow. This leads to the need of separating river discharge into base flow and runoff (Morgan, 2005).

2.1.1 Runoff

Runoff means the draining or flowing of precipitation from a catchment area through a surface channel. It represents the output from the catchment in a given unit of time. Consider a catchment area receiving precipitation. For a given precipitation, the evapotranspration, initial loss, infiltration and detention storage requirements will have to be first satisfied before the commencement of runoff. when these are satisfied, the excess precipitation moves over the land surfaces to reach the surface to reach smaller channels. this portion of surface runoff is called overland flow and involves building up of a storage over the surface and draining of the same. Usually the length and depth of over land flow are small and the flow is in the laminar regime. Flows from several small channels joins bigger channels and flow from these in turn combine to form larger stream, and so on till the flow reaches the catchment outlet. The flow in this mode, where it travels all the time over the surface as over land flow and through the channels as open channel flow and reaches the catchment outlet is called surface runoff (Suramanya, 2008).

A part of the precipitation that infiltrates moves laterally through upper crusts of the soil and turns to the surface at some location away from the point of entry into the soil. This component of runoff is known variously as inter flow, through flow, storm seepage, subsurface storm flow or quick return flow. Figure 2.1 shows the different routs of runoff.

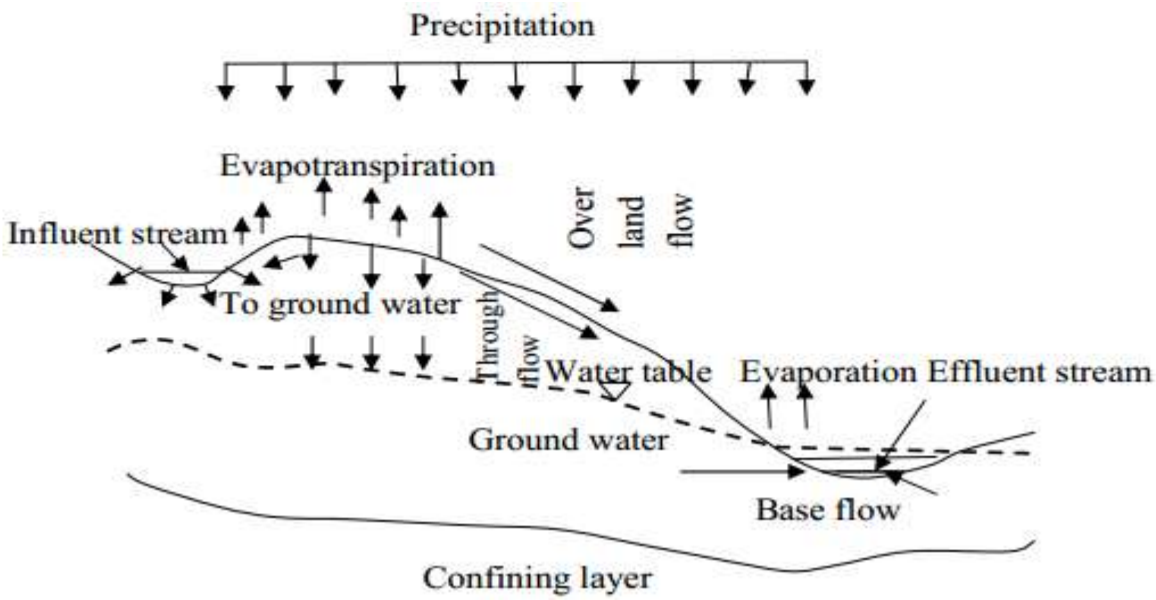


Figure 2. 1 : Different routs of runoff (source: Suramanya, 2008).

2.2 System Approach in Catchment Modeling

The in depth processes that link the rainfall over the catchment to the stream flow may be studied by applying physical laws that are reasonably well known. However hydrological phenomena are extremely complex, and may never be fully understood. 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. The sub division depends on catchment characteristics (soil type, land use, slope, vegetation cover, etc.) and these factors may also vary in space and time. Thus, representing the hydrological processes in simplified way by means of system concepts is very crucial (Chow et al., 1988). For these reasons, instead of exact representation of the processes effort is directed to the construction of a model by using system concepts relating input and outputs. Hydrologic system analysis is therefore, required to study the system operation and to predict its output.

A hydrologic system is defined as a structure or volume in a space, surrounded by a boundary that accepts water and other inputs, operates on them internally, and produces them as outputs (Chow et al., 1988). Schematic representation of the system operation is shown in

Figure 2.2. Where the symbol Ω represents a transformation between the input and the output.

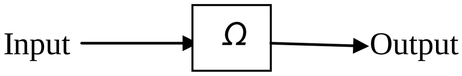


Figure 2. 2 : Diagrammatic representation of a hydrological system

The objective of the hydrologic system analysis is to study the system operation and to predict its output. A hydrological system model is an approximation of the actual system. Its input and output are measurable hydrological variables and its structure is the concept of the system transformation.

2.3 Hydrological Modeling

Models are representations of systems or processes. Some models are actually a miniature physical representation of natural systems. Sometimes, series of equations are used to represent the systems, thus forming mathematical models. The number, form, and interconnections of these equations in a model can range from very simple to highly sophisticated. The equations within the mathematical models can be produced from basic physical laws or from statistical analysis of observed data (empirical equations) (Butcher, 2008).

Watershed models simulate natural processes of the flow of water, sediment, chemicals, nutrients, and microbial organisms within watersheds, as well as quantify the impact of human activities on these processes (Butcher, 2008). These models play an important role in predicting water quantity and water quality, two key elements in watershed resources study. Researchers and engineers use model predictions to make decisions on engineering projects such as flood control, wetland restoration, and dam operation (Mishra, 2008). On the basis of process description the hydro into models can be classified into three main categories (Cunderlik, 2003) as cited in (Geremewu, 2013).

i) Lumped models: Parameters of lumped hydrologic models do not vary spatially within the basin and thus, basin response is evaluated only at the outlet, without explicitly accounting for the response of individual sub-basins. The parameters often do not represent physical features of hydrologic processes and usually involve a certain degree of empiricism. These models are not usually applicable to the 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.

ii) Distributed models: 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 variables together with computational algorithms to evaluate the influence of this distribution of 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 (Howard, 2008).

iii) 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. 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 (Geremewu, 2013).

Hydrologic models can be further divided into event-driven models, continuous-process models, or models capable of simulating both short-term and continuous events (Tamu, 2010). Event-driven models are designed to simulate individual precipitation-runoff events. Their emphasis is placed on infiltration and surface runoff. Typically, event models have no provision for moisture recovery between storm events and, therefore, are not suited for the simulation of dry-weather flows. On the other hand, continuous-process models simulate instead a longer period, predicting watershed response both during and between precipitation events. They are suited for simulation of daily, monthly or seasonal stream flow, usually for long-term runoff-volume forecasting and for estimates of water yield. Generally for this study, semi-distributed models are selected because of their structure is more physically-based than the structure of lumped model, and they are less demanding on input data than fully distributed models (Geremewu, 2013). According to parameter features and main functions, current hydrologic modeling environments are classified as Distributed models, Lumped and Parametric Models, Environmental Models, Monthly Water Balance Model and Real Time Flow Forecasting Models (Tamu, 2010).

2.4 Rainfall-Runoff modeling

Rainfall is known as the main contributor to the generation of surface runoff. Therefore there is significant and unique relationship between rainfall and surface runoff. Rainfall-Runoff modeling is an important in the study of water resources and watershed management. Rainfall-runoff models are mainly used for river flow forecasting for the management of water resources and to reduce the ill effects through early warning measures. Understanding the basic relationship between the rainfall over the catchment and the resulting runoff is important to know water resource potential and proper management of water resources in the catchment (Niravkumark et al., 2015).

A model used in water resource management should be sufficiently accurate to be used for the intended purpose. The existence of observation determines the validity of the model. The model prediction is compared with field measurement to evaluate its performance without any adjustment to model parameters (Oliveira et al., 2019). This process is known as model validation or verification.

Flood modeling is the processes of transformation of rainfall into a flood hydrograph and to the translation of that hydrograph throughout a watershed or any other hydrologic system. In this manner, the flooding processes, which consist of upstream watershed hydrological processes and river and floodplain hydraulic processes and approximated either physically or mathematically (through the use mathematical equations) where the relationships between system state, input and output are represented (Ramirez, 2000).

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. The following are some of the rainfall-runoff models (Asadi, 2013). Rational method, SCS method, unit hydrograph method, analysis of stream gage data, suitable computer programs and hydrologic modeling (HEC-HMS).

2.4.1 SCS Curve Number (CN) Method

One of empirical methods that is widely and global used by hydrologists, water project planners and water engineering, is the curve numbers method that has been suggested and supported by the department of agriculture natural resources conservation service of USA. Some applications of GIS are mapping curve number (CN) of catchment by using the digital data analysis, vegetation cover; land using and hydrologic soil groups (Abouzar & Hamid, 2014). This method is a versatile and widely used approach for quick runoff estimation and also relatively easy to use with minimum data and give adequate results (Gupta & Panigrahya, 2008).

The Curve Number (CN) is an index developed soil conservation service(SCS) now called the Natural Resource Conservation service(NRCS), is used to determine the amount of rainfall that infiltrate in to the soil and direct runoff from storm rain fall.

The major factors that determine CN are the hydrologic soil group (HSG) cover type, treatment, hydrologic condition, antecedent runoff condition, and impervious areas. On the other hand, Infiltration rates of soils vary widely and are affected by subsurface permeability as well as Surface intake rates. Soils are classified into four HSG's (A, B, C, and D according to their Minimum infiltration rate (TR-55, 1986).

According to the USDA Natural Resources Conservation service of national Engineering Handbook the four hydrologic soil groups(HSGs) are described as:

Group A: Soils in this group have low runoff potential when thoroughly wet. water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel. Some soils having loamy sand, sandy loam or silt loam texture may be placed in this group if they are well aggregated, of low bulk density or contain greater than 35 percent of rock fragments.

Group B: Soils in this groups have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt or sandy clay loam texture may be placed in this group if they are well aggregated, of low bulk density, contain greater than 35 percent of rock fragments.

Group C: Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soil typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sand clay loam, clay loam and silt clay loam textures. Some soils having clay, silt clay, or sand clay texture may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group D:Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. in some areas, they are also have high shrink-swell potential.

With regard to Hydrological Soil Group (HSG) of Ethiopia most of the hydrological studies in the country used the FAO soil database. Based on FAO, HSG classification in Ethiopia has HSG-A dominates with 48.2% areal coverage followed by HSG- B(30%) and HSG-D with a real coverage of 21.6% and the remaining area is covered by HSG - C (Belete et al., 2012).

2.5 Geographical information system (GIS) and Run of modeling

Geographical information system (GIS) technology was developed by Environmental systems Research institute, Inc. (Esri) established in1969. Esri developers began formulating the concepts that ultimately lead to the release in 1982 of ARC/INFO, the first commercial GIS. From this, the first ARC software other multiple versions have been developed up to the ArcGIS 10 used today (WalterMcDonald, 2010).

The use of geographical information system (GIS) to facilitate the estimation Run off from watershed have gained increasing attention in recent years. This is mainly due to the fact that Rainfall-runoff models include both spatial and geomorphologic variation (Jeongwoo Han, 2010).

Run off modeling needs integration of GIS and remote sensing (RS) and has two processes: (1) Hydrological parameter determination using GIS, and (2) hydrological modeling within GIS hydrological parameter determination using GIS entails preparing land cover, soil, and precipitation data that go into the SCS model, while hydrological modeling within GIS automates the SCS modeling processes using generic GIS functions. Remote sensing is used for obtaining land cover data each year and for obtaining information about the nature, rate, and location of land use and land covers changes (QihaoWeng, 2001).

2.6 Model selection

Selecting the best and appropriate model is an essential part in any research work. Currently there are numerous hydrological models simulating the hydrological process at different spatial and temporal scales. There are various criteria which can be used for choosing the right hydrological model for a specific problems. This criteria are always project dependent, since every project has its own specific requirements and needs. Further, same criteria are also uesr-depended(and therefore subjective). According to (Cunderlik, 2003) the choice depends mainly on the requirement and needs of the research or project under interest. Cunderlik put the following as criteria: - Required the model outputs important to the project, availability of input data, hydrologic processes that need to be modeled to estimate the desired out puts adequately, Prices and availability of the model.

The semi-distributed HEC-HMS model was selected depend up on the above criteria to model Rainfall-Runoff relationships of the Guder watershed. HEC-HMS is designed to simulate the rainfall-runoff process of dendritic watershed systems. It is designed to be applicable in wide range of geographical areas for solving widest possible range of the problems. This includes large river basin water supply, flood hydrology and natural watershed runoff.

2.7 HEC-Geo HMS

The hydrologic Engineering centers Geospatial hydrologic modeling Extension, HEC-Geo HMS, is a public domain extension to ESRI'S Arc GIS software and the spatial analyst extension. It is hydrology toolkit for engineers and hydrologists. The user can visualize information, document watershed characteristics, perform spatial analysis, and delineate sub basins and streams, construct inputs hydrologic models, and assist with report preparation. Eight data sets can be derived from DEM that collectively describe the drainage patterns of the watershed (Davis, 2009).

HEC-Geo HMS provides the connection for translating GIS spatial information into hydrologic models. The end result of the GIS processing is a spatial hydrology database that consists of the digital elevation model (DEM), soil types, land use information, rainfall, etc. HEC-Geo HMS operates on the DEM to derive sub-basin delineation and to prepare a number of hydrologic inputs. 30m*30m resolutions DEM were used for this study. HEC-HMS accepts the hydrologic inputs as a starting point for hydrologic modeling (Asadi, 2013).The relation between GIS, HEC-Geo HMS, and HEC-HMS is illustrated in Figure 2.3.

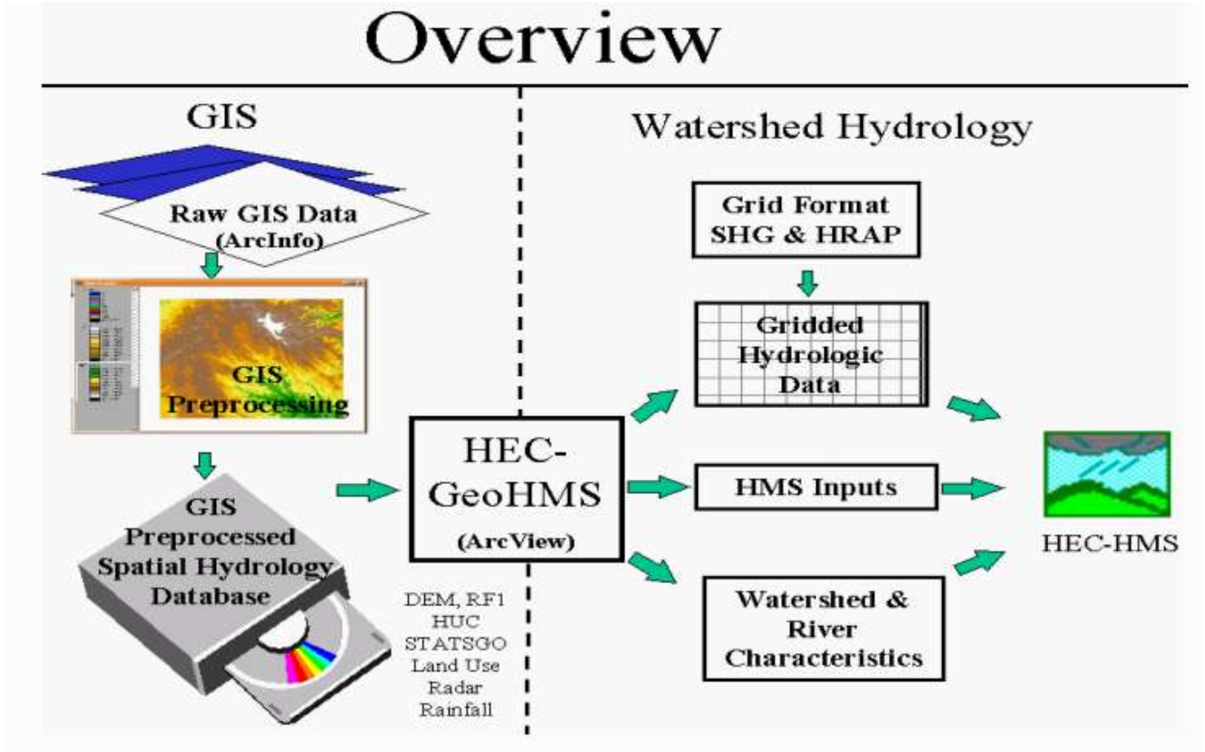


Figure 2. 3 : Overview of GIS, HEC-Geo HMS and HEC-HMS interrelation(source: davis,2009).

The following procedures describe the major steps in starting a project research and taking it through the arc hydro and Geo HMS development of a hydrologic model using DEM. These are: - Terrain Model Pre-Processing, Hydrologic Processing, Hydrologic Parameters and HEC-HMS.

2.8 HEC-HMS Model

HEC-HMS/Hydrologic Engineering center hydrologic modeling system is designed to simulate the precipitation -runoff process and developed by the hydrologic engineering center under the U.S. army Corps of Engineers. It is designed to be applicable in a wide range of problems. This includes large river basin water supply and flood hydrology to small urban or natural watershed runoff. Hydrographs produced by the program can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology, and systems operation (David Ford, 2008).

For runoff simulation HEC-HMS model has three major parts these are infiltration loss simulation, converting excess rainfall to run off and channel flow routing.

Infiltration loss simulation of HEC- HMS uses initial and constant rate, SCS-CN, Gridded SCS-CN, green and Ampt, deficit and constant rate, soil moisture accounting (SMA) and gridded SMA.

Converting excess rainfall to runoff model or modeling runoff hydrograph of HEC-HMS model uses seven methods these are: user specified unit hydrograph (UH), Clark' s UH, synder's UN, SCS-UH, Mod Clark, kinematic wave and S-graph.

The third part is modeling one dimensional open channel flow routing and HEC-HMS model uses standard methods such as kinematic wave, lag time, modified Puls, Muskingum, Muskingum Cunge (HEC-HMS, 2013).

Model components are used to simulate the hydrologic response in watershed. The primary model components are:- basin models, meteorological models and control specifications. There are also input data components. A simulation calculates the precipitation-runoff response in the basin model given input from the Metrologic model. The control specifications define the time period and time step of simulation run. Input data components, such as time-series data, paired data and gridded data are often required as parameter or boundary conditions in basin and Metrologic models (David Ford, 2008).

2.9 Limitations of HEC-HMS Model

Every simulation system has limitations due to the choices made in the design and development of the software (Scharffenberg & Fleming, 2010). 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.

2.9.1 Model Formulation

All of the mathematical models included in the program are deterministic. This means that the boundary conditions, initial conditions, and parameters of the models are assumed to be exactly known. This guarantees that every time a simulation is computed, it will yield exactly the same results as all previous times it was computed. During long periods of time, it is possible for parameters describing a watershed to change as the result of human or other processes at work in the watershed. There is a limited capability to break a long simulation into smaller segments and manually change parameters between segments (Bill et al., 2018).

All of the mathematical models included in the program are uncoupled. The program first computes evapo-transpiration and then computes infiltration. In the physical world, the amount of evapo-transpiration depends on the amount of soil water. The amount of infiltration also depends on the amount of soil water. However, evapo-transpiration removes water from the soil at the same time infiltration adds water to the soil. To solve the problem properly, the evapo-transpiration and infiltration processes must be simulated simultaneously with the mathematical equations for both processes numerically (Bill et al., 2018).

This program does not currently included such coupling of the process models. Errors due to the use of uncoupled models are minimized as much as possible by using a small time interval for calculations (Scharffenberg & Fleming, 2010). According to USACE(2010) preparation have been made to support the inclusive of couple plant-surface-soil models; none have been added at this software.

2.9.2 Flow Representation

The design of the basin model only allows for dendritic stream networks. The best way to visualize a dendritic network is to imagine a tree. The main tree trunk, branches and twigs correspond to the Main River, tributaries, and headwater streams in a watershed. The key idea is that a stream does not separate into two streams. The basin model allows each hydrologic element to have only one downstream connection. Hence, So it is not possible to split the outflow from an element into two different downstream elements. The diversion element provides a limited capability to remove some of the flow from a stream and divert it to a different location downstream in the network. Likewise, a reservoir element may have an auxiliary outlet. However, in general, branching or looping stream networks cannot be simulated with the program and will require a separate hydraulic model which can represent such networks (Bill et al., 2018).

The design of the process for computing a simulation does not allow for backwater in the stream network. The computer process begins at headwater sub-basins and proceeds down through the network. Each element is computed for the entire simulation time window before proceeding to the next element. There is no iteration or looping between elements. Therefore, it is not possible for an upstream element to have knowledge of downstream flow conditions which is the essence of backwater effects. There is a limited capability to represent backwater if it is contained within a reach element. However, in general, the presence of backwater within the stream network will require a separate hydraulic model (Bill et al., 2018).

2.10 Flood frequency analysis

Flood frequency studies relate the magnitude of discharge, stage, or volume to the probability of occurrence or exceedance. The resulting flood-frequency functions provide information required for:- Evaluating the economic benefits of flood-damage reduction projects, Sizing and designing water-control measures if a target exceedance level or reliability is specified, Establishing reservoir operation criteria and reporting performance success and Developing requirements for regulating local land use (David Ford, 2008).

Flood frequency analysis is a technique used by hydrologists to predict flow values corresponding to specific return periods or probabilities along a river. Flood frequency plays a vital role in providing estimates of recurrence of floods which is used in designing structures such as dams, bridges, culverts, levees, highways, sewage disposal plants, waterworks and industrial buildings (Chow et al., 1988). Knowledge of the magnitude and probable frequency of recurrence of floods is necessary for the proper design and location of structures.

In order to understand how flood frequency analysis works, it is essential to understand the concept of return period. The theoretical definition of return period is the inverse of the probability that an event will be exceeded in a given year. In general, return period, which is also referred as recurrence interval, provides an estimate of the likelihood of any event in one year. These events include natural disasters such as floods or earthquakes (Rakhecha & Singh, 2009). Return periods are used to convey the risks of rate events more effectively that simply stating the probabilities.

The flood frequency curve is used to relate flood discharge values to return periods to provide an estimate of the intensity of a flood event. The discharges are plotted against return periods using either a linear or a logarithmic scale. In order to provide an estimate of return period for a given discharge or vice versa, the observed data is fitted with a theoretical distribution using a cumulative density function (CDF). This helps the users in analyzing the flood frequency curve (SiddherthSakesena, 2017).

Probability distribution fitting is judging a suitable probability distribution to a given dataset. In flood frequency analysis accurate estimation of maximum flood are obtained by fitting probability distribution for specified return period (Vivekanandan, 2015). Objective is to predict the frequency occurrence of the magnitude of phenomena in a certain interval. This can lead to a good prediction of flood.

Selecting the best statistical distribution is the most important factor in frequency analysis. Therefore, different distribution must use and then, the most appropriate distribution of data should be selected (Amirataee et al., 2014). In flood frequency analysis, an assumed probability distribution is fitted to the available data to estimate the flood magnitude for a specified return period.

2.10.1 Rainfall intensity

The rainfall intensity(I) is the average rainfall rate in mm/hr for duration equal to the time of concentration for related return period. once a particular return period has been selected for design and a time of concentration calculated for the catchment area, the rainfall intensity can be determined from rainfall-intensity-duration curves. For drainage area in Ethiopia, rainfall intensity at any required time can be compute using 24 hr rainfall depth, which is known as a rainfall intensity- duration-frequency(IDF) relationship (ERA, 2013). IDF curve presents the probability of a given rainfall intensity and duration expected to occur at a particular location((Mirhosseini et al., 2012).

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location

Guder sub-basin which has a drainage area of 6597square kilometers is situated in the Northwest of Ethiopia; in the Southeastern part of the Blue Nile Basin approximately between 7°30' to 9º30' N latitude and 37º10' to 38º40'E longitude. The Guder River originates from the mountainous area of south of the towns of Ambo and Guder at an elevation of 3000 masl. The river flows from the south to the north and has its outlet to the Abbay River basin. The Guder sub-basin borders with the Muger sub-basin to the east, the Awash Basin to the south and the Fincha sub-Basin to the west. The tributaries of the Guder include Huluka, Indiris, Bello, Melke, Tinishu Duber Tiliku Duber and Feto.

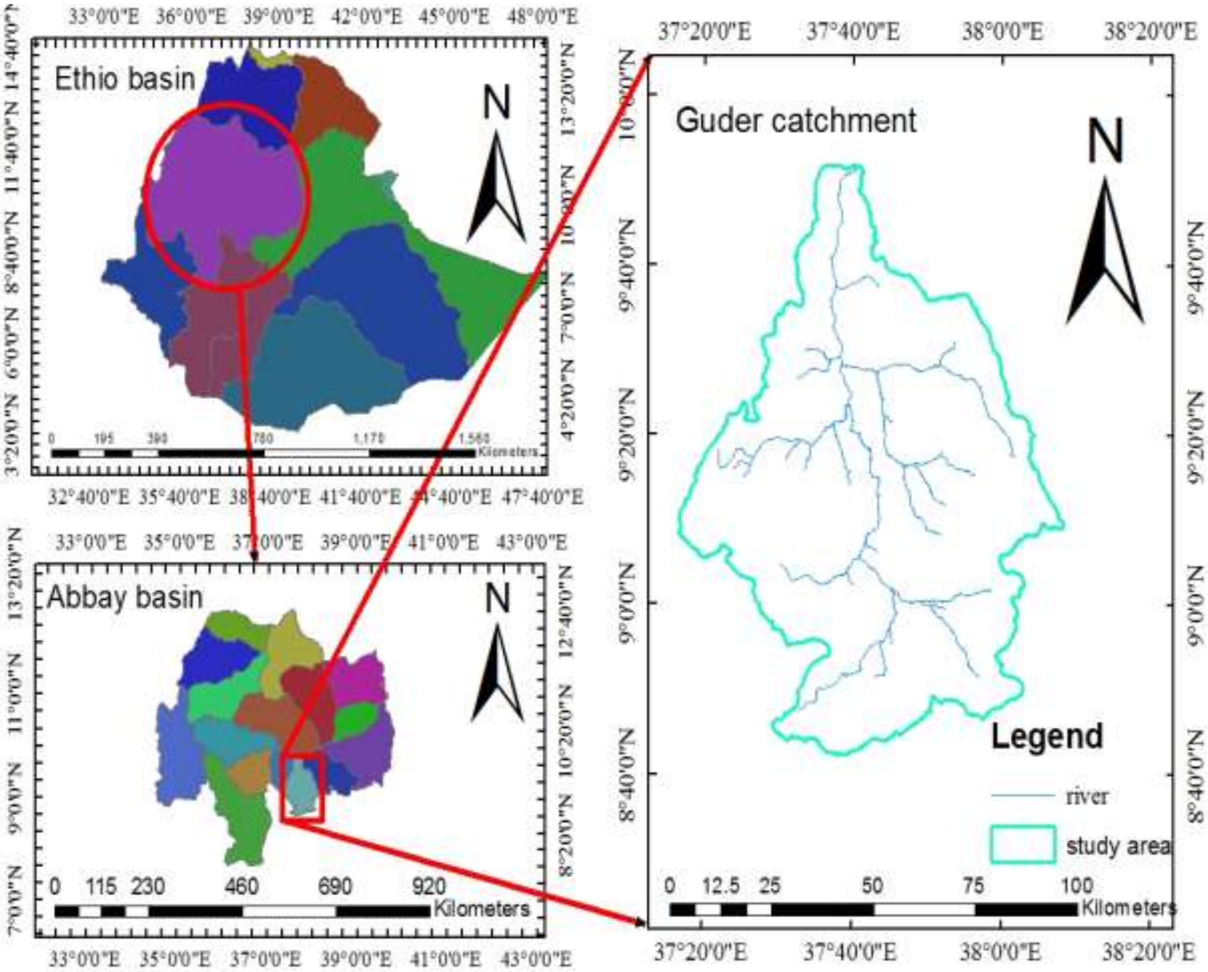


Figure 3. 1: Location of Guder watershed.

