JIMMA UNIVERSITY
SCHOOL OFPOST GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OFCIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC ENGINEERING CHAIR

Application of HEC-HMS Model for Rainfall Runoff Simulation of Weyb River Watershed, Genale Dawa River Basin, Ethiopia

By: Sead Burhan Husen

A thesis submitted to the school of Graduate Studies of Jimma University in partial fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

January, 2020

Jimma, Ethiopia

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Main Advisor: Dr.Zeinu Ahmed (PhD)
Co – Advisor: Mr. Mohammed Hussen (MSc)

January, 2020
Jimma, Ethiopia

DECLARATION

I, the under signed, declare that this thesis entitled" Application Of The HEC-HMS model For Rainfall-Runoff Simulation of Weyb River Watershed, Genale Dawa River Basin, Ethiopia " is my own original work and that it has not been presented or published by any other person for an award of a degree in Jimma University or other universities. I have acknowledged and quoted all materials in this thesis which is not my own work through appreciate referencing and acknowledgement

Sead Burhan Husen

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APPROVAL PAGE

We certify that the thesis entitled "Application of HEC-HMS Model for Rainfall-Runoff Simulation of Weyb River Watershed, Genale Dawa River Basin, Ethiopia" is the work of Sead Burhan Husen and we here by recommend for the examination by Jimma Institution of Technology in partial fulfillment of the requirements for degree of masters of science in hydraulic engineering.

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As member of board of examiners of the MSc. thesis open defense examination, we certify that we have read, evaluated the thesis presented by Sead Burhan Husen and examined the candidate. We recommended that the thesis could be accepted as fulfilling the thesis requirements for the degree of masters of Science in Hydraulic Engineering.

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Chair holder	________________________	______________

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ABSTRACT

Hydrologic studies on rainfall-runoff have been extensively conducted by water resource planners to simulate the hydrological response in many regions around the globe to fulfill various desirable needs with a purpose of effective and proper planning and managing of water resources for present and future uses. Whereas such study is not well drawn much attention to Weyb watershed (Genale Dawa River Basin, Ethiopia) in which may prevail to water insecurity. Therefore, this research thesis is intended to apply the Hydrologic Engineering Center – Hydrologic Modeling System (HEC–HMS) for the simulation of the rainfall-runoff of this watershed to evaluate whether the model performs sufficiently in this study area. Long term daily rainfall data from 6 rain gauging stations for 30 years from(1985-2014), daily River flow of 1 stream gauging station for 15 years from (1992-2006), land use and soil data of the watershed, and DEM were obtained from relevant sources. These data were then analyzed and interpreted and used to set up the HEC-HMS mode. In this study SCS-curve number (loss), SCS unit hydro-graph (transformation), monthly constant (base flow) and Muskingum (Routing) Methods were adopted. In order to clearly understand the horologic characteristics of each watershed, rainfall-runoff relation of the watershed was calibrated using 11 years stream flow data (1992-2002) and the remaining 4 years data (2003-2006) for model validation. The model simulation has been conducted using reasonable approximation and the initial results showed that there is a clear difference between the observed and simulated peak flows and the total volume. Therefore, a model calibration with an optimization method and sensitivity analysis was carried out and the model was run with the most identified sensitive parameters. After parameter optimization the difference between observed and simulated and error functions were so reduced and the results indicate values of Percent bias (%) =13.6, root mean square error (RMSE) =0.4, Nash-Sutcliffe Efficiency (NSE) =0.867 and coefficient of determination (R^2) =0.936. Moreover the calibrated model with optimized parameter was also used for model validation and found percent bias (%) =-3.306, RME=0.4, NSE=0.819 and R^2=0.929. The results obtained showed that the model is appropriate for hydrological simulations and to analyze rainfall-runoff in the Weyb River watershed. In this study, the rainfall-runoff relationship was also analyzed for the data used for validation using the scattered plot and found to have very mush relations. Finally, in this study the storm flows for different return period were also predicted using HEC-HMS and compared with other statistical models namely gamble, normal distribution and log Pearson (3p) to minimize the risk caused by flooding and drought. Using Kolmogorov-Smirnov (KS) test, log Pearson (3p) was found to be the best next to HEC-HMS model. The peak discharges obtained by HEC-HMS for the 2, 5,10,25,50 and 100 year storms are 196.2, 300.7, 375.1, 515.2, 692.4 and 850.0$m3\cdot s$–1 respectively. In doing so, this thesis will help and become an input in flood risk mitigation process.

Keywords: *HEC-HMS, Hydrologic Modeling, Rainfall Runoff, rainfall-runoff relationship Return period, Weyb Watershed.*

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ABBREVIATIONS AND ACRONYMS

ASRTM	Advanced Space borne Thermal Emission and Reflection Radiometer
CN	Curve Number
DEM	Digital Elevation Models
DMC	Double-Mass Curve Analysis
ERA	Ethiopian road authority
ESRI	Environmental Systems Research Institute
GIS	Geographic Information System
GUI	Graphical User Interface
HBV	Hydrologiska Byråns Vattenbalansavdelning
HEC- goeHMS	Hydrologic Engineering Center-Geospatial Hydrologic Modelling System
HEC-DSS	Hydrologic Engineering Center- Data Storage System
HEC-HMS	Hydrologic Engineering Center - Hydrologic Modeling
HSG	Hydrologic Soil Group
HSPF	Hydrological Simulation Program-Fortran
MIX	mixed moment
MoWIE	Ministry Of Water, Irrigation And Electricity of Ethiopia
NRCS	Natural Resources Conservation Service
NSE	Nash-Sutcliffe Efficiency
PWM	probability weighted method
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
R-R	Rain Fall Run Off
SCS	Soil Conservation Service
SWAT	Soil and Water Assessment Tool
UH	Unit Hydrograph
USACE	United states Army Corps of Engineers

1. INTRODUCTION

1.1Background

Sustainable management of limited fresh water sources is a major challenge and is extremely important for the people living in the world. Failure to manage the water sources in an effective manner will adversely affect the society and the economy of the country. Management of water resources in a basin essentially requires understanding of dynamics of basin water and assessment of basin water availability for development use (Cosgrove & Loucks, 2015).

The activities to estimate runoff volumes and flood peaks can be easily simplified by adopting a modelling concept and by understanding rainfall partitioning and the principal factors triggering runoff (ZHANG*et al*., 2004). The type of the modeling approach normally depends on the purpose, data availability and ease of use (Beven, 2012). Rainfall-runoff models are often used as a tool for a wide range of tasks, such as the modelling of flood events, the monitoring of water levels during different water conditions or the prediction of floods (Jia*et al*., 2009). More recently, flood modelling has been further improved with the advent of service-oriented architecture and numerical weather predictions (Shi *et al*., 2015). In the case of flood predictions, rainfall-runoff models are very practical because they are even useful in the watersheds with a limited amount of input data.

Hydrological modeling is a commonly used tool to estimate the basin’s hydrological response due to precipitation. It allows to predict the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practices (Kadam, 2011). It is evident from the extensive review of the literature that the studies on comparative assessment of watershed models for hydrologic simulations are very much limited in developing countries (Kumar and Bhattacharya, 2011; Putty and Prasad, 2000).

Proper water resources 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 need of such modeling system is stimulated, and sometimes even enforced, by the many activities required by River basin planning and management, ranging from timely flood alert to the demarcation of areas at risk of flooding, to the programming of water budget at the basin scale, according to the national and regional regulations in the field (Razi *et al.*, 2010).

The Hydrologic Modelling System HEC-HMS, which is a hydrologic modelling software developed by the US Army Corps of Engineers Hydrologic Engineering Center (HEC) is an integrated modelling tool for all hydrologic processes of dendritic watershed systems. It consists of different component processes for rainfall loss, direct runoff, and routing. HEC-HMS has become very popular and been adopted in many hydrological studies because of its ability in the simulation of runoff both in short and longtime events, its simplicity to operate, and use of common methods(Halwatura& Najim, 2013). Hydrographs developed by HEC-HMS either directly or in conjunction with other software's are used for studies of urban drainage, water availability, future urbanization impact, flow forecasting, flood damage reduction, floodplain regulation, and systems operation(USACE, 2015). Previous studies on HEC-HMS proved its ability to simulate and forecast stream flow based on different datasets and watershed types (Chu & Steinman, 2009).

Although the HEC-HMS model has been tested and calibrated at a global scale, little effort has been made in the context of Ethiopian watersheds. The Weyb River watershed is a multi-purpose River upon which diverse water resources schemes are involved to the flow of the River. The schemes comprise many current and future planned irrigation systems, visiting the attractions and fish agricultural at the distinct parts of the River. Even though the area has huge water potential, a lot of runoff water is lost through surface runoff in each year without giving any benefit to the society living in and around Weyb watershed. In addition to this overflow of the River in some season of the year flooded downstream areas cause frequent loss of property and life. Therefore, an accurate estimation of the peak flow and total volume from the respective rainfall events is critically important to implement appropriate soil and water conservation, erosion control, and flood protection measures in time.

1.2 Statement of problems

Water resource plays a crucial role in the economic development of the developing countries with water stressed water resource like Ethiopia. The region's explosive population growth and resulting new demands on limited water resources require efficient management of existing water resources and building new facilities to meet the challenge. In water resources management system, it is well known that to combat water shortage issues, maximizing water management efficiency based on runoff simulation was crucial. While short-term simulation such as hourly or daily simulation is crucial for flood warning and defense, long-term simulation based on monthly, seasonal or annual time scales is very useful in reservoir operations and irrigation management decisions such as scheduling releases, allocating water to downstream users, drought mitigation and managing river treaties or implementing compact compliance (Lemenih *et al*., 2006).

The Weyb watershed (Genale Dawa River Basin) has extensive agricultural practices and unpredicted flood. The assessment of water resources in the watershed has not well conducted yet, which has revealed a lacked comprehension on water resources systems with its potential water availability. The area is highly vulnerable to climate change that affects the magnitude of seasonality of surface flow that increases the frequency of extreme events such as drought and floods predicted to occur (Abdulkerim *et al*., 2016).

There is no reservoir in the study area, so most of the small-scale water developments existing water supply schemes draw directly on Rivers. The supply of drinking water for humans and livestock depends mainly on River flow. Since agriculture in the basin is mainly rain fed, an uneven distribution of rainfall and a decrease in or total failure of rainfall, deficient of soil moisture due to minimal infiltration and high evapotranspiration cause crops to fail. On the other hand, the increase in River flow in some months of the year cause floods as the Natural River and stream channels may not be able to accommodate the amount off flow and this floods agricultural fields and human settlements.

To alleviate or minimize these problem and to implement appropriate soil and water conservation, erosion control, and flood protection and to make right decision on water related project and to preventing the negative impact of runoff accurate estimation of the peak flow and total volume of the rain fall is critically

Despite the different modelling activities are practiced in the basin, the HEC-HMS model was not tested, calibrated, and validated Weyb Watershed. Therefore, considering watershed characteristics of the Weyb sub-watershed and applicability of HEC-HMS models, this study is intended to be undertaken with the application of HEC-HMS model combined with HEC-GeoHMS and ArcGIS to give solutions for the aforementioned problems of the study area.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this study is to apply HEC HMS model for simulating rainfall runoff of Weyb River watershed

1.3.2 Specific objective

- To evaluate whether HEC-HMS model will perform simulation of stream flow sufficiently in weyb watershed.
- To model the rainfall and the runoff interaction of the watershed.
- To predict and forecast the peak storm events for different return periods.

1.4 Research questions

- How well the HEC-HMS Model simulates stream flow in the watershed?
- Does the amount of flood generated from the watershed directly related to the amount of Rainfall of the study area?
- What are the peak storms that will be generated in the study area at different return periods?

1.5 Significance of the study

The significance of this study will be to update and expand information on rain fall-run off , and provide updated stream flow and precipitation statistics to water resource managing and planning sector. These will help them to have good information about how to prepare for and reduce a devastating drought or flooding if there will be any in the future. In addition to this, the outcome of this study will give the updated information for the downstream users about the characteristics of the trend in precipitation and stream flow in the Weyb River Watershed, so that they will have good information on the future water availability in the watershed. Furthermore it will serve as a lighting house for future researches in this particular area

1.6 Scope of the Study

This study primarily observed the performance of HEC-HMS model to better simulate Weyb watershed stream flow which is found in Genale Dawa River Basin, to evaluate whether HEC-HMS model will perform sufficiently in this study area, to determine the rainfall-runoff relationship and to analyze rainfall-runoff based on available data of Weyb watershed. This study used the rain fall data of 30 years (1985-2014) from six stations and a stream flow data of 15 years (1992-2006) for model comparisons proposes, and the result and conclusion have been drown based in these time series data. HEC-HMS is equipped to model a network of channels and helps to simplify the data that obtain from rainfall and runoff value Relationship between rainfall and runoff was then determined by producing hydrograph from this software.

1.7 Thesis outline

This thesis contains five chapters organized as follows. Chapter one gives a general introduction to the study with its background, study area, objective, relevance, research questions, significant and scope of the study. Chapter two gives a brief description of the reviewed literature related to the study. Chapter three deals with the procedures and methodology adopted for the study. Chapter four is concerned results and discussion. Chapter five lastly ends with the conclusions and recommendations by the study.

2. LITERATURE REVIEW

2.1 Hydrological Process

Hydrological process is a nature driving process, when precipitated water may be intercepted by vegetation, and the rain continues some part of precipitation overland flow over the ground surface, infiltrate into the ground, and flow through the soil as subsurface flow, and discharges into streams as surface runoff. The infiltrated water may percolate deeper to recharge groundwater, later emerging as spring, and seeping into streams to form surface runoff and finally flowing into the sea or evaporating into the atmosphere as the hydrological cycle continues (Astere, 2007). According to (Edwards *et al.* 2000), the major components of the hydrological process are: a. Interception and infiltration (loss) b. Evaporation and c. Runoff component Interception is the first component of the hydrological cycle to be lost directly back to the atmosphere. Caused by high wind speed, it blows in aerodynamically on 'rough' canopies.

Infiltration is the physical process involving the movement of water through the boundary area where the raindrops interfaces with the soil. Typically, the infiltration rate depends on the splashing of the water at the soil surface by the impact of raindrops, the texture and structure of the soil, the initial soil moisture content, the decreasing water concentration as the water moves deeper into the soil filling of the pores in the soil matrices, changes in the soil composition, and to the swelling of the wetted soils that in turn close cracks in the soil) (ESRI, 2009) In terms of the hydrological cycle and the water balance, evaporation and transpiration is the second largest component. It is the process of returning of moisture to the atmosphere and affected by different factors Runoff is flowing from a drainage basin or watershed that appears in surface streams. The flow is made up partly of precipitation that falls directly on the stream and partly it get from lateral flow.

Surface runoff is type of water that flows over the land surface and through channels, subsurface runoff that infiltrates the surface soils and moves laterally towards the stream and groundwater runoff from deep percolation through the soil horizons. Part of the subsurface flow enters the stream quickly, while the remaining portion may take a longer period before joining the water in the stream. When each of the components flows enters the stream, they form the total runoff. The total runoff in the stream channels is called stream flow and it is generally regarded as direct runoff or base flow (Edwards et al., 2000).

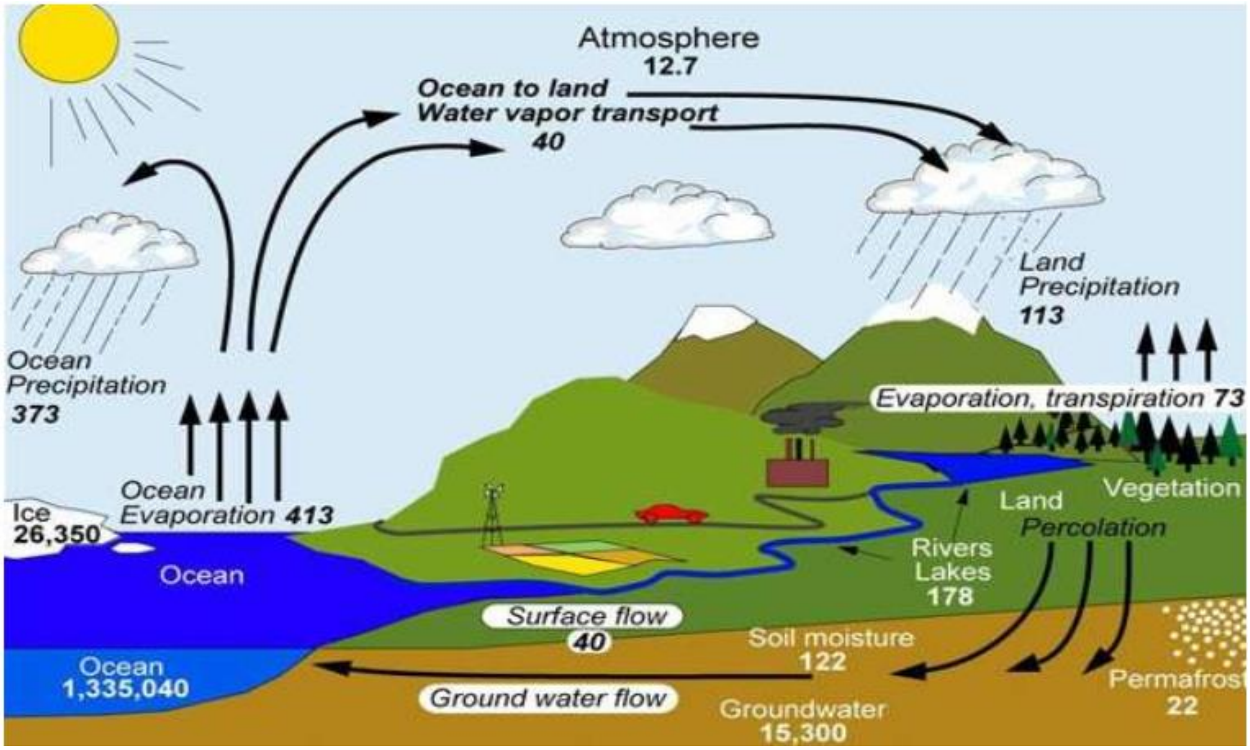


Figure 2.1: Hydrological Cycles

Source: Trenberth et al. 2007

Generally, the rate at which water enters the soil from the surface is a function of water-input rate (snow melt and rain fall) and soil infiltration capacity (the maximum rate at which soil will accept incoming water) (Lastoria, 2008). It is noted that through the concept of the hydrologic cycle seems simple, the phenomena are very complex and multiple it is not just one large cycle but it is rather many interrelated cycles of continental regional local extent. The major achievement and objectives of the rainfall-runoff modeling are thus to study a part of the hydrological cycle namely the land phase of the hydrological cycle on a watersheds scale. Then the problem becomes to express the runoff from the watersheds as a function of the rainfall and other watersheds characteristics (Astere, 2007).

2.2 Rainfall

Precipitation is a part of atmospheric moisture which reaches the earth’s surface indifferent forms. Some of the precipitation that might get intercepted while reaching the ground by trees and buildings and evaporates back is called the initial loss. The other parameters requirements like depression storage and infiltrates into the ground. The excess rainfall flows in streams to large water bodies. Factors like type of soil, vegetation, geology, and topography of area largely determine the quantity of rainfall excess available as stream flow from the perceptible water. One-fourth of the total precipitation that falls on land reaches large water bodies as direct runoff. The balance three-fourths of water returnsback to the atmosphere as evaporation (Patra, 2001).

2.3 Runoff

Precipitation is the primary source of all waters. When rain starts falling on a more or less pervious area, it is consumed in many ways such as the rainfall is intercepted by buildings, trees, grasses and other objects. Thus, preventing it from reaching the ground, some part of infiltrates into the ground, some part of it finds its way to innumerable small and large depression, if rain continues, the soil surface becomes covered with a film of water and is known as surface detention and flow begins to start to words an established surface channel. Runoff may be defined as that part of precipitation as well as of any other flow contribution which appear in surface streams (Gupta *et al*., 2001) .

Runoff, sometimes referred to as overland flow, is the process whereby water moves from the ground surface to a waterway or water body. Normally applies to flow over a surface. Rain falling in a watershed in quantities exceeding the soil or vegetation uptake becomes runoff. Runoff will be used to collectively describe the precipitation that is not directly infiltrated into the groundwater system. Runoff producing events are usually thought of as those that saturate the soil column or occur during a period when the soil is already saturated. Thus infiltration is halted or limited and excess precipitation occurs. This may also occur when the intensity rate of the precipitation is greater than the infiltration capacity (Gupta *et al*., 2001).

2.3.1 Factors affecting runoff

The amount of runoff generated can be affected by different Meteorological factors and Physical characteristics. The meteorological factors affecting runoff are; Type of precipitation (rain, snow, sleet, etc.), Rainfall intensity, Rainfall amount, Rainfall duration, Distribution of rainfall over the watersheds, Direction of storm movement, Antecedent precipitation and resulting soil moisture other meteorological and climatic conditions that affect evapotranspiration, such as temperature, wind, relative humidity, and season. The Physical characteristics affecting runoff are; Land use, Vegetation cover, Soil type, Drainage area, Basin shape, Elevation, Slope, Topography, Direction of orientation, Drainage network patterns, Ponds, lakes, reservoirs, sinks, etc. in the basin, which prevent or alter runoff from continuing downstream (Beven, 2012).

2.3.2 Advantage of Runoff Estimation

A watershed is a hydrologic unit which produces water as an end product by interaction of precipitation and the land surface. The quantity and quality of water produced by the watershed are an index of amount and intensity of precipitation and the nature of watershed management. In some watersheds the aim may be to harvest maximum total quantity of water throughout the year for irrigation and drinking purpose (Jain *et al.*, 2010). Runoff estimation resulted from precipitation is the basis of more study in various develop and exploit design from water resource, then its measure and calculation due to environmental bottlenecks, always have a plenty problem(Khosravi Khabat & Iman, 2013).

2.4 Rainfall Runoff Relationship

In order to represent and simplify a catchment in a computer model, one has to have knowledge about the processes in the watershed impacting the local hydrology. Flood runoff has often been considered to consist of surface runoff produced at the ground surface when the rainfall intensity exceeds the infiltration capacity. While this process, known as Hortonian overland flow, occurs in many situations, two other general storm runoff process i.e. Saturated overland flow and Through flow are now recognized, as a result of observations on natural basins during storm periods and many detailed studies of instrumented plots and small areas (Maidment, 2000). All these processes are discussed in the following paragraphs. Saturated overland flow occurs when one part of the drainage basin the surface horizon of the soil becomes saturated as a result of either the buildup of a saturated zone above a soil horizon of lower hydraulic conductivity or the rise of a shallow water table to the surface (Maidment, 2000).

Through flow is water that infiltrates into the soil and percolates rapidly, largely through macro pores such as cracks and root and animal holes, and then moves laterally in a temporarily saturated zone, often above a layer of low hydraulic conductivity. It reaches the stream channel quickly and differs from other subsurface flow by the rapidity of its response and its relatively large magnitude (Maidment 1993). Runoff processes operating at any location vary from time to time. Large variations in hydrologic characteristics, and therefore in runoff processes, also occur over small apparently homogeneous areas to the extent that all three runoff processes discussed above may occur during a single storm runoff event.

The type of runoff process and the location of source areas, whether close to the outlet and adjacent to stream channels or on the ridges remote from the channels, has considerable influence on the resulting hydrographs. However, practical methods for estimating storm losses and runoff have not yet been developed to explicitly account for mthese differences (Maidment 1993). Uniform or average conditions, at least over sub areas, are generally assumed.