3.1.2 Climate

Guder sub-basin, in spite of being near the equator, has a comparatively mild climate because of its high elevation (1500-3000masl). The annual climate may be divided in a rainy and dry season. The rainy season may be divided in to a major rainy season (Kiremt) and minor rainy seasons (Belg & Tsedey). During Kiremt season from June through August high rainfall occurs and in Belg season from March to May small rainfall occur. The dry seasons (Bega) occurs in December to February and Tsedey covers from September through November. The mean annual temperature of the Guder watershed ranges between 7°C and 29°C. Long term mean annual rainfall of Guder sub-basin at different station is shown in figure below.

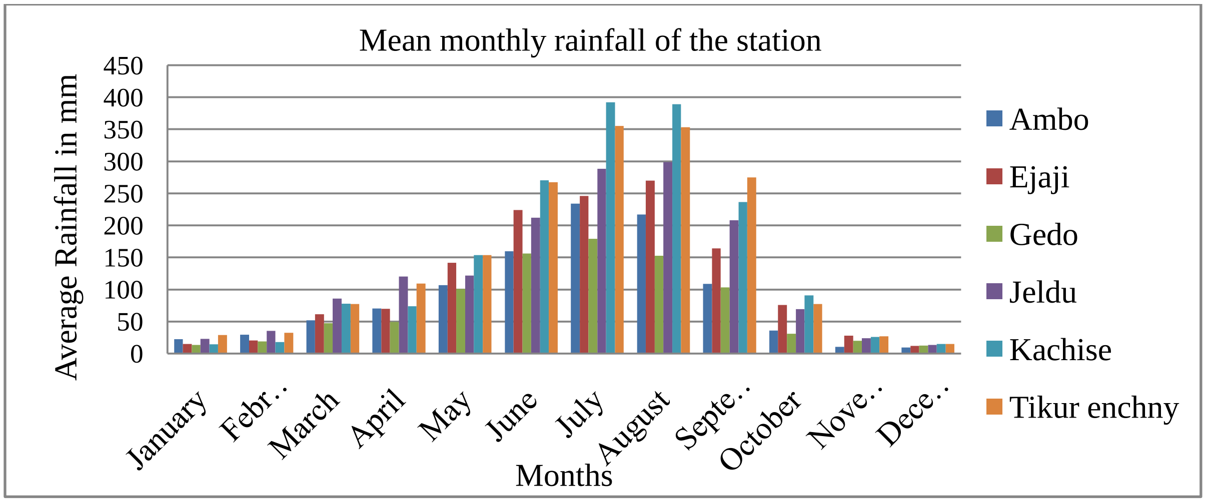


Figure 3. 2: Average monthly rainfall of the station

3.1.3 Land Cover and Land Use

The terms land use and land covers are often used interchangeably even though the distinction between the two is important. The land use refers to the actual economic activity for which the land is used whereas land cover refers to the cover of the earth's surface. Land use can be seen as the ultimate expression of everything else that is going on the basin. The land use of the study area can be categorized mainly as agricultural, forest, bare-land, dense forest, sparse forest, water bodies. The information contained in the land use map tells how the different uses of the surface are distributed inside the area under study.

The farming system in the watershed is mixed with dominantly oxen plough cereal crop production and livestock rearing, which is centuries old system. Accordingly, the major land use types in the watershed include cultivated, grazing, very spares and patches of shrub/bushes, plantations and miscellaneous lands. Figure 3.3 shows the land use land cover of the Guder watershed.

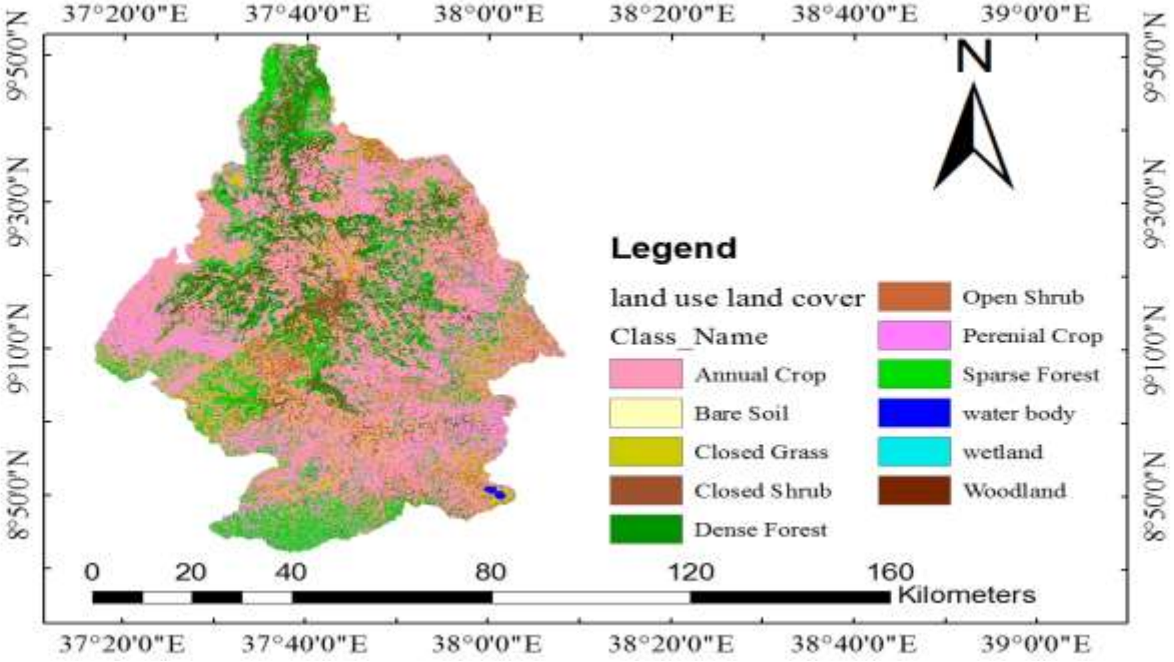


Figure 3. 3: Land use land cover of Guder Watershed

3.1.4 Soil

The Guder basin is mainly formed from clay and clay-loam soil type, but the riverbed has a loam and sandy-loam type of soil. The infiltration capacity of the soil depends among others, on the porosity of the soil, which determines its storage capacity and affects the resistance of the water to flow into deep layers. Since the soil infiltration capacity depends on the soil texture, the highest infiltration rates are observed in sandy soil. This shows that, surface runoff is higher in heavy clay and loamy which has low infiltration rate.

The major soil types in the study area includes: - Chromic Luvisols, Eutric Cambisols, Eutric Fluvisols, Eutric Leptosols, Eutric Regosols, Eeutric Vertisols, Haplic Luvisols, Haplic Alisols, Haplic Nitisols, Haplic Arenosols and Rendzic Leptosols. Figure 3.4 shows the major soil types of Guder watershed

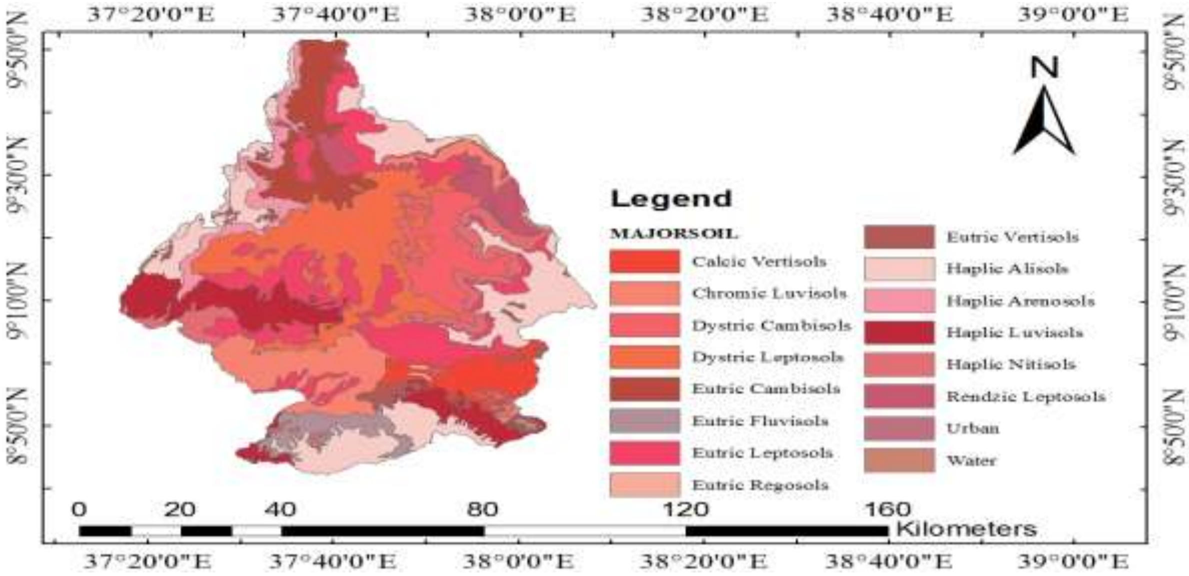


Figure 3. 4: soil type of Guder watershed

Table 3. 1: Major soil of Guder watershed

Major soils	Area coverage in Km^2	Area in percent(%)
Calcic Vertisols	300.58	4.71
Chromic luvisols	551.04	8.63
Drystric cambisoils	408.3	6.39
Drystric Leptosols	982.94	15.4
Eutric cambisols	429.4	6.72
Eutric Fluvisols	177.69	2.78
Eutric leptosols	1098.1	17.19
Eutric regsols	8.289	0.13
Eutric Vertsols	113.596	1.78
Haplic Alisols	1137.47	17.8
Haplic Arenosols	223.57	3.5
Haplic Luvisols	597.25	9.35
Haplic Nitisols	360.075	5.64
Rendzic Leptosols	193.45	3.03

3.2 Materials used

The materials(tools) indispensably used in conducting of this study were the following:- ArcGIS10.1, Arc hydro, HEC-GeoHMS10.1, HEC-HMS4.2.1, Easy fit 5.6 Rainbow, Excel spread sheet and other tools for data preparation.

ArcGIS Version 10.1: is public domain software which was developed by Environmental System Research Institute(ESRI). It was used for spatial data analysis for CN grid generation. Arc hydro: It was used for delineation of stream and watershed to be used as an input for HEC-Geo HMS.

HEC-Geo HMS Version10.1: It was developed by Hydrologic Engineering Center (HEC). It was released by HEC in august 2016. This version was selected for this study because it was compatible with ArcGIS10.1. It was used Generation of basin model file and importing into HEC-HMS. Generally HEC-Geo HMS was used for preparation of hydrologic input data for HEC-HMS model.

HEC-HMS Version4.2.1:- It was developed by USACE and released in august,2016. It is the recent version with several modifications. It was used to determine the peak flow, time of peak, volume discharge of the study area. Generally HEC-HMS model was used for simulation of rainfall-runoff process of the watershed.

Easy fit version 5.6:- 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).

Rainbow: Rainbow software is used to check the homogeneity of rainfall data. In Rainbow the tests for homogeneity is based on the cumulative deviation from mean. The another software used in this study were Microsoft Excel sheets which was used for analysis of hydro-metrological data.

3.2.1 Flow Chart of the Thesis

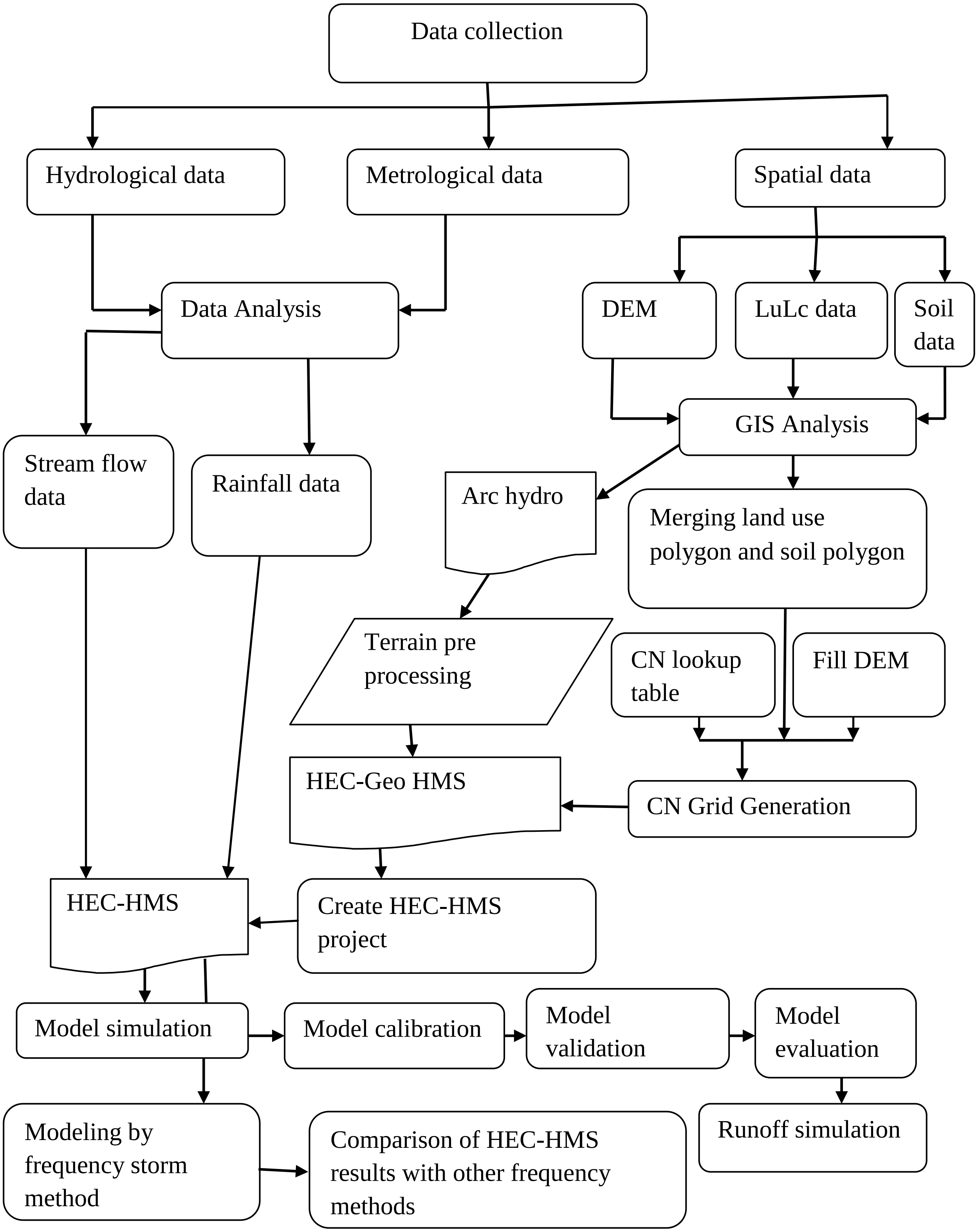


Figure 3. 5: General framework of the thesis

3.3 Data Collection And Analysis

Data collection is vital and requires the gathering of all necessary information for hydrologic analysis. The basic data sets that are necessary for the modeling work are: - meteorological data, hydrological (stream flow) data, the digital elevation model (DEM 30m resolution: source STRM), land use land cover data and soil data. These data were collected from the following sources:

Table 3. 2: Data type and Sources of data

S.No	Data type	Sources of data
1.	Hydrological data	Ministry of Water, Irrigation and Electricity(MWIE)
2.	Metrological data	National Metrological Service Agency(NMSA)
3.	Land use land cover prepared in 2013	Ethiopian Mapping Agency (EMA)
4.	Soil data	Ministry of Water, Irrigation and Electricity(MWIE)
5.	DEM(30m resolution)	Downloaded from the United States Geological Survey(USGS)

DEM data is used to describe topographic characteristics such as contour, slope, elevation difference, aspect, hill shed and others. DEM is the main data set used for development of the basin model components in HEC-HMS. Figure 3.6 Shows the DEM of the study area.

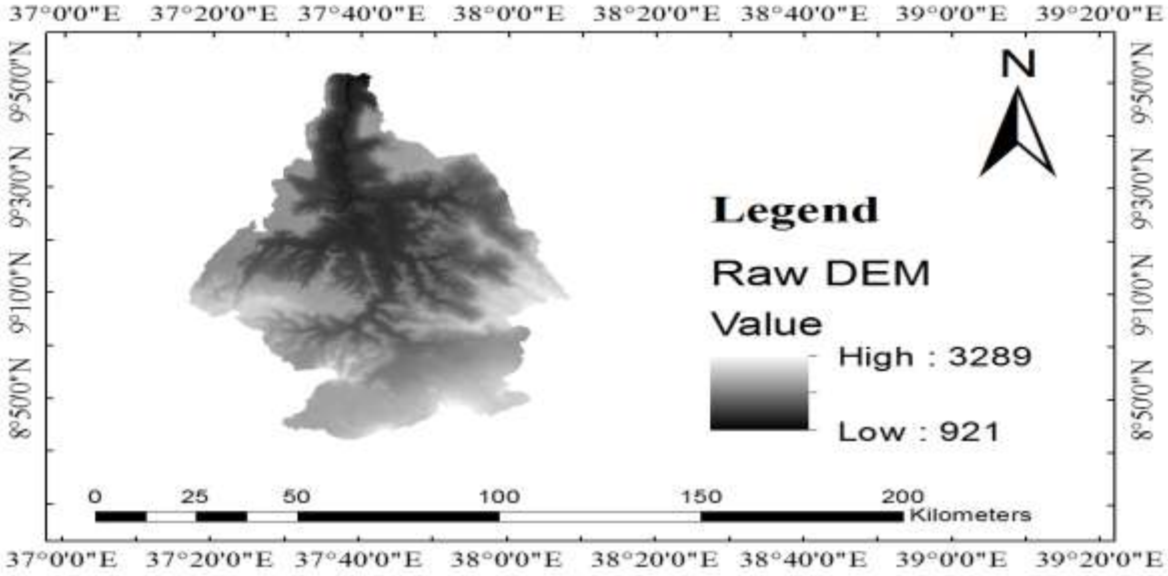


Figure 3. 6: 30m*30m DEM of the study area

3.3.1 Meteorological Data Availability and Processing

Before beginning any hydrological analysis, it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers (Vedula & Mujumdar, 2005). Basically a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. Daily rainfall of different record length for some stations were collected from National Meteorological Agency (NMA). Out of the entire available automatic recording stations those which are in or proximate to the watersheds considered for the research work were selected. Accordingly, a total of six rainfall stations were selected for use in the research work. The location of the selected meteorological stations is shown in figure 3.7 below.

Table 3. 3: location of selected Meteorological station used for this study

No	Station name	Elevation	Latitude	Longitude	Start year	End year
1	Ambo	2068	8.984667	37.83967	1987	2017
2	Ejaji	1732	9.0712	37.31667	1987	2017
3	Gedo	2520	9.021	37.4575	1986	2017
4	Jeldu	2952	9.25	38.02333	1987	2017
5	Kachise	2520	9.583333	37.86	1986	2017
6	Tikur Enchny	2467	8.83633	37.6677	1987	2017

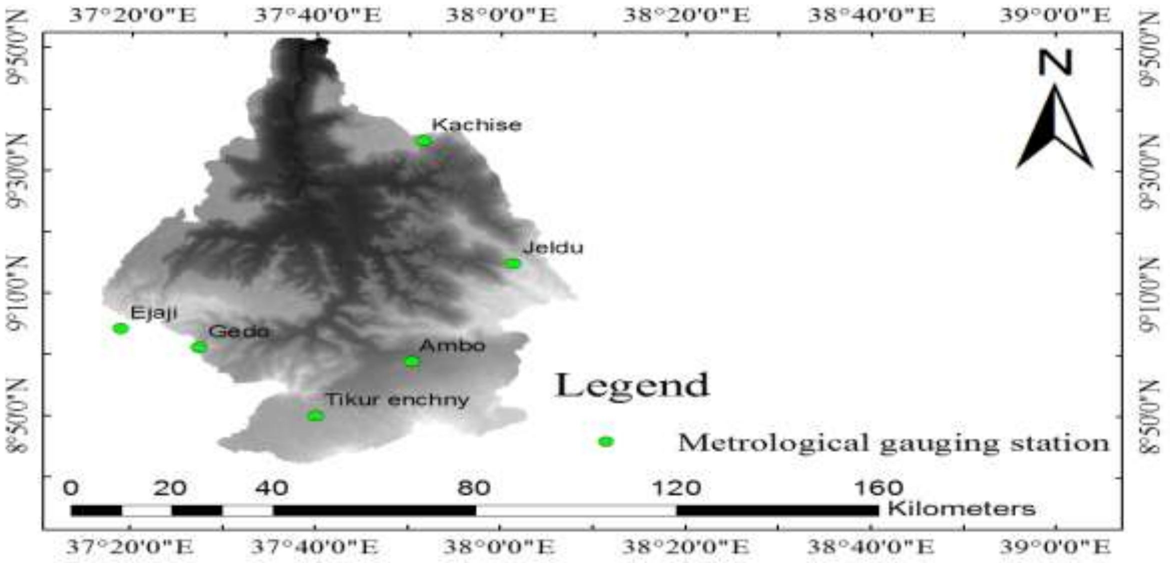


Figure 3. 7: Locations of selected metrological Gauging stations of Guder watershed

3.3.1.1 Estimating Missing Precipitation

Before using the rainfall records of a station, it was necessary to first check the data for continuity and consistency. The continuity of a record may be broken with missing data due to many reasons such as damage or fault in a rain gauge during a period. The missing data can be estimated by using the data of the neighboring stations. A number of methods have been proposed for estimate missing rainfall data (WMO, 2008). The station average method is the simplest method. The normal- ratio and quadrant methods provide a weighted mean, with the former biasing the weights on the mean annual rainfall at each gauge and the latter having weights that depend on the distance between the gauges where recorded data are available and the point where a value is required.

The station average method for filling missing data is conceptually the same as the simple weight method for estimating a mean daily precipitation. This method may not be accurate when the total annual rainfall at any of the n region gauges differs from the annual rainfall at the point of interest by more than 10%.

The normal-ratio method was conceptually simple; it differs from the station-average method of that the average annual rainfall was used in deriving weights. If the total annual rainfall at any of the m region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal- ratio method is preferable.

The normal ratio method and arithmetic average method was used to fill the missing rainfall data in this research paper. Normal ratio method is more advanced and simple. This method assigns weights of each surrounding stations. The general formula for computing missing precipitation by this method is:

$$P_X = \frac{NX}{M}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \frac{P4}{N4} + \frac{P5}{N5} + \text{----------}\frac{pm}{Nm}\right) \text{---} 3.1$$

Where : P_X = missing precipitation

NX = Average annual precipitation at the missing data

N_1, N_2, N_3, N_4, N_5----------Nm = average annual precipitation at the adjacent site.

P_1, P_2, P_3, P_4, P_5----------Pm = Adjacent station precipitation values

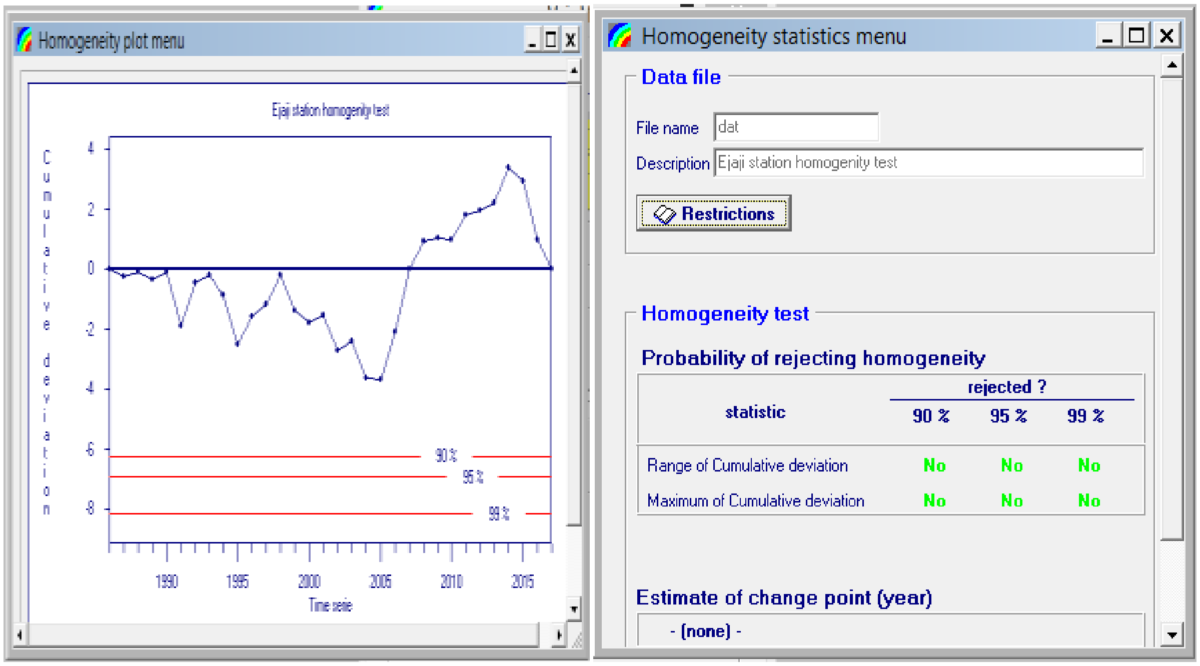
The arithmetic average method was used when average annual precipitation of the index stations differs by less than 10% of the missing stations. In this method, missing data is obtained by computing the arithmetic average of rainfall data recorded nearest to the considered gauge. The general formula for computing missing precipitation by this method is:-

$$P_X = \frac{P1+P2+P3+P4+---Pm}{M} \tag{3.2}$$

3.3.1.2 Homogeneity of the stations

Homogeneity test is an important to detect the variability of the data. Homogeneity of a time series data indicate that the measurement of the data are taken at a time with the same instruments and environments. However, it is a hard task when dealing with rainfall data because there might be a certain error due to change in measurement and observational procedure, location of measuring device and environmental characteristics.

Data homogeneity in this study were analyzed by using Rainbow software. In Rainbow software the tests for homogeneity is based on the cumulative deviation from the mean (Raes et al., 2006). The figure 3.8 shows the homogeneity test of Ejaji station. The probability of rejecting homogeneity test is accepted at all significance levels(90,95and99%) for both range of cumulative deviation. The homogeneity tests result for other stations annual rainfall was attached in appendix B.



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Description: Ejaji station homogenity test

Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure 3. 8: Homogeneity test results of Ejaji station station

3.3.1.3 Test for Consistency of the station

The errors can be introduced due to different reasons in point measurement of rainfall. Relocation of a gauge, the growth of trees closes to gauge site, or the use of shields may alter gauge catching significantly. After a number of years, it is may be felt that data of that station is not giving consistent rainfall values. In order to detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique called double mass curve method is generally adopted. In general, time series observational data is relatively consistent and homogenous if the periodic data are proportional to an appropriate simultaneous period. The proportionality can be tested by double mass curve analysis in which the cumulative precipitation of doubt full station is plotted against the cumulative of the group average (Suramanya, 2008).

If a rainfall record is a consistent estimator of the hydro-meteorological occurrences over the period of record, the double-mass curve has a constant slope. A change in the slope of the double mass-curve would suggest that an external factor has caused changes in the character of the measured values. If a change in slope is evident, then the record needs to be adjusted, with either the early or later period of record adjusted. Conceptually, adjustment is nothing more than changing the values so that the slope of the resulting double-mass curve is a straight line. The rainfall records of the station i were adjusted by multiplying the recorded values of rainfall by the ratio of slope of straight lines before and after changing in environment. Mathematically, it can be expressed as follows:

$$p_2 = \left(\frac{S2}{S1}\right)P1 \text{--} 3.3$$

Where: p_2 = Corrected precipitation at station i

P_1 = the original recorded precipitation at station i

S1 = the original slope of double mass curve

S2 = the slope of double mass curve to adjusted

Depend on the results obtained, the rainfall data at ambo station, Ejaji station, Gedo station, kachise station, Tikur enchny station were consistent have R^2 value of 0.999, 0.999, 0.998, 0.999,0.999 respectively. However, it was relatively inconsistent at jeldu station with R^2 value of 0.993. By using the double mass curve analysis the R^2 value was adjusted to 0.998. Figure 3.9 Shows the consistence test result for combined meteorological station. The individual consistence station graph was attached in appendix A.