The rainfall runoff process is well described in many literatures. Numerous papers on the subject have been published and many computer simulation models have been developed. All these models, however, require detailed knowledge of a number of factors and initial boundary conditions in a catchment area, which in most cases are not readily available..

2.5 Rainfall-Runoff Modelling

Reliable estimates of stream flow from a watershed are required to help policy makers to inform decisions on water planning and management. There are ranges of methods available to estimate stream flow from watersheds, using observed data wherever possible, or using empirical and statistical techniques to estimate River discharge, more commonly known as rainfall-runoff models (Vaze*et al*., 2012).

All Rainfall-Runoff (R-R) models are the simplified characterizations of the real-world system (Moradkhani & Sorooshian, 2009). Runoff models help to visualize the response of water systems due to changes in the land-use and meteorological events. Physical processes that converts rainfall to runoff is conceptualized with set of equations by employing various parameters that describes the watershed. Modelling surface runoff is challenging as the calculation involves complexities with many interconnected variables. However general model components include inputs, governing equations, boundary conditions or parameters, model processes, and outputs.

There are wide ranges of R-R models currently used by researchers and practitioners; however their applications are highly dependent on the purposes for which the modelling is undertaken. As many of the R-R models are used merely for research purposes for the purpose of understanding the hydrological processes that govern a real-world system, some are developed and employed as tools for simulation and prediction that in turn allows decision makers for proper planning and operation in context of flood risk management (Moradkhani & Sorooshian, 2009). For instance, the real-time flood forecasting and warning, currently operational in many countries, employs the results of rainfall-runoff modelling.

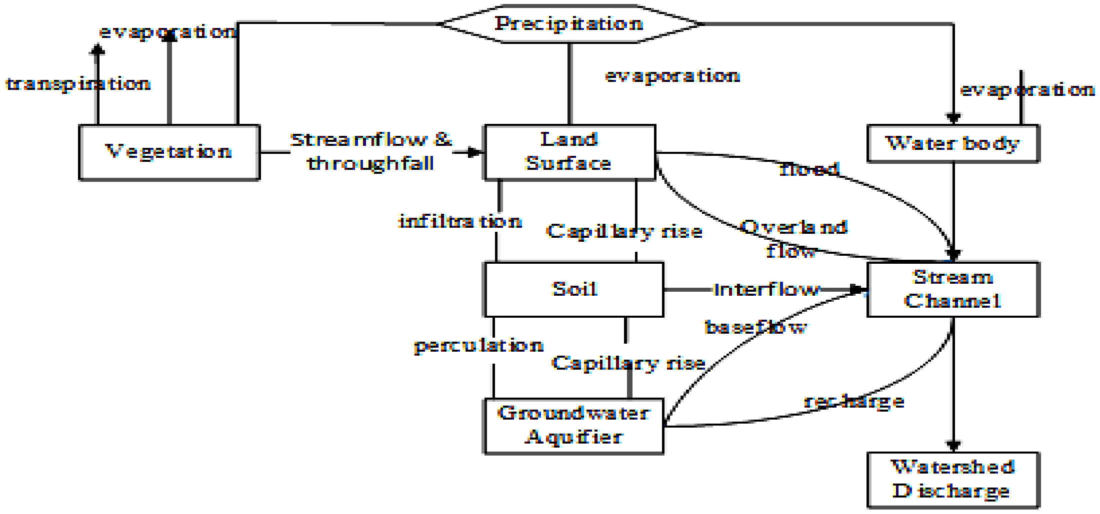


Figure 2.2:System Diagram of Runoff Process

Source: (Feldman, 2000)

2.5.1 Classification of hydrological Models

Rainfall-runoff models are often used as a tool for a wide range of tasks, such as the modelling of flood events, the monitoring of water levels during different water conditions or the prediction of floods (Jia*et al*., 2009). Generally, hydrological models can be classified as stochastic and deterministic. The stochastic models will produce outputs that have partial randomness but the deterministic models on the other hand do not give randomness.(Cunderlik, 2003) Further classified deterministic hydrologic models into three major categories: Firstly, the lumped model, which assesses the watershed response simply at the outlet without obviously counting for an individual sub-basins response. Secondly, the semi-distributed model, which is partly permitted to change in space with a division of the watershed into a number of sub-basins. The third type of model is the distributed model, which permits its parameters to change in place at a resolution normally chosen by the client.

Distributed hydrological models such as the European Hydrological System Model and Modular Modeling System (MMS), and semi-distributed models like the Hydrological Engineering Center Hydrological Modelling System, Soil and Water Assessment Tool (SWAT),Topography Based Hydrological Model (TOPMODEL), Hydrologiska Byråns Vattenbalansa vdelning (HBV) and Hydrological Simulation Program-Fortran (HSPF) are developed for a runoff estimation based on the data availability and complexity of the hydrological systems. Flood modelling has been greatly improved in recent years with the advent of geographic information systems, ”radar-based” rainfall estimation using next-generation radar (NEXRAD), high-resolution digital elevation models, and distributed hydrological models (Bedient *et al*., 2003). More recently, flood modelling has been further improved with the advent of service-oriented architecture and numerical weather predictions (Shi*et al*., 2015) . In the case of flood predictions, rainfall-runoff models are very practical because they are even useful in the watersheds with a limited amount of input data.

2.6 Hydrologic Model Selection Criteria

As per stated Beek and Elko (2005) the selection of an existing model to be used in any project depends in part on the processes that will be modelled the data available and the data required by the model. An important practical criterion is whether there is an accessible manual for operating the model program and a help desk available to address any possible problems. The decision to use a model, and which model to use, is an important part of water resources planning formulation. Even though there are no clear rules on how to select the right model to use, a few simple guidelines can be stated by Elko were:

- Define the problem and determine what information is needed and what questions need to be answered.
- Use the simplest method that will yield adequate accuracy and provide the answer to your questions.
- Select a model that fits the problem rather than trying to fit the problem to a model.
- Whether increased accuracy or increased effort and increased cost of data collection.
- Required model outputs important to the project and therefore to be estimated by the model
- Hydrologic processes that need to be modeled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous processes?)
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?)
- Price (Does the investment appear to be worthwhile for the objectives of the project)

Based on above selection criteria, HEC-HMS was identified as one of the appropriate rainfall-runof.

The main reasons behind selecting the models for this study are;

- ➢ The HEC-HMS program was selected for the current study due to its versatility, capability for Stream flow generation, automatic parameter optimization and its connection with GIS through HEC-GeoHMS.
- ➢ The HEC-HMS model outputs is used by the HEC-ResSim as an input which help to further analyze the project.
- ➢ Hydrological processes that can be properly modeled will be directly result in the desired output from the model.
- ➢ They are freely available software's.
- ➢ They have been used in wide geographical area including water balance and water allocation studies f models for this study.

2.7 Description of the Selected Model

2.7.1 HEC-HMS model

The HEC-1 hydrologic model was originally developed in 1967 by Leo R. Beard and other staff members of the Hydrologic Engineering Center, with the U. S. Army Corps of Engineers, to simulate flood hydrographs in complex River basins (Singh, 1982). Since then, the program has undergone a revision: different versions of the model with greatly expanded capabilities have been released. The current version of HEC-HMS and this study used the HEC-HMS Version. The HEC-HMS model is designed to simulate the surface runoff response of a watershed to precipitation by representing the watershed with interconnected hydrologic and hydraulic components. It is primarily applicable to flood simulations (Oleyiblo& Li, 2010). Hydrologic elements are arranged in a dendritic network, and computations are performed in an upstream-to-downstream sequence. Computations are performed with SI (System international units) units.

However you can enter input and view output with units in the U.S. Customary system, and can readily convert input results from one unit system to the other. HEC-HMS includes four main components: basin, meteorological, control specifications component, and time series data component. The basin model stores the physical datasets describing the watershed properties and the meteorological model includes precipitation, evapotranspiration, and snowmelt data. Six different historical and synthetic precipitation methods, two evapotranspiration methods, and one snowmelt method are included. The time span of a simulation is controlled by control specifications including a starting date and time, ending date and time, and computation time step. The last component used for controlling time series data such as rainfall, discharge and evapotranspiration data. HEC-HMS provides a variety of options for simulating precipitation-runoff processes.

In addition to unit hydrograph and hydrologic routing options similar to those in HEC-1, HEC-HMS capabilities currently available include: a linear-distributed runoff transformation that can be applied with girded (e.g., radar) rainfall data, a simple "moisture depletion" option that can be used for simulations over extended time periods, and a versatile parameter optimization option. The latest version also has capabilities for continuous soil moisture accounting and reservoir routing operations. HEC-HMS also includes an automatic calibration package that can estimate certain model parameters and initial conditions, for the given observations of hydro meteorological conditions. It also links to a database management system that permits data storage, retrieval and connectivity with other analysis tools available from HEC and other sources (Feldman, 2000).

2.7.2 HEC-GeoHMS Model Description

The computer program Hydrologic Engineering Center-Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) is developed by the U.S Army Corps of Engineers and available on the Internet. The advances in GIS and its ability to manipulating data and perform spatial analysis to develop the hydrologic models has made it a necessary tool for engineers and hydrologist. Since using GIS, efficiently needs enough knowledge and experiences, the US army Corps of engineers, Hydrologic Engineering Center, developed a Geo-Spatial Hydrologic Modeling Extension for the Arc-GIS for limited experienced engineers and hydrologist. The extension provides users with interface, menu, tools, bottoms to generate hydrologic inputs for directly use of Hydrologic Modeling System, (Geo-HMS, 2003).

Geo-HMS has capability to create the background map containing the stream alignments and sub-basin boundaries, which provides users with sub-basin delineation and manipulation's tool; for instance it is possible to delineate sub-basins by supplying point data set as desired outlets. It also creates lumped basin model which contains hydrologic elements and their connectivity to represent the water movement through the sub-basins. Creating a grid-cell parameter file and distributed basin model are also of its capabilities. It also can generate the Table of physical characteristics of watersheds and streams as well as having the ability to analysis the DEM data. Computing the CN value of sub-basin is also possible with Geo-HMS along with generating the meteorological model and control specification (Geo-HMS, 2003). HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. The hydrological results from HEC-GeoHMS are then imported by the HEC-HMS, where simulation is performed.

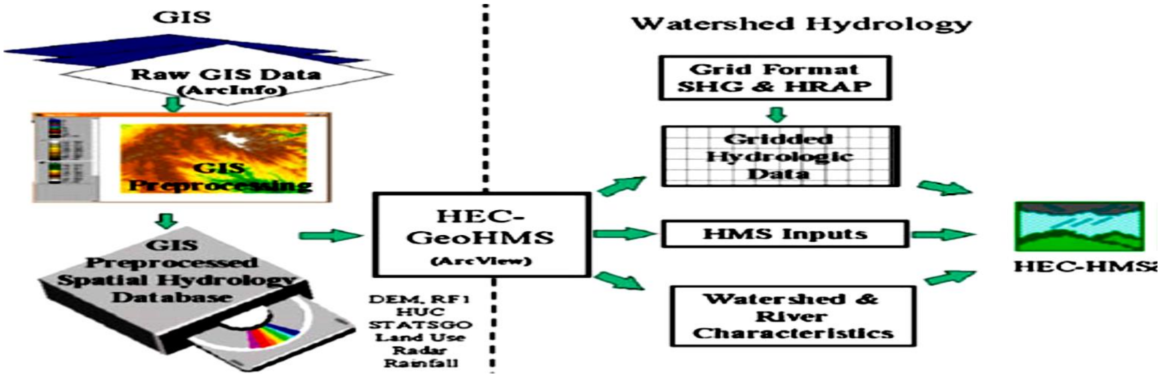


Figure 2.3: Overview of GIS, HEC-GeoHMS

Source: (USACE, 2015)

2.8 Hydrological Modelling in HEC-HMS

HEC-HMS is designed to simulate hydrological processes in dendritic watershed systems. The program includes several models which can be used to perform different simulations. HEC-HMS includes primarily lumped models which mean that there is no spatial variation in the model processes and characteristics. The program contains both empirical and conceptual models. A conceptual model is built by knowledge of the actual processes that influence the input, while an empirical model is built up by observations of the input and output, without trying to explicitly represent the transformation process. All the models in HECHMS are deterministic which means that all the input data and processes are free of random variation thus the model will always yield the same result from a set initial data (Feldman, 2000).

The aim of the simulations is to describe how the watershed will respond to the fallen precipitation to produce runoff. The model will represent the watershed behavior and simulate the runoff process. There are numerous methods available for the estimation of each process; HEC-HMS uses separate models for each component of the runoff process(Feldman, 2000).

2.8.1 HMS MODEL Components

HMS has four main model components (you can see these by selecting components on the menu bar): basin model, meteorological model, control specifications and input data (time series, paired data and gridded data). The Basin Model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, River reach connectivity, or reservoir data. Likewise, the Meteorological Model holds rainfall data. The Control Specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval you want to use in the model, etc. Finally, the input data component stores parameters or boundary conditions for basin and meteorological models. HEC-HMS model components are used to simulate the hydrologic response in a watershed (Biswa *et al.*, 2008).

1. Basin Model Components - The basin model represents the physical watershed. The user develops a basin model by adding and connecting hydrologic elements. Hydrologic elements use mathematical models to describe physical processes in the watershed.

Following are the different hydrologic elements:-

i. Sub-basin– Used for rainfall-runoff computation on a watershed.

ii. Reach – Used to convey (route) stream flow downstream in the basin model.

iii. Reservoir – Used to model the detention and attenuation of a hydrograph caused by a reservoir or detention pond.

iv. Junction – Used to combine flows from upstream reaches and sub-basins.

v. Diversion – Used to model abstraction of flow from the main channel.

vi. Source – Used to introduce flow into the basin model (from a stream crossing the boundary of the modeled region). Source has no inflow.

vii. Sink – Used to represent the outlet of the physical watershed. Sink has no outflow.

2. Meteorological Model Component - The meteorological model calculates the precipitation input required by a sub-basin element. The meteorological model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapotranspiration. The newly added snowmelt method uses a temperature index algorithm to calculate the accumulation and melt of the snow pack. Theevapo-transpiration methods include the monthly average method and the new Priestly Taylor and gridded Priestly Taylor methods. An evapo-transpiration method is only required when simulating the continuous or long term hydrologic response in a watershed (Biswa *et al.*, 2008).

3. Control Specifications Component - The control specifications set the time span of a simulation run. Information in the control specifications includes a starting date and time ending date and time, and computation time step.

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.

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

1. Loss method

This model computes the runoff volume of the watershed by calculating losses through interception, surface storage, infiltration, evaporation, transpiration and then subtracting it to the precipitation at each time step. HEC-HMS provides eight options for calculating the losses.

- ✓ Initial and Constant Rate Loss Model
- ✓ Gridded Deficit Constant Rate Loss Model
- ✓ Gridded Green and Ampt Rate Loss Model
- ✓ Gridded SCS Curve Number Rate Loss Model
- ✓ Gridded Soil Moisture Accounting Rate Loss Model
- ✓ SCS Curve Number Rate Loss Model
- ✓ Smith Parlange Rate Loss Model
- ✓ Soil Moisture Accounting

From the above Runoff-Volume Model s SCS-CN method is selected for modeling of watershed in this particular study and discussed as shown below.

a. 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 watershed by using the digital data analysis, vegetation cover, land using and hydrologic soil groups (Abouzar Nasiri and

Hamid Alipur,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 P. K. And Panigrahya S., 2008)

The SCS Runoff Curve Number (CN) method developed by Natural Resources Conservation Service (NRCS) used for estimating direct runoff from storm rain fall described on the following equation;

$$Q = \frac{(P-I_a)2}{(p-I_{a)+}\ S} \qquad 2.1$$

Where: Q= run off, P= rainfall, S= potential maximum retention after run off begins and Ia= initial abstraction

Initial abstraction (Ia) is all losses before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is highly variable but generally is correlated with soil and cover parameters. Through studies of many small agricultural watersheds, Ia was found to be approximated by the following empirical equation:

$$Ia = 0.2S \qquad 2.2$$

By removing Ia as an independent parameter, this approximation allows use of a combination of S and P to produce a unique runoff amount. Substituting equation 2.2 into equation 2.1 gives:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad 2.3$$

S is related to the soil and cover conditions of the watershed through the CN. CN has a range of0 to 100, and S is related to CN by:

$$S = \frac{1000}{CN}\text{-}100 \qquad 2.4$$

1. **Transform method**

Transform methods is an approach for computing direct runoff at the outlet of watershed area from the excess precipitation falling over it and this is done based on principles of unit hydrograph. Unit hydrograph can be defined as the runoff hydrograph produced from excess rainfall of unit depth occurring over the watershed. The theories of unit hydrograph are:

i) excess precipitation and runoff produced are directly proportional to each other,

ii) excess precipitation is distributed uniformly with respect to time and space over the watershed area and

iii) Runoff produced from given excess rainfall is independent of time of occurrence and precedent moisture content (Subramanya, 2008) .

The transformation method used for this study was SCS Unit Hydrograph. The resulting runoff hydrograph from this model is described by properties of unit hydrograph using one or more equations of the parameters involved. The peak of unit hydrograph and its time of peak are given by following equations.

$$UP = 2.08 * \frac{A}{TP} \ and \qquad 2.5$$

$$TP = \frac{\Delta t}{2} + tlag \qquad 2.6$$

Where, Up = Peak of unit hydrograph, A = Area of watershed, Tp = Time of peak, Δt = Excess precipitation duration and tlag = Basin lag time (Feldman, 2000).

Basin lag can be defined as the time difference between the peak of unit hydrograph and centroid of the associated excess rainfall hyetograph which is depicted in the *Figure 2.4* below.

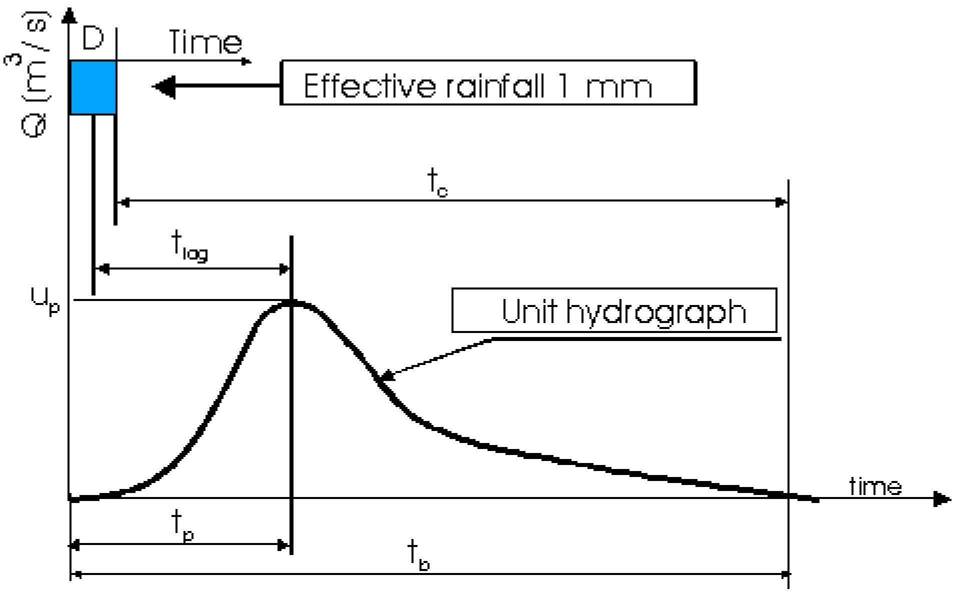


Figure 2.4: Characteristics of the Unit Hydrograph

Source: (Feldman, 2000)

In this Figure, tp = time of peak, Up = Peak of unit hydrograph and tr = rainfall duration.

3. Base-flow Method

Subsurface flow in the watershed is illustrated by base flow in HMS. Base flow comprises of interflow and flow in groundwater aquifer. There is insignificant contribution of base flow in case of short rainfall event, so it can be ignored. While in case of long rainfall event, the base-flow contributes to the recession limb of hydrograph and has a significant contribution in flood volume (Cunderlik & Simonovik., 2004).

HEC-HMS includes five models for modeling the base flow.

- Constant Monthly
- Bounded Recession method
- Linear Reservoir
- Nonlinear Boussinesq
- Recession

In this study constant monthly method was selected as base flow method.

Constant Monthly

This is the simplest base flow model in HMS. It represents base flow as a constant flow; this may vary monthly. Initial flow was given a value in the order of the average monthly outflow from the individual sub-basins which was estimated with reference to the monthly flow series at key station Chena-Mansa. This user-specified flow added to the direct runoff computed from rainfall for each time step of the simulation.

4. Route Method

Flood routing is a technique of determining the flow hydrograph at the downstream point of watershed with sound information regarding hydrograph at its upstream. It is an approach to estimate how the magnitude and celerity of a flood wave varies than that at the inflow point as it moves along the watershed. Flood routing along the watershed is a function of basin characteristics such as slope and length of channel, channel roughness, channel shape, downstream control and initial flow condition (Rahman, 2017). The hydrologic modelling is based on continuity equation while hydraulic modelling is based on combination of continuity and momentum equation which is known as Saint-Venant equations (Larsson, 2017). In this study, Muskingum method has been used for River routing because of its high accuracy over other methods. The Muskingum channel routing method is based on two equations (Linsley*et al.*, 1982). The first is the continuity equation or conservation of mass.

$$\frac{I_1+I_2}{2}\Delta T-\frac{O_1+O_2}{2}\Delta T=S_1-S_2 \qquad 2.7$$

Where, $I_1$and $I_2$are inflow discharges at time 1 and time 2,$O_1$and$O_2$are outflow discharges at time 1 and time 2,ΔT= time difference between time 1 and time 2, S_1 and S_2 are values of reach storage at time 1 and time

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

$$S=K\,\{XI+(1-X)\,O\} \qquad 2.8$$

Where, S = reach storage,

I = inflow discharge, O = outflow discharge, K = storage constant, X = weighting factor

Combining equations 2.7 and 2.8 and simplifying results (Ponce, 1981):

$$O_2=C_1I_1+C_2I_2+C_3+O_1 \qquad 2.9$$

Where, C_1= ((Δt/k) +2x)/C_0, C_2= ((Δt/k)-2x)/C0, C_3=2(1-x)-Δt/k)/c0and C_0=Δt/k+2(1-x)

C0, C1, C2, and C3 are dimensionless parameters.

An approximation for K is the travel time through the reach (length of reach divided by the average flow velocity). The value of X is between 0.0 and 0.5. A value of 0.0 gives maximum attenuation from the procedure and 0.5 provides the minimum attenuation. (Linsley& Kohler, 1982) Describe a procedure to determine K and X from hydrographs.

2.9 Modeling Outputs

Simulation is being run based on the defined control specification(s). The simulation(s) compute the outlet flow of the sub-basins, all stream junctions and reaches. The results of the simulation are available in the form of graphs and Tables. Results are tabulated at global summary Tables which tabulated all hydrologic elements and also it is possible to see each element individually as either graphs or Tables (Feldman, 2000)

2.10 Arc GIS

"A geographic information system (GIS) integrates hardware, software, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information" (ESRI, 2009). GIS is a very practical tool regarding spatial and also temporal analysis in many fields of studies such as water resources management. GIS is capable of storing high amount of data over geographical area. It's being practical is more considered because of capability of GIS in spatial operation on different sets of data and linking all of them together. GIS uses two type of information, the first one is Spatial Information describing location and shapes and the second one is Descriptive Information relating features (Chen et al., 2004). The GIS software used in this project is ArcGIS Developed by ESRI. The capability of ArcGIS is to use data as input, manipulate and prepare data as output compatible with HEC-HMS which is one of the advantages of using this tool.

2.11 Flood Forecasting

Flood forecasting is a process of estimating and predicting the magnitude, timing duration and duration of flooding based on the known characteristics of river basin, with the aim to prevent damages to human life, properties and to the environment. The application of statistical frequency curves to floods was first introduced by Gumbel. Using annual peak flow data that is available for a number of years, flood frequency analysis is used to calculate statistical information such as mean, standard deviation and skewness which is further used to create frequency distribution graphs. The best frequency distribution is chosen from the existing statistical distributions such as Gumbel, Normal, Log-normal, Exponential, Weibull, Pearson and Log-Pearson. Among these key influencing flood variables, rainfall and the spatial examination of the hydrologic cycle had the most remarkable role in runoff and flood modeling. This is the reason why rainfall prediction, including used for flood prediction, especially in the prediction of floods depths for short-term flood prediction is highly relied on the availability of data.(Mosavi *et al*., 2018).

In this study the frequency analysis was carried out by using HEC-HMS and other good fitted probability distributions. Yearly maximum observed flood were used as input data for probability distributions and the analysis has been carried out using the calculate data for the study area from the available data on Era Drainage Manual (ERA 2013) for region 3 for HEC-HMS model.

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

The study was conducted at Weyb watershed, which is found in southeastern part of Ethiopia in Genale-Dawa River basin, and it is located between 6°30′–7°30′N latitudes and 39°30′–41°02′E longitudes. It covers a total drainage area of4472.949 km^2. The Weyb River originates from the northern flanks of the Bale Mountains and first flows generally northeastward then flows to east and southeastward for the remainder of its course. Finally, it joins with Genale Dawa Rivers near Ethiopia–Somalia border strengthening its journey to the Indian Ocean.

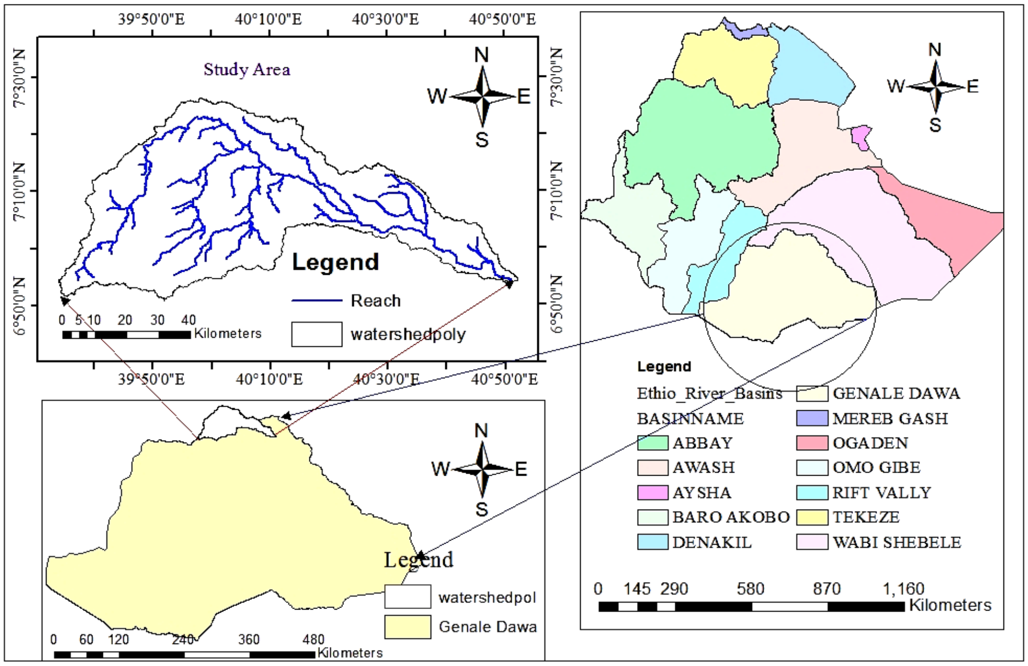


Figure 3.1: Location map and River networks of the study area

It originates from the Bale Mountains extreme points locally called Sanette. The upper most part of the watershed is covered with the afro-alpine ecosystem, which is known to be the largest, such area in Ethiopia.

3.1.2 Climate

The main summer season, locally known as Kiremt and a minor rainy season, locally known as Belg are the two distinct seasonal weather patterns that characterize the climate of the Weyb watershed .The wet season runs from July to mid-October. The dry season spans from November to February. However, in some part of the watershed, there is a third season with moderate rainfall (Belg) occurring from mid-March to mid-Jun.

3.1.3 Rainfall

The variation in the seasonal distribution of rainfall in Ethiopia can be attributed by the references to the position of the Inter-Tropical Convergence Zone (ITCZ), the relationship between upper and lower air circulation, the effects of topography and the role of local convection currents and the amount of rainfall (Daniel, 2001).The seasonal rainfall distribution within the study area results from the annual migration of then ITCZ. The rainfall pattern of Weyb Watershed follows symmetric bimodal profile with peaks in April and October Months.

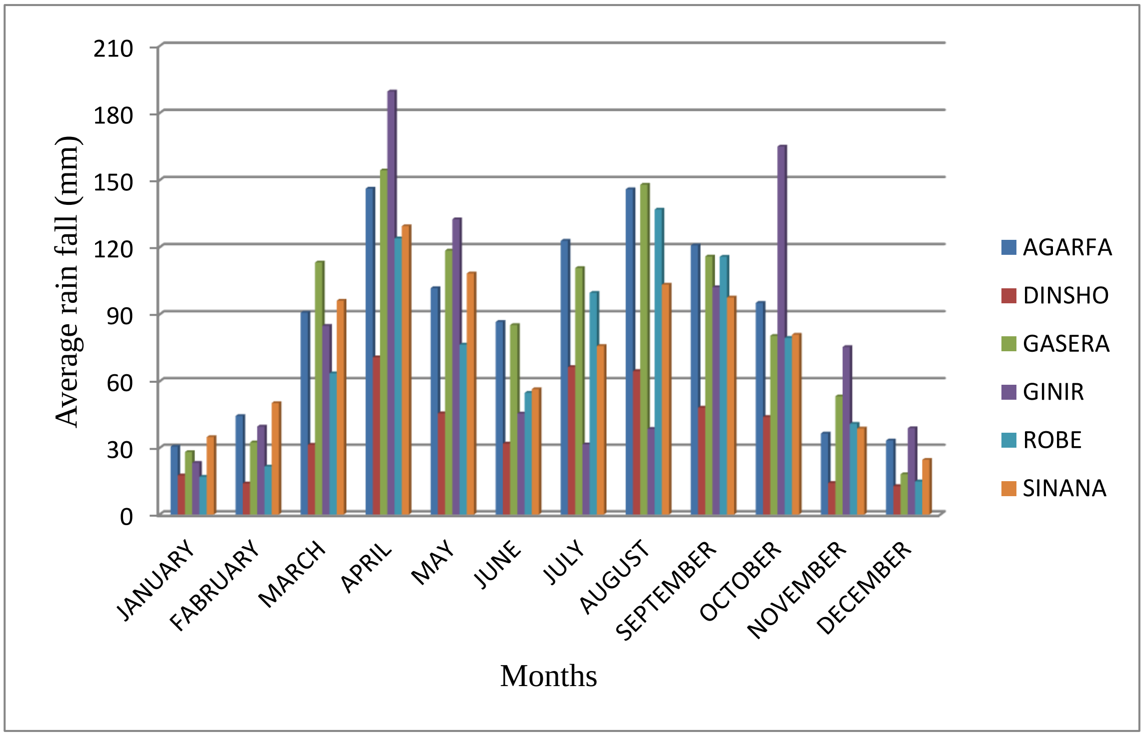


Figure 3.2: Monthly Distribution of Average Rain Fall in the Weyb River Watershed

3.1.4 Temperature

Air temperature of the Weyb River watershed was analyzed using monthly minimum and maximum data from all stations. As depicted in (Figure 3.3), the monthly distributions of the watershed temperature suggest that the maximum occurs in the month of March (15.559 ◦c) and the minimum in the month of November (13.369 ◦c). On the average in the watershed, there is a drop in average air temperature of 1 ◦c for every 161 m increase in elevation.

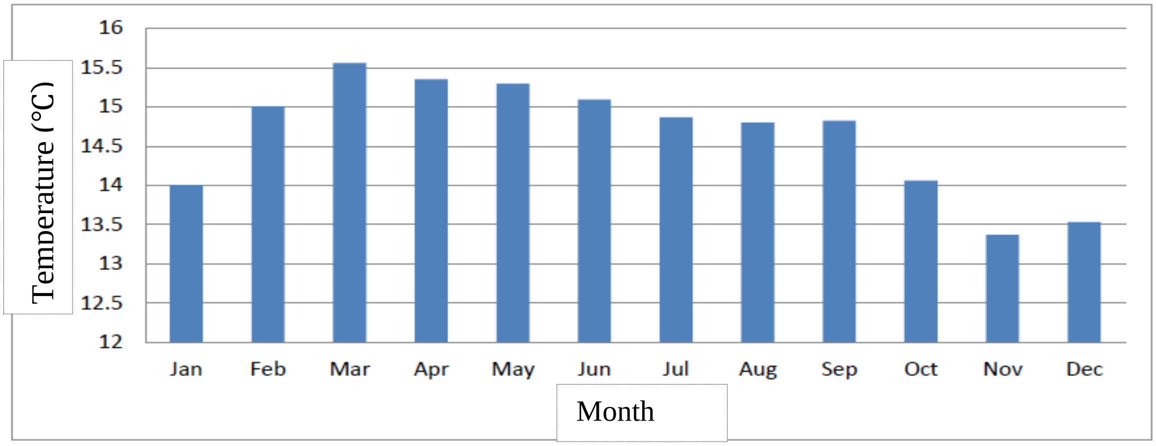


Figure 3.3: Monthly Distribution of Mean Air Temperature in the Weyb River Watershed

3.1.5 Topography

The elevation of the watershed ranges from 4343m at its origin and 117m at its outlet. The upper reaches of the River is fairly forest land with rugged slope of Batu mountainous ridge, while the lower part of the drainage area is narrowed gorge and is very flat at its lower reaches.

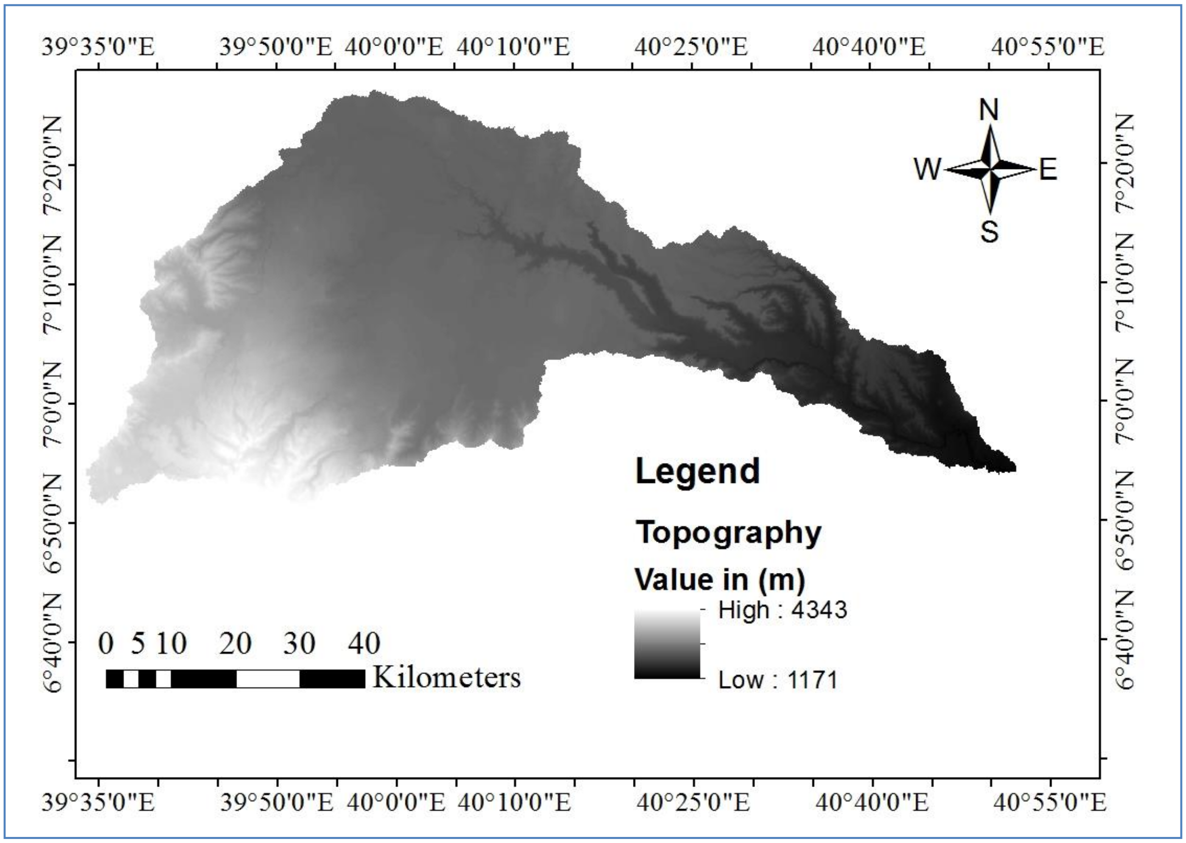


Figure 3.4: Elevation Map Of The Watershed

3.1.6 Soil

According to FAO (2002), the soils of the Weyb River watershed can be divided into six broad groups for agro ecological purposes. Leptosols, Regosols, Cambisols, Luvisols, vertisols, and Arenosolsa;The shallow soils, with limited or zero agricultural potential are generally grouped as Leptosols and Regosols and are commonly associated with steep slopes their depth is determining in recognition of the associated agro ecological units. The moderately deep soils, classed as Cambisols, some Luvisols include most of the lighter textured soils of the watershed, and they are therefore suitable for cultivation. The heavy textured vertisols are deep soils with poor drainage and properties of swelling and cracking.. Arenosols have a course texture accountable for the generally high permeability and low water and nutrient storage capacity.

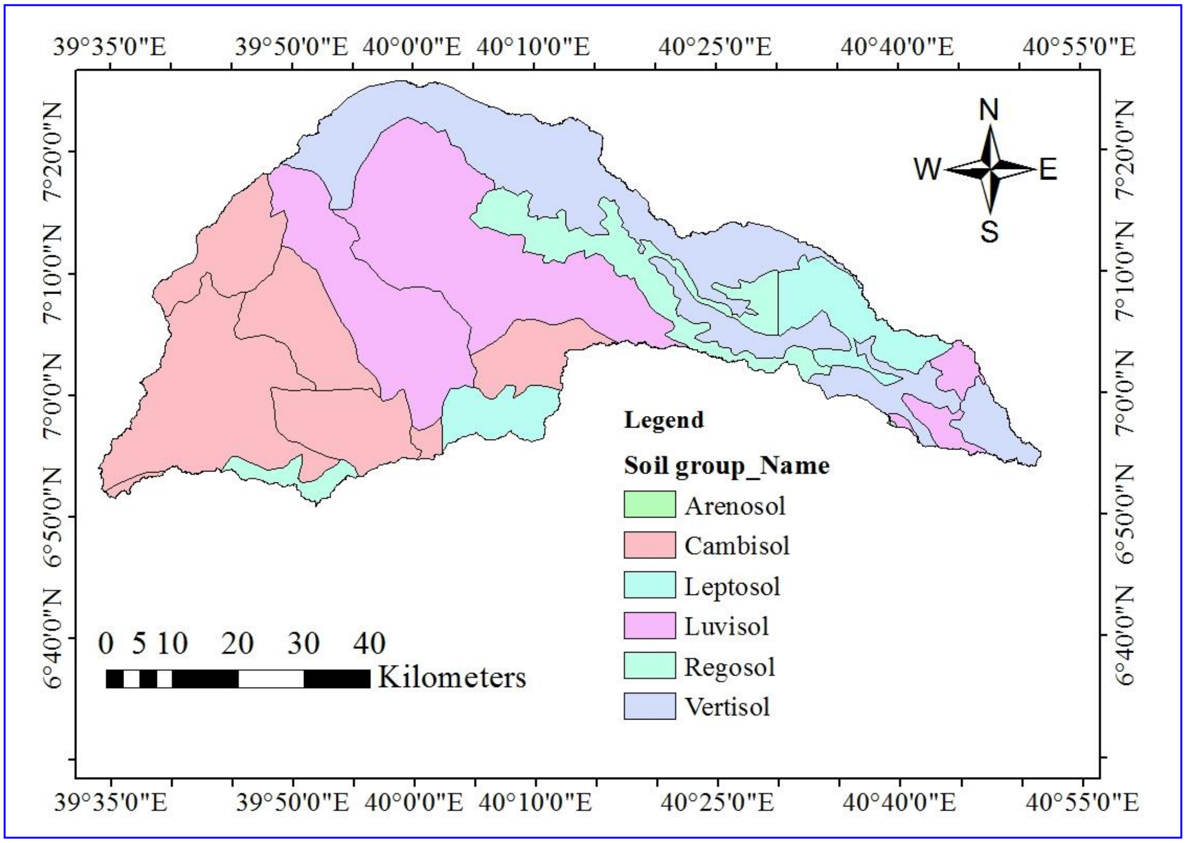


Figure 3.5: Soil map of Weyb watershed

3.1.7 Land use / Land cover

The Land use map of the Weyb River watershed which was obtained from MOWIE shows that the watershed has a mosaic of land cover including cultivated land, Shrub land, Bush land, Settlement, Forest, Grass land wood land. The variations are due to the topography, rainfall distribution and landscape of the watershed.

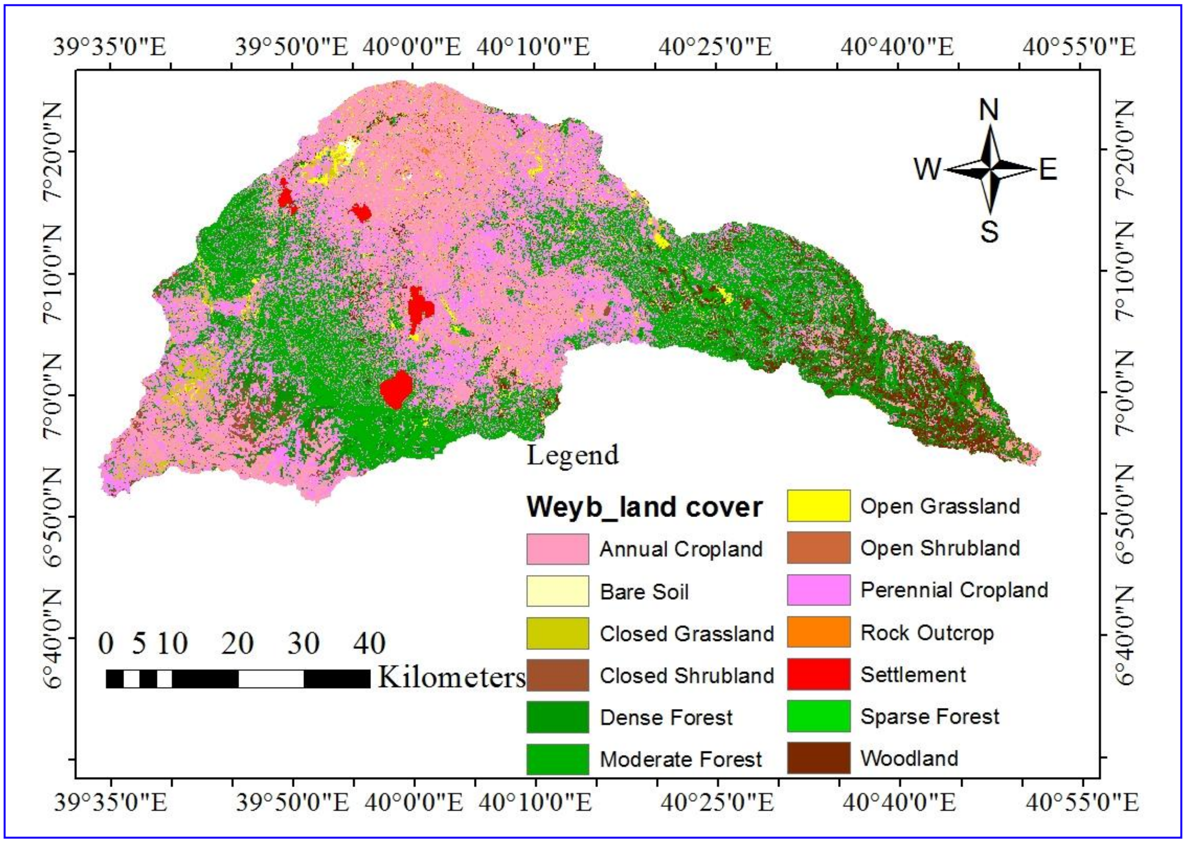


Figure 3.6: land use land cover of the Weyb River watershed

3.2 Materials and models used

The materials used for this thesis work include the following, but not limited to:

- ARC-GIS10.1 to obtain hydrological and physical parameters and spatial information of the watersheds of the study area.
- HEC-GeoHMS 4.2 to sub-divide the basin to more manageable form and determine basin characteristics
- HEC-HMS 4.3 for rainfall-runoff simulation.
- Rain Bow2.0.5.0 software to analysis rain fall data homogeneity test.
- Easy-fit software 5.6 to select the best probability distribution method of flood distribution method for the observed data.

3.3 Data Collection and Analysis

The basic data required for the rainfall-runoff simulation are rainfall information, time series of discharge data, Digital Elevation Model (DEM), Soil types and Land use/Land-cover data of the study area. These data sets were collected and procured from different sources as shown in Table 3.1: below

3.3.1 Data Applied For the Model

Table 3.1: Data Type and Sources

S. no.	Data	Source
1	DEM	Ethiopian mapping agency (30mX30m)
2	Meteorological	National Service Agency of Ethiopia (NMSA)
3	Hydrological	Hydrology department of the Ministry of Water, irrigation and electricity of Ethiopia
4	LULC	Ethiopian Mapping Agency (2013)
5	SOIL	GIS department of Ministry of Water, Irrigation And Electricity of Ethiopia (MoWIE)

Table 3. 2: Hydro-Metrological Data Obtained and Their Location

No	Data type	Station name	Latitude(^{o} N)	Longitude(^{o} E)	Elevation(m)	Recorded year
1.	Meteorological data	Dinsho	7.096	39.767	3072	1985-2014
2.		Robe	7.137	40.046	2480	1985-2014
3.		Sinana	7.134	40.2167	2400	1985-2014
4.		Agarfa	7.267	39.881	2550	1985-2014
5.		Gasera	7.311	40.108	1680	1985-2014
6.		Ginir	7.17	40.656	1750	1985-2014
7.	Stream flow data	Sofumer	6.907	470.857	1171	1992- 2006

3.3.2 Data Quality Analysis

Before beginning any hydrological analysis it is important to make sure that data are homogeneous, consistent, 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, 2005). Generally, data should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques. Basically a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. In particular, the following steps were taken in this study to improve the quality of the raw data collected.