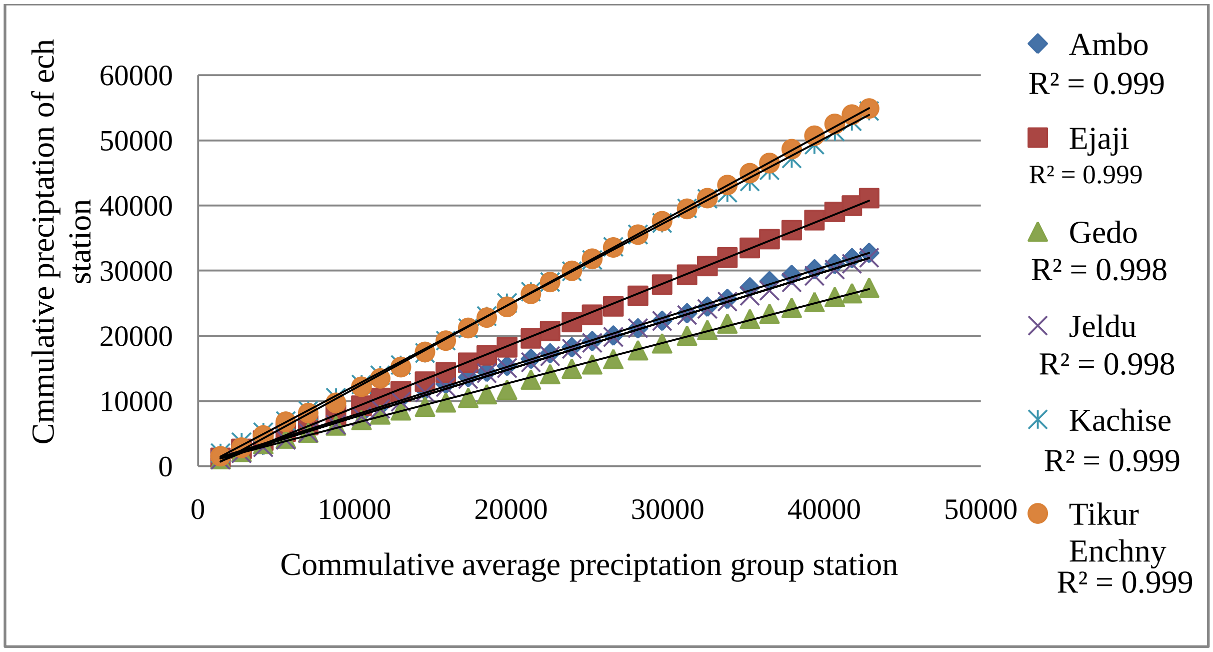


Figure 3. 9 : DMC of the combined metrological station

3.3.1.4 Areal precipitation

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of rainfall over the area under the area under consideration is one of the most important parameter in hydrological analysis.

There are many methods available to Calculate the areal rainfall over the catchments from the rain gauge measurement: Arithmetic Mean, Thiessen Polygon, Isohyetal, Grid Point, etc. are available for estimating average precipitation over a drainage basin (Shaw, 1988). Choice of methods requires judgment in consideration of quality and nature of the data, the importance, use, and required precision of the result.

In order to determine the average depth of rainfall contribution from the Guder River watershed was analyzed using a Thiessen polygon method which is most widely used method compared to others and is used in this research paper. For catchment having rainfall-gauging station in vicinity of the boundary of the watershed, the thiessen polygon is used to compute the areal rainfall.

The perpendicular bisector of these lines forms a pattern of polygons with one station in each polygon. The area with which each station is taken represents the area of its polygon, and this area is used as a factor for weighting the station precipitation. The contribution of the rainfall from each gauging station is limited by its weighing factor.

According to Thiessen polygon, the average rainfall over the area can be computed from the following equations:

$$R_{areal} = \sum_{i=1}^{n} \frac{RiAi}{At} ----------------------------- 3.4$$

Where: R_i = Rainfall at station i

A_i = Polygon area of station i

A_t = Total catchment area and

n = number of stations

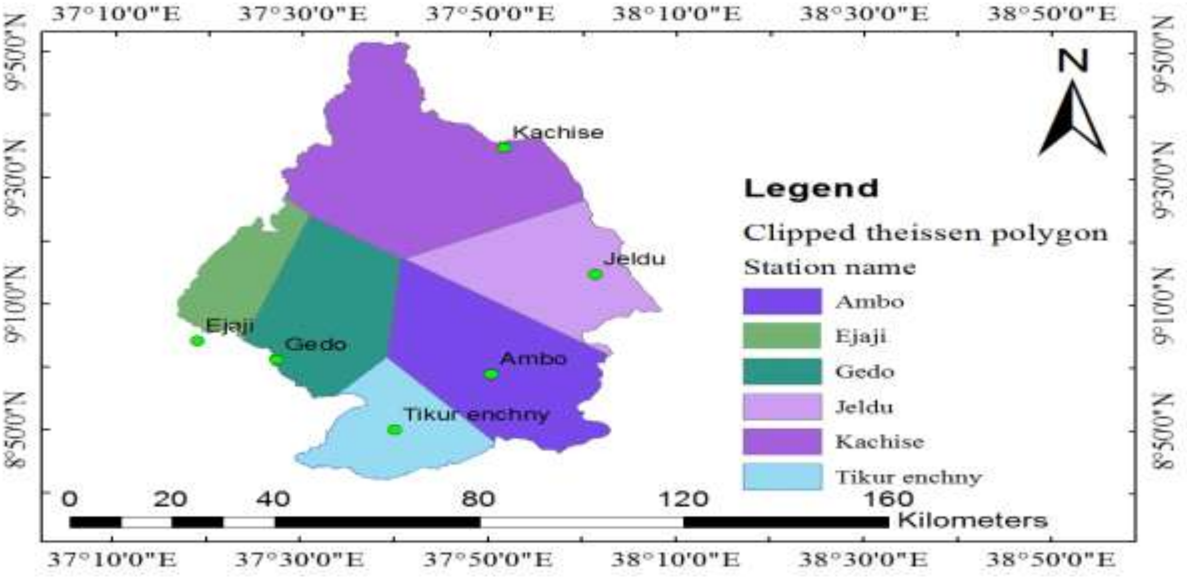


Figure 3. 10: Clipped Thiessen polygon of Guder River watershed

Table 3. 4: Thiessen gauge weight developed for Guder Watershed

SN$_{\underline{O}}$	Rainfall station	Area Weight (Km^2)	Gauge Weight(%)	Mean annual precipitation(mm)
1	Ambo	1417	21.48	1056.027
2	Ejaji	487	7.38	1326.88
3	Gedo	1029	15.6	884.56
4	Kachise	1945	29.48	1757.7
5	Jeldu	1008	15.28	1499.58
6	Tekur Enchny	711	10.78	1771.1
	Total	6597	100	

3.3.2 Hydrological data

The flow data was required for performing sensitivity analysis, calibration and validation of the Hydrological model. In the Guder Sub-Basin there are some flow gauging stations located on Guder relatively small tributaries and/or near the head waters of the main river that have record of daily stream flow data. This data was obtained from Ministry of Water, Irrigation and Electricity, Hydrology department at Addis Ababa office. Depending on the extent of calibration and validation, flow data was collected and arranged as per the requirement of HEC-HMS model. The selected site was Guder flow gauge station. This site was selected as it this station has long term, reliable stream flow data and it is located on the main river.

The daily discharge data from 1994-2009 of the study area were collected from the FDRE Ministry of Water, Irrigation and Electricity hydrology department at Addis Ababa office. Unlike the daily meteorological data, the daily discharge data has limited data composition for the considered stations to represent the study area. The missing data can be estimated by using data of the neighboring station. There are different methods used for filling the missing flow data records of a given gauging station. For this study, missing data were filled by using linear regression method. This methods was selected due to the following reason: it is the most widely used methods when compared with other methods, it is applied by creating a correlation with nearby station and estimation of significant missing observations as accurate as possible.

The missing flow data of Guder watershed was filled by linear regression techniques of based Guedr at Guder observed stream flow with stream flow nearby station that included Indrisa near Guder and Fato near Guder gauging station through the help of micro excel sheet software for the same period.

The equation for linear regression is given as: -

$$Y = ax + b \text{---} 3.5$$

Where X and Y- instantaneous daily stream flows(m^3/s) a and b- constants. In this study, regression with corrected station by scatter plot was checked and used to obtain missing daily flow data, using nearby station by deriving a common using scatter graph.

3.4 Input data preparation for HEC-HMS model

Input data for HEC-HMS model was prepared by two main processes. These processes are terrain preprocessing and hydrologic processing. Terrain processing was done by using arc hydro tools. While, hydrologic processing was done by using HEC-Geo HMS tools. HEC-Geo HMS is a set of ArcGIS tools specifically designed to process geospatial data and create input data for the HEC-HMS.

3.4.1 Terrain Processing Using Arc Hydro tools

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, and stream network density. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. In this study, the Arc Hydro (tools version that works with Arc-GIS 10.1) was used 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 results from terrain processing can be used to create input files for many hydrologic models using HEC- Geo HMS. All the steps in the Arc Hydro Terrain Pre-processing menu should be performed in sequential order. The procedure followed for terrain processing using Arc Hydro were explained under using 30x30 DEM extracted for the respective sub basins and river feature class of the study area. For simplicity the main steps undertaken by arc hydro 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 and Adjoint catchment processing. The step by step results of terrain processing using arc hydro tools was attached in appendix- C.

3.4.2 Curve Number (CN) Grid Generation

The U.S. natural resource conservation service (NRCS) (formerly the soil conservation service (SCS)) curve number method used in this study to estimates the effective rainfall as a function of the cumulative rainfall, the land use, the soil type and the antecedent moisture condition of the soil.

The runoff curve number is an empirical parameter uses for estimating direct runoff or infiltration from rainfall excess. The runoff curve number is generated from the study area's land use and hydrologic soil groups.

Watershed land cover has great importance in estimating the basin's curve number with the identification of soil texture and its permeability. SCS method is widely applied to estimate storm runoff depth for every patch within a watershed based on run off curve numbers (CN) (QihaoWeng, 2001). The steps for curve number generation was preparing land use land cover data, preparing soil data, Merging land use land cover data and soil data and Preparing Lookup table, by using Arc GIS 10.1. Then finally CN grid was generated by using HEC-Geo HMS.

3.4.2.1 Preparing land use data for CN Grid

Eventually, it was used this land use classes and soil group type, in conjunction with SCS curve number, to create curve number grid. The SCS CN table gives CN for different combinations of land use and soil group. The Guder land use grid has 11 different land use categories. The land use grid was reclassified to reduce the number of land use classes to make task easier. The land use grid was reclassified into three major classes: - water, forest and agricultural. The final steps in preparation of land use data is converting the reclassified land use grid into polygon feature classes which was merged with the soil polygon.

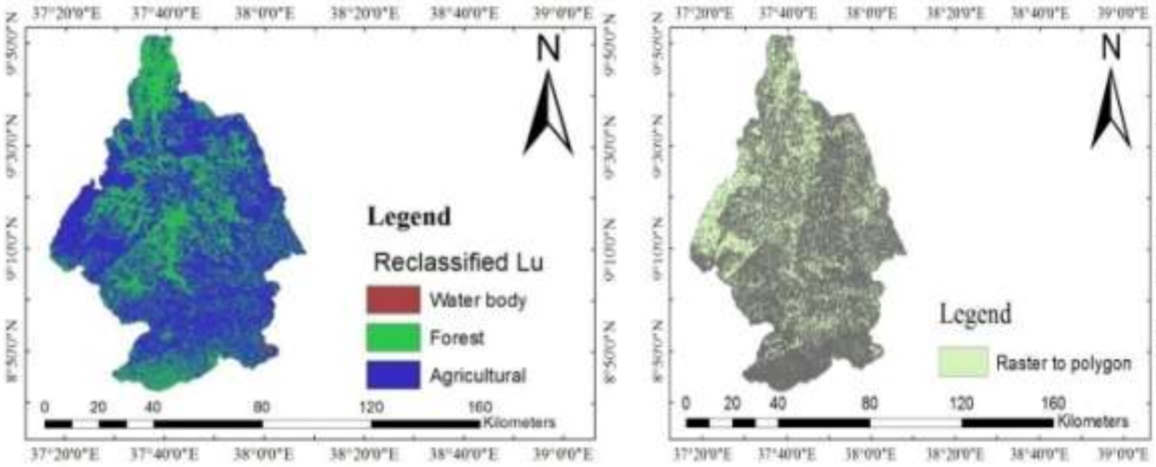


Figure 3. 11: Reclassified land use and polygon feature classes

Table 3. 5: Reclassified land use and area coverage

S.No	Land use	Area in km^2	Area percentage
1	Water body	113.46	1.72
2	Forest	2715.39	41.16
3	Agriculture	3768.15	57.12
Total		6597	100

3.4.2.2 Preparing soil data for CN Grid

According to the classification of (USDA, 1986), soils classified into four hydrologic groups namely A, B, C and D. A soil types has high infiltration rate; B soils types has moderate infiltration rate; C soil types has slow infiltration rate and D soil types has very low infiltration rate.

Since the group for each polygon soil feature class from spatial feature dataset of the study area for extracting CN number is needed, a field was developed for storing soil group data. So the first step is creating an empty field for storing soil group data. Create a field named "Soil Code") in study area soil clip.

Next step was creating a name like PctA, PctB, PctC, and PctD in the soil clip feature class. For each feature (polygon) in Guder soil clip PctA will define what percentage of area within the polygon has soil group A, PctB will define what percentage of area within the polygon will have soil group B and so on.

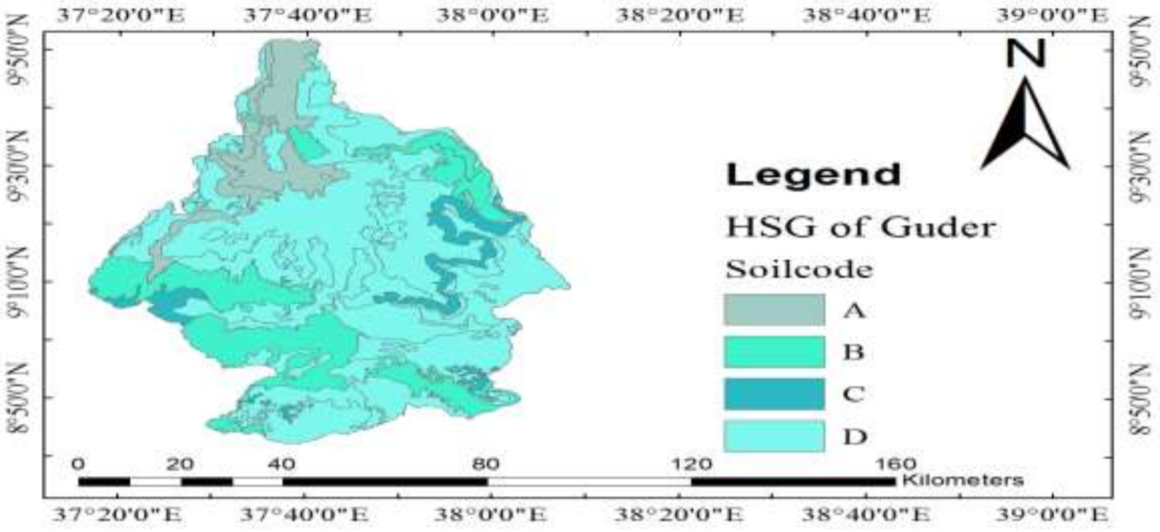


Figure 3. 12: Hydrological soil group of study area

Table 3. 6: Hydrological soil group of the study area

Hydrological soil group(HSG)	Surface Area coverage (Km^2)	Surface area coverage(%)
A	652.987	9.89
B	1341.69	20.34
C	359.466	5.44
D	4242.86	64.31

3.4.2.3 Merging of soil and land use data

As previously discussed both the land use class and soil class of the study are prepared in shape file format which are very important data's for curve number (CN) generation. But to utilize this data for CN generation the two shape files are merged by using union function of Arc GIS 10.1software package. The union function uses the both land use and soil feature classes as input. The output of merged features contains attributes values from both inputs.

3.4.2.4 Creating CN Look-up Table

Curve number look-up table is the most fundamental in put table for CN grid generation and created by using create table function of Arc GIS10.1 and assigned hydrological soil group (HSG) for each land use type as shown in table below.

Table 3. 7: CN Lookup table

S No	Description of land use type	Hydrological soil group (HSG)			
		A	B	C	D
1	Water	100	100	100	100
2	Forest	30	58	71	78
3	Agriculture	67	77	83	87

3.4.3 HEC-HMS Project Creation

HEC-Geo HMS provides the connection for translating GIS spatial information in to model files for HEC-HMS. To create an HMS project different tools of HEC- Geo HMS are used which are found on four main views namely; project setup, basin characteristics, HMS input parameters and HEC- HMS menus.

3.4.3.1 Project setup

a) Data Management window: The necessary data sets used for HMS project generation are added. These are:- Raw DEM, Filled DEM, flow direction grid, flow accumulation grid, stream network grid , stream link grid, Catchment, adjoint catchment. These data are checked on the data management window of HEC-Geo HMS and assigned based on corresponding map layers used to generate the project.

b) Creating new project and Generate the project: Start new project and assign Guder river watershed project area. Before generating the project the data management window of HEC-Geo HMS is checked and Project is generated by creating a mesh(by delineating watershed for previously created main outlet of the Guder watershed.

3.4.3.2 Stream and Watershed Characteristics

When the stream and sub-basin delineation has been finalized, physical characteristics for a stream line such as length, upstream and downstream elevations, and slope are extracted from the terrain data. Similarly, physical characteristics for a sub-basin, such as longest flow length, centroidal flow lengths, and slopes are extracted from the terrain data.

3.4.3.3 HMS input/parameters

After the physical Characteristics of streams and sub-basins, HMS parameters are defined such as HMS process (loss method, transform method, base-flow type, and routing method), river auto name, basin auto name, Sub basin parameter, CN Lag method are computed.

3.4.3.4 Develop HEC-HMS Model Files

HEC-Geo HMS produces a number of files that can be used directly by HEC-HMS. These files include background map files, the basin model file, the meteorological model file and a project file. The activities accomplished using those HEC-Geo HMS menu are: - Map to HMS Units, HMS Data Check, HEC-HMS Basin Schematic, HMS Legend, Add Coordinates, Prepare Data for Model Export, Background Map File, Basin File, met model file, create HEC-HMS project and import the HMS file.

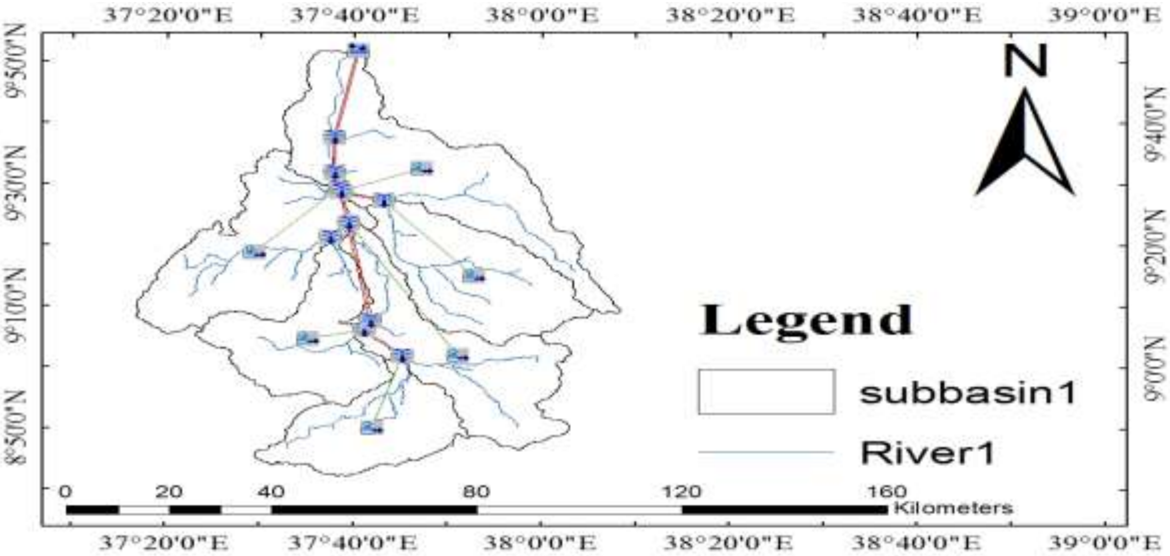


Figure 3. 13: Generated HEC- HMS project by using HEC-Geo HMS

3.5 HEC-HMS Model setup

The main input data used for HEC-HMS are:- precipitation, observed flow and different watershed characteristics obtained from HEC-Geo HMS. HEC-HMS model setup consists of four main model components: These are Basin Model, the Meteorological Model, Control Specifications and input data (time series, paired data and grided data). The Basin Model contains a schematic consisting of any combination of the six objects (sub-basin, reach, junction, source, sink and reservoir). The Basin Model stores information about the properties and connectivity of the objects in the schematic. In this research paper only the first three components are used. The Meteorological Model contains time series information consisting of rainfall data. These data are associated with rain gages that the user defines in the Meteorological Model. The Control Specifications component defines simulation properties such as duration and time step. Input data is required as parameters or boundary condition in basin and meteorological model. The components of the model used for this study were explained in detail as follows.

3.5.1 Basin model

A general basin model consisting of sub-basinW710, sub-basinW760, sub-basinW800, sub-basinW820, sub-basinW1040 and sub-basinW1220 were set up in HEC-HMS generated with HEC-Geo HMS 10.1 for the study area. In addition to six sub-basins, an out let element was used in the basin model to relate the simulated flow to the historical observed total flow of the sub-basins. Basin model contains the modeling components that describe infiltration, surface runoff, base flow and channel routing.

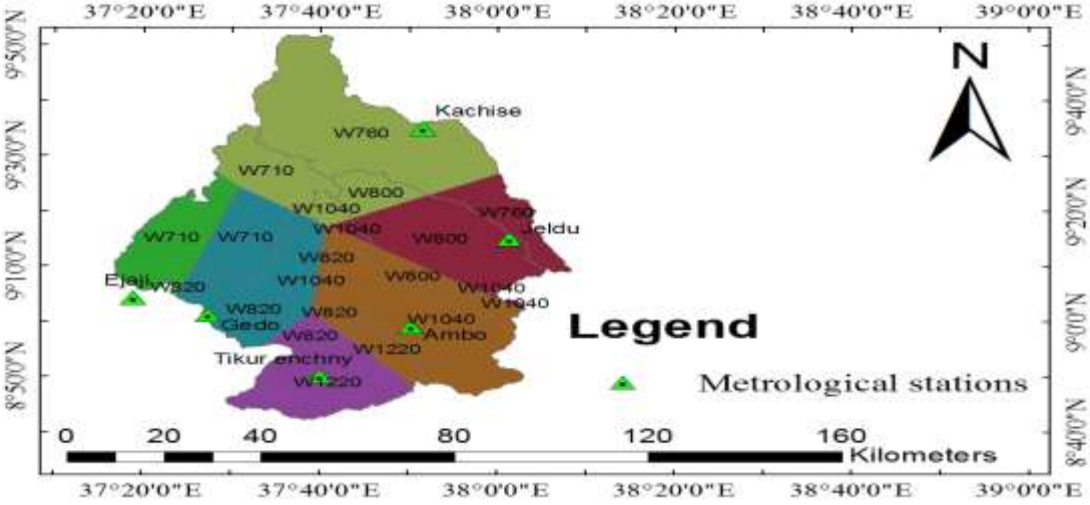


Figure 3. 14: Sub-basins of thiessen polygon developed from metrological stations

Table 3. 8: Sub-basin area and contributing rainfall stations

Sub-basin name	Basin Area (Km^2)	Contributing RF station	Area(km^2) of contribution	Areal weight
W710	1217.99	Ejaji	478.9	0.393
		Gedo	368	0.302
		Kachise	371	0.305
W760	1581.71	Kachise	1314	0.831
		Jeldu	266.7	0.169
W800	1042.55	Jeldu	707	0.68
		Ambo	156	0.15
		Kachise	179.6	0.172
W820	892.38	Gedo	659	0.74
		Tikur enchny	119	0.13
		Kachise	8	0.009
		Ambo	98.4	0.11
		Ejaji	8	0.009
W1040	1111	Ambo	1006	0.91
		Jeldu	34	0.031
		Kachise	68	0.06
		Gedo	3	0.003
W1220	751.77	Tikur Enchny	594	0.79
		Ambo	157.8	0.21

The basin model consists of four main hydrological processes. These are: - Loss method, transform method, base flow method and routing methods.

3.5.1.1 Loss method

The term loss refers to the amount of precipitation infiltrated into the soil. HEC-HMS supports the most common methods for calculating losses such as: - Deficit constant, soil moisture Account, Exponential, initial + constant, SCS Curve Number, gridded SCS Curve Number and the Green Ampt, and provides a moisture depletion option for simulations over extended periods of time. SCS Curve number loss method was applied, because it has been us model that has been used successfully in many studies throughout the US (USACE, 2003), easy to set up and use, widely used and efficient method for determining the approximate amount of runoff from a rainfall.

The soil conservation service (SCS) curve number (CN) model estimates precipitation excess as function of cumulative precipitation, soil cover, land use, and antecedent moisture, using the following equation (Feldan, 2000):

$$Q = \frac{(P-Ia)^2}{P-Ia+s} \text{--}3.6$$

Where Q is accumulated direct runoff(mm), P is accumulated rainfall(mm), Ia is initial abstraction including surface storage, interception, and infiltration prior to runoff (mm) and S is potential maximum retention (mm).

The relationship between Ia and S was developed from experimental catchment area data. It removes the necessity for estimating Ia for common usage. The empirical relationship used in the SCS runoff equation is:

$$Ia = 0.2S\text{--}3.7$$

By removing Ia as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Which is as the following: -

$$Q = \frac{(P-0.2S)^2}{(P + 0.8S)}\text{--}3.8$$

Soil storage or retention Volume, S is related to the soil and cover conditions of the catchment area through the CN. S is related to Curve number(CN) by: -

$S = 25.4(\frac{1000}{\mathrm{CN}} - 10)$---3.9

Where: CN is curve number and the other parameter were mentioned in equation3.6.

3.5.1.2 Transform method

When rainfall occurs it satisfies all the basin requirement such as infiltration, initial abstraction, storage, etc. The runoff transformations convert excess precipitation on a sub-basin to direct runoff at the sub-basin outlet. To calculate the direct runoff there are different methods, such as: - user-specified S-graph, SCSunit hydrograph, Modified Clark, Kinematic wave, Snyder, user specified unit hydrograph, Clark unit hydrograph, snyder-tulsa and Snyder -fort worth. The SCS Unit Hydrograph model for direct runoff computation was chosen because of not only due to simplicity and minimum data requirements but also it gives a good performance than the other models. In addition, it is suitable for conceptual models to transform rainfall to runoff process.

At the heart of the SCS UH model is a dimensionless, single-peaked UH. This dimensionless UH, expresses the UH discharge U_t, as a ratio to the UH peak discharge, *Up*, for any time *t*, a fraction of T_p, the time to UH peak.

SCS suggests that the UH peak and time of UH peak are related by:

$\mathrm{Up} = C\frac{A}{TP}$---3.10

Where : A = Watershed area, Tp = time to peak, C = Conversion constant(2.08 in SI and 484 in foot-pound system). The time of peak (also known as the time of rise) is related to the duration of the unit of excess precipitation as:

$T_p = \frac{\Delta t}{2} + T_{lag}$ --3.11

Where *t* = the excess precipitation duration and T_{lag} = the basin lag, defined as the time difference between the center of mass of rainfall excess and the peak of the UH. The basin lag time is calculated for each watershed based on the time of concentration Tc, as:

$T_{lag} = 0.6Tc$ --3.12

Where Tlag and Tc are in minute.

The time of concentration can be estimated based on the basin characteristics including to topography and the length of reach by kirpich's formula.