- Filling the missing data
- Checking for consistency
- Homogeneity test

3.3.2.1 Filling missing observed data

Precipitation is that part of atmospheric moisture, which reaches the earth's surface in different forms. Hydrologists start working when the precipitation reaches the ground. This connects hydrology with meteorology. Rainfall data plays a central role in developing rainfall – runoff models. Measured precipitation data are important for many problems in hydrologic analysis and design purposes. The main problem in hydrologic analysis is that these data's are not fully available as expected. The reason behind for the shortage of these data is either of the including extreme natural phenomena and human induced phenomena such as mishandling of the observed data by field personnel, wars etc. malfunctioning of the gauge or may be due to absence of an observer to make the necessary visit to the gauge. These gaps in rainfall record data's can be filled with several approaches. The commonly used methods are Station Average, Regression, Inverse Distance Weighting and Normal Ratio. In this study normal ratio and station average are used due to the compatibility of the methods.

1. Station Average Method

The missing record is computed as the simple average of the values at the nearby gauges. (McCuen, 2003) recommends using this method only when the annual precipitation value at each of the neighboring gauges differs by less than 10% from that for the gauge with missing data.

$$p_{x=\frac{1}{M}[P_1+P_2+\cdots+P_n]} \qquad 3.1$$

Where: Px = The missing precipitation recordP1, P2…., Pn = Precipitation records at the neighboring stations, M = Number of neighboring stations

In this study the metrological stations that have the annual precipitation value less than the neighboring stations such as Robe and Gasera are filled using this method.

2. Normal Ratio Method

If the annual precipitations vary considerably by more than 10 %, the missing record is estimated by the Normal Ratio Method, by weighing the precipitation at the neighboring stations by the ratios of normal annual precipitations (Simanton & Osborn, 2003). The historical record missing daily rainfall data of each considered station, Dinsho, Sinana, Agarfa and Ginir stations) was checked and was found to have annual rainfall among stations differ by more than10%. Therefore the missing data of these stations were estimated using this method. This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values (Yemane, 2004).

$$\%\ \text{Daifference} = \left(\frac{NX-Ni}{NX}\right) * 100 \qquad 3.2$$

NX-Ni must be positive. If Ni>NX the numerator will become Ni-Nx. Then, the b means of the nearby stations' differences are determined.

$$Px = \frac{1}{n} * (\left(\frac{NX}{N1}\right) * P1 + \left(\frac{NX}{N2}\right) * P2 + \cdots + \left(\frac{NX}{Nn}\right) * Pn \qquad 3.3$$

Where Px is the missing data at station x, Nx is the missing data stations normal annual rainfall, Ni is normal annual rainfall at station i. and n is number of nearby gauges. The station-average method for estimating missing data uses n gages from a region to estimate the missing point rainfall, Px, at another gage:

$$\mathrm{Px} = \frac{1}{\mathrm{n}} \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{Pi} \qquad 3.4$$

In which Pi is the rainfall at gage I (Equation 3.7) is accurate when the total annual rainfall at any of the n regional gages when the mean of percent difference is more than 10%. This method gives equal weight to the rainfall at each of the regional gages. The value 1/n is the weight given to the rainfall at each gage used to estimate the missing rainfall.

3.3.2.2 Checking the consistency of rain data

Consistency is the ability of something to maintain a particular standard or repeat a particular task with minimal variation or it is to mean when something behaves or performs in a similar way .If the conditions relevant to the recording of rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. According to (James, 1960) some of the common causes for inconsistency of record are:

- Shifting of a rain gauge station to a new location
- The neighborhood of the station may have undergoing a marked change
- Change in the immediate environment due to damage, due to deforestation, obstruction
- Occurrence of observational error from a certain date both personal and instrumental, etc.

The most common method of checking for inconsistency of a record is the Double-Mass Curve analysis (DMC). The curve is a plot on arithmetic graph paper, of cumulative precipitation collected at a gauge where measurement conditions may have changed significantly against the average of the cumulative precipitation for the same period of record collected at several gauges in the same region. A change in proportionality between the measurements at the suspect station and those in the region is reflected in a change in the slope of the trend of the plotted points.

If a Double Mass Curve reveals a change in slope that is significant and is due to changed measurement conditions at a particular station, the values of the earlier period of the record should be adjusted to be consistent with latter period records before computation of areal averages. The adjustment is done by applying a correction factor, on the records before the slope change given by the following relationship. If a break in slope is observed then the data of the station is adjusted by multiplying it with the ratio of the two slopes (Equation 3.5).

$$p_a = \left(\frac{b_a}{b_0}\right) p_0 \qquad 3.5$$

Where;

Pa = adjusted precipitation, Po = observed precipitation, ba= slope of graph to which records are adjusted, bo= slope graph at time Po was observed

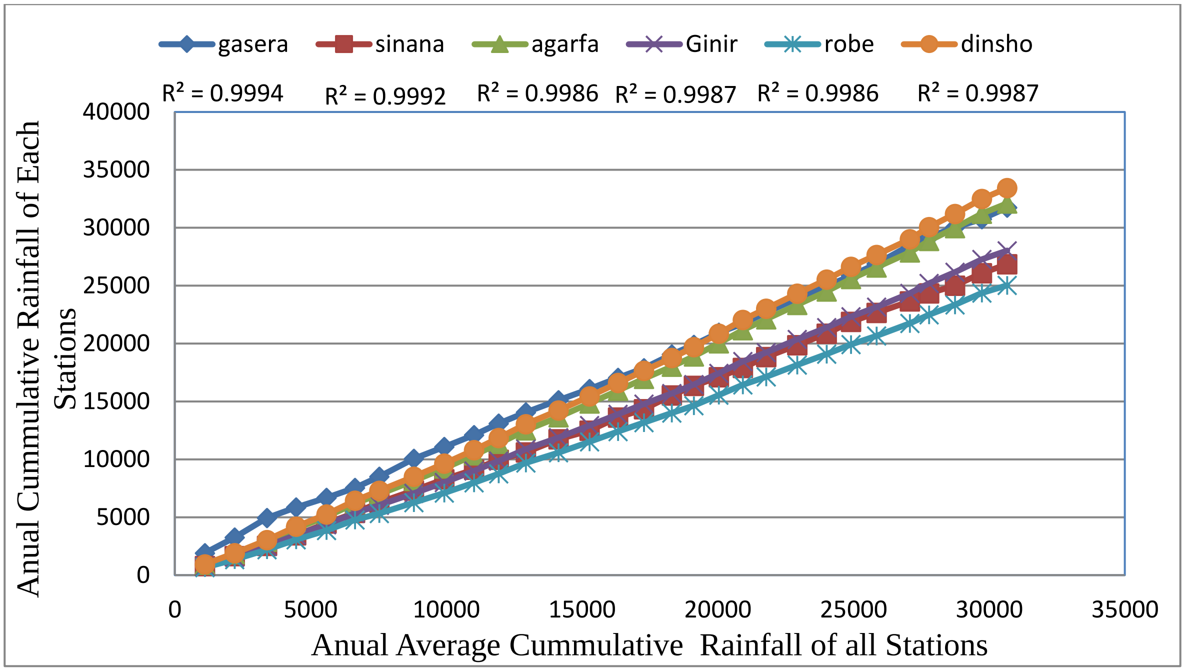


Figure 3.7: Consistency Checks of the Selected Meteorological Stations by Double Mass Curve

3.3.2.3 Homogeneity test

Homogeneity analysis is used to separate a change in the statistical properties of the time series data or to ascertain that the rainfall data are from the same population distribution. The causes of change can be either natural or man-made. These include alterations to land use and relocation of the observation gauging station. Therefore in order to select the representative meteorological station for the analysis of areal rainfall estimation, checking homogeneity of group stations is essential (Tadesse, 2016). In this study, the rainfall-homogeneity test was carried out using Rain Bow software.

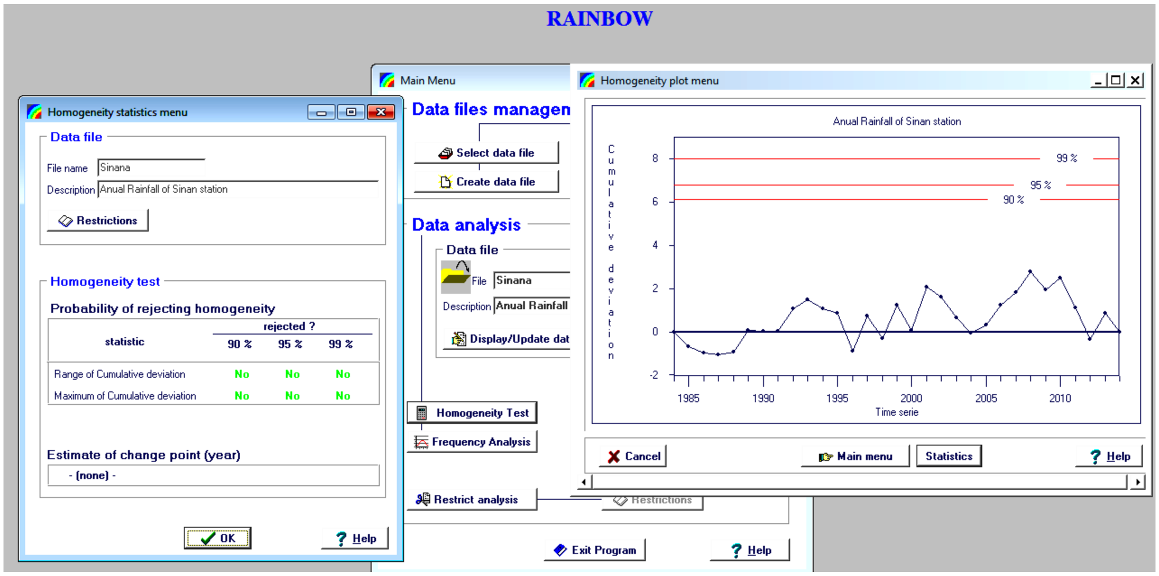
Rainbow is a software package developed by the Institute for Land and Water Management of the K.U.Leuven. The programme is designed to test the homogeneity of hydrologic records and to execute a frequency analysis of rainfall and evaporation data. The program is especially suitable for predicting the probability of occurrence of either low or high rainfall amounts, both of which are important variables in the design and management of irrigation systems, drainage network, and reservoirs.

Homogeneity test is based on the cumulative deviation from the mean as expressed using the mathematical equation proposed by (Raes *et al*., 2006).

$$S_K=\sum_{i=1}^{K}(X_i-\bar{X})k=1,-n \qquad 3.6$$

Where; *X*- *i* = the record for the series X1,X2 --- Xn, X= the mean, Sks = the residual mass curve

For a homogeneous record, one may expect that the Sks fluctuate around zero in the residual mass curve since there is no systematic pattern in the deviation Xi's from the average values *X*. To perform the homogeneity test, annual cumulative rainfall data of the stations were computed and analyzed using the Rainbow software and the result of the homogeneity test are presented in Figure 3.8.



File name: Sinana

Description: Anual Rainfall of Sinan station

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) -

File: Sinana

Description: Anual Rainfall

Figure 3.8: Homogeneity Test and Statistics of Sinana Station Rainfall Data

Results of Figure 3.8 shows that the data point fluctuate around the zero centers line an indication that the rainfall data are statistically homogeneous. To further confirm that the rainfall data are statistically homogeneous, test of hypothesis was done as follows; H0: Data are statistically homogeneousH1: Data are not homogeneous. The null and alternate hypothesis were tested at 90%, 95%and 99% confidence interval that is 0.1, 0.05 and 0.01 degree of freedom and results obtained are presented in Figure 3.8. From the result of the null hypothesis (H0) was accepted, and it was concluded that the rainfall data collected from Sinana station is statistically homogeneous at 90%, 95% and 99% confidence interval that is 0.10, 0.05 and 0.01df. In this study the homogeneity of the other five stations were also analyzed in the same manner and presented in appendix A.

3.4 Generation of Curve Number Grid

The soil losses or abstraction is an important part of calculation of overland flow. In fact the rainfall can freely overflow unless it is not trapped. The rainfall is trapped either by interception by vegetation, or infiltration to the soil or even stored in the soil surface. Rainfall runoff or direct runoff therefore is the amount of water which is remaining on the surface (Chow*et al*., (1988)). Therefore having information of losses process is important for data preparation. There are different methods provided for HMS model. Among them Soil Conversation Method (SCS) (Now the Natural Resources Conservation Service, NRCS) is used to calculate the amount of losses. This method uses Curve Number methodology for losses calculation (HEC-HMS, 2006)

3.4.1 Soil Conservation System (SCS) Curve Number

Soil Conservation Service (SCS) runoff curve number method is most commonly used method for estimating rainfall excess (Hydrology, 1992). The SCS Curve Number is used to characterize the runoff properties of a region (sub-basin) for its particular land use and soil infiltration characteristics. The CN value is between 30 and 100. The high values show that the region does not retain water so much and most of the rainfall turns to overland flow, while low values correspond to high ability of retaining water and therefore high losses rate and low over land flow for the region. The SCS-CN model assumes that the accumulated rainfall-excess depends upon the cumulative precipitation, soil type, land use and the previous moisture conditions as estimated in the following relationship.

The SCS runoff equation: (NRCS, 1986)

$$\boldsymbol{Q} = \frac{(\boldsymbol{P}-\boldsymbol{I_\alpha})\mathbf{2}}{(\boldsymbol{P}-\boldsymbol{I_\alpha})+\boldsymbol{S}} \qquad 3.7$$

Where:

Q=runoff, P=Rainfall, S=Potential maximum retention after runoff begins, $I\alpha$=Initial abstraction According to the (Hydrology, 1992) Initial abstraction is “all losses before run off begin”. Water retained in the surface depressions, water intercepted by vegetation, and evaporation and infiltration constitute the initial abstraction. $I\alpha$as an empirical equation is:

$$I\alpha=0.2S \qquad 3.8$$

To get an equation independent from initial abstraction value, substituting eq. above gives:

$$Q = \frac{(P-0.2S)^2}{P+0.8S} \qquad 3.9$$

Where Q is the accumulated precipitation excess at time t (mm); P is the accumulated rainfall depth at time t (mm); and S is the potential maximum retention (mm), a measure of the ability of a watershed to abstract and retain storm precipitation.

In the curve number method, the runoff is directly proportional to the precipitation with an assumption that the runoff is produced after the initial abstraction of 20% of the potential maximum storage (Heshmatpoor, 2009). The maximum retention, S, and watershed characteristics are related through an intermediate dimensionless parameter, the curve number (CN) as:

$$S = 25400 - \frac{254xCN}{CN} \qquad 3.10$$

where CN is the SCS curve number used to represent the combined effects of the primary characteristics of the watershed area, including soil type, land use, and the previous moisture condition. The CN values range from 100 (wetland) to approximately 30 for permeable soils with high infiltration rates (NRCS, 1986).

The value CN is for different land uses affiliated to the soil type which is determined in the Tableof SCS Runoff Curve .The SCS’s soil type classification is in four groups A, B, C & D. where, as a short description group A is constitute of deep sand, deep loess and aggregated silts. Group B made up of shallow loess and sandy loam while clay loams, shallow sandy loam, soil low in organic content and soils usually high in clay mare known as group C and finally group D is assigned to the soils that swell significantly when wet as well as to the heavy plastic clays and certain saline soils (McCuen, 2004). The curve number (CN) values for each sub-basin result from the land use and soil type information. To deal with the huge amount of data in the field of study, Arc-GIS is used as a tool to calculate CN value for each cell in the region and Geo-HMS is used to find out the average CN value for each sub-basin in the Weyb watershed.

3.4.2. Land/land cover map

There are different aspects covered the earth's surface, in turn, influence the behavior of water flow on terrain surfaces such as objects and sets of land uses and human activities, Land use information is on GIS format and should be processed to get ready and merge with the soil type data. To incorporate the effect of land use, the Weyb watershed is classified into four dominant and very same classes. The Land use identified in watershed are primarily agricultural, forest, residential and range land and this classified land use then prepare in the form of look up Table to be used during CN_Grid computation. A map was produced to show these different classes of land use in Weyb watershed.

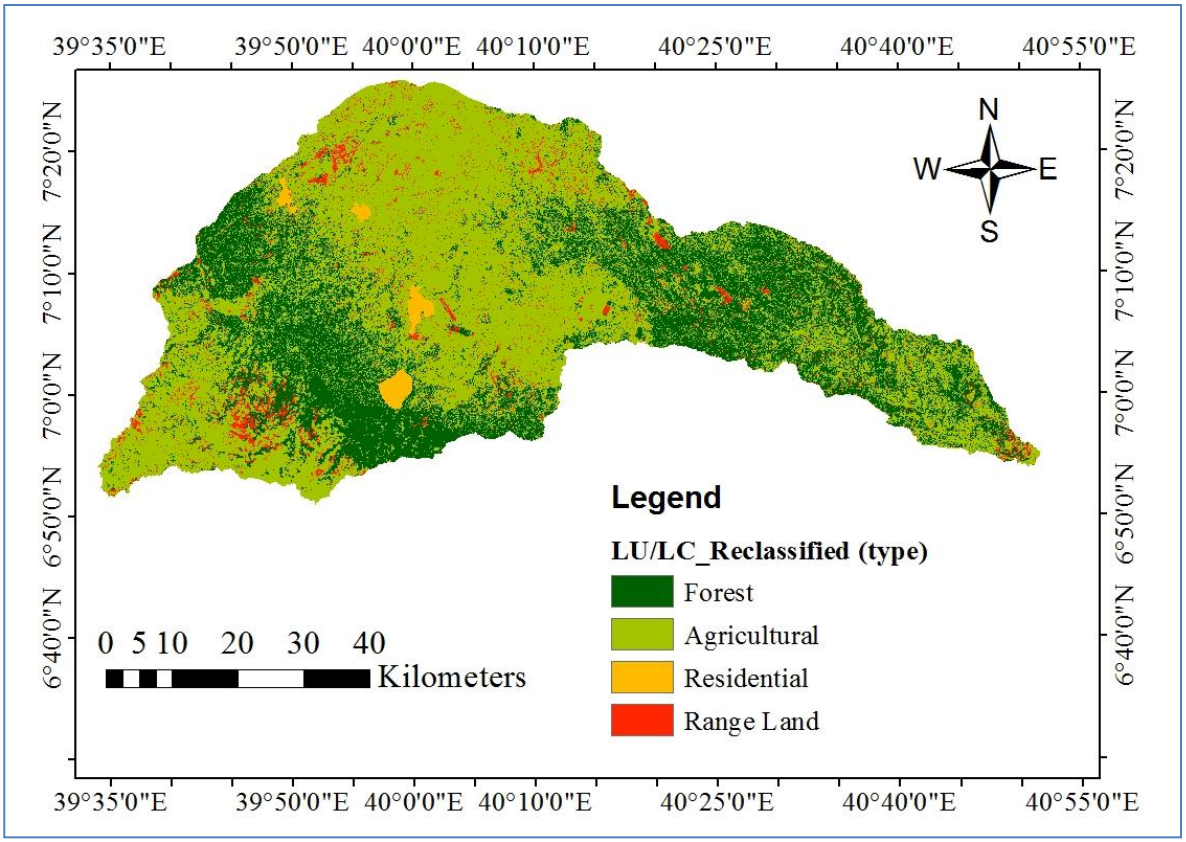


Figure 3.9: Lu/lc re-classification

Based on the generated land use map the total study area have four major Land use classes (Agriculture, Forest, residential areas and range land) which show the majority land cover for the study area are Agriculture which covered about for 57.41% then the Forest comes in the second with 29.5% of total area while the residential areas and range land areas up to 13.1%.

Table 3.3: LU/LC of the watershed in percentage

Lu class	**Area (km2)**	**Area (%)**
Agricultural	2567.5	57.41

Forest	1319.484	29.5
Residential	574.3	12.84
Range land	11.21	0.25
Total	4472.949	100

3.4.3 Soil map

The soil resource data of the watershed is classified in to different hydrologic soil groups by using look up Tables (i.e. internationally developed hydrological soil group classification Tables). Hydrologic soil groups are group of soils having similar runoff potential under similar storm and cover conditions. Soil properties that influence runoff potential are those that influence the minimum rate of infiltration for a bare soil after prolonged wetting and when not frozen. These properties are depth to a seasonally high water Table, intake rate and permeability after prolonged wetting, and depth to a very slowly permeable layer.

After pre-processing of soil maps using GIS Based on the rules of hydrologic soil group classifications developed by the US Natural Resource Conservation Service (NRCS), the hydrologic soil map of Weyb watershed was generated and grouped: as A,B,C and D (fine sand, loam, silt, and clayey) respectively. This is later used for computation of Curve Number (CN) to be used in the SCS method of runoff estimation. The soil map and the area under different soil group are shown in Fig. 3.10 and Table 3.4, respectively

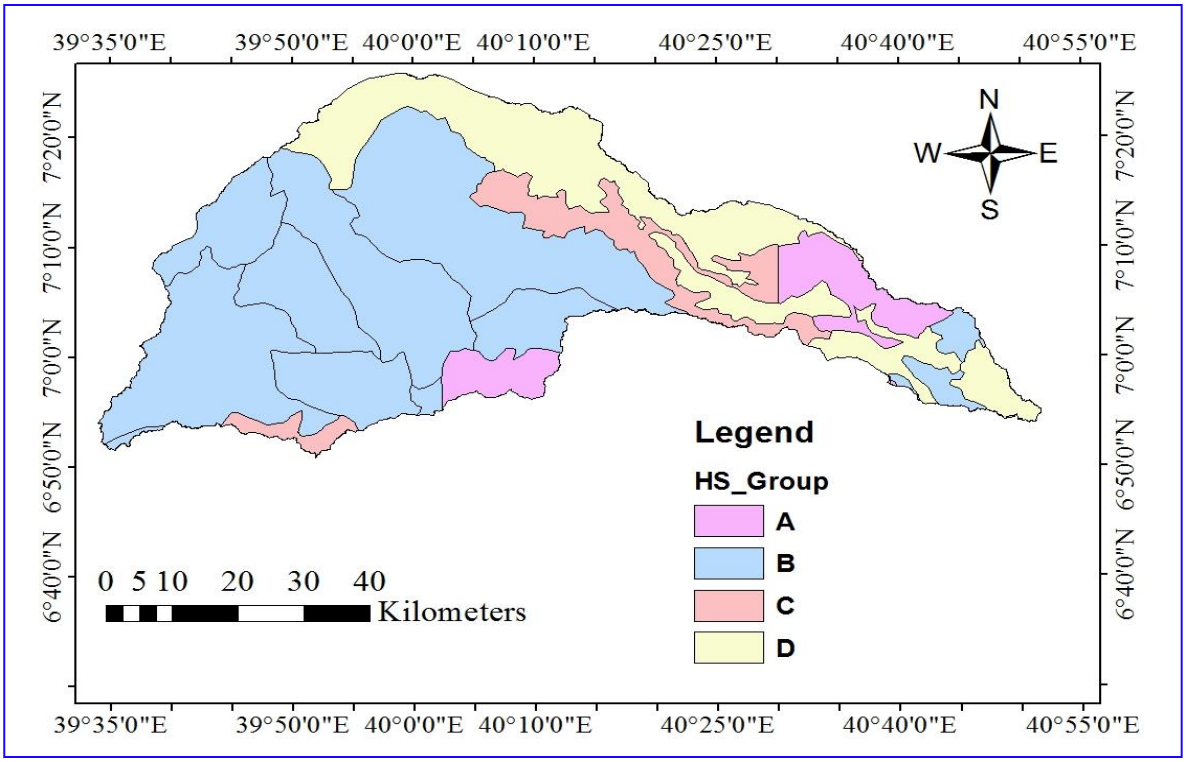


Figure 3.10: Hydrological Soil Group of the Watershed

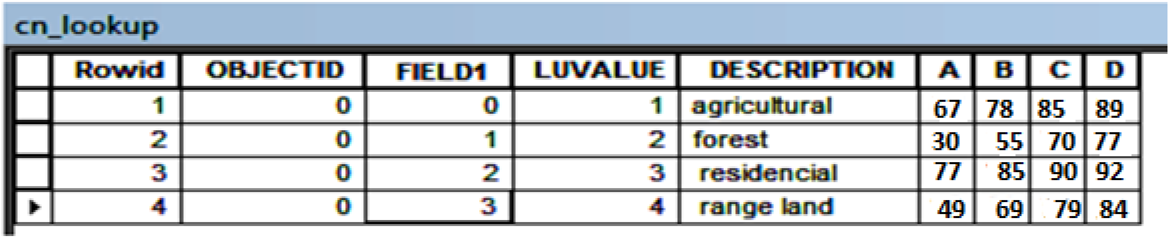
Table 3.4: Hydrologic Soil Group (HSG) Their Area Coverage of Weyb Watershed

Soil group (HSG)	**Area (km2)**	**Area (%)**
A	332.691	7.25
B	3008.058	69.25
C	184.42	2.123
D	955.78	21.368
Total	4472.949	100

From Table 3.4two HSG namely (D) and (B) were found to dominate the Weyb watershed. The soils in the northern and some north eastern part of the watershed were found to be of HSG (D) meaning they have highest runoff potential in the watershed hence limiting infiltration and favoring runoff which constitutes about 21.368% of the total area of the basin. The western and southern part parts of the watershed were found to be dominated by HSG (B) which has moderate infiltration rate and moderate runoff potential and having moderate infiltration rates. It constitutes most of the basin area about 69.25% of the total area of the basin.

The required sets data to generate the CN grid are ready now. By joining attribute of land use and soil type there is a final layer for soils in which each cell has its own values for both soil type and land use class. The value of each class affiliated with specific soil type is set in a CN_Look-up Table (Table 3.5) that Geo-HMS use to calculate the CN value for each cell. The final is a grid set of data consisting CN values which is used by Geo-HMS again to calculate the average value of each sub-basin and convert that to a compatible format for HMS model. The look up table was prepared based on the TR-55 (NRCS, 1986) appendix B Table:7.7

Table 3.5: CN_Look up Table



cn_lookup

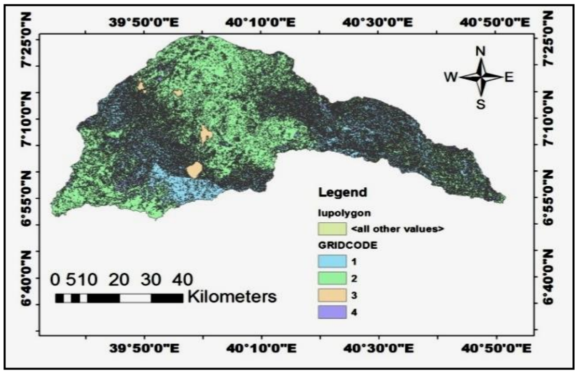
Rowid	OBJECTID	FIELD1	LUVALUE	DESCRIPTION	A	B	C	D
1	0	0	1	agricultural	67	78	85	89
2	0	1	2	forest	30	55	70	77
3	0	2	3	residencial	77	85	90	92
4	0	3	4	range land	49	69	79	84

3.4.4 Estimating CN_ Grid values

The CN is used to compute the volume of rainfall excess in the HEC-HMS and is therefore used as the description of watershed soil and land use characteristics in this modeling study. The Curve number is calculated in ArcGIS trough the union processing attributes combined to one of the land and Hydrological soil groups. (NRCS, 1986)The creation of the CN Table that has curve numbers values for different combinations of soil hydrologic groups and land uses have been made.

The SCS CN Table gives CN for different combinations of land use and soil group, the Curve Number parameter is dimensionless and varies from 30 (maximum infiltration) to 100 (low infiltration) (NRCS, 1986) . After elaborating of the data necessary to compute the CN indicator, the CN map has been obtained from the intersection of the soil hydrological group and land use. The following steps were done to get a Curve Number grid for the area of interest from LULC and HSG maps:Vectorization of both the LULC and HSG maps, Table or vector operation (Union) to get polygons of unique combination of both the maps in Arc-GIS., CN value generation from unique polygons by query operation in Arc-GIS and Geo-

HMS create the grid Map.CN value determination for each sub-basin. The CN grid map of the watershed is presented in Fig. 3.13.



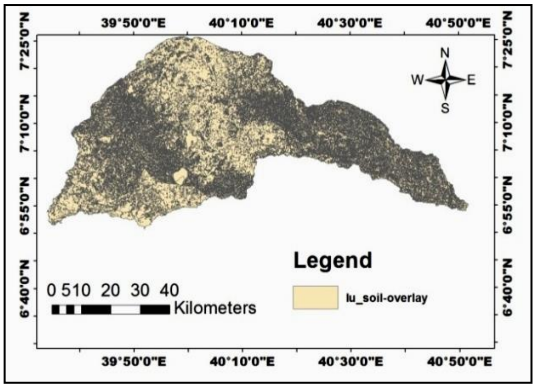


Figure 3.11: Lu_Polygon Figure 3.12: Lu_Soil_Union

In the above figure the number 1,2,3,4 shows the land cover reclassified type agricultural, forest, residential and range land respectively.

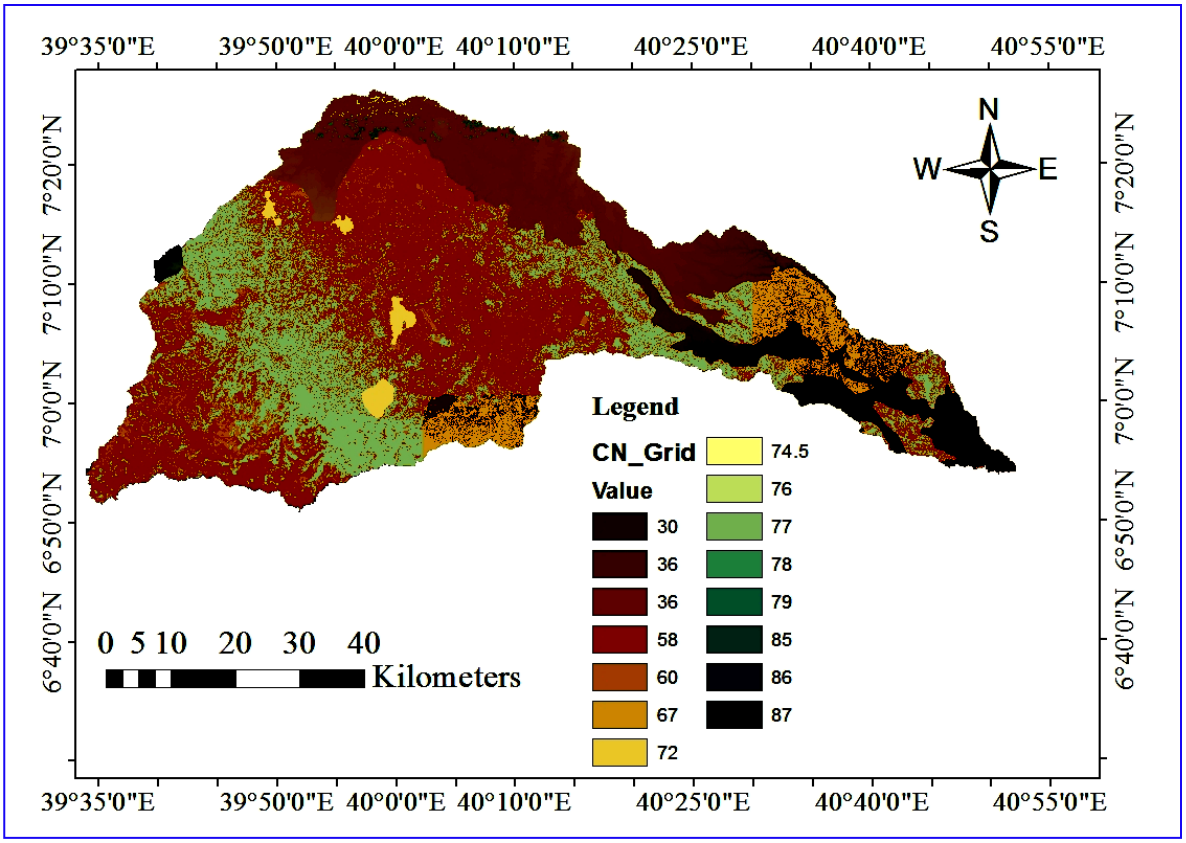


Figure 3.13: CN_Grid

3.5 Areal rainfall determination

In a given drainage basin rain gauge stations are evenly distributed into sub-basin. The rain of one station in a basin may be different from that of the second station in the same watershed. From this idea the average precipitation value on the entire basin is worked out, so as to get average rain watersheds to have the limits of the watershed carefully defined. Therefore, rainfall over an area of interest has to be estimated from these point measurements. There are usually three ways of determining the areal precipitation over a watershed from rain gauge measurement. These methods are the Arithmetic means, the Thiessen polygon and the Isohyetal method (Daniel, 2008).

In this study the thiessen polygon method was used to determine the mean areal rainfall, the rainfall amount of each station was multiplied by the area of its polygon and the sum of these products was divided by the total area of the watershed. If P1, P2, P3……Pn are the rainfall magnitudes recorded by the gauging stations 1, 2…….n, respectively and if the areas of Thiessen Polygon A1, A2, and A3...…An, then the average rainfall over the watershed is given by:

$$Pav = \frac{P1*A1+P2*A2+P3*A3+\cdots+Pn*An}{A} \qquad 3.11$$

Where: - Pavg = areal precipitation over the sub-basin (mm); P1, 2…n = precipitation depth in each station (mm); A1, 2 …n = area of each polygon (km^2); A = total watershed area of sub-basin (km^2).Therefore, rainfall over an area of interest has to be estimated from these point measurements (Daniel, 2008)..

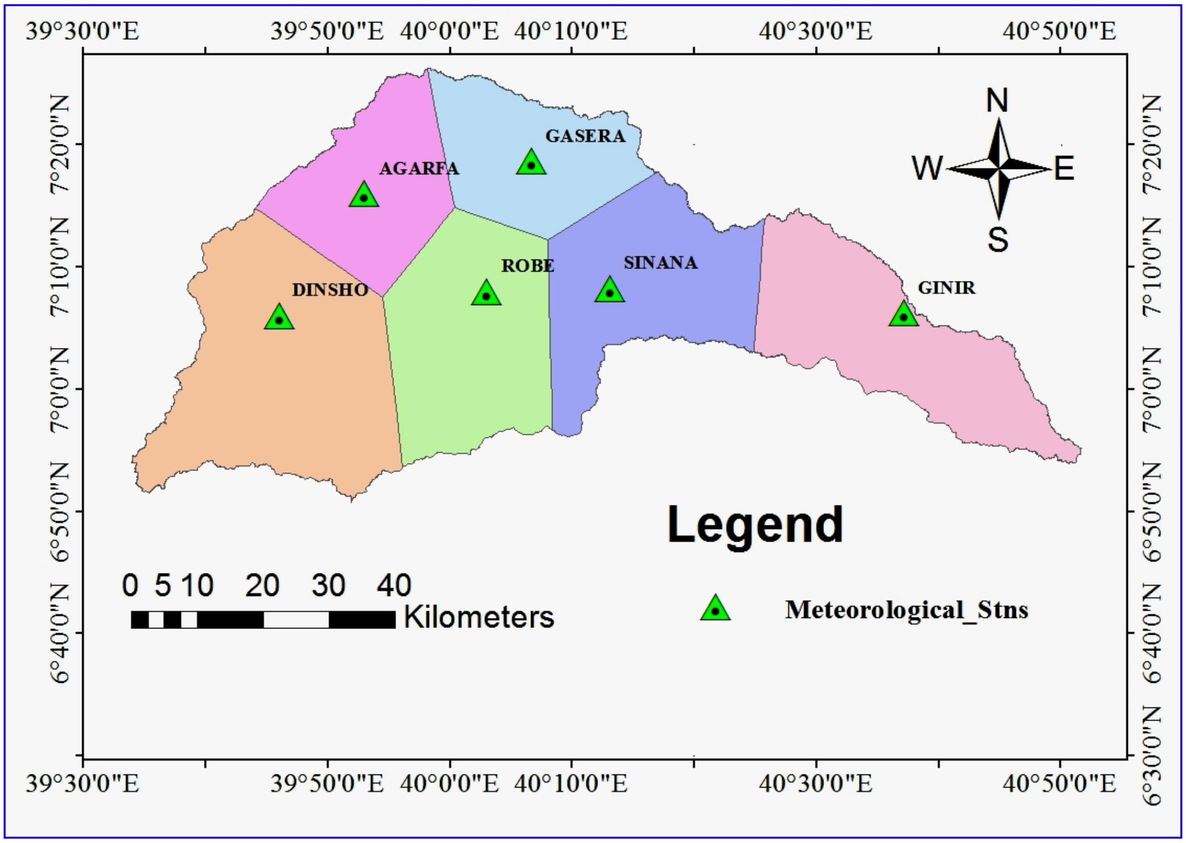


Figure 3.14: Thiessen Polygon for Selected Rainfall Stations

Table 3.6: Areal Rainfall Interpolated Using Thiessen Polygon Method for Sub Basin

SN	Stations	Area in (Km^2)	Area ratio	Annual rainfall(mm)
1	Dinsho	1085.4	0.243	1153.9
2	Agarfa	584.3	0.13	1054.83
3	Robe	931.4	0.21	1058.27
4	Sinana	448.3	0.1	896.41
5	Gasera	398.2245	0.09	986.27
6	Ginir	1025.4	0.23	967.02
	Total	4472.949	1.00	

3.6 Research Approaches

The methodology applied to the rainfall-runoff estimation of Weyb River watershed is conducted by integrating GIS and with HEC-HMS hydrologic modeling software. HEC-HMS is a very flexible program that allows the user to choose among different loss rate, sub-basin routing, and base flow models for the sub-basins, as well as different routing methods for the reaches. The HEC_HMS depend on hydrologic parameters that cannot be extracted from readily available spatial data. Hence, to make the spatial data readily available to the model the integration of ArcGIS10.1 with its water resource utility extensions such as HEC-GeoHMS are vital. Using this software the determination of the spatial parameters the watershed for HEC-HMS rainfall-runoff modeling is the first precondition to accelerate the process. The process of generating input data for the basin component and the overall activities of the research is set here in the diagram below(figure 3.15).

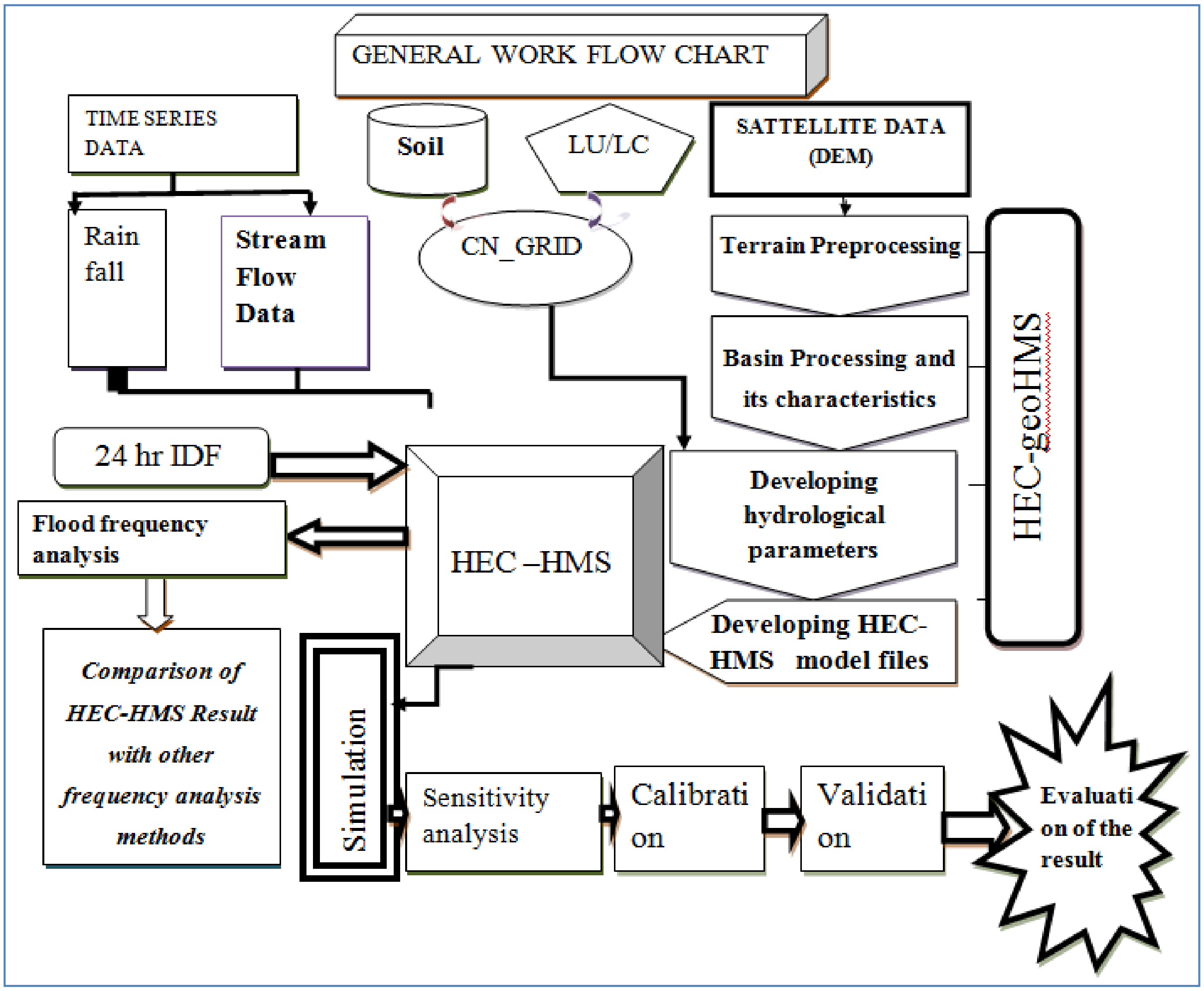


Figure 3.15: Schematic Diagrams Showing the Overall Research Methodology Approach

3.7HEC-HMS Model

The HEC-HMS model was developed by the US Army Corps of Engineers (USACE) Hydrologic Engineering Center‘s (HEC) and is well known hydrological model of the most widely used rainfall-runoff models. HEC-HMS was designed to simulate the rainfall-runoff process of a dendritic watershed system (USACE, 2000).The model is suitable for small and larger watershed hydrologic applications in addition to lumped and distributed rainfall-runoff modelling such as water balance studies, flood studies, impact of land use and climate change on runoff generation and flooding. Before going to HEC-HMS the input data files are prepared using HEC-GeoHMS and Arc-GIS which are describe below.

3.7.1 Input data for HEC-HMS

The input data for HEC-HMS model setup includes Digital Elevation Model (DEM), rainfall, stream-flow gauge data, soil types, and land-use/land-cover data. Data describing the terrain should be in ESRI‗s ARC Grid Format while vector data, such as stream alignments and stream flow gauge locations, should be in the shape file format.

In the present study ASTER DEM with 30 m by 30m resolution is assessed in watershed delineation and drainage network generation. This ASTER 30 m DEM in ESRI Arc Grid format has been used to develop HEC-HMS basin model. Hydro-meteorological parameters like rainfall, discharge are collected from the different gauging station in the watershed. Land-use/land-cover data and soil data are prepared in Arc GIS environment.

3.8 HEC-GeoHMS Model

The Geospatial Hydrologic Modelling Extension (HEC-GeoHMS) has been developed in year2000 by Hydrologic Engineering Centre (HEC), California, USA, as a geospatial hydrology toolkit for engineers and hydrologists with limited GIS experience. HEC-GeoHMS uses ArcView and the Spatial Analyst extension to visualize spatial information, document watershed characteristics, perform spatial analysis, and delineate sub basins, streams and develop a number of hydrologic modelling inputs for the HEC-HMS. The following steps describe the major steps in starting a HEC-HMS project and taking it through the HEC-GeoHMS process (Geo-HMS, 2003). The overall steps process performed in HEC-geoHMS are shown in the flow chart (figure: 3.16).

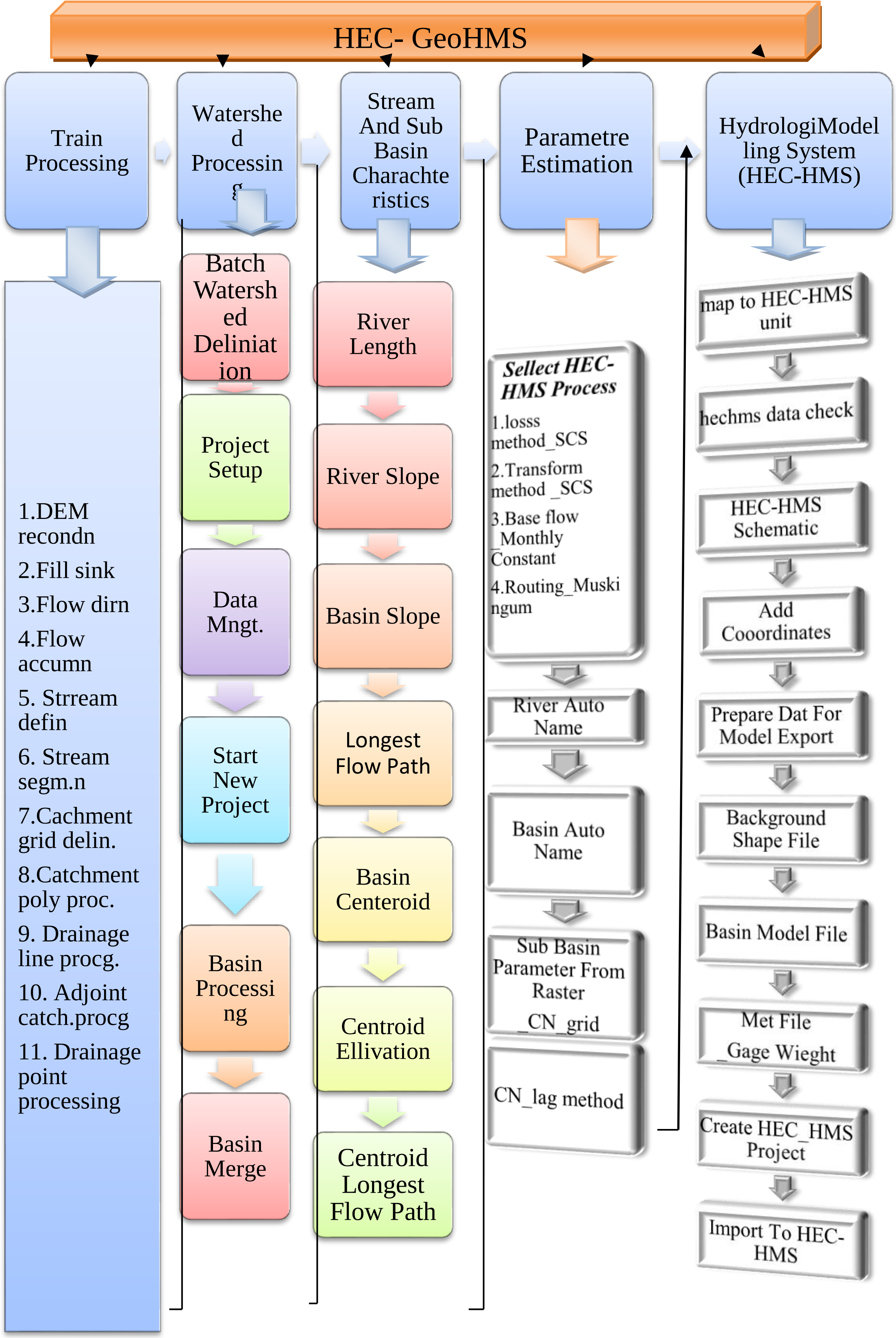


Figure 3.16: Steps in HEC –GeoHMS

The background-map file and basin file were created in HEC-geoHMS for exporting them to HMS. Gauge weight method was chosen for creating meteorological model file. For using this method, Thiessen polygon for the available precipitation stations within or in the periphery of the basin area was created in ArcGIS as shown in Figure 3.14 and Table 3.6.Thiessen polygon was then intersected with the basin model output of the HEC-geoHMS as seen below.