$Tc = 0.0078*(\frac{L^{0.77}}{S^{0.385}})$ ---3.13

Where L is the reach length, and S is the slope.

3.5.1.3 Base Flow Method

Base flow can be an important parameter in runoff studies because it define minimum river depth over which additional runoff accumulates. Four alternative models of base flow are included in HEC-HMS program. These are Exponential recession, Linear reservoir, monthly constant and Bounded recession methods. Constant monthly-varying base flow method was selected for this study, because it is simple methods than others, it represents base flow as constant flow, may vary monthly. it allows the specification of a constant base flow for each month of the year.

3.5.3.4 Routing method

When a watershed receives rainfall as an input and produce a runoff as output, the output or out flow hydrograph differs from the input or inflow hydrograph of rainfall in shape, duration and magnitude; these differences being attributable to storage properties of the watershed system. The HEC-HMS contains different flood routing methods, such as: - Kinematic wave, Muskingumcung, Muskingum, Modified plus, lag and straddle stagger. For this study, Muskingum routing model was selected for flow routing in reach elements. This methods was selected considering the availability of information for parameter estimation. The Muskingum channel routing method is based on two equations (Linsley et al., 1982).The first is the continuity equation or conservation of mass.

$$\frac{I1+I2}{2}\Delta T-\frac{O1+O2}{2}\Delta T=S1-S2 \text{---} 3.14$$

Where I_1 and I_2 inflow discharge at time 1and time 2, $O_1$and O_2 are outflow discharge at time1 and 2, $\Delta T =$ time difference between time 1and 2, $S_1$and S_2 are value of reach storage at time 1 and time 2.

The second equation is a relationship of storage, inflow, and outflow of the reach.

$$S = k\{XI(1-X)O\} \text{--} 3.15$$

Where, S = reach storage, I = inflow discharge, O = outflow discharge, K= storage constant, X = weighting factor.

Combining equations 3.14 and 3.15 and simplifying results

$$O_2 = C_1I_1 + C_2I_2 + C_3O_1 \text{--} 3.16$$

Where $C_1 = ((\Delta T/K)+2X)/C_0$, $C_2 = ((\Delta T/K)-2X)/C_0$, $C_3 = (2(1-X)-\Delta T/K)/C_0$,

$C_0 = \frac{\Delta T}{K} + 2(1 - X)$. C_0,C_1,C_2 and C_3 are dimensionless parameters.

An approximation for K is the travel time through the reach (length of reach divided by the average flow velocity) and the value ranges from (0.0 to 100hrs). The value of X is between 0.0 and 0.5. For this study the wave travel time (K) for each reach was calculated from the equation 3.17 as the initial value. Running the model with this initial value, later the parameter where optimized.

$K = \frac{L}{V}$---3.17

Where K = flood travel wave length(hr), V = permissible velocity(m^2/s), L= reach length(m)

The permissible velocity value should be in the range of neither causes erosion of the channel nor causes the deposition of sediment in the channel.

3.5.2 Meteorological Model

The precipitation model is a set of information required to define historical or hypothetical to be used in conjunction with a basin model. The meteorological model are used to prepare meteorological boundary condition for sub-basins. The meteorological models were matched with the sub-basins in the basin model using the name of sub-basins.

precipitation is the driving factor for the watershed response in the case of HEC-HMS model. in turn the major effort was made to compute the meteorological model to receive spatially and temporally distributed precipitation input data.

3.5.3 Control Specifications

The time span of a simulation was controlled by control specifications. Control specifications include a starting date and time, ending date and time, and computation time step. A computation run was created by combining a basin model, meteorological model, and control specifications.

The available records of 6 precipitation stations and one outlet stream flow gauge station were used for calibration and verification of the HEC-HMS model. The calibration was done using daily data for the period from 01 January, 1994 to 31 December, 2003 (10years) and also Validation was done using daily data for the period from 01 January, 2004 to 31 December, 2009(6Years).

3.5.4 Input Data Components

Time-series data, paired data and gridded data are often required as parameter or boundary conditions in basin and meteorological models. Input data can be entered manually or referenced to an existing record in a HEC-DSS file. All gridded data must be referenced to an existing HEC-DSS record

3.6 Sensitivity Analysis

The model sensitivity analysis is potentially useful in all phases of the modeling processes (model formulation, model calibration and model validation) (McCuen, 2003). Sensitivity analysis is method to determine which parameters of the model have the greatest impact on the model result. The sensitivity analysis can be applied to the response of output variable to a change in model input or parameter value. Model parameters are ranked based on their contribution to overall error in model predictions. The most sensitive parameter corresponding to greater change in output response. This information is important during model calibration.

3.7 Model calibration and validation

The successful application of the hydrologic watershed model depends upon how well the model is calibrated which in turn depends on the technical capability of the hydrological model as well as the quality of the input data. The objective of the model calibration is to match observed simulated runoff volumes, runoff peaks and timing of hydrographs with the observed ones. The calibration procedure involves a combination of both manual and automated calibrations. The manual calibration proceeds the automate optimization to ensure a physically meaningful set of initial parameters generated from HEC-Geo HMS and Arc Hydro for the catchment.

Model Validation is the process of testing the model ability to simulate observed data, other than those used for the calibration, within acceptable accuracy. During this process, calibrated model parameter values are kept constant. The quantitative measure of the match is again the degree of variation between computed and observed hydrographs.

3.7.1 Objective Function

Automated calibration (optimization) was found to give optimum and reliable model parameters. The quantitative measure of the match is described by the objective function that measures the degree of variation between computed and observed hydrographs. The objective function used for automated calibration (optimization) for this study is Peak-Weighted RMS Error. The peak-Weighted RMS was selected because, it gives more weight to large errors than small errors and gives a greater overall weight to errors near the peak discharge.

3.7.2 Search Algorithms

The key to automated parameters estimation is search methods for adjusting parameters to minimize the objective function value and find the optimal parameter. The HEC-HMS model has two search methods: - Univariate gradient and Nelder Mead search algorithm.

a) Univariate Gradient Search Method: The Univariate gradient method is based on Newton's method and uses Taylor's series to approximate the objective function. This method evaluate and adjusts one parameters at a time while holding other parameters constant.

b) Nelder Mead Search Method: This method uses a downhill simplex to evaluate all parameters simultaneously and determine which parameter to adjust. The tolerance determine the change in the objective function value that will terminate the search. When the objective function changes less than the specified tolerance, the search will terminate. If multiple parameters are adjusted simultaneously, it will be difficult to know the most sensitive parameters that affect the model. For this reason, Univariate gradient method was used for this study.

3.8 Model efficiency/performance

The model performance must be evaluated before it receives any application. The model performance was being evaluated through visual inspection of the simulated and observed hydrograph through a set of objective functions that measure the goodness-of-fit between simulated and observed hydrograph. Assessing performance of a hydrologic model requires subjective and/ objective estimates of the closeness of the simulated behavior of the model to observations. For the Guder watershed study, model simulation has been evaluated using efficiency criteria such as coefficient of determination (R^2), Root mean square error(RMSE) and Nash-Sutcliffe model efficiency coefficient (NSE).

The R^2 coefficient and ENS 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 (ENS) values range from 1.0 (best) to negative infinity. The root mean square error(RMSE) is a frequently used to measure the difference between simulated value predicted by the model and observed value.

The Nash-Sutcliffe Efficiency (NSE), is estimated by:

$$NSE = 1- \frac{\sum_{i=1}^{n}(Qobs,i-Qsim,i)^2}{\sum_{i=1}^{n}(Qobs,i-\overline{Qobs,i})^2} \text{------------} 3.18$$

Where, NSE = Nash and Sutcliffe Efficiency

Q_{obs} = observed value at the i th time interval

Q_{sim} = simulated value at the ith time interval

$\bar{Q}_{obs}$ = mean of the observed discharge

n = number of observation

NSE ranges between -∞ and 1(1inclusive), with NSE = 1 being the target value. Values between 0.5 and 1.0 are generally viewed as acceptable level of performance, whereas values NSE= 0.0 indicate that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. The model simulation can be judged as satisfactory if Nash-Sutcliffe Efficiency is greater than 50%, good if it is greater than 65%, and very good if it is greater than 75% (Moriasi et al., 2007).

Coefficient of determination (R^2) is estimated by:

$$R^2 = \frac{[\sum_{i=1}^{n}(Qsim,i-\overline{Qsim,i})(Qobs,i-\overline{Qobs,i})]^2}{\sum_{i=1}^{n}[(Qsim,i-\overline{Qsim,i})]^2 \sum_{i=1}^{n}[(Qobs,i-\overline{Qobs,i})]^2} \text{------------} 3.19$$

Where, R^2 = Coefficient of determination,

Q_{obs} = observed value at the ith time interval,

Q_{sim} = simulated value at the ith time interval

$\bar{Q}_{obs}$ = mean of observed discharges and

$\bar{Q}_{sim}$ = mean of simulated discharges

Root mean square error(RMSE) is estimated by:

$$RMSE = \sqrt{\sum_{i=1}^{n}\frac{Qobs,i-Qsim,i}{n}} \text{------------} 3.20$$

Where, Q_{obs} = observed value at the i^{th} time interval,

Q_{sim} = simulated value at the i^{th} time interval,

3.9 Modeling by frequency storm method

With the input from HEC-Geo HMS and some edition from the main HEC-HMS, the model was simulated for rainfall intensity of 2, 10,25, 50 and 100 years return periods. The frequency intensity values are found from the Ethiopian Roads Authority drainage manual (ERA, 2013). According to ERA classification Guder watershed was found in region A2(RR-A2). ERA has developed 24hr rainfall depth for different rainfall regions of Ethiopia for corresponding return periods. By using the 24hr rainfall depth, the rainfall depth for 1,2,3, 6 and 12 hour were developed by using the equation 3.21 and the result was input to HEC-HMS for peak discharge estimation.

$$R_{Rt} = \frac{t}{24}\frac{(b+24)^n}{(b+t)^n} \text{-----------------------------------} 3.21$$

Where: R_{Rt} = rainfall depth ratio Rt: R_{24}, R_t = Rainfall depth in given duration t

R_{24}= 24 hour rainfall depth

b and n = coefficient b = 0.3 and n = (0.78- 1.09)

Table 3. 9: IDF for the study area

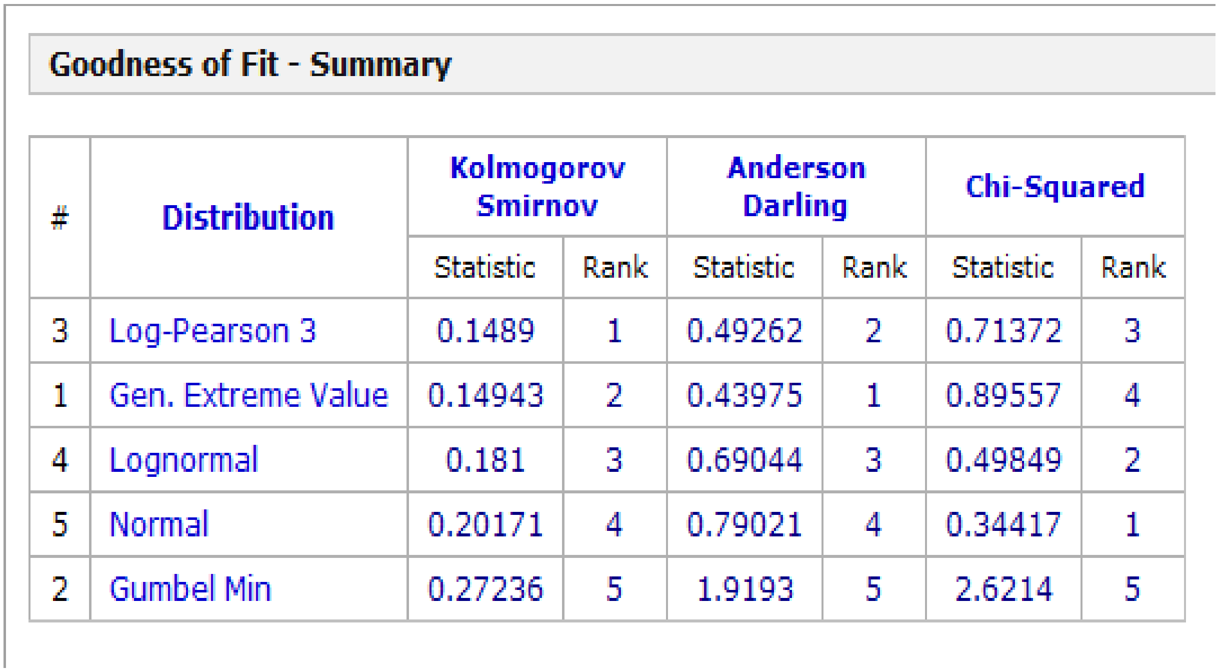
Duration(hr)	Return period(year)				
	2	10	25	50	100
1hr	33.91	48.66	55.98	61.45	66.92
2hr	39.68	56.94	65.49	71.89	78.29
3hr	42.39	60.83	69.97	76.81	83.65
6hr	46.18	66.26	76.23	83.67	91.13
12hr	49.24	70.65	81.27	89.21	97.16
24hr	51.92	75.45	85.70	94.07	102.45

3.10 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. For this study five flood probability distribution with General extreme value, Log-Pearson 3, Normal, Gumbel Min and Log-Normal distribution are considered to test the goodness of fit. From this flood probability distribution methods the only three distribution was used for the discharge comparison with the HEC-HMS. The selected three methods of flood distribution for comparison of discharge with HEC-HMS are:- General extreme value, Log-Pearson 3 and Log-Normal.

The analysis of observed data was prepared with the help of Easy Fit software and Microsoft Excel. Easy Fit software was used to select the best probability distribution method for the observed data. 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. The Anderson-Darling, Kolmogorov-Smirnov and Chi-Squared tests were used for goodness of fit tests. The goodness of fit between statistical and the observed distribution was determined based on Kolmogorov-Smirnov Test. The selection of good fit methods was depends on the ranks given by the Kolmogorov-Smirnov fitness method.

Table 3. 10: Easy fit software Evaluation for the Goodness of fit summary



Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
3	Log-Pearson 3	0.1489	1	0.49262	2	0.71372	3
1	Gen. Extreme Value	0.14943	2	0.43975	1	0.89557	4
4	Lognormal	0.181	3	0.69044	3	0.49849	2
5	Normal	0.20171	4	0.79021	4	0.34417	1
2	Gumbel Min	0.27236	5	1.9193	5	2.6214	5

4. RESULTS AND DISCUSSIONS

4.1 Curve Number Grid Generation

HEC-Geo HMS was used to create the curve number grid. To create the curve number grid HEC- Geo HMS needs the following files; merged land use and soil data, sink filled DEM and CN lookup table. All of those data are created in the appropriate format and using these three inputs the CN grid is generated by using generated grid function of HEC-Geo HMS model.

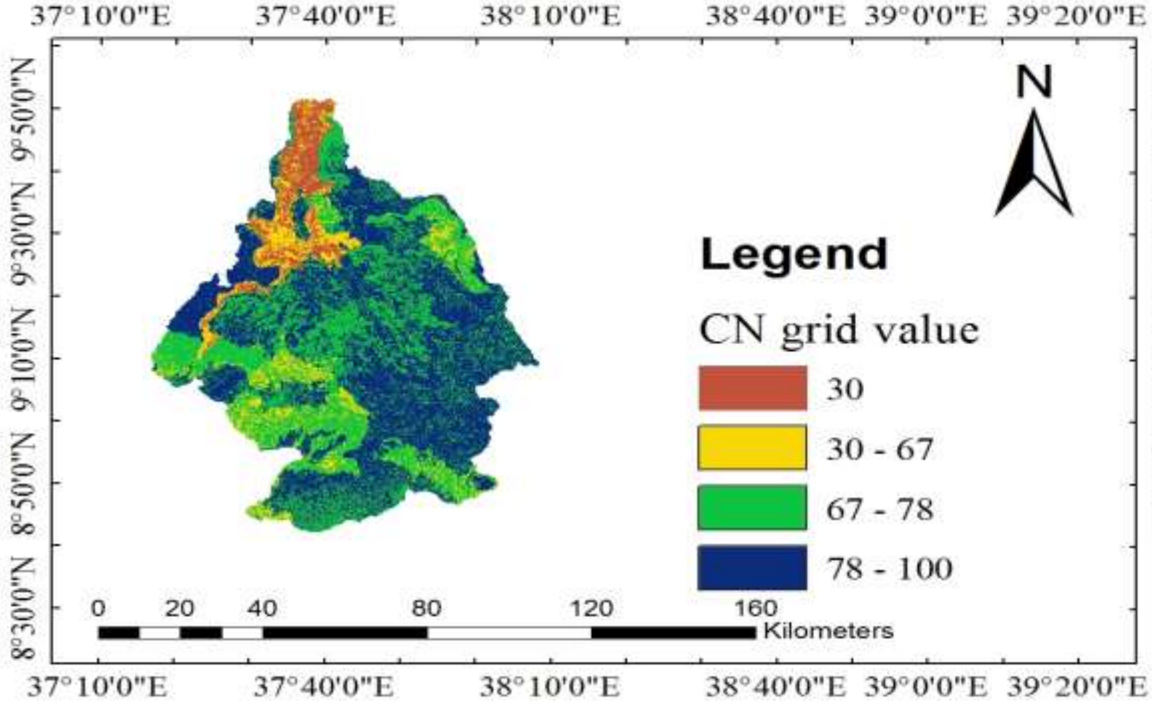


Figure 4. 1: Generated curve number(CN) results

4.2 HEC-HMS Project Generation Using HEC-Geo HMS

To create an HMS project different tools of HEC-Geo HMS are used which are found on four main views namely: HEC-HMS project setup, basin characteristics, HMS input parameters & HMS menu.

By using tools found in the HMS menu input files for HEC-HMS are created. activities accomplished using those HEC-Geo HMS menus are HMS unit assigned, data checking, HMS schematic, HMs legend, add coordinates, prepare data for model export, back ground shape file, basin model, meteorological created and finally HMS is created. Now the project is ready for Export to HEC-HMS as shown in figure 4.2.

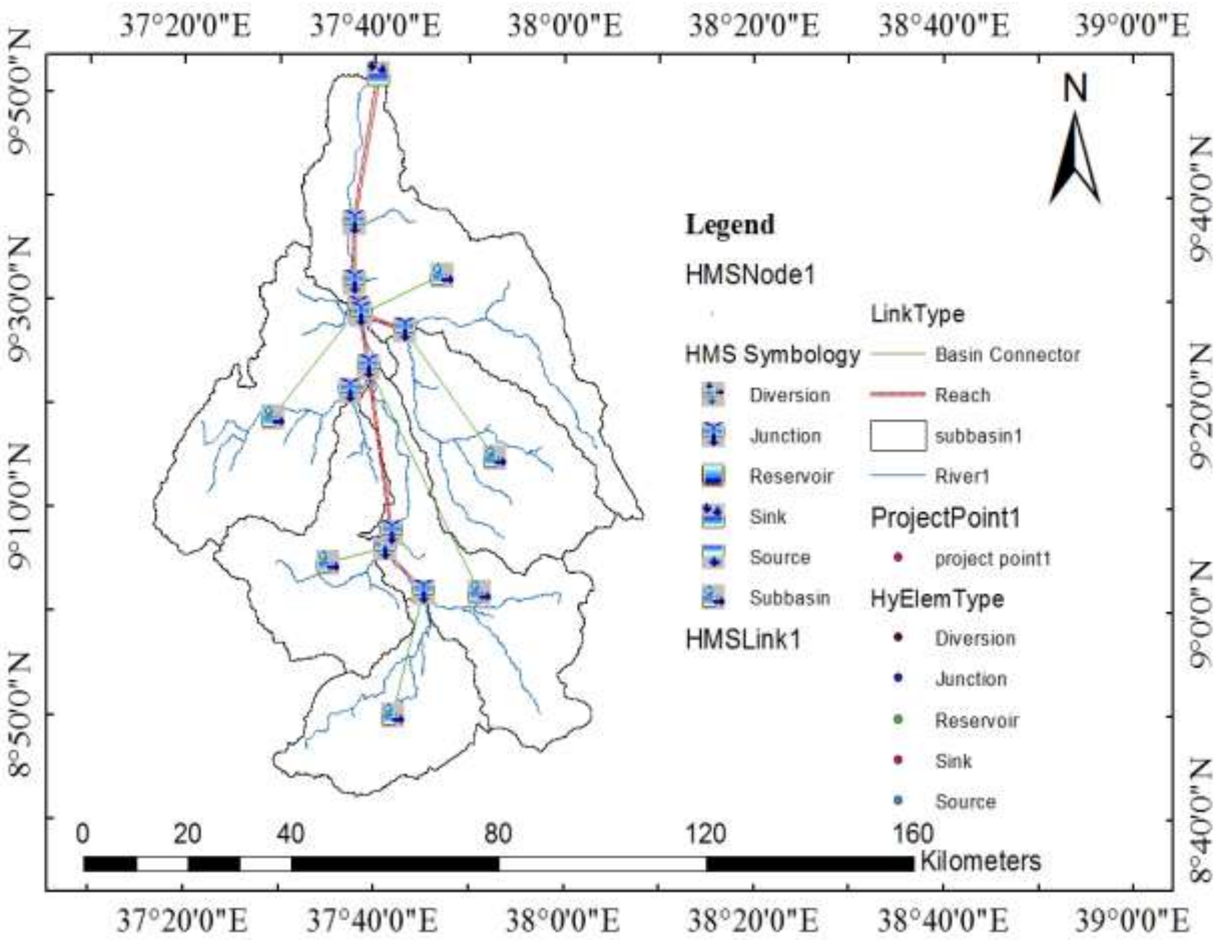


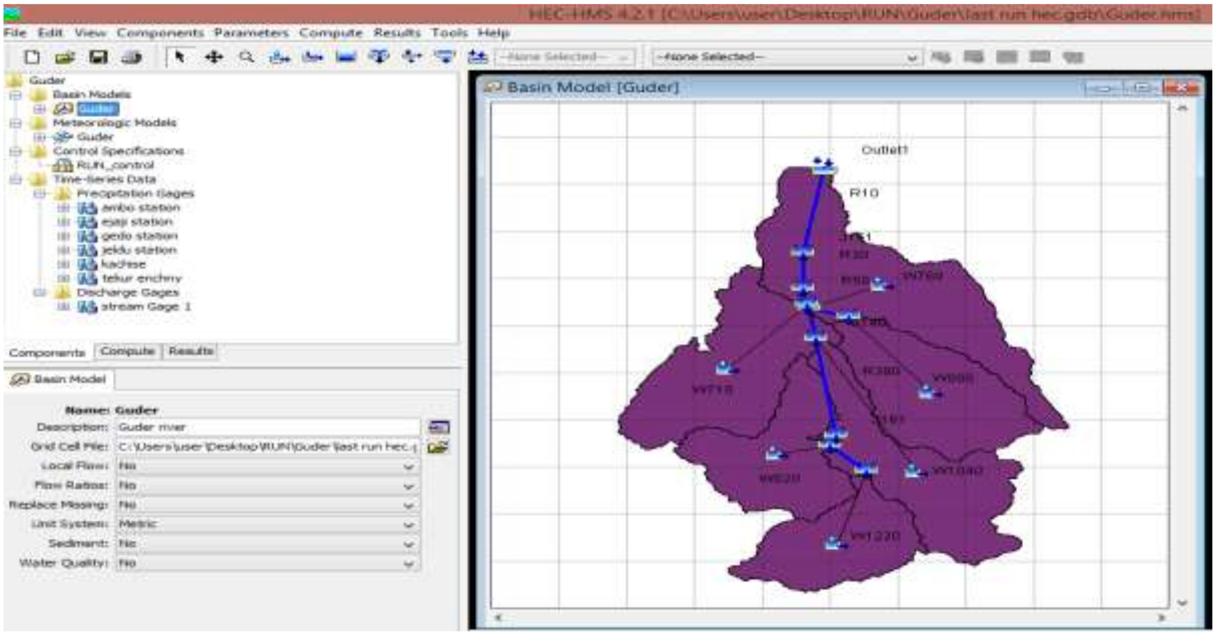
Figure 4. 2: HMS legend and Created HEC-HMS Project.

The output from terrain processing in Arc Hydro and hydrologic processing in HEC-Geo HMS is not only delineation and schematic for the catchment but also extraction of basin characteristics from physical properties of the catchment. Among the basin characteristics soil and land use are the major ones. According to the output from the model the following parameters are created (table4.1).

Table 4. 1: Catchment characteristic parameters extracted with Arc Hydro and HEC-Geo HMS

Sub-basin name	Parameter	Unit	Value
W710	CN	Dimensionless	74.7
	Ia	mm	17.2
	Im	%	0.0
	Lag time	Min	493.75
W760	CN	Dimensionless	70.9
	Ia	mm	20.9
	Im	%	0.0
	Lag time	Min	134.95
W800	CN	Dimensionless	82.9
	Ia	mm	10.5
	Im	%	0.0
	Lag time	Min	295.85
W820	CN	Dimensionless	76.6
	Ia	mm	15.5
	Im	%	0.0
	Lag time	Min	189.52
W1040	CN	Dimensionless	81.9
	Ia	mm	11.2
	Im	%	0.0
	Lag time	Min	373.8
W1220	CN	Dimensionless	80.2
	Ia	mm	12.5
	Im	%	0.0
	Lag time	Min	218.34

The average weighted curve number(CN) for each sub-basin was computed using sub-basin parameter tool of HEC-Geo HMS. The result indicates that the curve number(CN) values for sub-basin W710,W760,W800,W820,W1040 and W1220 were 74.7, 70.9, 82.9, 76.6, 81.9, 80.2 respectively. The maximum and minimum values of CN were 82.9 and 70.9 for su-basin W800 and W760 respectively. These values shows that the Guder watershed generates more runoff for a given rainfall in areas having greater curve number(CN) values. Because sub-basin with high curve number value will produce high runoff potential. According to table 4.1 maximum and minimum runoff potential were generated in sub-basin W800 and sub-basin W760 respectively.



Name: Guder
Description: Guder river
Grid Cell File: C:\Users\user\Desktop\RUN\Guder\last run hec.
Local Flow: No
Flow Ratios: No
Replace Missing: No
Unit System: Metric
Sediment: No
Water Quality: No

Figure 4. 3: HEC-HMS schematic imported from HEC-Geo HMS

4.3 HEC-HMS Simulation

The rainfall-runoff modeling of Guder river watershed was conducted using SCS curve number(CN), SCS unit hydrograph transform, Muskingum routing and constant monthly base flow. The initial values of parameters was obtained from the catchment characteristics which are extracted using Arc-GIS software, Arc hydro and HEC-Geo HMS tool. Using the initial parameters values the HEC-HMS model was ran and captured the hydrograph pattern.

The first simulation result was investigated and there is the deference between simulated hydrograph and observed hydrograph or there is mismatch between observed and simulated hydrograph (figure 4.4). The model performance was evaluated using the three statistical tests of error functions and the result was under estimated with Nash-Sutcliffe(NSE) of -0.458, Coefficient of determination(R^2) of 0.497 and Root mean square error(RSME) of 37.7m^3/s. This error can be improved by model calibration and the mismatch between simulated and observed hydrograph can be also improved through model calibration. The hydrograph of observed flow and simulated flow by using initial parameter before calibration is shown in figure 4.4 as follow.