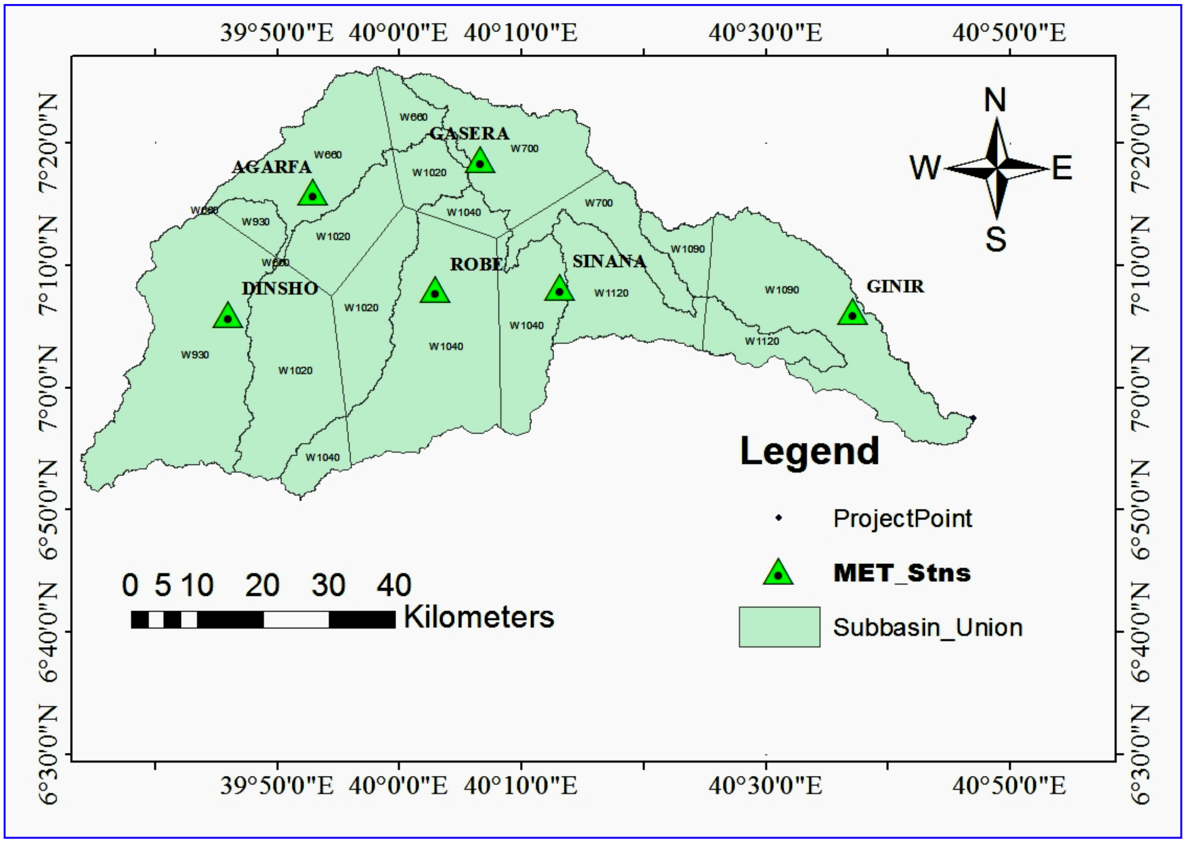


Figure 3.17:Sub-basins and Thiessen Polygon and Their Area Coverage

Table 3.7: Metrological Stations Included In The Sub-Basin And Their Percentage Of Coverage

Sub Basin name	Total area In (km2)	Met stations included	Area of met_ station in the basin in (km2)	Percentage of the met_stn area in the sub-basin (%)
W600	402.355	Agarfa	317.67	78.95
		Dinsho	2.3313	0.579
		gasera	82.22	20.43

W700	483.706	Sinana	169.10	34.95
		Gasera	314.42	65.0
W930	724.834	Agarfa	54.38	7.50
		Dinsho	668.64	92.25
W1020	833.484	Agarfa	175.02	20.998
		Robe	205.95	24.709
		Dinsho	365.62	43.866
		Gasera	86.46	10.373
W1040	917.840	Sinana	232.20	25.298
		Robe	560.39	61.055
		Dinsho	73.43	8.00
		Gasera	51.97	0.0087
W1090	578.707	Sinana	74.81	12.827
		Ginir	502.42	86.817
W1120	367.623	Sinana	252.64	68.722
		Ginir	115.04	31.293

HEC-HMS Data entry can be performed for individual basin elements such as sub-basins and stream reaches or simultaneously for entire classes of similar elements. Tables and forms for entering necessary data are accessed from a visual schematic of the basin. Each HEC-HMS project requires three data components: a Basin Model, a Meteorological Model, and Control Specifications.

3.8.1 Basin Model Data

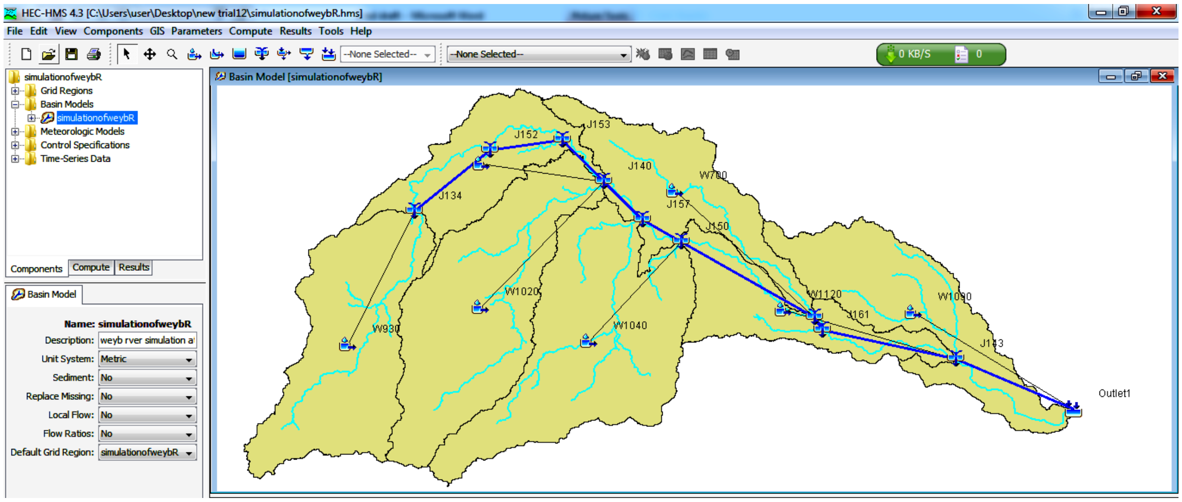
The basin model contains data, which represents the physical system. The descriptive data is entered by the user or imported from GIS and can be edited. Such data includes specification of the hydrologic elements of which the basin model is comprised, information on how the hydrologic elements are connected, and values of parameters for the hydrologic elements. A basin model consists of hydrologic elements, of which there are seven types: sub basin, routing reach, junction, reservoir, diversion, source, and sink. The development of a basin model requires the specification of such elements and data that controls their 'behavior'.

3.8.2 Meteorological Model

The Precipitation Model is a set of information required to define historical or hypothetical precipitation to be used in conjunction with a basin model. Types of hypothetical storm include frequency-based and the Corps of Engineers ‘Standard Project Storm. Frequency-based storms require that the user provide rainfall depths for various durations. Gauge weights of each rain gauge station are defined in meteorological model manager.

3.8.3 Control Specifications

Lastly, the Control Specifications define time related information for a simulation, including the starting and ending dates and the time interval for computations. The function of control specifications is to set the starting and ending dates and times and time (computation) interval.



Name: simulationofweybR
Description: weyb rver simulation a
Unit System: Metric
Sediment: No
Replace Missing: No
Local Flow: No
Flow Ratios: No
Default Grid Region: simulationofweybR

Figure 3.18: HEC-HMS Basin Model Map of Weyb River Watershed

3.8.4 HEC-HMS Simulation

The HEC-HMS model components such as basin models, meteorological models, and control specifications had been created and populated with data, and simulations had been executed with various inputs. HEC-HMS allows many combinations of different model parts to run for various scenarios.

The Soil Conservation Service Curve Number, SCS Unit hydrograph, and Muskingum routing methods were selected for each component of the runoff process as runoff depth, direct runoff, and channel routing respectively as stated earlier. These methods were chosen on the basis of applicability and limitations of each method, availability of data, suitability for the same hydrologic condition, stability, wide acceptability, and well established researcher recommendations.

(i) Loss Model

The loss models in HEC-HMS normally calculate the runoff volume by computing the volume of water that is intercepted infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation(Hawkins *et al*., 2009). In this study, the Soil Conservation Service Curve Number loss method was selected to estimate direct runoff from a specific or design rainfall. SCS method has several advantages over other methods in that: It is a simple conceptual method for the estimation of the direct runoff amount from a storm rainfall event, and is well supported by empirical data; it relies only on the curve number, which is a function of the soil type and land use/cover that are the major runoff-producing watershed characteristics. However, there are several problems associated with the SCS-CN method. For example, it does not account for rainfall intensity and temporal variation of rainfall as well as for average ground slope (Mockus, 1949). Despite the above problems, the SCS-CN loss method was chosen for HEC-HMS analysis in this study because of the following reasons: It is commonly used in different environments and provides better results compared to initial and constant loss rate method (Sardoii *et al*., 2012). Its calculation is made easier by the fact that only a few variables need to be estimated based on hydrologic soil group, land use and slope maps. And despite its simplicity, it yields results that are as good as those of complex models (Lastra *et al*., 2008).

(ii) The Transform Model

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

$T_{lag}=0.6T_C$ 3.12

Where, Tlag and Tc are in minute.

The time of concentration can be estimated based on basin characteristics including topography and the length of the reach by Kirpich's formula (Kirpich, 1940).

$$TC = 0.0078X\left(\frac{L^{0.77}}{S^{0.385}}\right) \quad 3.13$$

Where; L is the reach length in feet, and S is the slope in (ft/ft).

(iii) Routing Model

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

The Muskingum routing method is a simple approximate method to calculate the outflow hydrograph at the downstream end of the channel reach from the inflow hydrograph at the upstream end. Among many models used for flood routing in Rivers, it is a straightforward hydrological flood routing technique used in natural channels (Shaw, 1994) , and it has been extensively applied in River engineering practice since its introduction (Tewolde & Smithers, 2006). In this model calibration, two parameters are needed; travel time (K) of the flood wave through routing reach; and dimensionless weight (X) which corresponds to the attenuation of the flood wave as it moves through the reach. The routing parameters in the models are usually derived through calibration using measured discharge hydrographs (Birkhead & James, 2002).

$S=K[XI+(1-X)Q]$ 3.14

In which the prism storage in the reach is KQ, where K is the travel time through the reach (length of reach divided by the average flow velocity) or a proportionality coefficient, and the volume of the wedge storage is equal to KX (I - Q), where X is a weighting factor having a range of $0 \leq X \leq 0.5$.

3.9 Model Calibration and validation

Model calibration is an essential process needed to assure that the simulation outputs are close to real observations. Once a model was developed and simulated for the initial parameter estimates, it was calibrated against known discharge runoff rates measured at the gauging station.

The calibration for this study was done using daily time series data for the time period of 11 years (1992-2002) by adjusting the method parameter values until the results matched the field data. The process was completed manually by repeatedly adjusting the parameters, computing, and inspecting the goodness of fit between the computed and observed hydrographs. The process can also be done automatically by using the iterative calibration procedure called optimization. The measure of the goodness of fit is the objective function (Kathol *et al*., 2003). HECHMS allows the user to calibrate the model to the best-fit condition by selecting various objective functions to provide the best calibration results (HEC, 2005). The objective function measures the variation between computed and observed hydrographs, and is equal to zero when the hydrographs are identical.

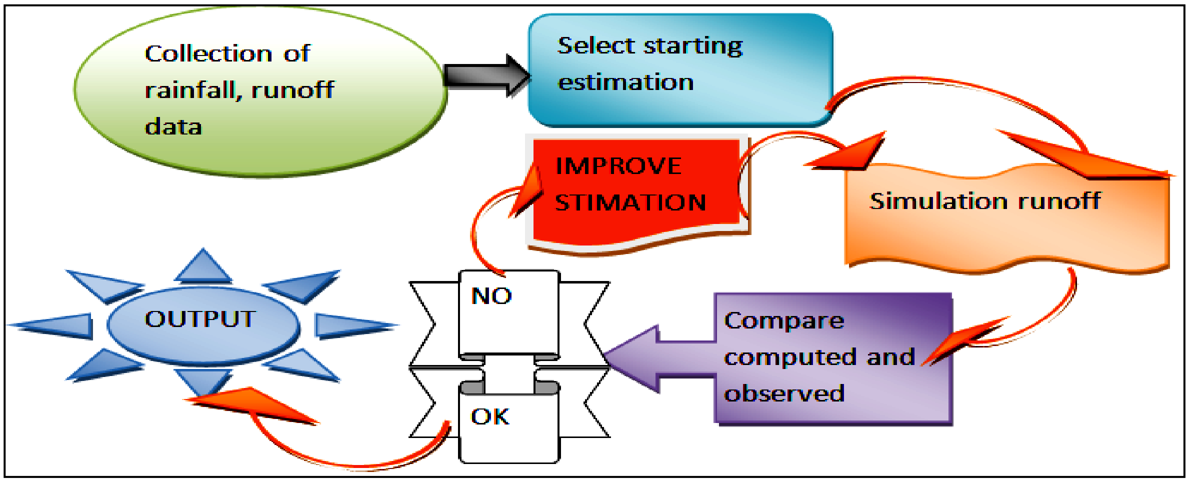


Figure 3.17: Schematic of Calibration Procedures

The automated calibration was used to adjust initial losses, curve number and lag time to minimize the objective function value and to find optimal parameters. When manual validation of the observed and simulated hydrograph was not acceptable, initial parameters were adjusted to provide a better optimization target value for the optimization process

(USACE, 2000). The model calibration was done with the Univariate as searching method Gradient optimization package and Peak-Weighted Root Mean Square Error as objective function (PWRMS) objective function because of their simplicity and performance (Deng *et al*., 2010). The optimization procedure required the use of a search method for minimizing an objective function and finding optimal parameters. Univariant method evaluated and adjusted one parameter at a time while holding all other parameters constant. Besides evaluating the objective function for determining if the process produced an accurate calibration, graphical comparisons were made between the fit of the model and the actual measured data. Graphical comparisons of scatter plots and time series plots of residuals between computed and observed flow were used to visually inspect the results of the calibration (Kathol *et al.*, 2003).

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. For this study the model is validated for a period of 4 years (2003-2006) at sofumer gauge station.

3.10 Evaluation of Model Performance

The performance of the model was evaluated comparing daily and monthly simulated discharge with the observed discharge. The statistical tools such as Nash-Sutcliffe Efficiency (NSE), Coefficient of determination (R^2) and percentage of bias were used to measure the model outputs.

a. Nash-Sutcliffe Efficiency:

It is calculated as,

$$\boldsymbol{NSE = 1 - \frac{\sum(Q_{obs(t)} - Q_{sim(t)})^2}{\sum(Q_{obs} - \overline{Q_{obs}})^2}} \qquad 3.15$$

Where,

NSE is Nash-Sutcliffe Efficiency, $Q_{obs}(t)$ is observed discharge at time t, Q_{sim}(t) is simulated discharge at time t and Qobs is average observed discharge. The “t” used in the calculation is the time period used. The value varies from - ∞ to 1. With the increase in performance, the numerical value increases and becomes maximum 1 in ideal case when simulated and observed hydrograph exactly match each other (Nash & Sutcliffe, 1970) .

B. Coefficient of determination (R^2)

The R^2 value is an indicator of strength of relationship between the observed and simulated values it is the magnitude linear relationship between the observed and the simulated values. Determination coefficient ranges from 0 (which indicates the model is poor) to 1 (which indicates the model is good), with higher values indicating less error variance, and typical values greater than 0.6 are considered acceptable (Santhi et al., 2001). The R^2 is calculated using eq 3.16

$$R^2 = \frac{(\sum Q_{obs(t)} - \bar{Q}_{obs}) \sum (Q_{sim(t)} - \bar{Q}_{sim(t)}))^2}{\sum (Q_{obs(t)} - \bar{Q}_{obs(t)})^2 \sum (Q_{sim(t)} - \bar{Q}_{sim(t)})^2} \qquad 3.16$$

Where,

Q_{obs} and Q_{sim} are observed and simulated discharge; Q_{obs} and Q_{sim} are mean observed and simulated discharge (Krause *et al.*, 2005).

c. percentage of bias

Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts (Gupta et al., 2000). The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias. For stream flow PBIAS Values up to ±20 are considered acceptable (Gupta et al., 1999). PBIAS is computed using equation 3.17.

$$\text{pbias} = \frac{(V_{sim} - \bar{V}_{obs})}{\bar{V}_{obs}} * 100 \qquad 3.17$$

Where, V_{sim} and V_{obs} are average simulated and observed volume of stream flow.

d. Root mean square error (RMSE)

$$\boldsymbol{RMSE} = \sqrt{\frac{1}{n} \sum_{i=1}^{n} (Q_O - Q_P)^2} \qquad 3.18$$

RMSE is always greater than 0, and closer the values to 0 better the model performance (Singhie *et al.*, 2004). Where Q_O and Q_P are observed and predicted run off respectively

Table 3.8: Performance Rating Of Recommended Statistics (Moriasi *Etal.*, 2007).

Performance rating	NSE	PBIAS	RMSE	R^2
Very good	$0.75<NSE\leq1$	Pbias <10	$0.0< RMSE\leq0.5$	$0.8< R^2\leq1$

Good	$0.65<NSE\leq 0.75$	$10 <Pbias \leq 15$	$0.5< RMSE\leq 0.6$	$0.65< R^2\leq 0.8$
Satisfactory	$0.5<NSE\leq 0.65$	$15< Pbias \leq 25$	$0.6 < RMSE\leq 0.7$	$0.5< R^2\leq 0.65$
Unsatisfactory	$NSE\leq 0.5$	$Pbias \geq 25$	$RMSE\geq 0.7$	$R^2\leq 0.5$

3.11 Flood Frequency Estimation

An important problem in hydrogly is the estimation of flood magnitudes, especially because planning and design of water resource projects and flood plain management depend on the frequency and magnitude of peak discharges. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. Flood frequency distributions could take on many forms according to the equations used to carry out the statistical analyses. At present, there is no universally accepted frequency distribution model for frequency analysis of extreme floods, rather a whole group of models such as Gumbel, Normal, Log normal, Log Pearson Type III etc. have been suggested in the literature such as (Topaloglu, 2002) for the prediction of extreme flood events. To check the validity of accepting a distribution, goodness-of –fit test is used.

If a prediction is to be based on a set of hydrologic data, then the distribution that best fits the set of data may be expected to give the best estimates usually an extrapolation of the probability of an event occurring. The probability distributions selected for these studies are, Log normal (3p), Gumble and Log Pearson Type III distributions. Their essential properties are given below.

Table 3.9: Probability Distribution Parameters In Relation To Sample Moments

(Ojha, 2008);(Chow et al., 1988)

Distribution	Probability distribution function	Range	Equation of parameters in terms of sample moments
Log normal	$f(x)=\frac{1\sqrt{\pi}}{x\sigma}\exp[\frac{-1}{2}\frac{(lnx-\mu)^2}{\sigma}]$	x>0	$\mu_y=\overline{y}$ $\sigma_y=s_y$
Gumbel	$f(x)=\frac{1}{\beta}\exp[-\frac{x-u}{\beta}-\exp\left(-\frac{x-u}{\beta}\right)]$	$(-\infty<x<\infty$	$u=\overline{x}-0.5772\beta$ $\beta=\frac{S_y\sqrt{6}}{\pi}$
Log Pearson Type III	$f(x)=\frac{(lnx-u)^{\gamma-1}\exp[\frac{(lnx-u)}{\beta}]}{\lvert\beta\rvert(\gamma)}$	$lnx\geq x$	$u=\overline{y}-S_{\gamma}\sqrt{\gamma}$ $\beta=\frac{\sqrt{\gamma}}{s_y}\gamma=(\frac{2}{c_s})^2$

3.11.1 Estimation of parameters

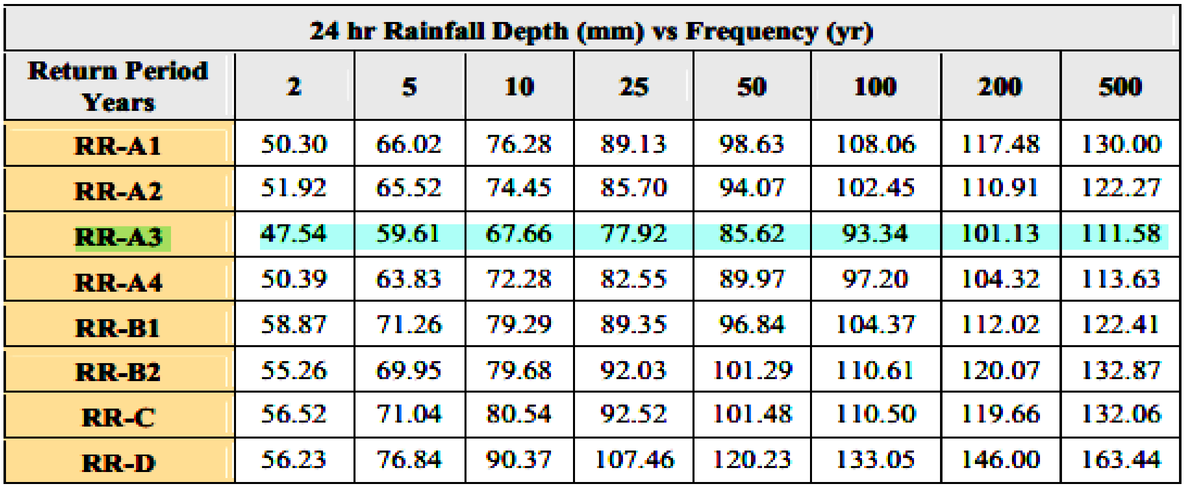
After a distribution or a number of distributions are selected to fit the data series, their parameters must be estimated. There are a variety of methods to estimate the parameters of a statistical model. Among these approaches are the method of moments, the maximum likelihood method, least squares, the probability weighted moments method (PWM), maximum entropy, mixed moments (MIX), the generalized method of moments, and incomplete means method. The most efficient approach for parameter estimation for a specified model should be applied. Three of the more commonly used methods of parameter estimation are Method of Moments (MOM), Method of Maximum Likelihood (MLM) and Probability Weighted Method (PWM)

In this study, maximum Likelihood and Probability weighted moments are used for parameter estimation(using Easy fit Application Tool).Distributions fitted by using these methods are tested by using the Chi-Square, Kolmogorov-Smirnov, Anderson daring tests The results of these goodness –of –fit tests are used to select a distribution for study.

3.11.2 Flood Modeling by Frequency Storm Method

The rain fall intensity used for this study is found from ERA rainfall intensity-duration curves. Based on the Ethiopian Road Authority (ERA) 2013 drainage manual the country has divided into different meteorological regions as shown in appendix: B(table:7.6). Meteorological regions and stations used for ERA drainage manual development. The frequency intensity values are found from the Ethiopian Roads Authority drainage manual (ERA, 2013).

Table 3.10: 24hr Rainfall Depth Vs Frequency (Era Drainage Manual, 2013)



24 hr Rainfall Depth (mm) vs Frequency (yr)								
Return Period Years	**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

My current study area is classified under A3 (AA-A3) meteorological region according to era drainage manual. Therefore in this study the rain fall depth for each return period for the selected time interval of my study was computed by the equation (3.19) below by taking the 24 hr maximum rain fall depth given for RR-A3 in the Table 3.10.

$$R_{Rt}=\frac{t(b+24)^{n}}{24(b+t)^{n}} \qquad 3.19$$

Where:

R_{Rt}= Rainfall depth Ratio R_t: R24, R_t= Rainfall depth in a given duration't', R_{24}= 24 hr rainfall depth, **b** and **n** = coefficients b=0.3 and n= (0.78-1.09).

4. RESULTS AND DISCUSSION

4.1 Rainfall-Runoff Modelling

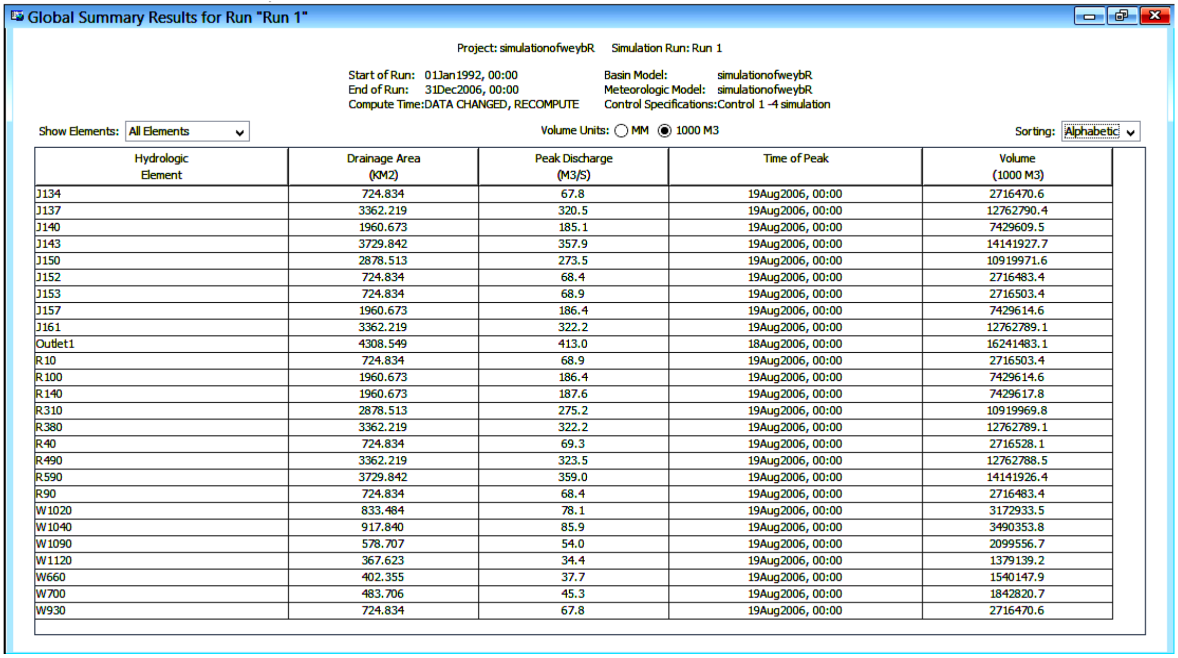
The output from terrain processing in HEC-geoHMS is not only delineation and schematic for the catchment but also extraction of basin characteristics from physical properties of the catchment. Among the basin characteristics soil and land use are the major ones. According to the output of the model the following parameters were generated.

Table 4.1: Catchment Characteristic Parameters Extracted With HEC-GeoHMS

Components	Parameters			
	Area (Km^2)	CN	Lag time (min)	Ia (mm)
W700	483.706	78.168	483.706	14.12
W1020	833.484	78.418	331.47	13.99
W930	724.834	65.779	374.91	26.4
W660	402.355	84.034	718.36	9.67
W1040	917.840	77.418	279.34	14.8
W1120	367.623	66.476	339.13	25.6
W1090	578.707	49.03	534.77	52.8

4.2 Model Simulation

In this study the hydrologic representation imported into HEC-HMS were combined with precipitation data and control specifications to create flow and time series data for use in Hydrologic Data Model HEC-HMS and simulations had been executed with various inputs. In analyzing of rain fall run off simulation, the most important aspect of the hydrograph is the peak flow, because the peak flow corresponds to the maximum downstream flooding. In contrast, peaks that are significantly less than the maximum may correspond to increased water levels. Figure (4.1) provides the various Hydrological elements such as Sub-basin, reach, junction with the area of the drainage and the discharge of the corresponding hydrological element at the outlet of the watershed after simulation graphs and their scatter plot are shown.



Project: simulationofweybR Simulation Run: Run 1

Start of Run: 01Jan1992, 00:00
End of Run: 31Dec2006, 00:00
Compute Time:DATA CHANGED, RECOMPUTE

Basin Model: simulationofweybR
Meteorologic Model: simulationofweybR
Control Specifications:Control 1 -4 simulation

Show Elements: All Elements

Volume Units: ○ MM ● 1000 M3

Sorting: Alphabetic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
J134	724.834	67.8	19Aug2006, 00:00	2716470.6
J137	3362.219	320.5	19Aug2006, 00:00	12762790.4
J140	1960.673	185.1	19Aug2006, 00:00	7429609.5
J143	3729.842	357.9	19Aug2006, 00:00	14141927.7
J150	2878.513	273.5	19Aug2006, 00:00	10919971.6
J152	724.834	68.4	19Aug2006, 00:00	2716483.4
J153	724.834	68.9	19Aug2006, 00:00	2716503.4
J157	1960.673	186.4	19Aug2006, 00:00	7429614.6
J161	3362.219	322.2	19Aug2006, 00:00	12762789.1
Outlet1	4308.549	413.0	18Aug2006, 00:00	16241483.1
R10	724.834	68.9	19Aug2006, 00:00	2716503.4
R100	1960.673	186.4	19Aug2006, 00:00	7429614.6
R140	1960.673	187.6	19Aug2006, 00:00	7429617.8
R310	2878.513	275.2	19Aug2006, 00:00	10919969.8
R380	3362.219	322.2	19Aug2006, 00:00	12762789.1
R40	724.834	69.3	19Aug2006, 00:00	2716528.1
R490	3362.219	323.5	19Aug2006, 00:00	12762788.5
R590	3729.842	359.0	19Aug2006, 00:00	14141926.4
R90	724.834	68.4	19Aug2006, 00:00	2716483.4
W1020	833.484	78.1	19Aug2006, 00:00	3172933.5
W1040	917.840	85.9	19Aug2006, 00:00	3490353.8
W1090	578.707	54.0	19Aug2006, 00:00	2099556.7
W1120	367.623	34.4	19Aug2006, 00:00	1379139.2
W660	402.355	37.7	19Aug2006, 00:00	1540147.9
W700	483.706	45.3	19Aug2006, 00:00	1842820.7
W930	724.834	67.8	19Aug2006, 00:00	2716470.6

Figure 4.1: Simulation Global Summery

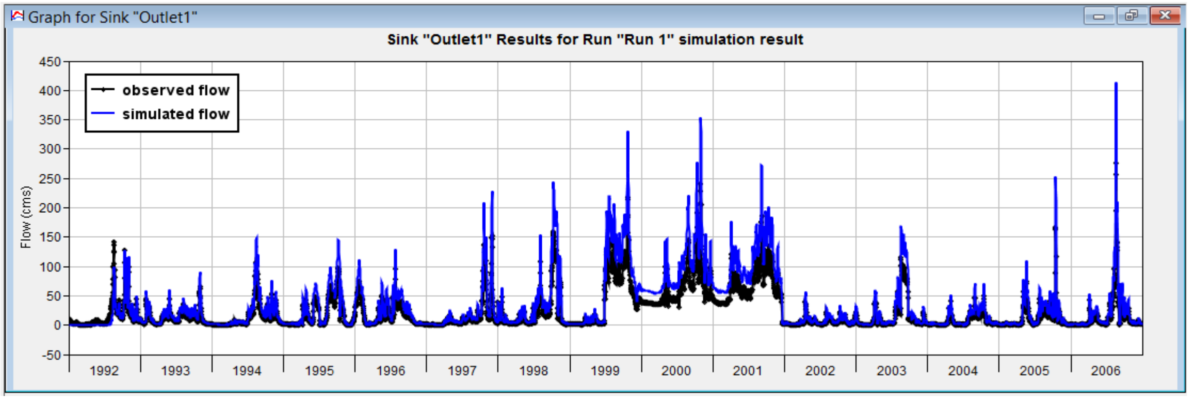


Figure 4.2: Graph of the Model Simulation Result before Optimization

Figure 4.2 is the graph comparing observed flow to the simulated flow before calibration. The black dotted lines denote observed outflow measured at gauge stations and the blue solid line denotes the total simulated outflow at that outlet. Initial results showed that there is clear difference between observed and simulated peak flows as shown in appendix B (Table:7.5).

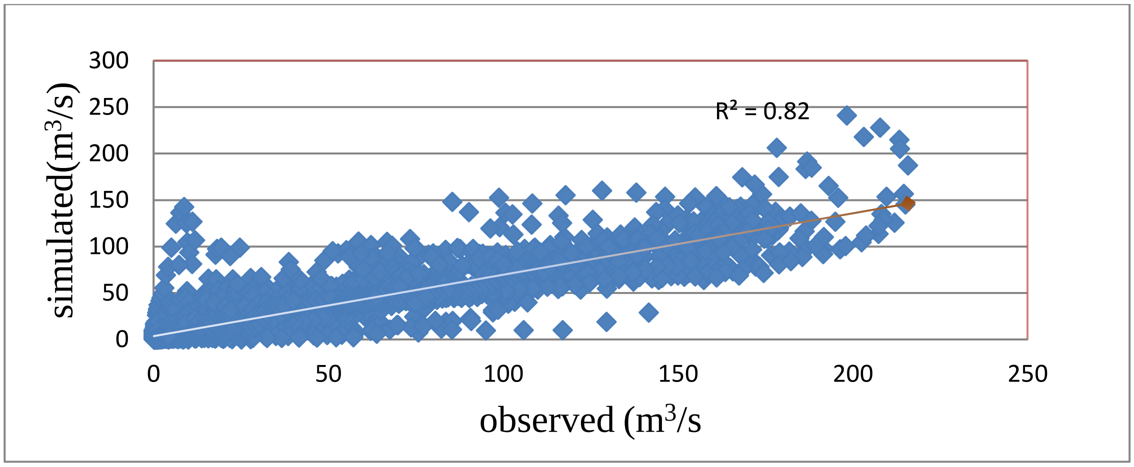


Figure 4.3: Scatters Plot before Calibration

Figure 4.3 shows the scatter plot between simulated and observed flow from 1992-2006 at the gauging station. In the graph, the straight dotted line denotes linear line and the dots denote flow. The accuracy of prediction of runoff is close to 0.82 which gives good result for flow pattern.

4.3 Sensitivity analysis

The calculated values of the percent error both in total volume and peak flow between simulated and observed value of simulation before optimization was high, which falls in the range between the absolute value of 48.92% which is in the range of unsatisfactory. Considering this result, a sensitivity analysis was done to identify the most sensitive parameter for the loss, transform, and routing methods. The sensitivity analysis was carried out by selecting one parameter at a time holding the other parameters constant. After many iterations it was found that the travel time through the reach (Muskingum-k), curve number, initial abstraction, and lag time were more sensitive, the second more sensitive, less sensitive and insensitive parameters of the model, respectively.

4.4 Calibration of HEC-HMS Model

Once all the initial parameters were obtained the HEC-H-MS model was calibrated to optimize the parameters using the hydro-meteorological dataset. The HEC-HMS model has a self- calibrating utility based on optimization techniques that allows the user to select different approaches of objective function. Hence, the selected gauged watershed is modelled and the results are presented. To determine the accuracy of modeled results, the simulated hydrograph at outlet is compared to the historically observed hydrograph at outlet of the watershed. Parameters of different hydrographs along with hydro-meteorological data are provided and parameters are adjusted after calibration using the optimization method.

The objective function used in this study for calibration was the peak weighted RMS error method. This function was selected because it gives greater weight to matching the peak of the hydrograph. The peak weighted RMSerror method focuses solely on the peak of the hydrograph. It also takes into account the volume and time of the peak as well. The univariate gradient method and was used to minimize the peak weighted RMS error-objective function. In optimization trials are done with changing the more sensitive parameters using this method. The resultants of hydrograph after optimizing (calibration) and the scatter plot between observed and simulated discharge is shown in figure 4.4and figure 4.5 respectively.

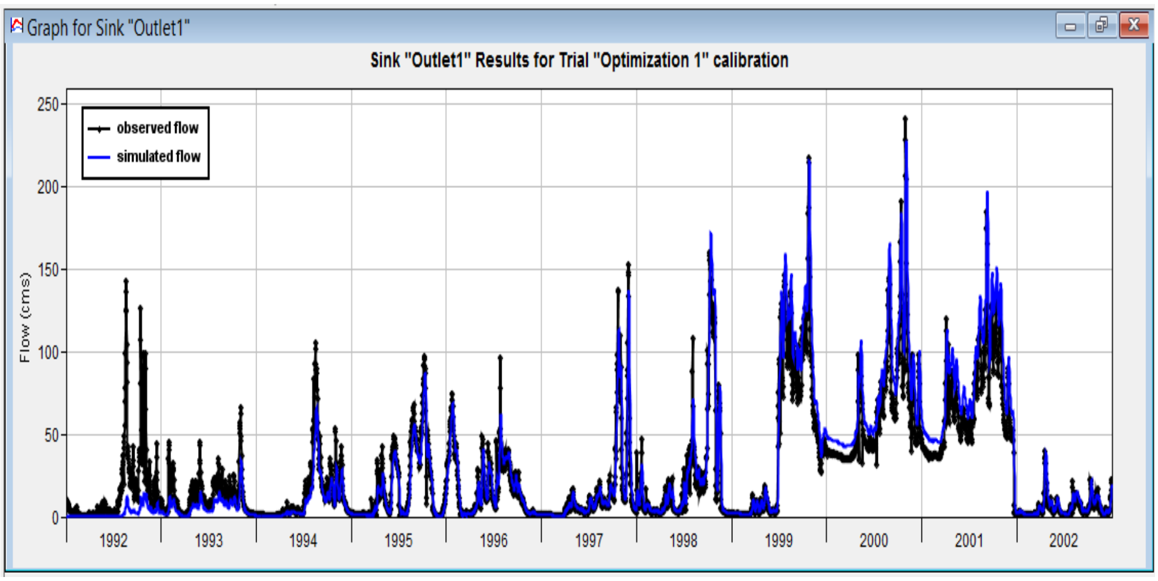


Figure 4.4: Graph of Calibration Result

Figure 4.4 is the graphs comparing observed flow to the simulated flow after calibrated. The black dotted lines denote observed outflow measured at gauge stations and the blue solid line denotes the total simulated outflow at that outlet.

The initial results showed that there is clear difference between observed and simulated peak flows. Therefore, model calibration with optimization method and sensitivity analysis has been done. After optimization the peak flow and total volume are close to the observations with a very small error in peak and volume. The results of the hydrological model in this study showed a reasonable fit between the model and observations after optimization; the hydrograph shape and timing of peaks matched well, although the model tended to overestimate the runoff and the total volume before optimization. The hydrograph shape was accurately reproduced in the model output. However, the calibration of the model improved the results greatly by decreasing the overestimated the volume and the runoff.

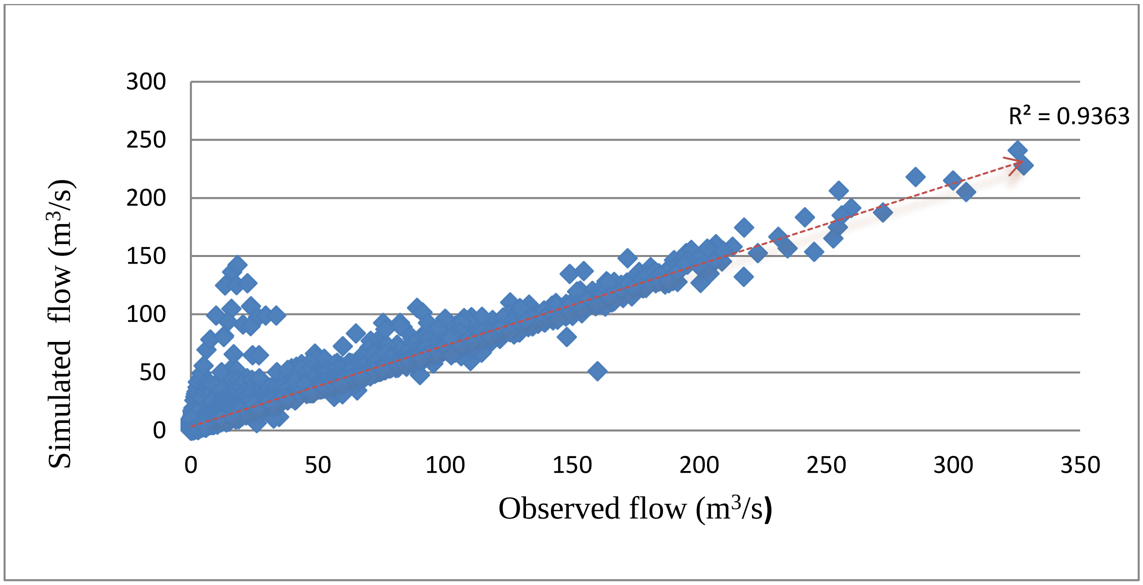


Figure 4.5: Correlations between Observed and Simulated Flow Values after Calibration

The calibration model was further evaluated using scatter plot (R^2) between simulated and observed Figure 4.5 shows the scatter plot of the calibrated year from 1992 -2002. In the graph, the straight dotted line denotes linear line and the dots denote flow. The accuracy of prediction of runoff is 0.936 which is classified as very good according to the performance evaluation criteria.

4.5 validation

The purpose of validation was to demonstrate the applicability of the HEC-HMS model to predict stream flow in the watershed by comparing model prediction with observed data to evaluate if the models were able to predict the runoff at the discharge stations for the period other than calibrated one. Validation was done by running the model with the respective optimized parameters for the watersheds with different input data set the output result during validation was seen in(Figure 4.6).

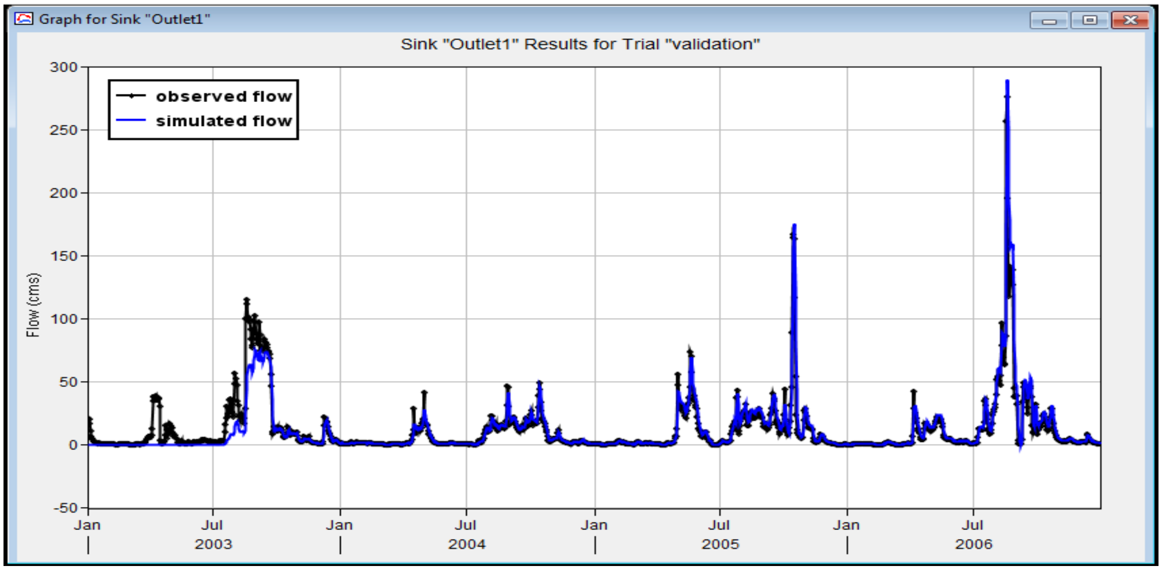


Figure 4.6: Graph of the Model Validation Result

As can be seen from the Figures 4.6, the pattern of simulated and observed flow is almost identical to each other. The volume error (pbias) obtained was (<15%) during validation (Table 4.2) which showed that the validated flow fairly represents the basin outflow pattern as seen in Figure 4.7. The validated model was further evaluated using scatter plot (R^2) between simulated and observed flow and it shows that the there is strong relations between simulated and observed flow.