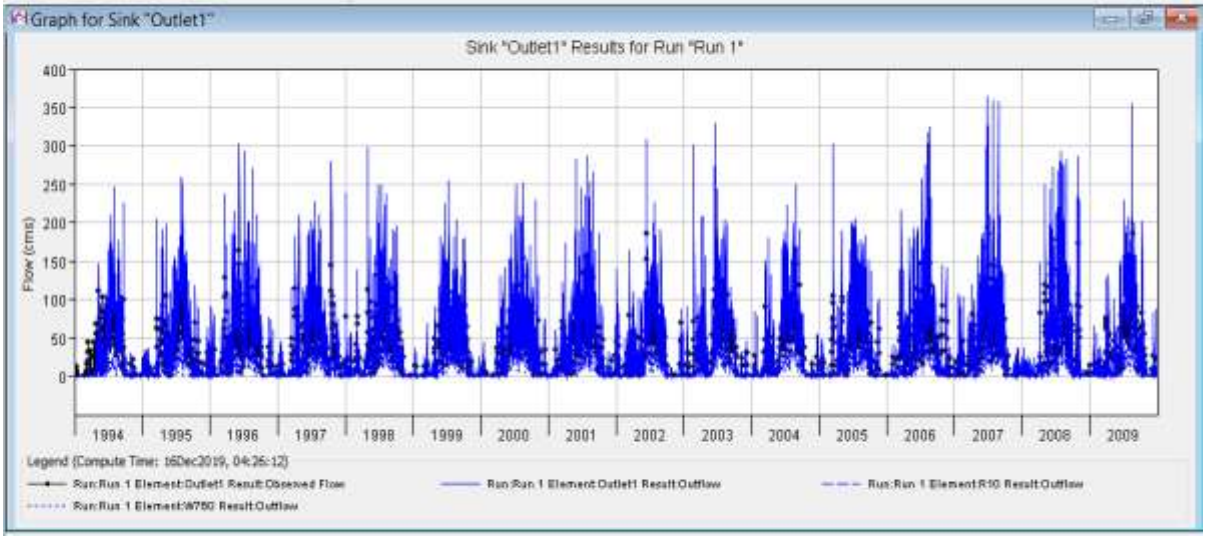
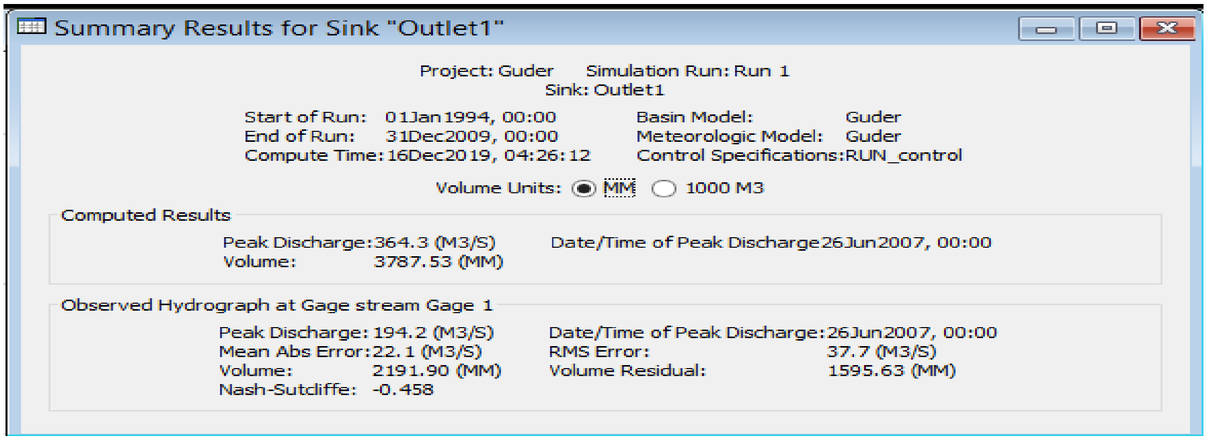


Figure 4. 4: Observed discharge versus simulated discharge by using initial parameters value for simulation(without calibration).



Summary Results for Sink "Outlet1"

Project: Guder Simulation Run: Run 1
Sink: Outlet1

Start of Run: 01Jan1994, 00:00
End of Run: 31Dec2009, 00:00
Compute Time: 16Dec2019, 04:26:12

Basin Model: Guder
Meteorologic Model: Guder
Control Specifications: RUN_control

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 364.3 (M3/S)
Volume: 3787.53 (MM)
Date/Time of Peak Discharge 26Jun2007, 00:00

Observed Hydrograph at Gage stream Gage 1

Peak Discharge: 194.2 (M3/S)
Mean Abs Error: 22.1 (M3/S)
Volume: 2191.90 (MM)
Nash-Sutcliffe: -0.458
Date/Time of Peak Discharge: 26Jun2007, 00:00
RMS Error: 37.7 (M3/S)
Volume Residual: 1595.63 (MM)

Figure 4. 5: Summary Results for sink: outlet before calibration

4.3.1 HEC-HMS Calibration

HEC-HMS calibration was performed for a period of ten years (01 January1994 to 31 December 2003) on the Guder river watershed of the area using daily flows basis. The long period of observed flow was selected for model calibration. The model calibration period should have both dry and wet extremes.

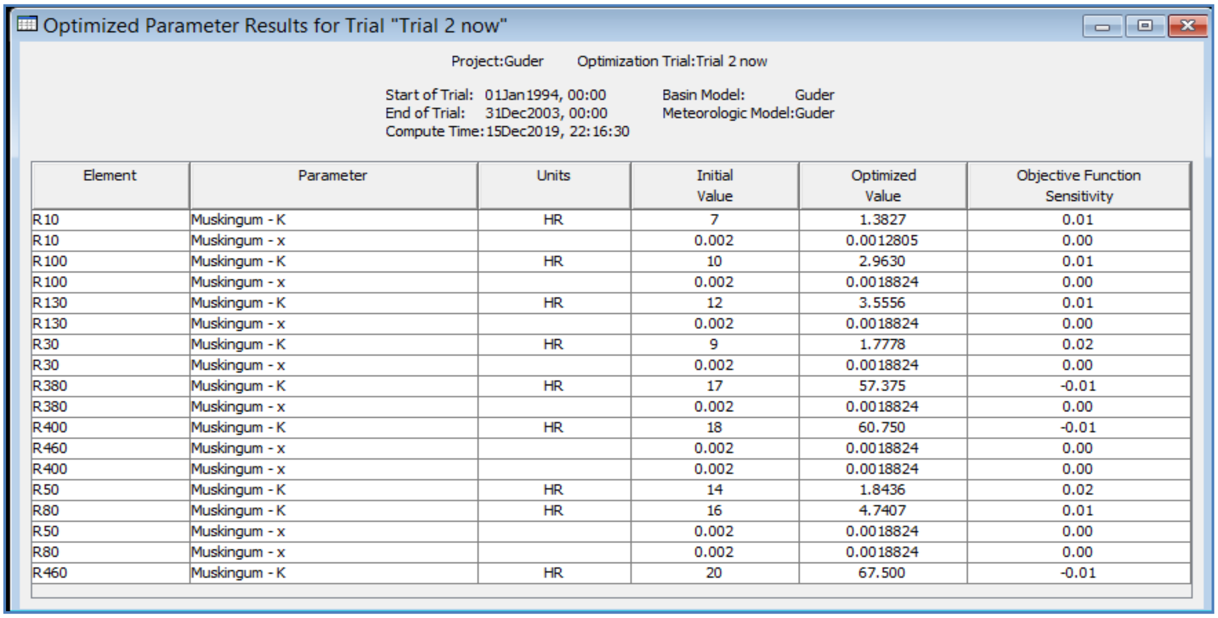
Sensitivity analysis was conducted to determine the most sensitive parameter that affects runoff model. The objective was to minimize the number of parameters that was estimated by optimization. The parameters checked for sensitivity for this study are: - SCS Curve number, SCS unit hydrograph-lag time, SCS curve number-initial abstraction, Muskingum K and Muskingum x.

The initial values of these parameters were entered into HEC-HMS manually. Initially, the simulation was done with model input values and the output was collected. Then simulation was run by varying each of the above parameter within prescribed range keeping the other constant. The output values were analyzed to determine their variations with respect to the base output set. Depend on the results the flood travel time(Muskingum-K) and weighted coefficient of discharge(Muskingum-X) were the most sensitive parameters. Calibration was carried out by considering these parameters.

The model results as obtained from the final automatic calibration using the peak weighted root mean square error objective function showed that there was a good agreement between the simulated and observed Guder watersheds. This was demonstrated by the correlation coefficient, root mean square error(RMSE) and the Nash-Sutcliffe (1970) efficiency values for watersheds.

Optimization begins from initial parameter estimates and adjusts them so that the simulated results match the observed stream flow as closely as possible. Table 4.2 indicates the initial and optimized value of parameters and objective function sensitivity value.

Table 4. 2: Optimized Parameters of HEC-HMS for Guder watershed



Project:Guder Optimization Trial:Trial 2 now

Start of Trial: 01Jan1994, 00:00
End of Trial: 31Dec2003, 00:00
Compute Time: 15Dec2019, 22:16:30

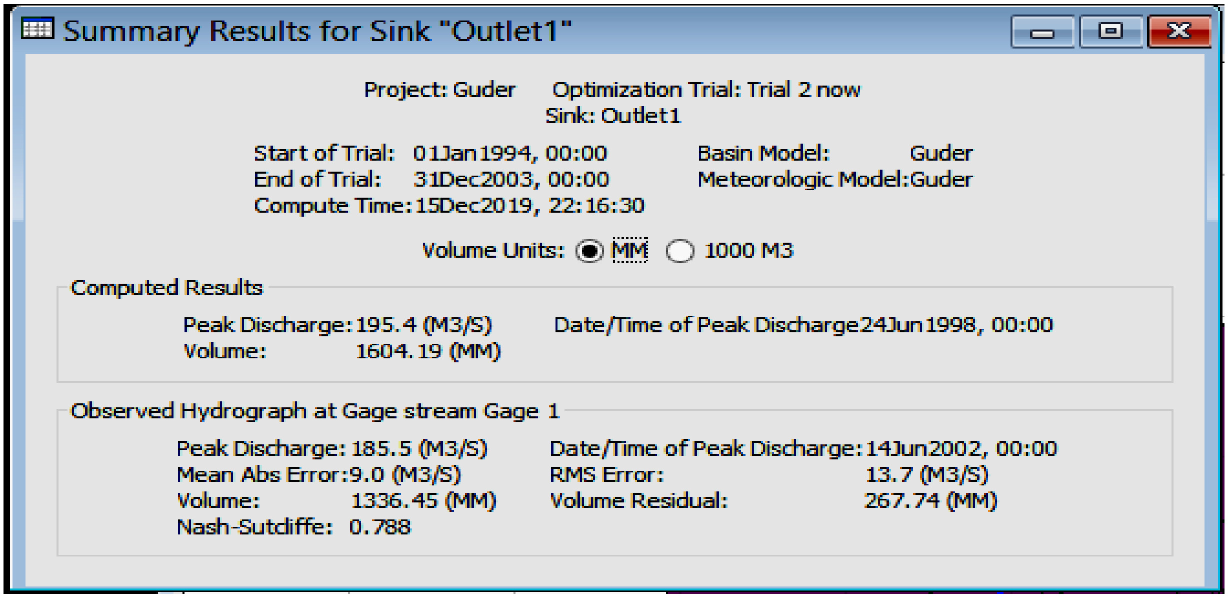
Basin Model: Guder
Meteorologic Model:Guder

Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
R10	Muskingum - K	HR	7	1.3827	0.01
R10	Muskingum - x		0.002	0.0012805	0.00
R100	Muskingum - K	HR	10	2.9630	0.01
R100	Muskingum - x		0.002	0.0018824	0.00
R130	Muskingum - K	HR	12	3.5556	0.01
R130	Muskingum - x		0.002	0.0018824	0.00
R30	Muskingum - K	HR	9	1.7778	0.02
R30	Muskingum - x		0.002	0.0018824	0.00
R380	Muskingum - K	HR	17	57.375	-0.01
R380	Muskingum - x		0.002	0.0018824	0.00
R400	Muskingum - K	HR	18	60.750	-0.01
R460	Muskingum - x		0.002	0.0018824	0.00
R400	Muskingum - x		0.002	0.0018824	0.00
R50	Muskingum - K	HR	14	1.8436	0.02
R80	Muskingum - K	HR	16	4.7407	0.01
R50	Muskingum - x		0.002	0.0018824	0.00
R80	Muskingum - x		0.002	0.0018824	0.00
R460	Muskingum - K	HR	20	67.500	-0.01

Algorithm included in the program search for the model parameters that yield the best value of an index, also known as objective function. Out of objective functions in HMS, Peak-weighted mean square error was selected for this research paper. This function is an implicit measure of comparison of the magnitudes of the peaks, volumes and times of peak of the two hydrographs. Univariate Gradient and Nelder Mead Algorithm method of search parameter that minimizes the value of the objective function. Univariate Gradient was used for this study. Finally, the optimization trail, the difference between observed and simulated hydrograph was decreased as shown in figure 4.7 and 4.8. The blue line represent the simulated hydrograph and black line represent observed hydrograph in figure 4.7. The graph shows that there was minimum difference between the simulated and observed hydrograph throughout the calibration period. The direct HEC-HMS calibration results was attached as bellow.

Table 4. 3:The objective function results of Guder watershed during calibration

Measure	Simulated	observed	deference	Percent deference
Volume(MM)	1604.19	1336.45	267.74	20.03
Peak Flow(m^{3}/s	195.4	185.5	9.9	5.3
Time of peak	24jun1998	14 jun2002		



Project: Guder Optimization Trial: Trial 2 now
Sink: Outlet1
Start of Trial: 01Jan1994, 00:00 Basin Model: Guder
End of Trial: 31Dec2003, 00:00 Meteorologic Model:Guder
Compute Time:15Dec2019, 22:16:30

Volume Units: ● MM ○ 1000 M3

Computed Results
Peak Discharge:195.4 (M3/S) Date/Time of Peak Discharge24Jun1998, 00:00
Volume: 1604.19 (MM)

Observed Hydrograph at Gage stream Gage 1
Peak Discharge: 185.5 (M3/S) Date/Time of Peak Discharge:14Jun2002, 00:00
Mean Abs Error:9.0 (M3/S) RMS Error: 13.7 (M3/S)
Volume: 1336.45 (MM) Volume Residual: 267.74 (MM)
Nash-Sutcliffe: 0.788

Figure 4. 6: Summary Results for sink: outlet during calibration

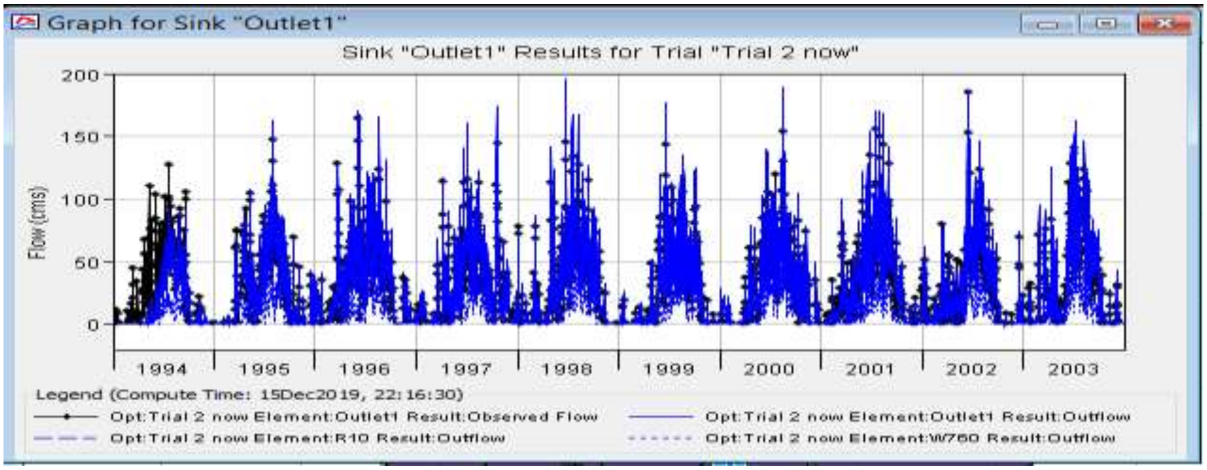


Figure 4. 7: Calibration of HEC-HMS Observed and Simulated Daily Flow Hydrographs

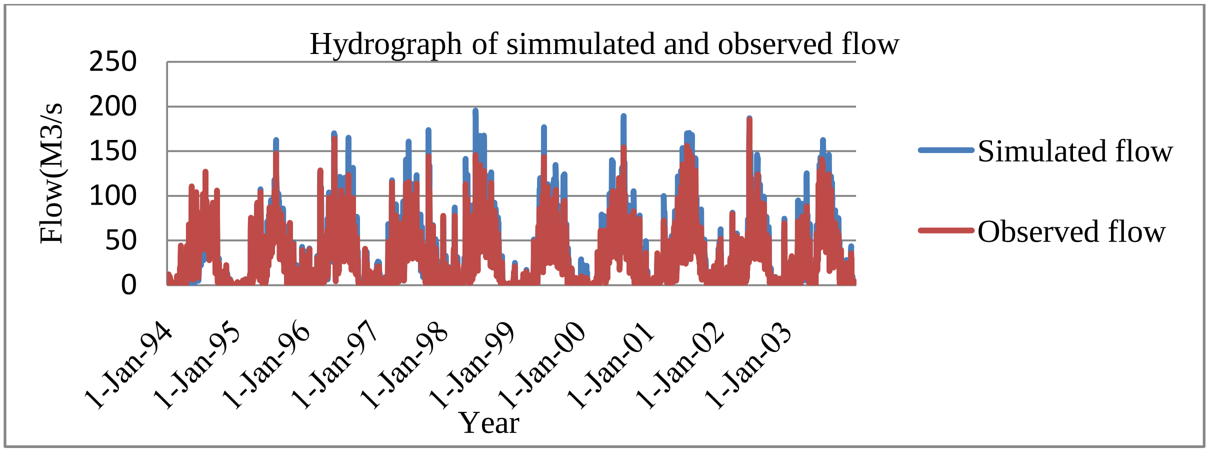


Figure 4. 8 : Daily hydrograph of simulated flow and observed flow during calibration

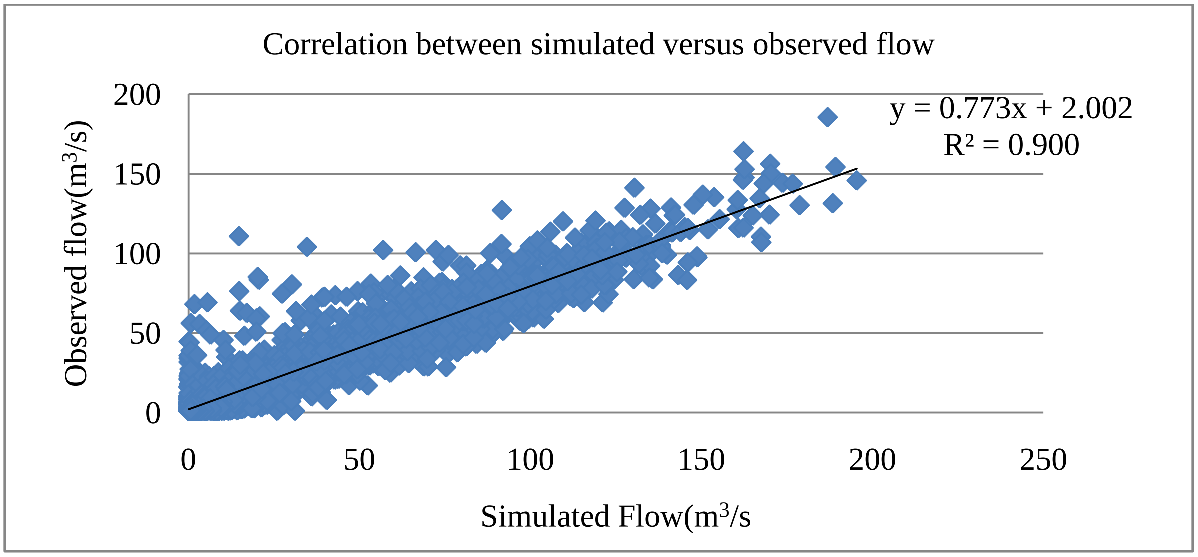


Figure 4. 9 : Correlation between simulated flow and observed flow for calibration

For the Guder watershed case the Nash-Sutcliffe (ENS) has a value of 0.788, coefficient of determination (R^2) has value of 0.900 and Root mean square error (RMSE) has value of 13.7m^3/s. Therefore, the values of the statistical test of error function indicate that there is good agreement between simulated and observed hydrograph.

The observed and simulated peak discharge during calibration were 185.5m^3/s and 195.4m^3/s respectively and the difference between simulated and observed discharges were 9.9m^3/s (table 4.3). This indicates that peak discharge was well predicted during the calibration of the model.

4.3.2 HEC-HMS Validation

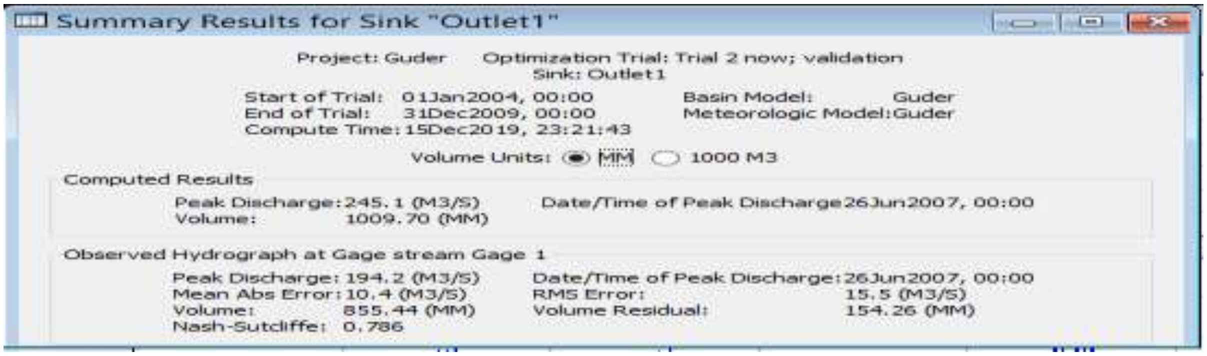
Model validation is processes of testing model ability to simulate observe data other than those use for calibration, with acceptable accuracy. During this process, calibrated model parameters are not subject to change, their values are kept constant.

For this study, to validate the model data of 6 years (01Jan 2004 to 31Dec 2009) was used by applying the optimized parameters in the calibration process. After processing the input data the model was generated very good results without any parameter adjustment.

The output of the validation process has a value of the Nash-Sutcliffe (ENS) 0.786, coefficient of determination (R^2) of 0.873 and Root mean square error of 15.5m^3/s. The values of the statistical test of error function indicate that there is good agreement between simulated and observed hydrograph during validation process. The statistical test of error functions justifies the soundness of HEC-HMS model for simulation of Rainfall-runoff for Guder watershed.

The simulated and observed peak discharge were 245.1m^3/s and 194.2m^3/s respectively and the difference between simulated and observed discharge was 50.9m^3/s (table 4.4). This indicate that the peak discharge was slightly over predicted by the model.

Generally, the calibration and validation results of the model was NSE, R^2 and RMSE were found to be 0.788,0.900 and13.7m^3/s for calibration and 0.786, 0.873 and15.5m^3/s for validation respectively. Therefore, HEC-HMS model has performed well in simulating rainfall-runoff for study area.



Summary Results for Sink "Outlet1"

Project: Guder   Optimization Trial: Trial 2 now; validation
Sink: Outlet1

Start of Trial: 01Jan2004, 00:00   Basin Model: Guder
End of Trial: 31Dec2009, 00:00   Meteorologic Model: Guder
Compute Time: 15Dec2019, 23:21:43

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge: 245.1 (M3/S)   Date/Time of Peak Discharge 26Jun2007, 00:00
Volume: 1009.70 (MM)

Observed Hydrograph at Gage stream Gage 1

Peak Discharge: 194.2 (M3/S)   Date/Time of Peak Discharge: 26Jun2007, 00:00
Mean Abs Error: 10.4 (M3/S)   RMS Error: 15.5 (M3/S)
Volume: 855.44 (MM)   Volume Residual: 154.26 (MM)
Nash-Sutcliffe: 0.786

Figure 4. 10: Summary Results for sink: outlet1 during validation

Table 4. 4:The objective function results of Guder watershed during validation

Measure	Simulated	observed	Difference	Percent deference
Volume(MM)	1009.70	855.44	154.24	18.03
Peak Flow(m^3/s)	245.1	194.2	50.9	26.2
Time of peak	26jun2007	26 jun2007		

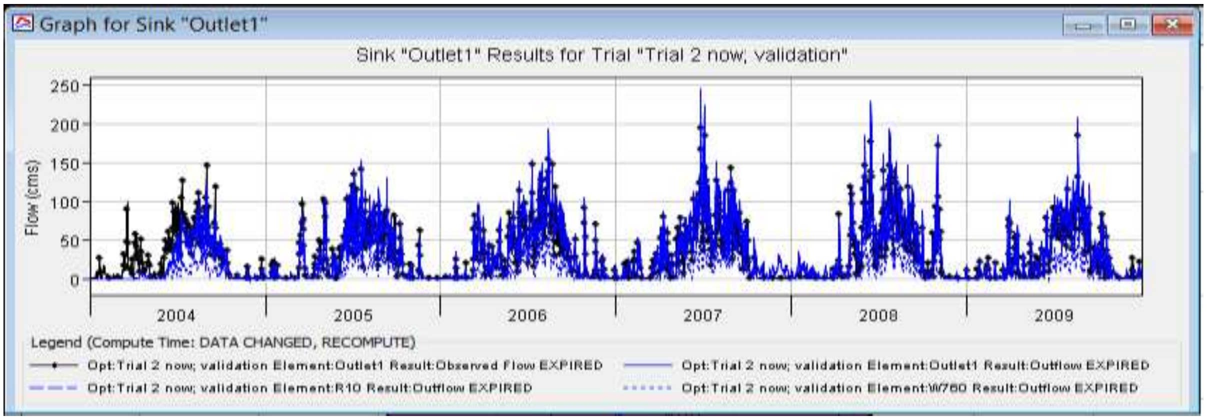


Figure 4. 11: Validation of HEC-HMS Observed and Simulated Daily Flow Hydrographs

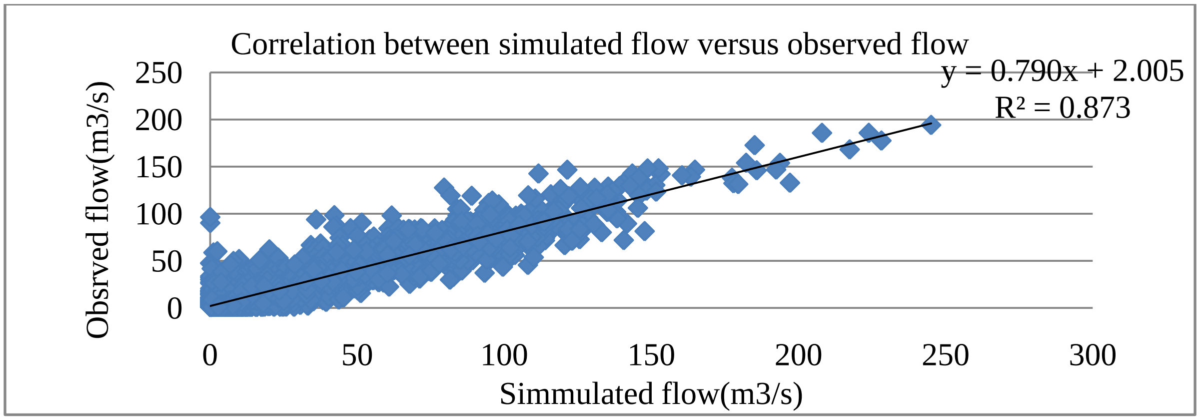


Figure 4. 12 : Correlation between simulated flow and observed flow for validation

4.4 Daily Run off potential of watershed

The runoff depends on total precipitation, evaporation and soil water storage. The objectives of checking the performance of any runoff hydrological model are to estimate the watershed runoff yield in hourly, daily, monthly and yearly basis. Estimating the amount of runoff potential from watershed is important in construction of any hydraulic structures at the outlet of watershed. The daily runoff potential of the was generated after calibration and validation of the model. The maximum peak discharge for different hydrologic element was computed using validated HEC-HMS model.

The daily runoff potential of the Guder watershed was generated from 01january 1987 to 31 December 2017.

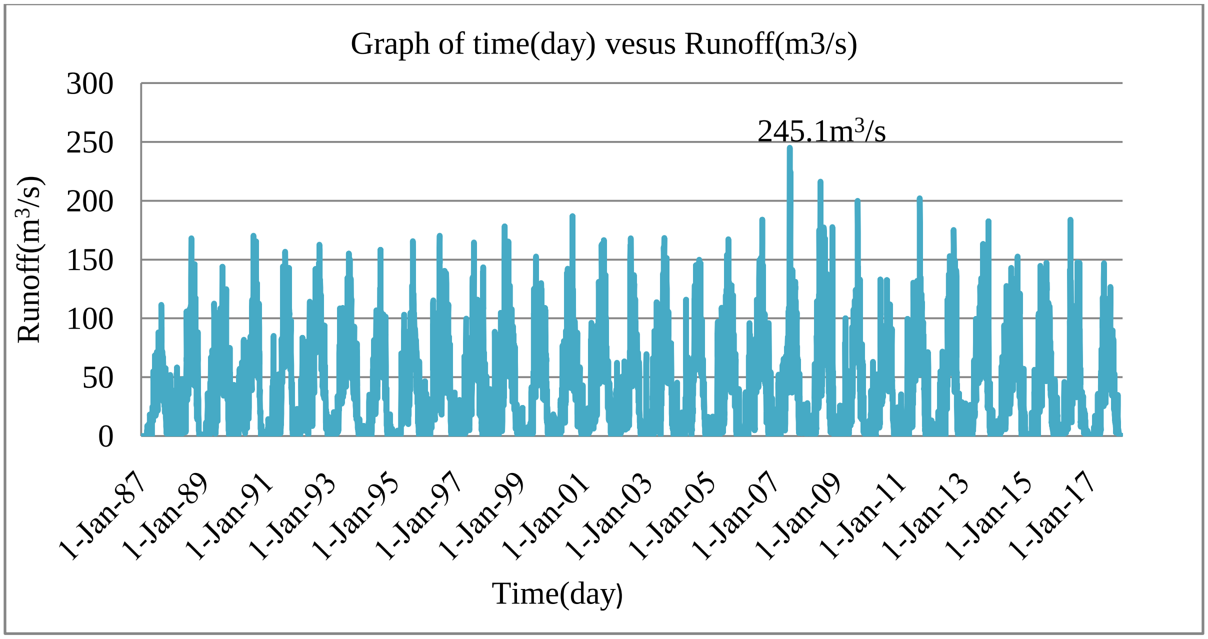


Figure 4. 13 : Daily runoff potential of Guder Catchment

The result is indicates that the maximum simulated value of runoff from the Guder watershed was 245.1m^3/s and the minimum simulated runoff value of Guder watershed was 0m^3/s.

4.5 Output of HEC-HMS by Frequency Storm

The model has a capability to produce and generate peak flow for different return periods. By using the parameters obtained from the daily basis the model results peak flows for the following return periods 2,10,25,50 and 100 years and the flow values are found accordingly. From the result table the minimum peak flow for the Guder river is occurred for 2 years return period for 24 hours storm duration and the maximum occurred with 100 years frequency for 24 hours storm duration. The value being 174.7m^3/s and 879.8m^3/s for 2 year and 100-year frequency respectively.

Table 4. 5: Determination of Peak flow using HEC-HMS Frequency Method

S.No	Return period(years)	Peak flow(m^3/s)
1	2	174.7
2	10	351.9
3	25	525.3
4	50	685.3
5	100	879.8

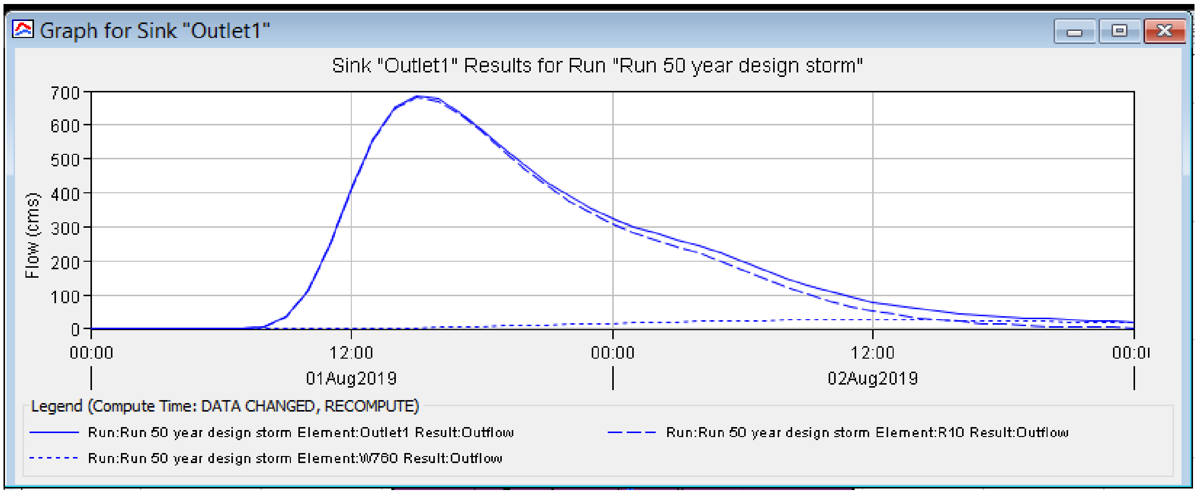


Figure 4. 14: 50 year HEC-HMS Frequency storm Flow of Guder

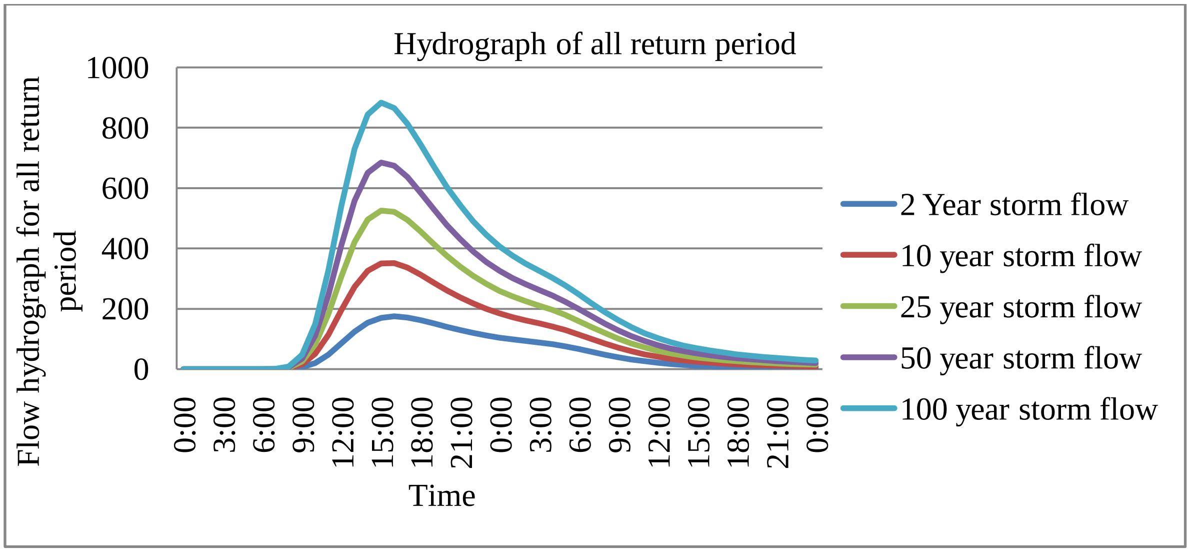


Figure 4. 15 : Hydrograph of resulted flow from frequency analysis in HEC-HMS

4.5.1 Comparison of HEC-HMS results with other frequency methods

The HEC-HMS model result was compared with the frequency analysis results considering different techniques. They are selected using software called Easy Fit Software for selection of methods. The Easy Fit software was used to select the best probability distribution methods for the observed data. According to the output the following three methods are selected. such as:- General extreme value(GEV) method, Log-Pearson III method and Log-Normal methods. The peak discharge from probability distribution and HEC-HMS are shown in the table below.

Table 4. 6: Comparison of peak discharge from probability distribution and HEC-HMS

Return period	Peak discharge(m^3/s)			
	Log-Pearson(III)	Log-Normal	GEV	HEC-HMS
2	140.423	175.365	151.156	174.7
10	321.436	268.84	279.669	351.9
25	488.88	365.06	422.79	525.3
50	644.16	475.03	546.386	685.3
100	830.64	580.21	660.693	879.8

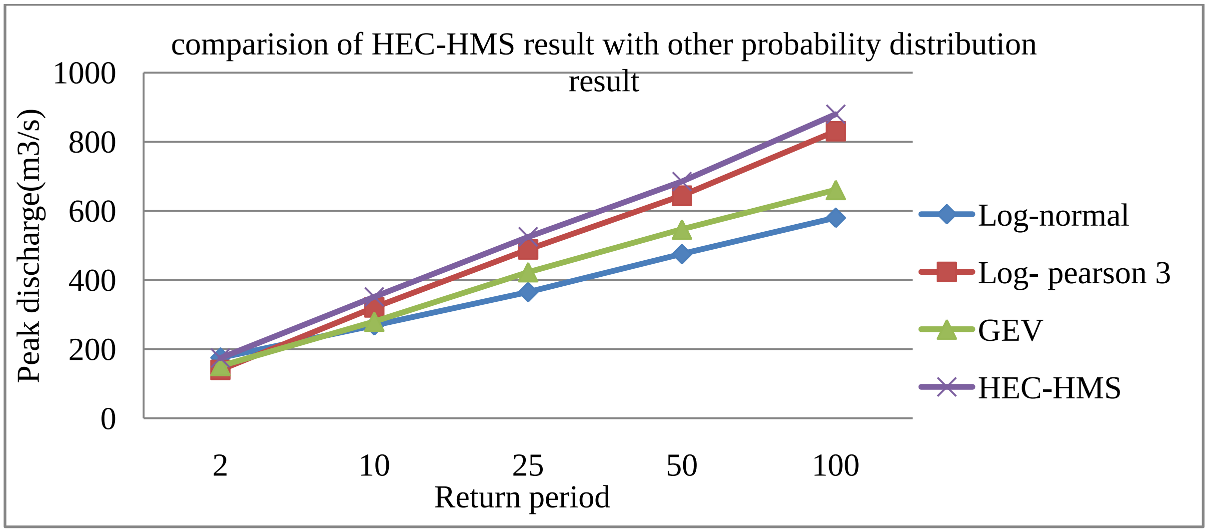


Figure 4. 16 : Comparison of probability distribution with HEC-HMS

Based on the above results frequency discharge value derived using Log-Pearson(III) method show high similarity with the HEC-HMS than other probability distribution methods. This shows, there is good performance of HEC-HMS model in frequency analysis of study area.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Modeling of rainfall-runoff process in Guder watershed by using HEC-HMS hydrological model is the main objective of this research. The model is based on the hydrological characteristics, soil type and land use of the study area. The soil conservation service-curve number(SCS-CN) is selected to calculate loss rate, soil conservation service unit hydrograph(SCS-UH) have been applied to simulate the runoff rate, constant monthly base flow for base flow estimation and Muskingum routing have been applied to route the channel for hydrological modeling.

Basin characteristics and initial values were analyzed using Arc hydro and HEC-Geo HMS in ArcGIS in order to start the model calibration. The rainfall-runoff simulation was conducted using initial parameter, the results showed that there is a difference between observed and simulated flows and volumes in the study area. Therefore, the model calibration was conducted to optimize the parameters. To know the most influential parameter in the simulation a sensitivity analysis was carried out. The analysis shows that the Muskingum K and X were more sensitive parameters. From the different objective functions available in HEC optimization manager, root mean square error(RMSE) was used for this study. From two Algorithm method of search parameter that minimizes the value of the objective function univariate Gradient was used for this study.

After optimization the peak flow and total volume of all are close to the observed peak and volume. Overall performance of the HEC-HMS model was good in terms of relative error functions, Nash-Sutcliffe Efficiency(NSE), Root mean square error(RMSE) and Coefficient of determination(R^2) has a value of 0.788, 13.7m^3/s and 0.900 for calibration and 0.786, 0.873 and 15.5m^3/s for validation based on the selected loss, transform ,base flow and flow routing methods. The daily maximum and minimum runoff potential of Guder watershed was 245.1m^3/s and 0m^3/s respectively.

The hydrologic frequency 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 174.7m^3/s, 351.9m^3/s, 525.3m^3/s, 685.3m^3/s and 879.8m^3/s respectively. These value will be useful as input for flood mapping and flood risk assessment.

5.2 Recommendation

This study was conducted under limited data availability. Therefore, the following recommendations are made for the further studies in the future.

Flow data: There was no gauged flow data at the outlet of the river specially at downstream of the river, flow data of long time duration is also necessary for the calibration and validation of hydrologic model. In addition the hydrological, station measured historical flow data 10 years ago, so it is difficult to argue as a recent output, Therefore it's better to use the recent data for future studies.

A digital elevation model of (30*30m) was used for the delineation of the basin for this study, which has medium resolution. So, DEM which has high resolution should be used in order to improve the result.

The other thing which is highly recommended is that the metrological stations should be improved both in quality and quantity in order to improve the performance of the model. The distribution gauging station are relatively well organized rather than other portion of the upper Guder river sub-basin the quality of the data, unexpected value recording and continuous many missed value fall in question some selected station in the study. Therefore, providing well-organized recording material with trained and responsible person are very important for future studies.

The land use land cover of the watershed may change from time to time due to different factors. Therefore, the future study should be consider the effect of dynamic change in major categories of land use land cover on runoff. Effective watershed management strategies should be implemented to minimize the effect of man-made activities and natural phenomena on watershed runoff.

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ANNEXES

Appendix-A Double mass curve of stations

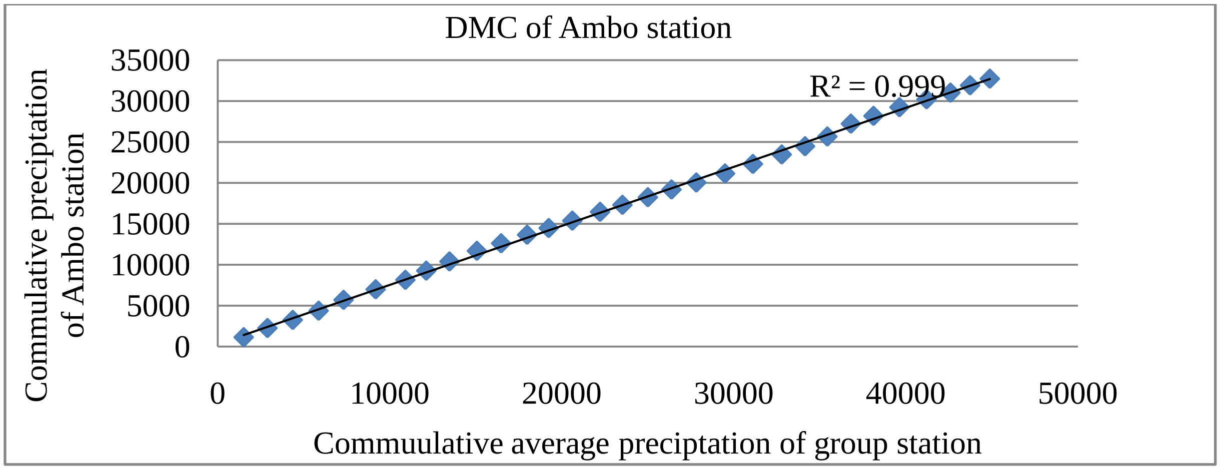


Figure A1.DMC of ambo station

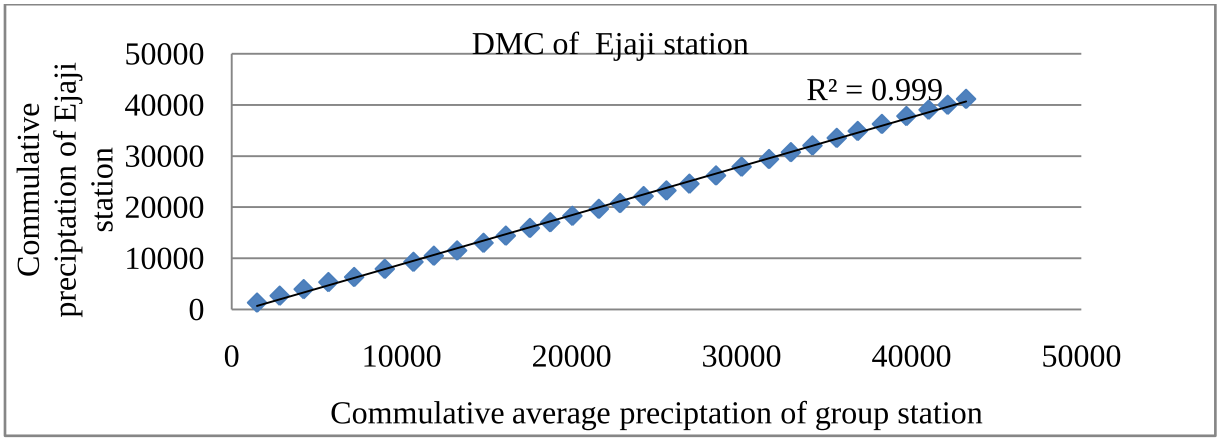


Figure A2: DMC of Ejaji station

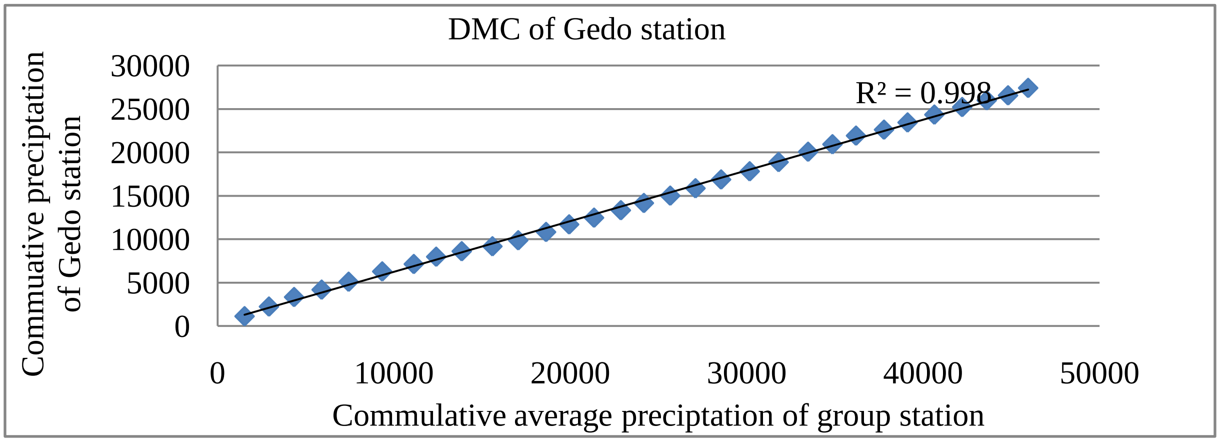


Figure A3: DMC of Gedo station

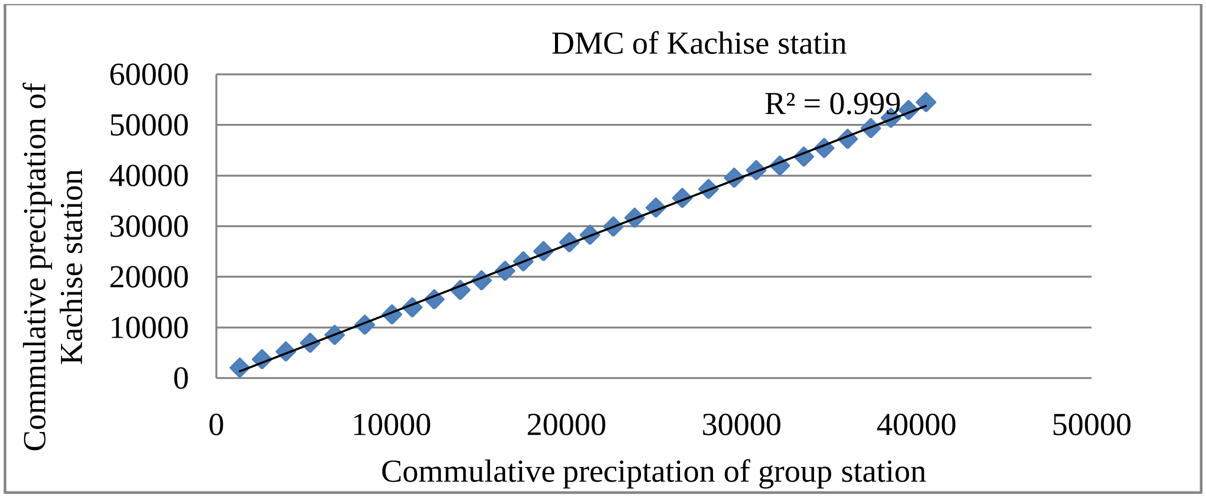


Figure A4. DMC of kachise Station

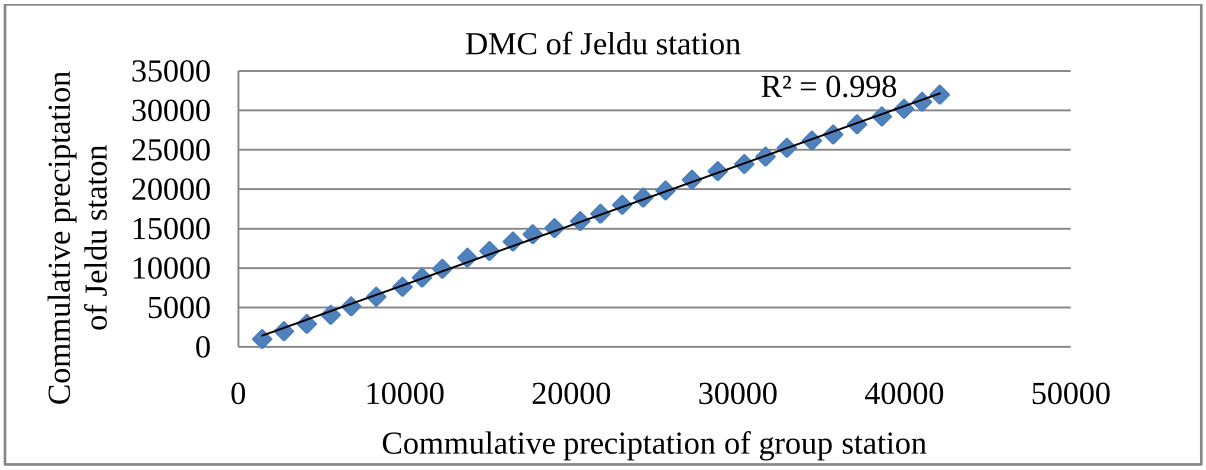


Figure A5. DMC of Jeldu Station

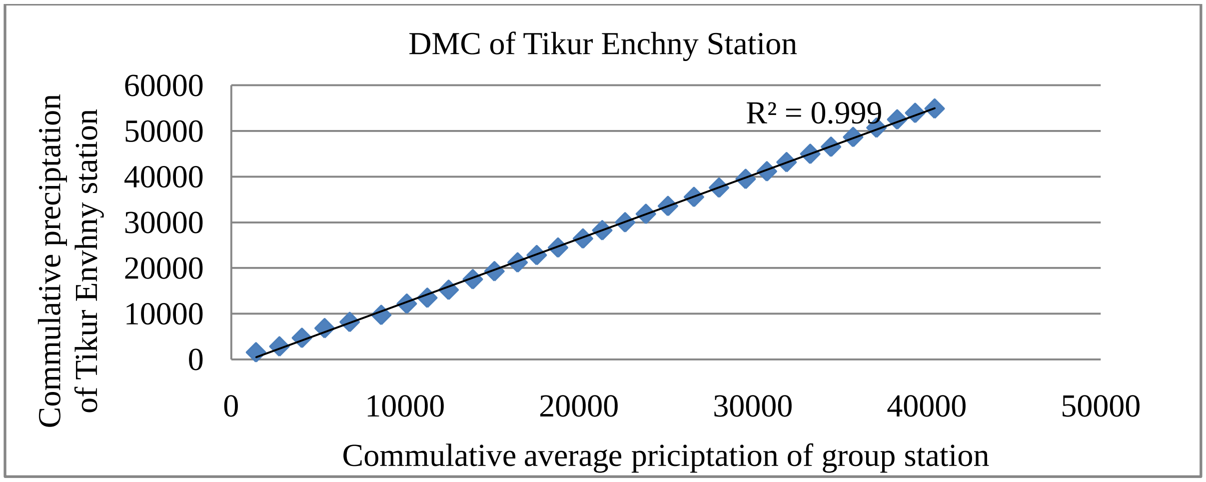
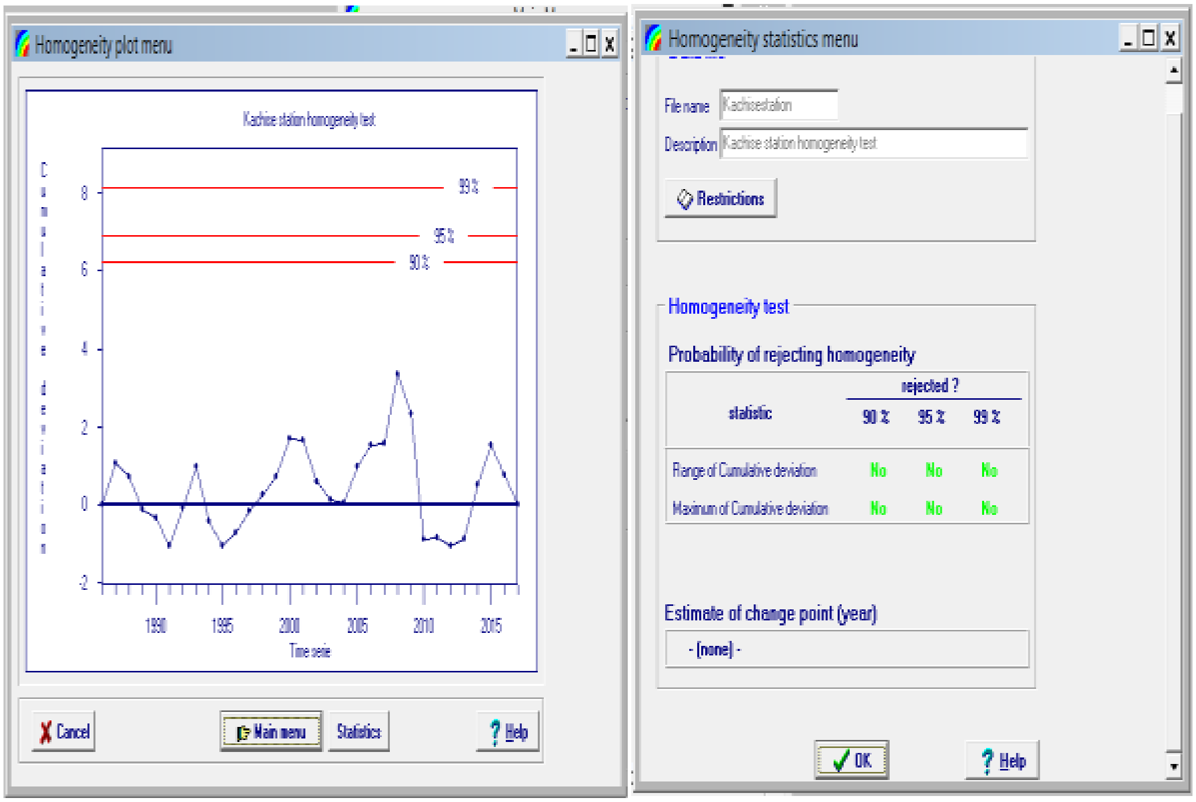


Figure A6 DMC of Tikur Enchny Station

Appendix B: Homogeneity Test Analysis



File name: Kachisestation

Description: Kachise station homogeneity test

Homogeneity test

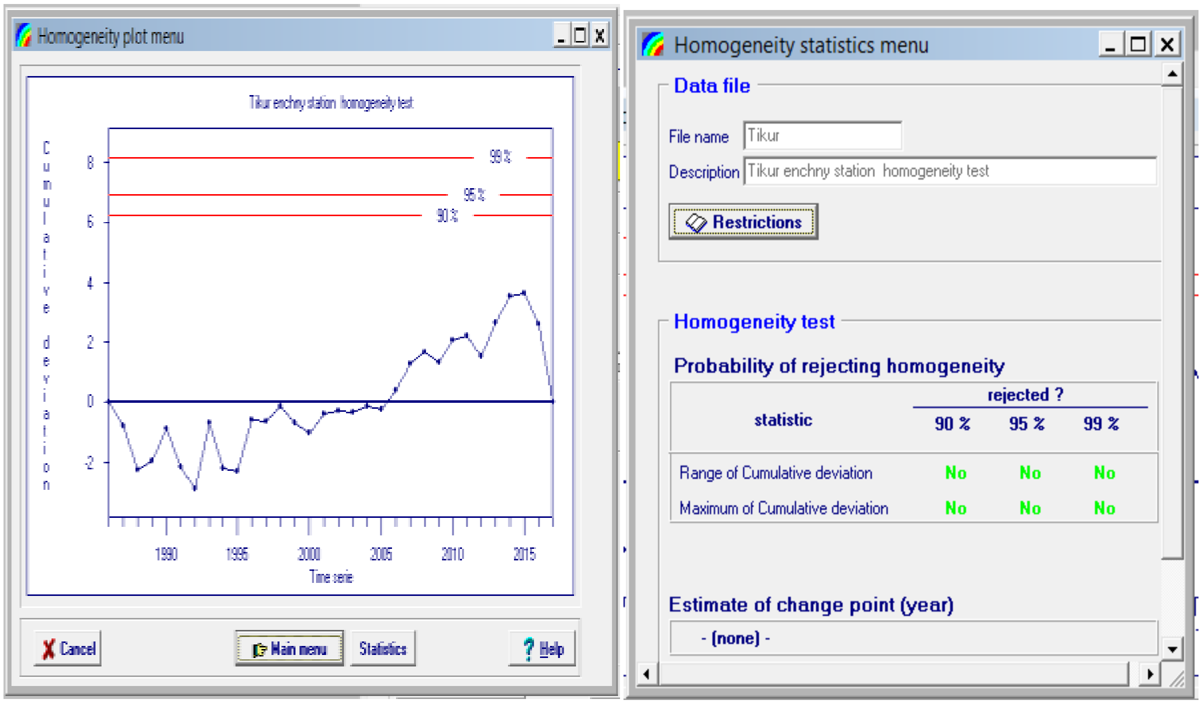
Probability of rejecting homogeneity

statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure B1 Homogeneity test results of Kachise station



Data file

File name: Tikur

Description: Tikur enchny station homogeneity test

Homogeneity test

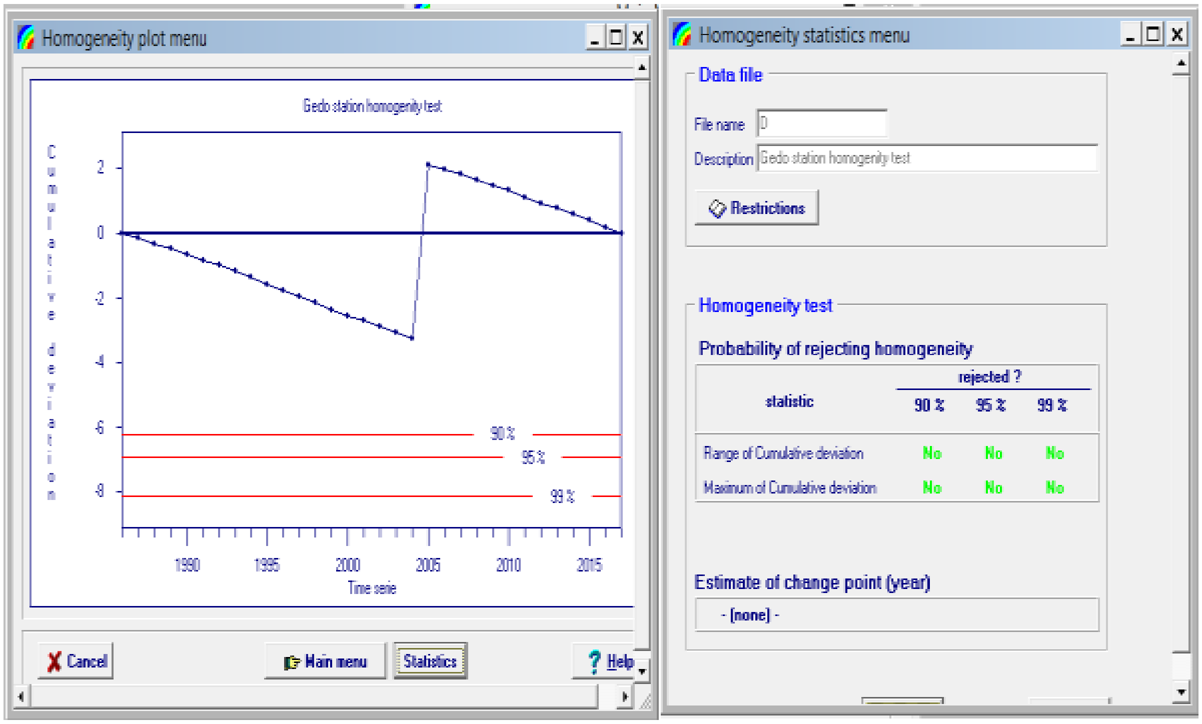
Probability of rejecting homogeneity

statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure B2 Homogeneity test results of Tekur enchny station



Data file

File name: D

Description: Gedo station homogenity test

Homogeneity test

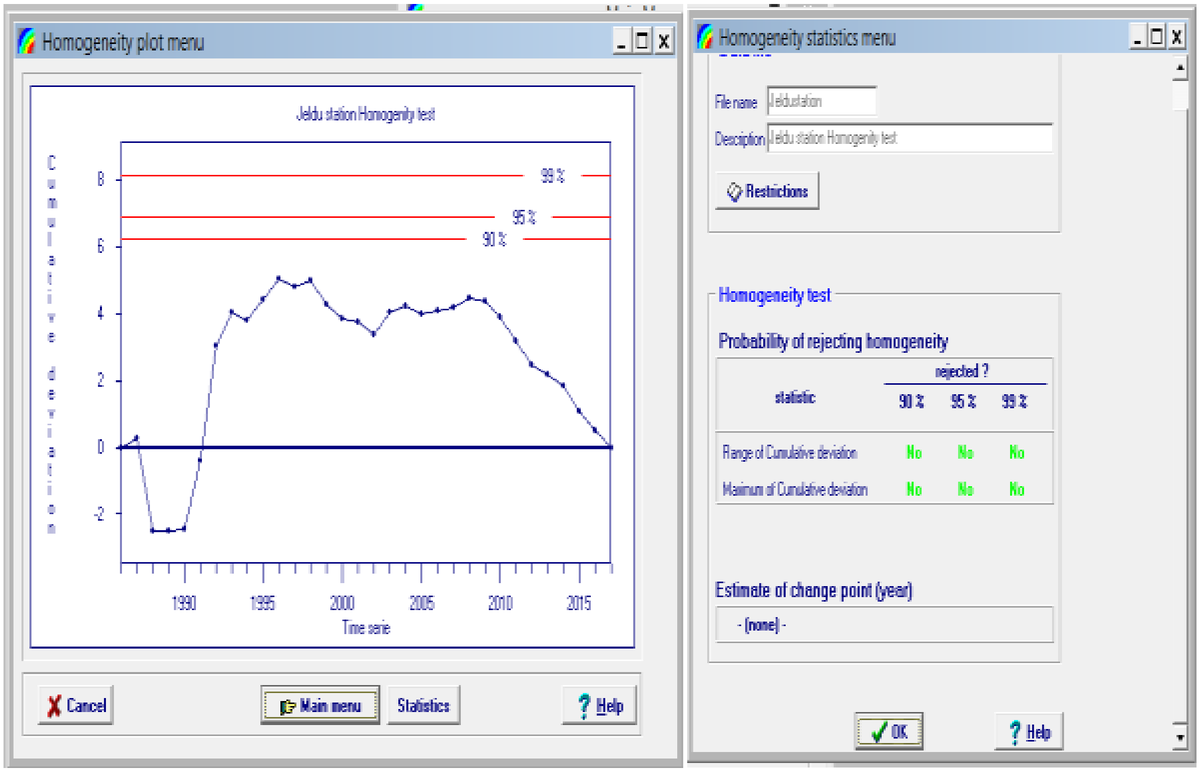
Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure B3 Homogeneity test results Gedo station



File name: Jeldustation

Description: Jeldu station Homogenity test

Homogeneity test

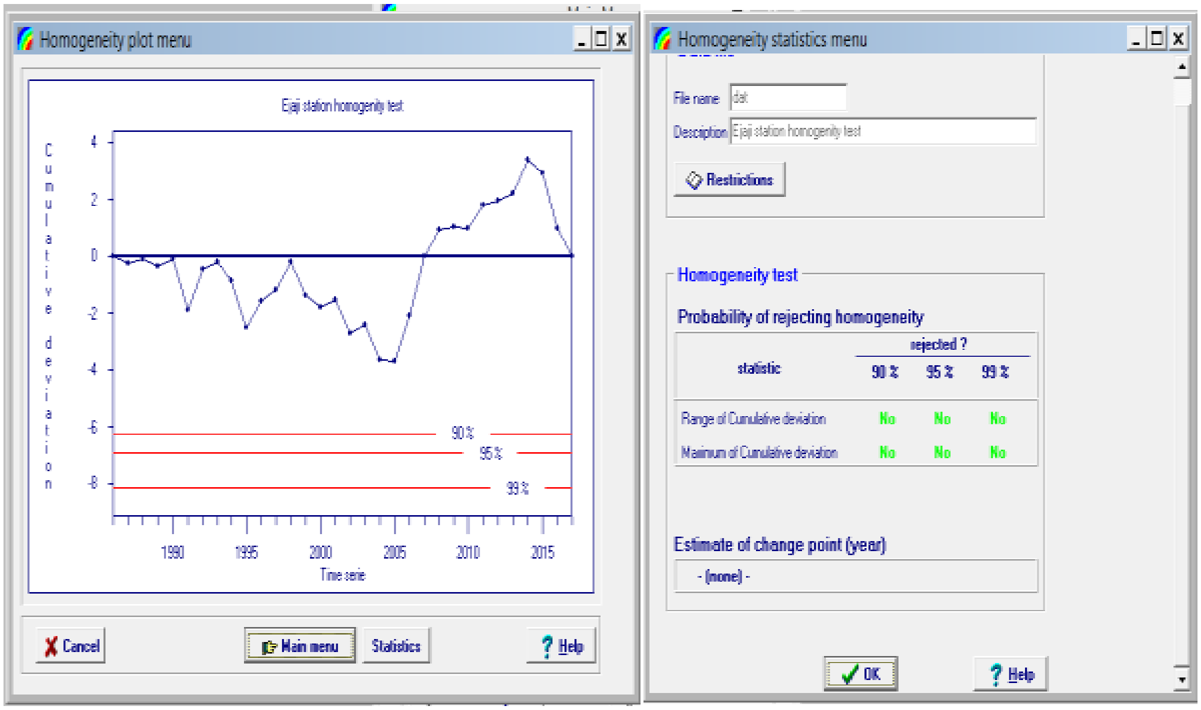
Probability of rejecting homogeneity

statistic	rejected ? 90 %	95 %	99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure B4: homogeneity test results of Jeldu station



File name: dat

Description: Ejaji station homogenity test

Homogeneity test

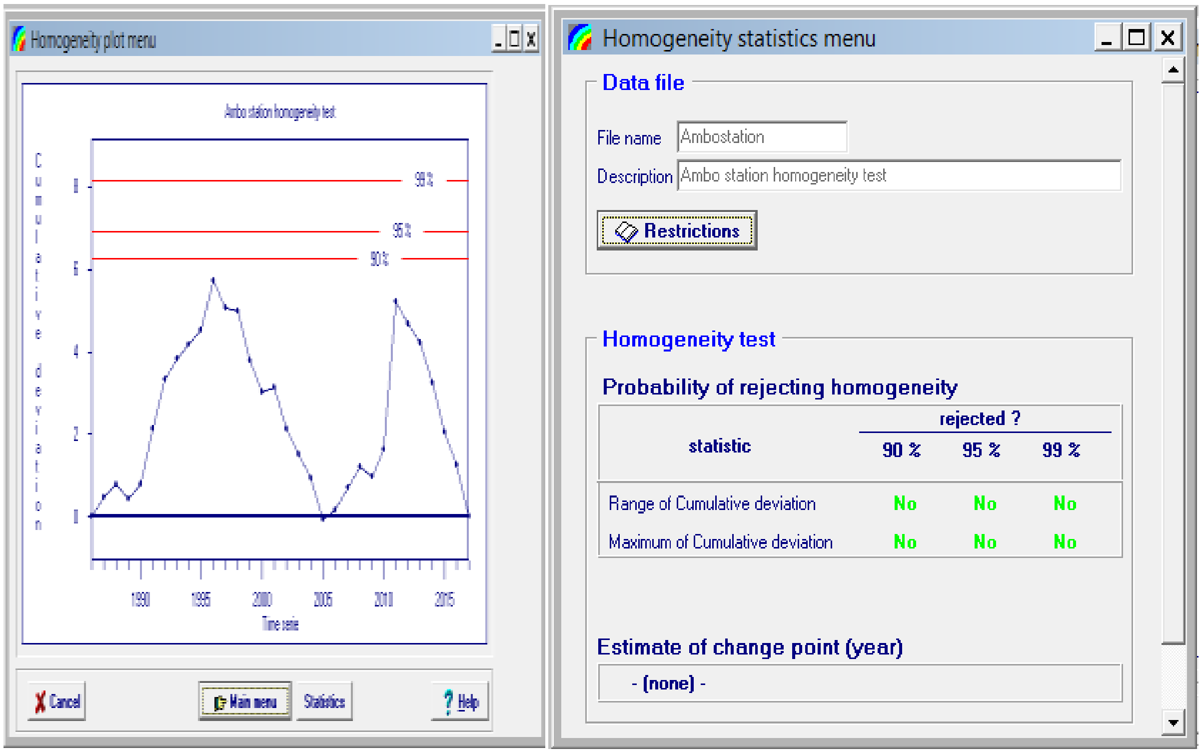
Probability of rejecting homogeneity

statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

- (none) -

Figure B5: Homogeneity test result of Ejaji station



Data file

File name: Ambostation

Description: Ambo station homogeneity test

Homogeneity test

Probability of rejecting homogeneity

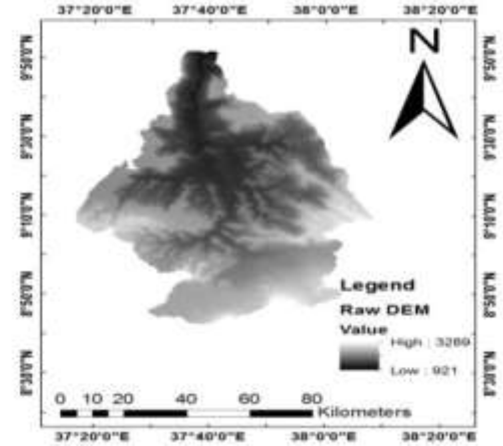
statistic	rejected ? 90 %	rejected ? 95 %	rejected ? 99 %
Range of Cumulative deviation	No	No	No
Maximum of Cumulative deviation	No	No	No

Estimate of change point (year)

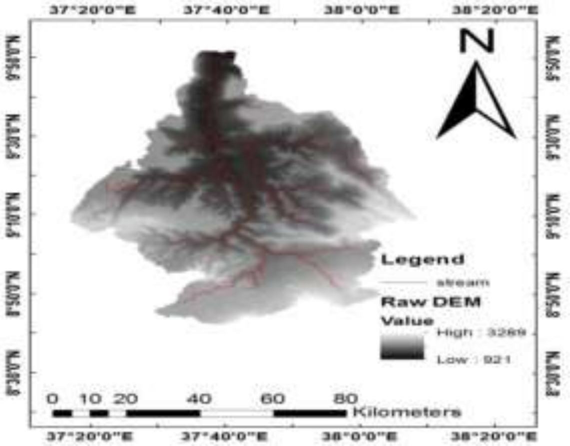
- (none) -

Figure B6: Homogeneity test results of Ambo station

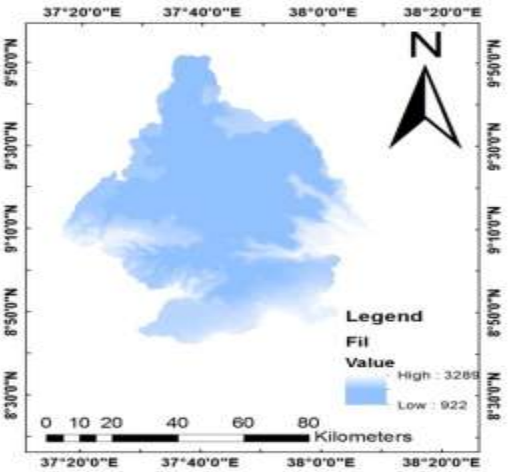
Appendix C: Terrain processing results



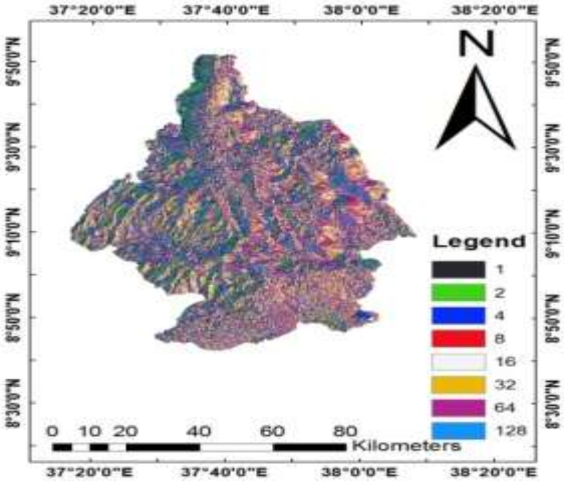
Raw DEM



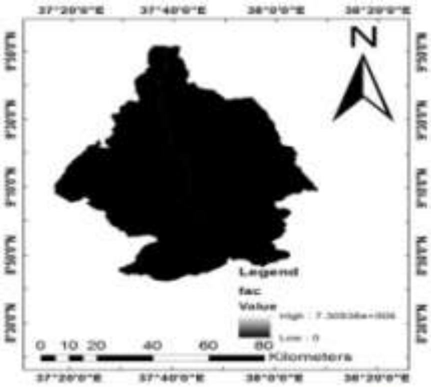
DEM Reconditioning



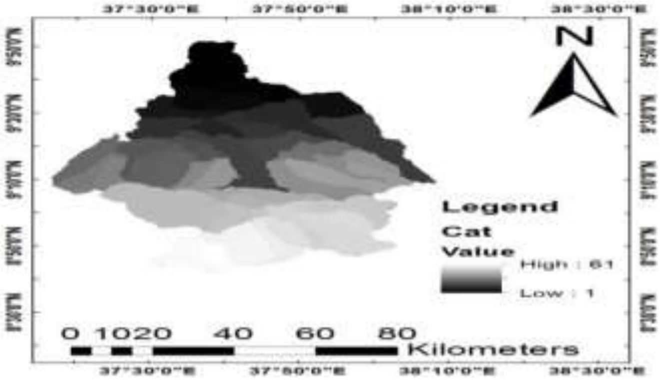
Fill sink



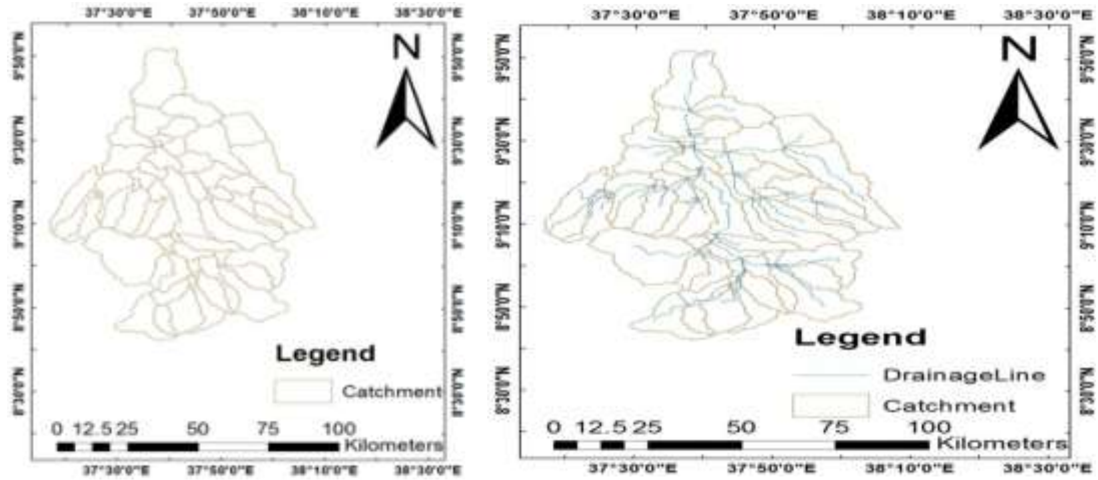
Flow direction



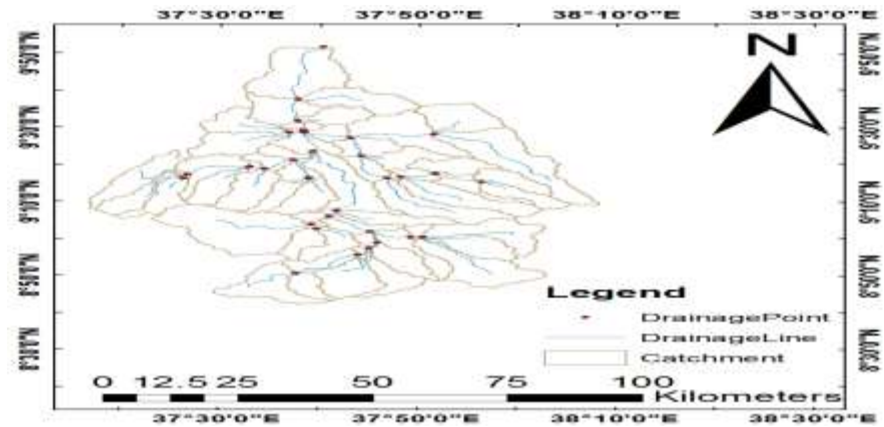
Flow accumulation



Catchment grid delineation



Catchment polygon processing Drainage line processing



Drainage point processing

Figure C1: terrain pre processing results by using Arc hydro tools

Appendix D: HEC-HMS Outputs

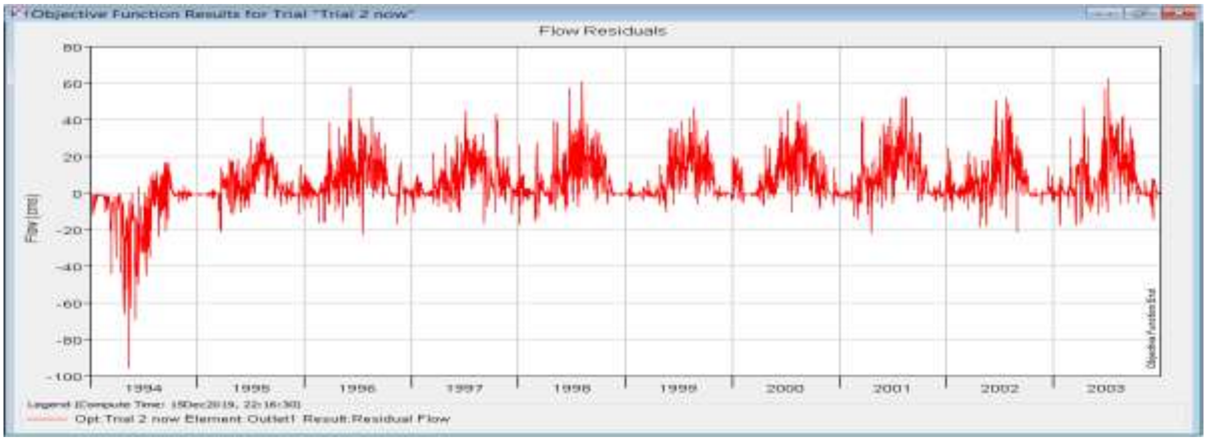


Figure D1: flow residuals during calibration

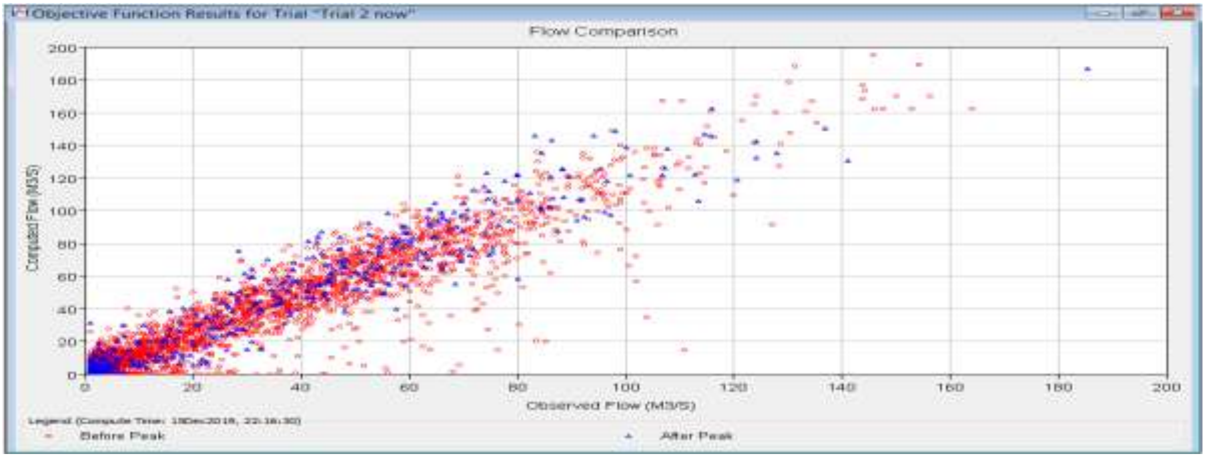


Figure D2: Observed flow Versus computed flow in calibration

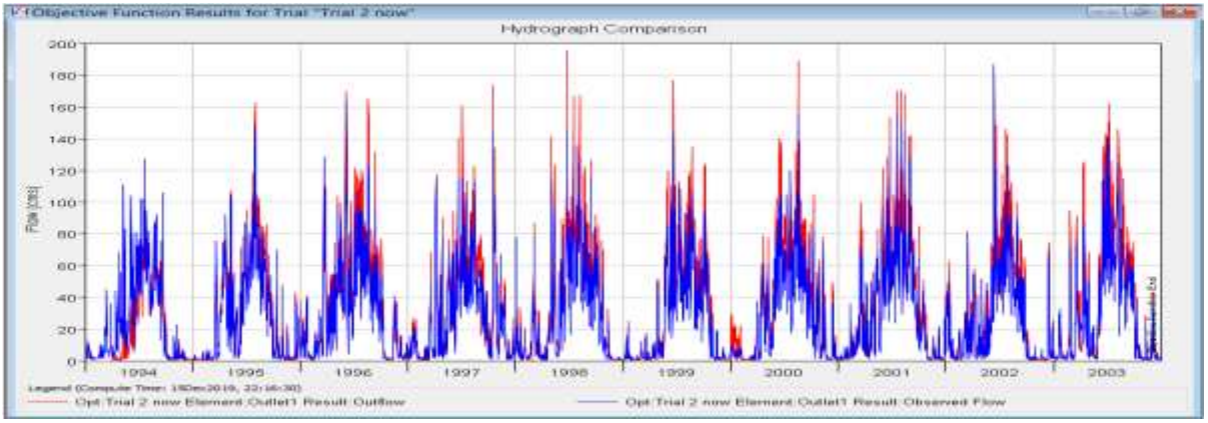


Figure D3 : Daily hydrograph comparison between resulted HEC- HMS out flow versus observed flow

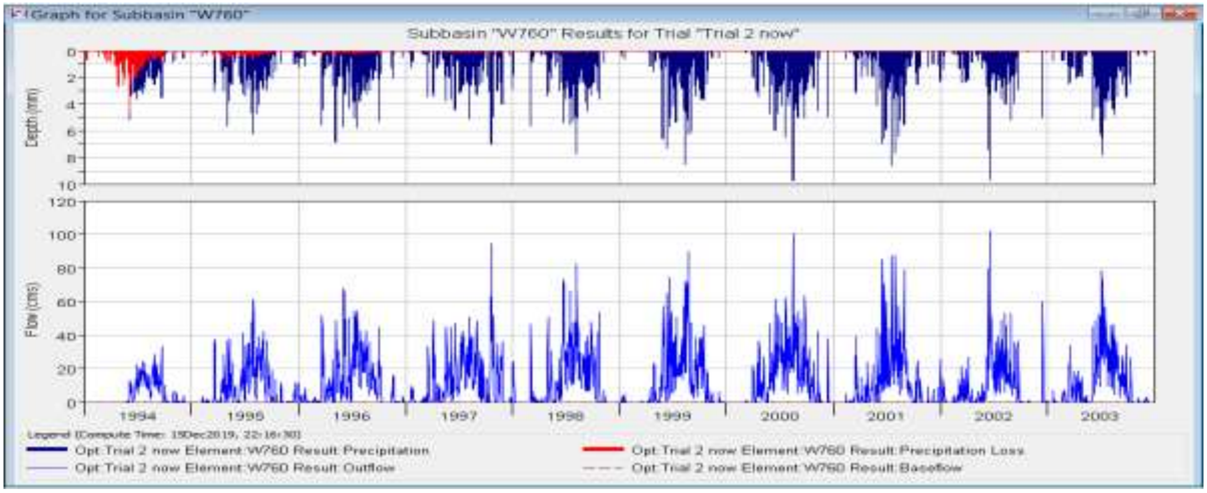


Figure D4: sub basin W760 results near the outlet

Appendix E**:** HEC-HMS Output Which Was Analyzed By Microsoft Excel sheet

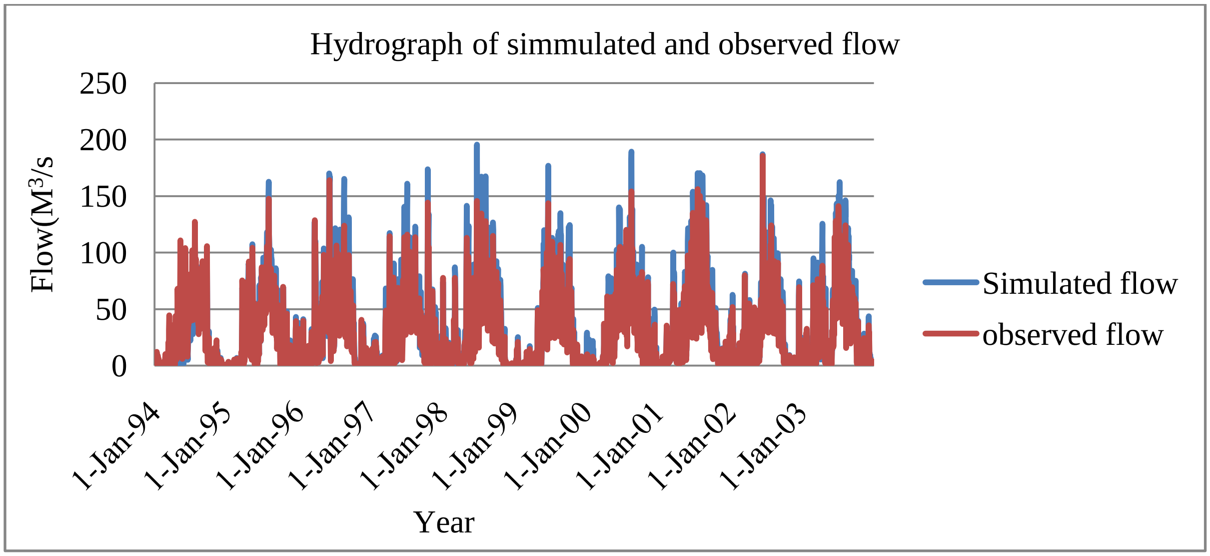


Figure E1 : Calibration result of simulated and observed hydrograph

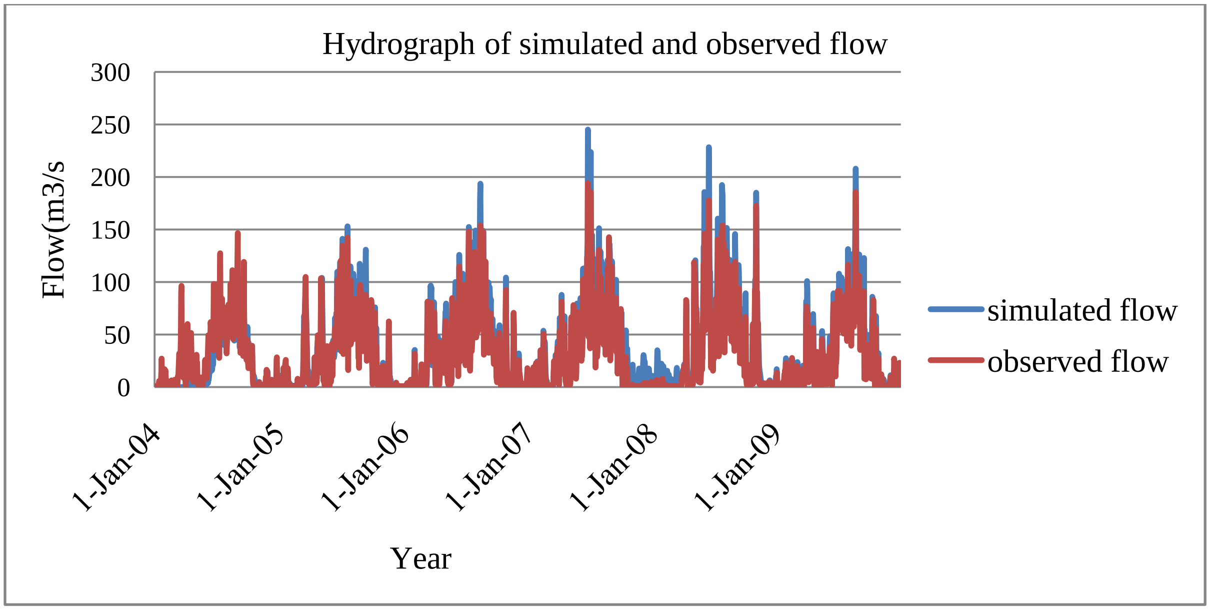


Figure E2: validation result of simulated and observed hydrograph

Appendix F: Output Of HEC-HMS By Frequency Storm

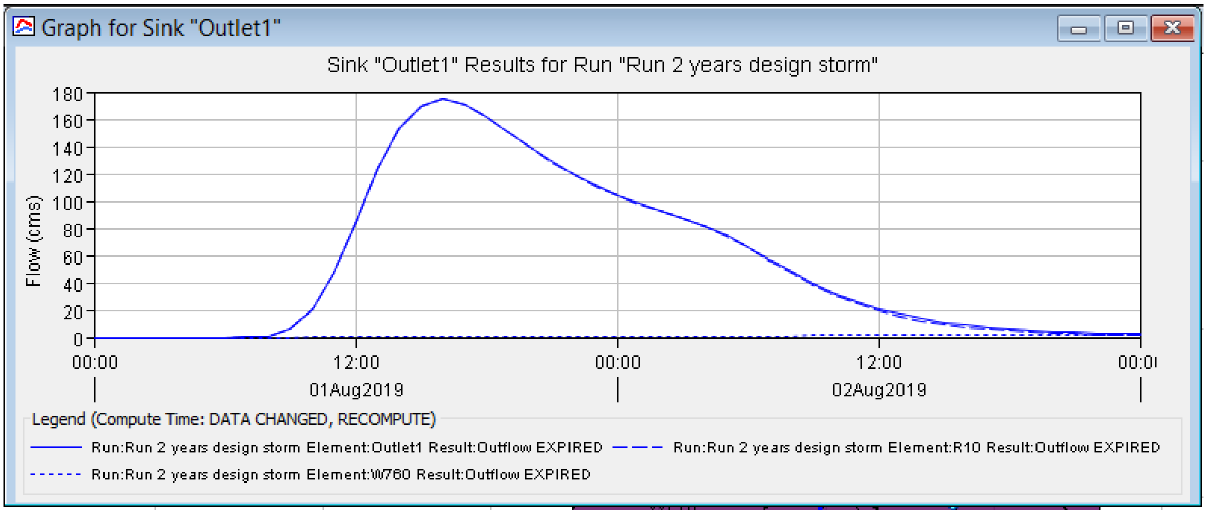


Figure F1: 2 year flow hydrograph of Guder river

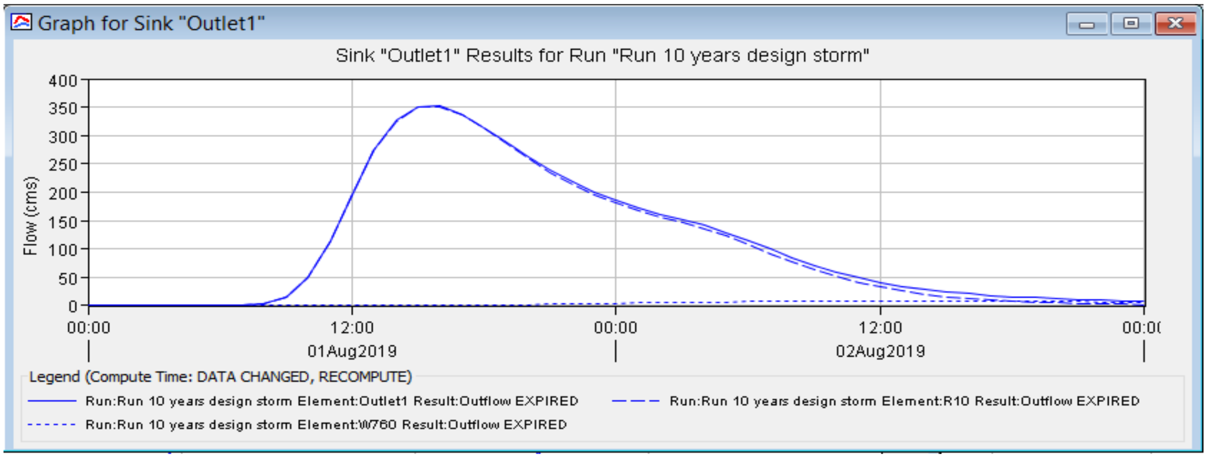


Figure F2 : 10 year flow hydrograph of Guder river

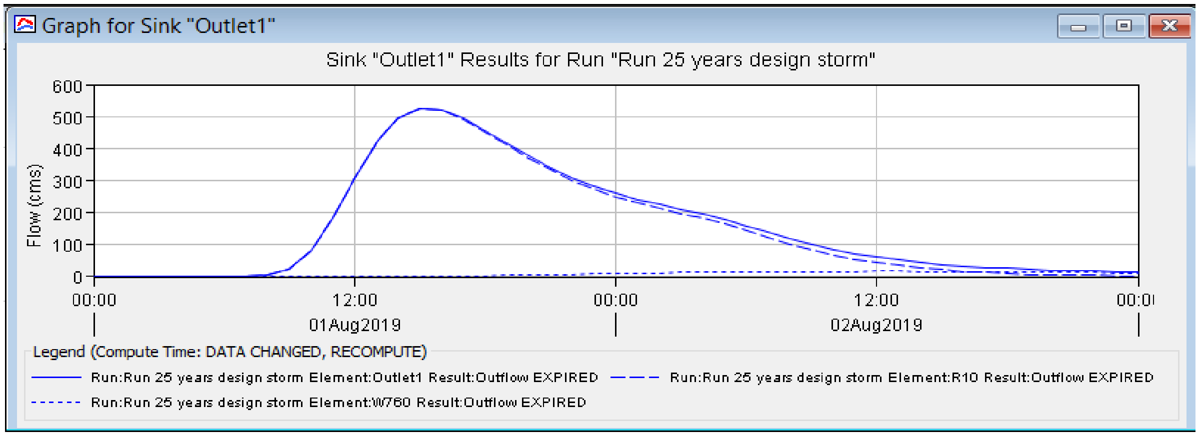


Figure F3: 25 Year flow hydrograph of Guder river

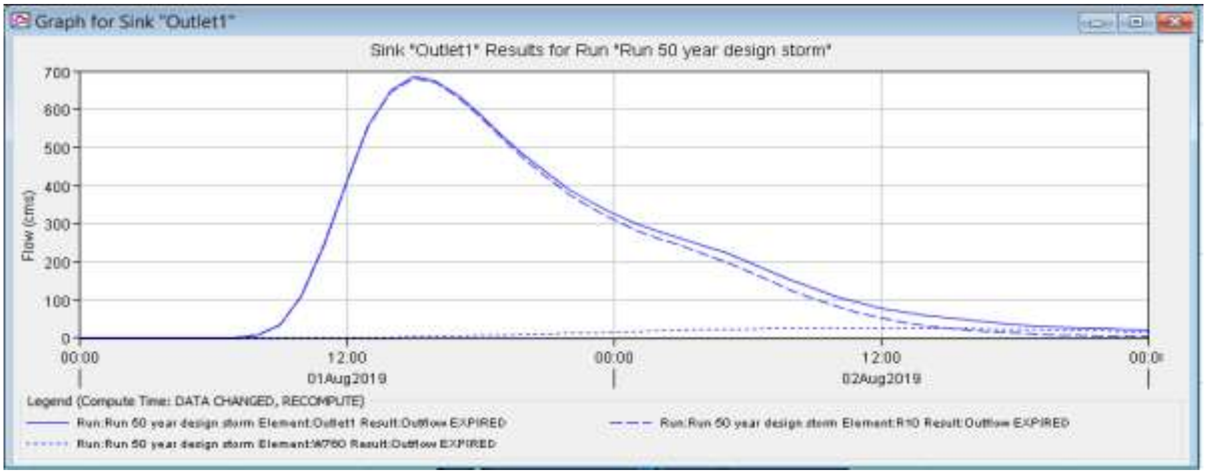


Figure F4: 50 year flow hydrograph of guder river

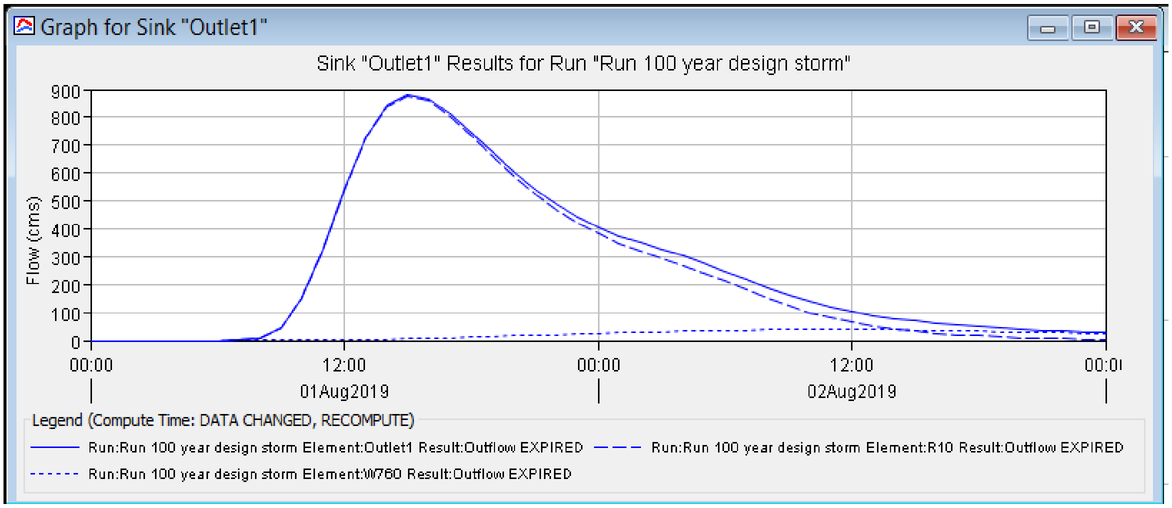


Figure F5 : 100 year flow hydrograph of guder river

Table F1: 24 hr Rainfall depth versus Frequency

Return Period Years	24 hr Rainfall Depth (mm) vs Frequency (yr)							
	2	5	10	25	50	100	200	500
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B1	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	69.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146.00	163.44

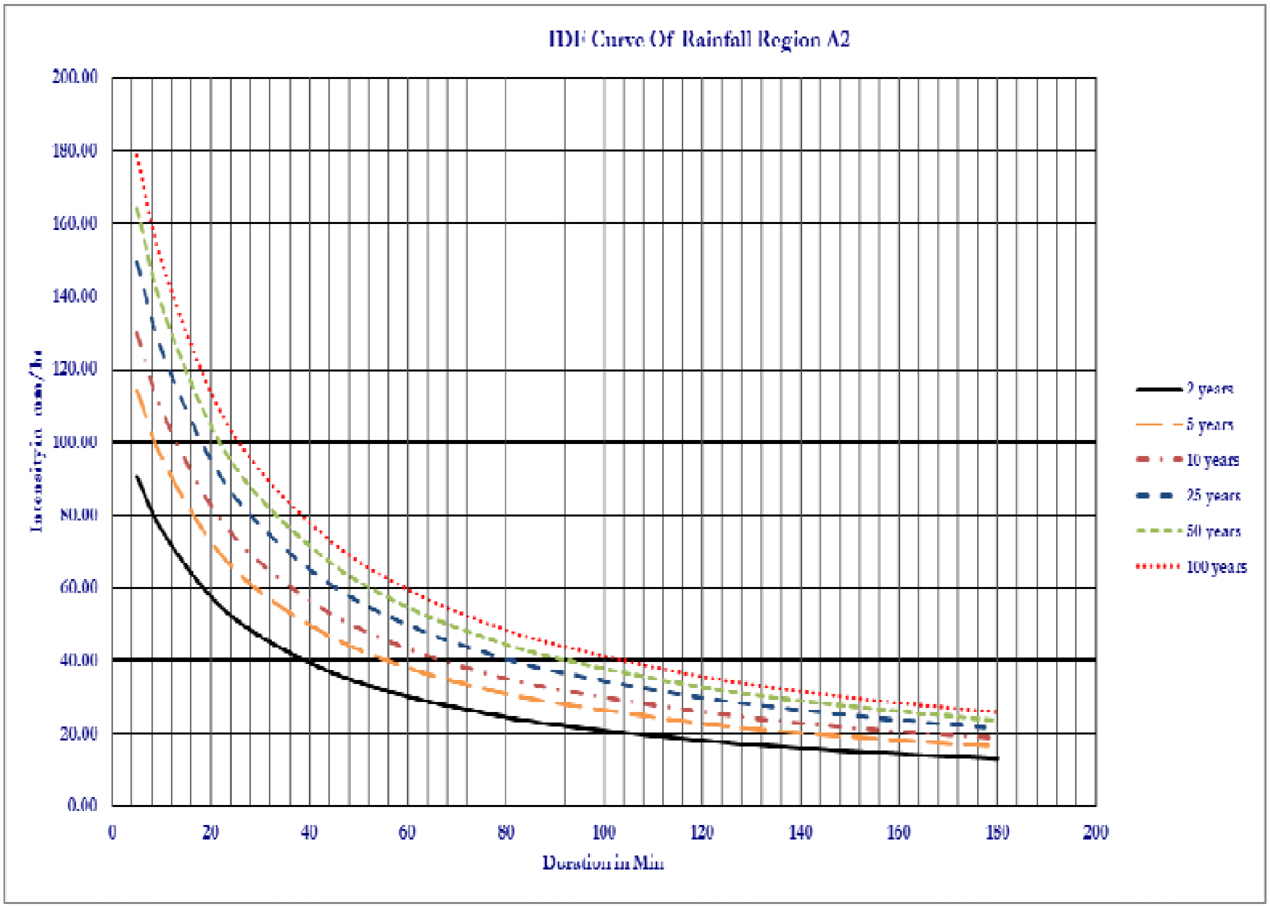
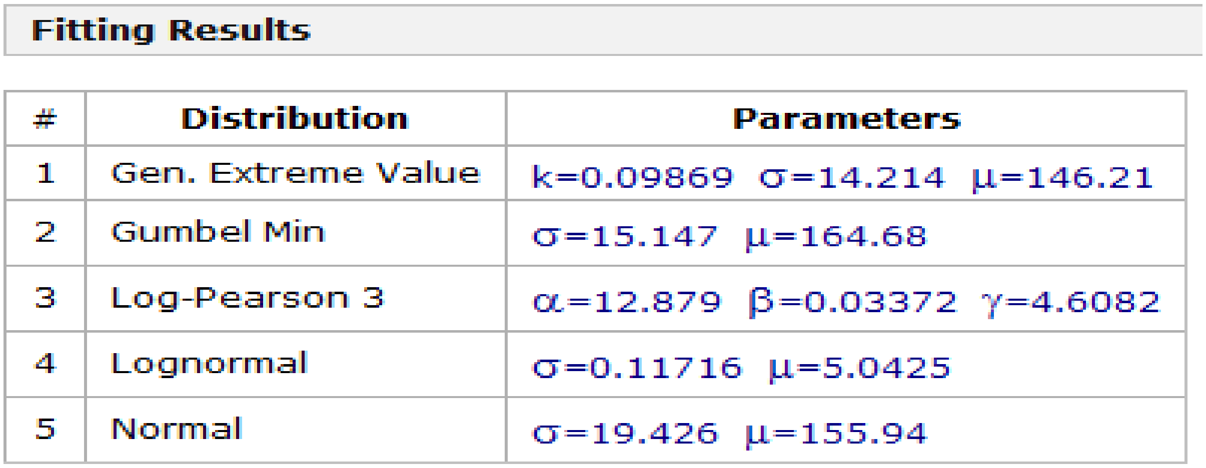


Figure F6 : IDF Curve for Rainfall region A2

Appendix G : Output of Easy Fit software

Table G1: Statistical parameters for selected frequency distribution methods



Fitting Results

#	Distribution	Parameters
1	Gen. Extreme Value	$k=0.09869$ $\sigma=14.214$ $\mu=146.21$
2	Gumbel Min	$\sigma=15.147$ $\mu=164.68$
3	Log-Pearson 3	$\alpha=12.879$ $\beta=0.03372$ $\gamma=4.6082$
4	Lognormal	$\sigma=0.11716$ $\mu=5.0425$
5	Normal	$\sigma=19.426$ $\mu=155.94$

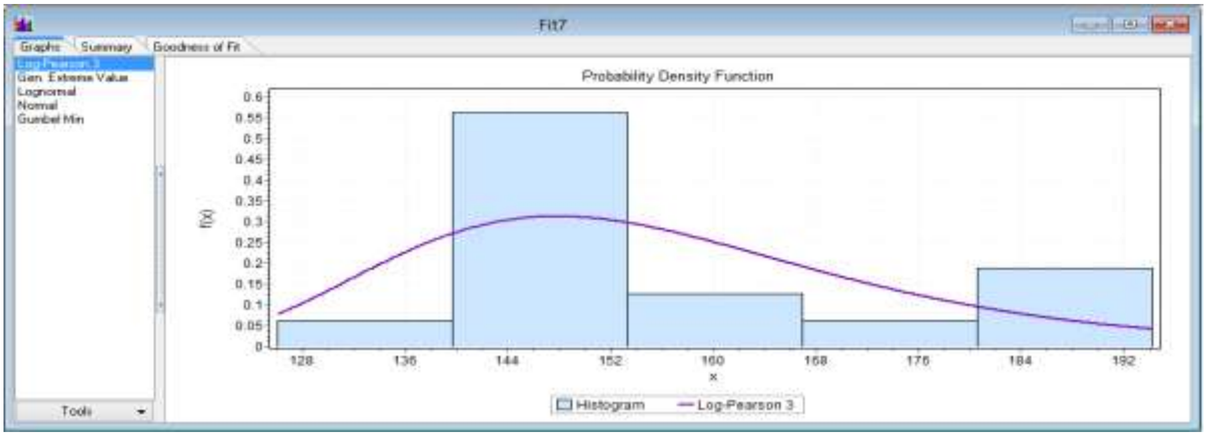


Figure G1: probability distribution density function for Log-Pearson 3

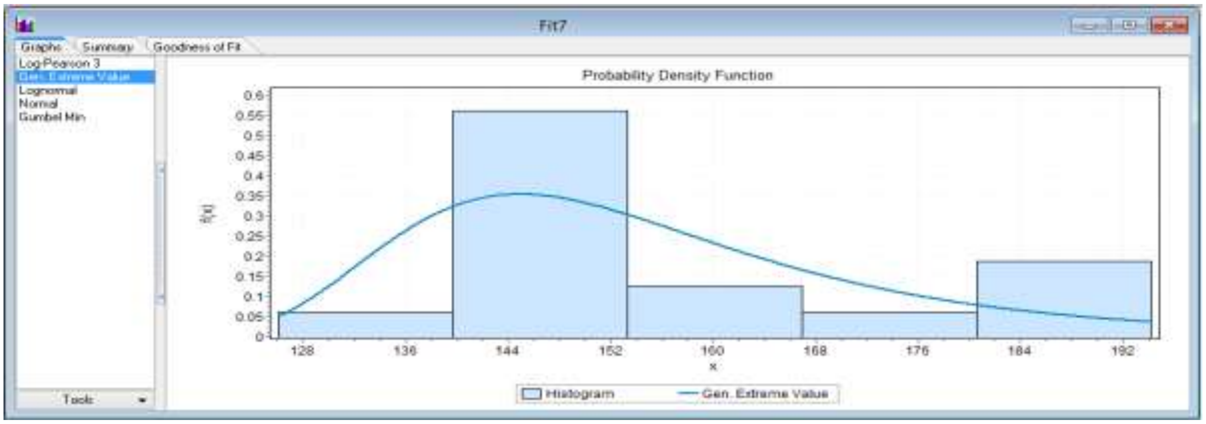


Figure G2 : Probability distribution function for General Extreme value

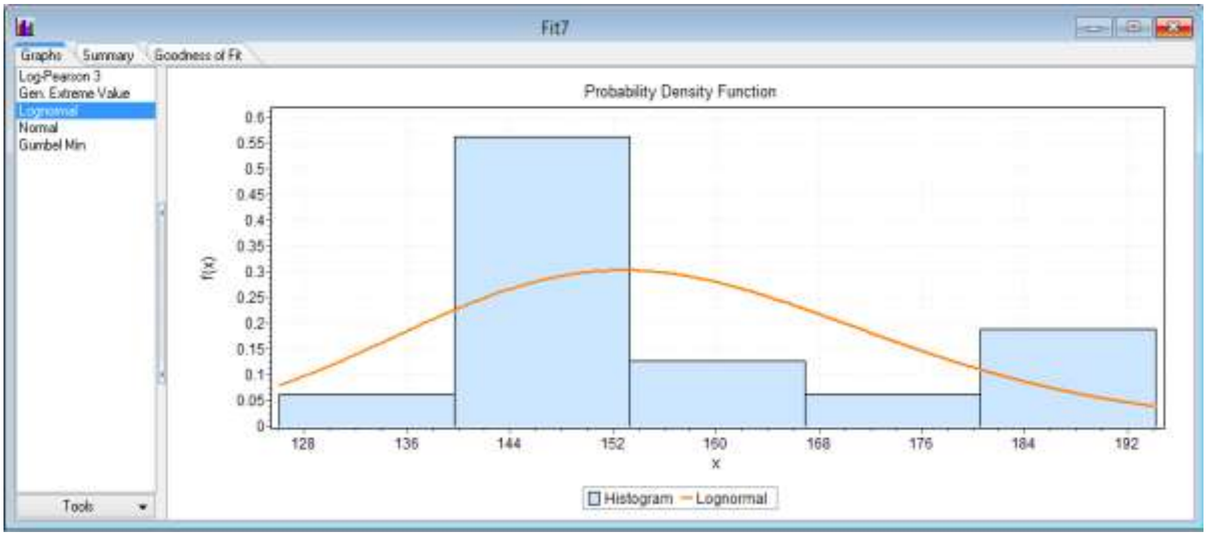


Figure G3: probability density function for Log-Normal