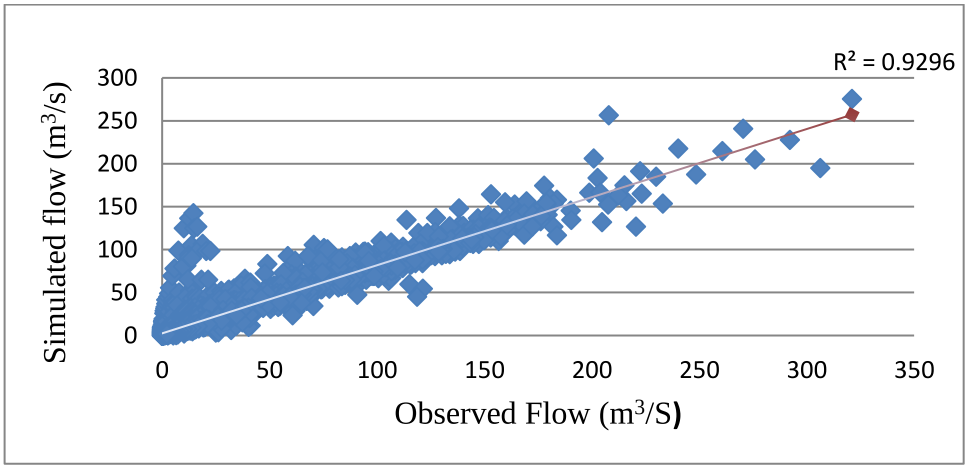


Figure 4.7: Correlation between Observed and Simulated Flow Values after Validation

In the graph, the straight dotted line denotes linear line and the dots denote flow. The accuracy of prediction of runoff is 0.929 which is classified as very good according to performance evaluation criteria.

The summery of the performance evaluation of HEC-HMS models before calibration, during calibration and validation were presented in the Table 4.3.These performance were evaluated in terms of different performance indices such as: Coefficient of Determination (R^2), Nash-Sutcliffe efficiency (ENS), root mean square error (RMSE), and percentage of bias (pbias).

Table 4.2: Performance Comparison of the Model by Different Performance Indicators

Methods	Peak discharge (m^3/s)		Total Volume (MM)		Performance indicators			
	Q_{sim}	Q_{ob}	V_{sim}	V_{ob}	P bias (%)	RMSE	NSE	R^2
Before opt.	413.0	275.6	3769.59	2531.10	48.92	0.8	0.412	0.67
Calibration	286.2	241.1	2462.73	2161.06	13.96	0.4	0.867	0.941
Validation	289.8	275.6	358.69	369.72	-3.03	0.4	0.819	0.93

Where; Q_{sim}=simulated discharge, Q_{ob}= observed discharge, V_{sim}= simulated volume, V_{ob}= observed volume, opt. =optimization, Pbias= percentage of bias

According to the result of the flood volume relative error, as can be seen in Table 4.2, the error is relatively small after calibration. The result is good according to (Najim *et al.*, 2006);(Sabzevari*et al.*, 2009) , who recommended that the acceptable ranges of relative percent errors between the observed and simulated values should be below ±20%. The study (Cheng*et al.*, 2002) also indicated that the runoff model is considered good if the percentage error of the runoff volume is less than 20% according to the criteria for flood forecasting in China. In this statistical evaluation criterion, the positive values indicate model overestimation bias, and the negative values indicate model underestimation bias (Gupta *et al.*, 2001).

The result also show a relatively close agreement between the observed and simulated peak flow values at the period of calibration (R^2 = 0.936) after optimization. According to the classification range mentioned in (Zou *et al*., 2003) the mean correlation coefficient obtained in this study can be considered as strong (>0.8). Considering the Nash–Sutcliffe Efficiency (NSE) criteria, better results were obtained between the simulated and observed values, with a mean NSE value of 86.7% (Table 4.2). Therefore, the model performs well. 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). Overall, in this study the three statistical evaluation criteria with mean values of RMSE= 0.4, Percent bias (%) =13.96, NSE= 0.869 and R^2=0.936 after calibration showed good simulation between the estimated and observed values.

Generally, from the results of the statistical evaluation criteria a good performance of the HEC-HMS model was obtained in simulating the runoff volume and peak flow. The results of this study provide basic information of total volume and peak flow generated in the watershed that in turn is useful for the planning, designing and management of different water resources activities.

4.6 Rainfall-runoff relationship

In this study the rainfall-runoff relationship of the study was also using the validate data. As it can be seen from the figure 4.8 below the rainfall and the runoff of the watershed has very much relationship.

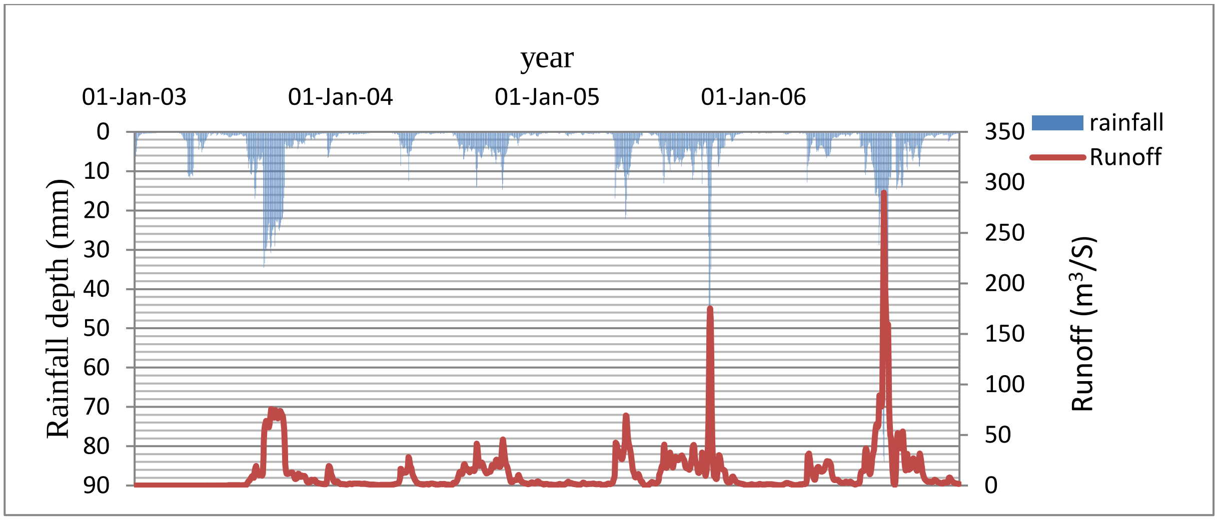


Figure 4.8: Daily Rainfall-runoff relationship of the watershed for the validated data

Moreover, the relationship between rainfall and the run off of the study was also analyzed using scattered plot (coefficient of determination).

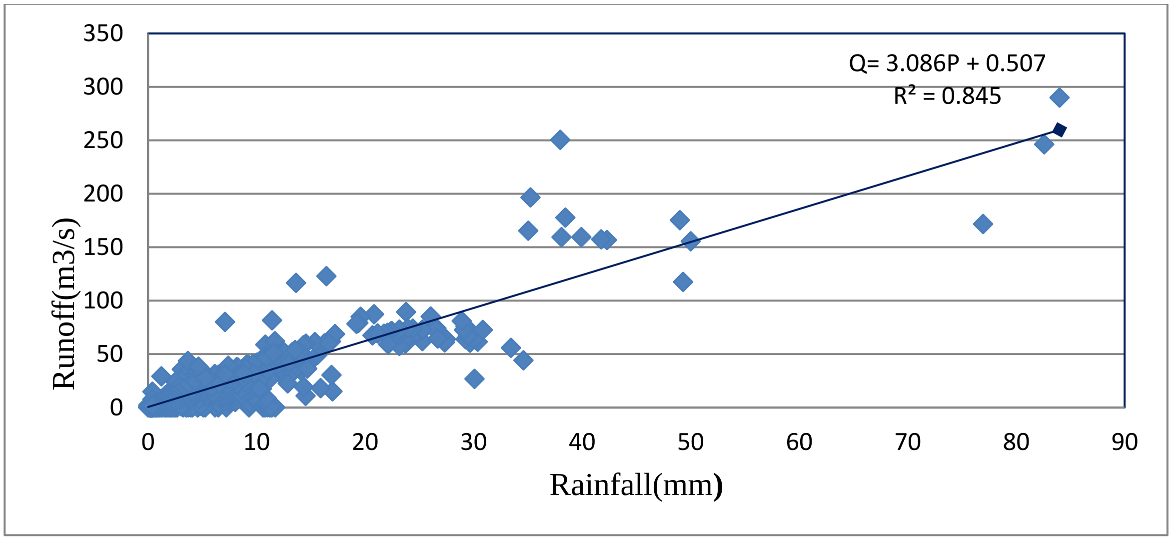


Figure 4.9: Scattered Plot of daily Rainfall- Runoff Relation Ship

In the linear equation of the above graph Q is the runoff generated due to the rainfall p

Where: Q= runoff and p=precipitation

In the graph, the straight dotted line denotes equality line and the dots denote flow. The accuracy of prediction of runoff is 0.845 which is shows that the rainfall and the run off pattern of the watershed have very good relationships according to performance evaluation criteria.

4.7 Frequency Storm Method Analysis

Based on frequency storm method analysis peak discharge of each return periods were obtained. Table 4.3 is the 24hr rain fall incremental computed using equation 3.19 from ERA Drainage Manual 2013(Table 3.10). By using the 24hr rainfall incremental in table 4.3 The peak discharge for different selected return periods or different frequency storms were obtained using HEC-HMS model (Table 4.4). From the result table minimum peak flow for the Weyb River is occurred for 2 year return period for 24 hour storm duration and the maximum obtained with 100 year frequency storm for the same duration. The value being 196.2 m^3/s and 850.0m^3/s for 2 year and 100 year frequency storm respectively.

Table 4.3: 24hrs Incremental Rainfall for Each Return Period

Duration in (minute)	Rain fall depth in (mm) with return period					
	2	5	10	25	50	100
5	10.4	13.11	14.88	17.14	18.8	20.54
15	21.9	27.43	31.33	35.86	39.32	42.35
60	37.09	46.4	52.69	60.68	66.68	72.69
120	41.9	52.8	59.57	68.6	75.3	75.37
180	43.8	54.9	62.27	71.72	78.8	82.18
360	45.84	57.47	65.24	75.13	82.56	85.9
720	46.9	58.6	66.03	76.96	84.58	90.17
1440	47.54	59.61	67.66	77.92	85.62	93.34

Table 4.4: HEC-HMS Result of Peak Discharge Obtained for Different Return Period

No	Return period (years)	Peak discharge (m3/s)
1	2	196.2

2	5	300.7
3	10	375.1
4	25	515.2
5	50	692.4
6	100	850.0

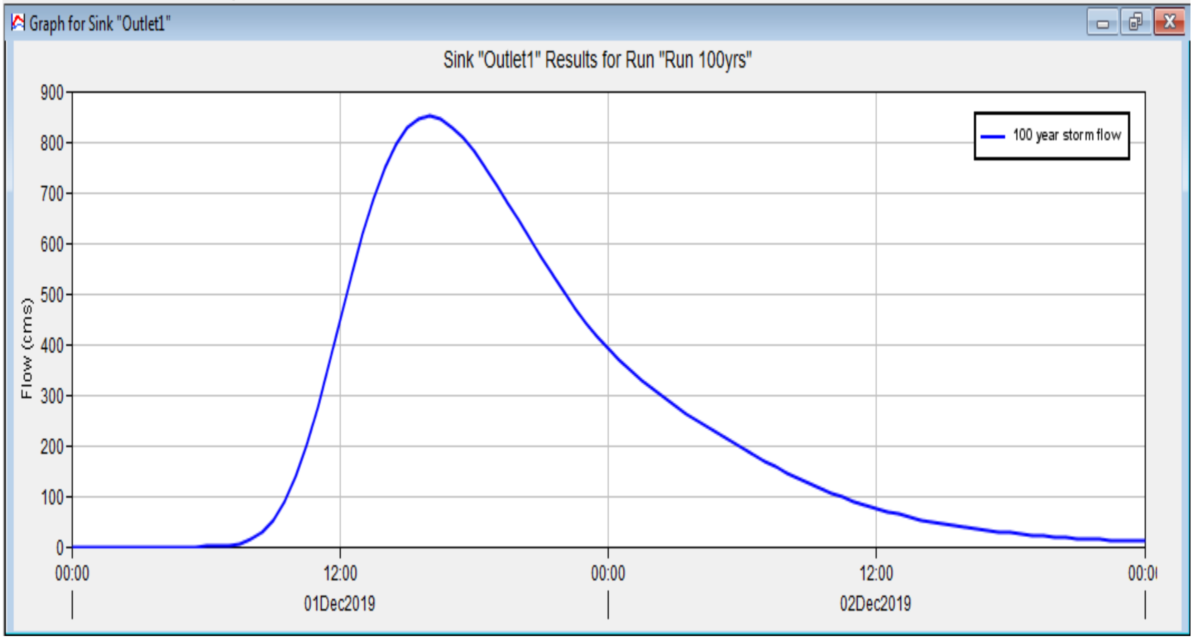


Figure 4.10: 100 Years Storm Flow Hydrograph

The figure 4.10 is the sample of the frequency storm graph obtained using HEC-HMS model. As can be seen from the figure 4.11 and table 4.4 the frequency storm (discharge) estimated to be occurring in the coming 100 years is about 850 m^3/sec which is very big compared to the discharges obtained through observation so far. So it is recommended that, the design of hydraulic structure that will be constructed along or across the river should take this max flood into consideration in order to minimize the negative impact that come by the flood. The other graphs of 2, 5, 10, 25 and 50 year flood storm are shown in appendix B (figure 7.4). following is also the graphs of different return period storm flow all in one.

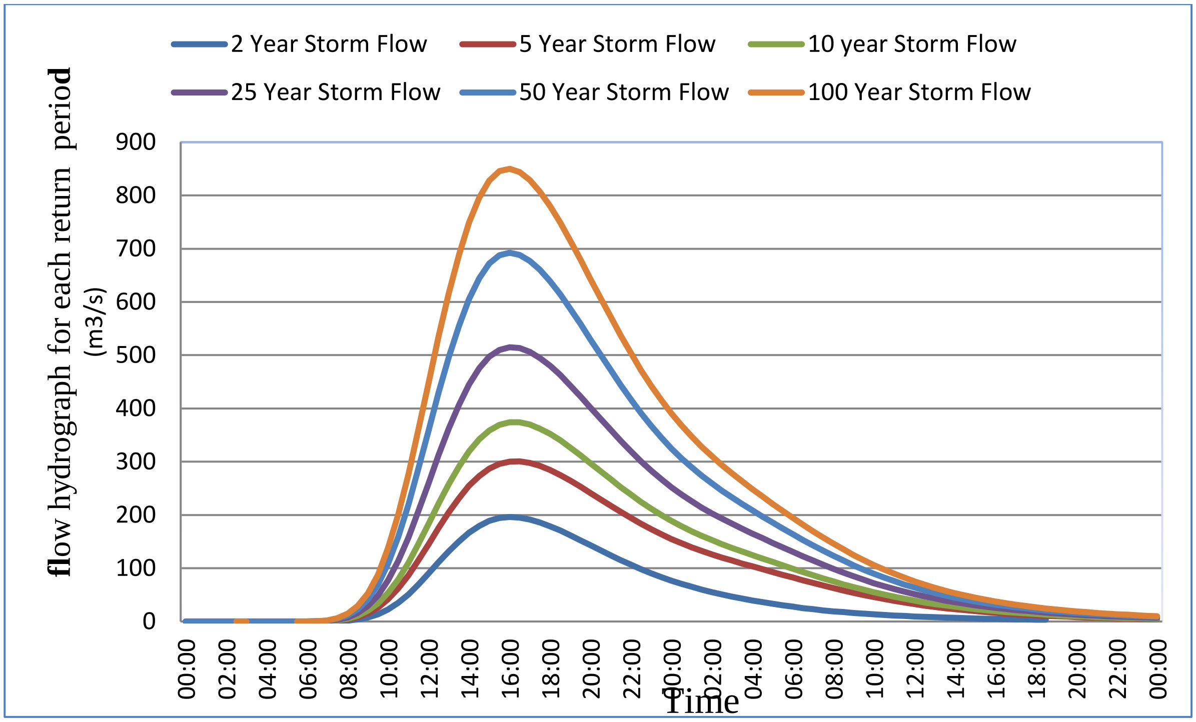


Figure 4.11: Hydrograph of Resulted Flow Frequency Analysis in HEC-HMS Model

4.7.1 Comparison of HEC-HMS Result with other frequency analysis methods

The frequency analysis of hydrological extremes requires fitting a probability distribution to the observed data to suitably represent the frequency of occurrence of rare events. The choice of the model to be used for statistical inference is often based on subjective criteria, or it is considered a matter of probabilistic hypotheses testing.

In this study Easy Fit 5.6 Professional software was used to select the best probability distribution method for the observed data. The Anderson-Darling (AD), the Kolmogorov-Smirnov (KS), and the Chi-Squared tests were used for the goodness of fit test. The goodness-of-fit between each statistical and the observed distribution was determined based on the Kolmogorov–Smirnov test from the above three methods since it is more performed. Then the selection of the best fit method was based on the ranks given by the Kolmogorov–Smirnov fitness method.

Table 4.5: Output of Easy Fit 5.6 Professional and Ranks of Fitting Statistical Distributions

SNO.	Distribution	Kolmogorov Smirnov		Anderson ` Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.2053	6	0.78327	5	0.1592	1
2	Exponential (2P)	0.17099	5	2.5079	6	0.21721	2
3	Gumbel Max	0.16177	2	0.45033	4	0.75096	3
4	Log-Pearson 3	0.14535	1	0.34221	1	0.78208	4
5	Lognormal	0.17067	4	0.42453	3	0.91366	6
6	Lognormal (3P)	0.16808	3	0.42295	2	0.89684	5

The result shows log -person 3, Gambel Max and Lognormal (3p) are the most fitted statistical distributions to the observed data of the study area.

Table 4.6: Statistical Parameters for selected distribution methods

SNO.	**Distribution**	**Parameters**
1	Exponential	λ=0.00789
2	Exponential (2P)	λ= 0.00954 γ=21.911
3	Gumbel Max	σ=65.962 μ=88.673
4	Log-Pearson 3	α=29.001 β=-0.14675 γ=8.8423
5	Lognormal	σ=0.76349 μ=4.5864
6	Lognormal (3P)	σ=0.73907 μ=4.6188 γ=-2.4199

Having these distribution parameters the peak discharge for each return period was calculated using the above selected probability distribution methods to compare with HEC-HMS frequency analysis methods.

Table 4.7: The Peak Discharge from probability Distributions and HEC-HMS

Return period	DISCHARGE(M3/S)			
	HEC-HMS	Log Pearson-III	Gumbel-max	Log normal
2	196.2	175.4	167.89	125.89
5	300.7	155.23	208.58	157.01
10	375.1	304.55	257.6	227.19
25	515.2	418.79	321.2	281.968
50	692.4	589.1	367.8	324.19
100	850.0	756.728	449.78	367.45

Finally the HEC-HMS model result was compared with the frequency analysis results of three selected methods according to their rank. As it is seen from the result the output of the HECHMS model result show high similarity with Log Pearson-III which is the most fitted probability distribution among the other three distribution methods. This shows the good performance of HEC-HMS model in frequency analysis for the study area

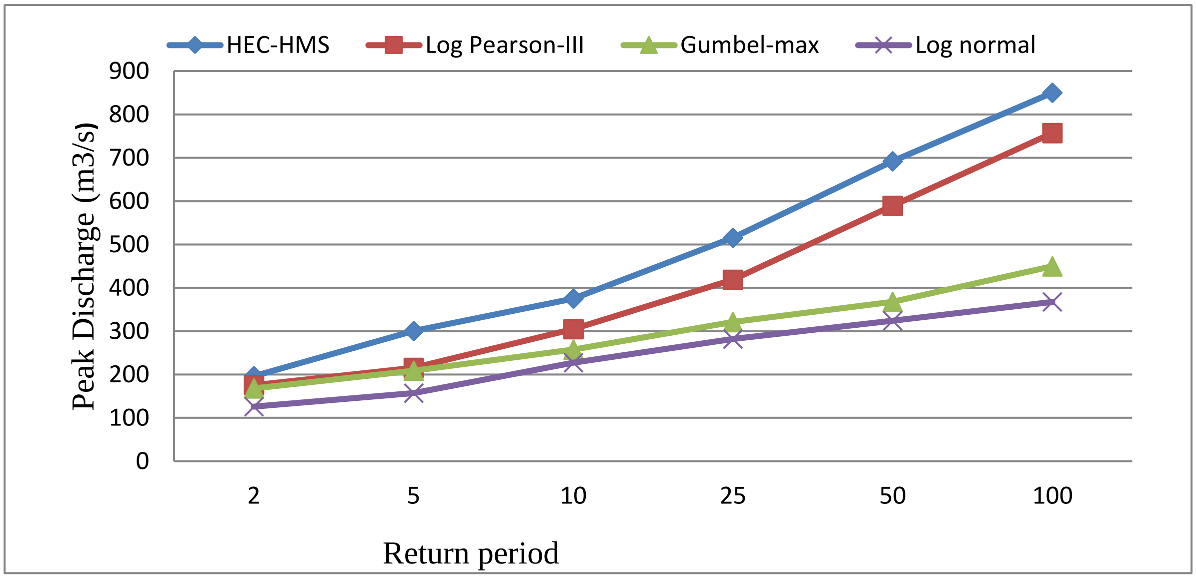


Figure 4.12: Comparison of HEC-HMS result with probability distribution result

In the above Figure the frequency discharge value derived using log-Pearson-III method show high similarity to the HEC-HMS. The other three are much lower than the result of the HEC-HMS.

5. CONCLUSION AND RECOMMENDATION

5.1Conclusion

In this study, rainfall-runoff modeling is carried out using HEC-HMS hydrologic model, remote sensing and GIS techniques in preview of simulating runoff the Weyb River watershed. The required rainfall and runoff data were collected for 30 years (1985–2014) from six stations and 15 years (1992-2006) from one station respectively, and geographical parameters were extracted using the DEM of the study area. The model is based on the hydrological characteristics, topography, and soil type and land use of the study area. Basin characteristics and initial values were analyzed using HEC-GeoHMS in ArcGIS in order to start the model calibration. For simulating of stream flow by the HEC-HMS model, the SCS curve method was used to compute direct surface runoff hydrographs and SCS unit hydrograph was used to transform excess precipitation into runoff. Rainfall-runoff simulation has been conducted. Initial results showed that there is clear difference between observed and simulated peak flows. Therefore, model calibration with optimization method and sensitivity analysis has been done and the Muskingum-k was found to be the most sensitive parameters and the model was the optimized with this sensitive parameter. After optimization the peak flow and total volume are very close to the observations with a small error in peak and volume. The performance of HEC-HMS model was assessed using different performance parameters and by graphical and visual interpretation. It showed that the overall performance of the HEC-HMS model is good in terms of percentage of bias, Nash-Sutcliffe Efficiency, coefficient of determination and root mean square error. The results of the model during calibration were pbias=13.96, NSE=0.867, R^2=941 and RMSE=0.4.

Model validation using optimized parameter values also showed reasonable difference in peak discharge and outflow volume. This result is surprising since the verification results are more or less good in general. The result obtained were, pbias=-3.03, NSE=0.819, R^2=0.93 and RMSE=0.4. Therefore, it can be concluded that there are relatively unique input–output relations and that the runoff formation is dominated by the only mechanism. Finally, Based on the analysis of the results obtained in this study, it can be concluded that model can be used with reasonable approximation in hydrologic simulation in Weyb watershed.

In this research thesis the flood discharge of different return periods 2, 5, 10, 25, 50, and 100 years were derived by different statistical methods such as gamble, lognormal and log Pearson III and compared with HEC-HMS results and log Pearson III shows high similarity with HEC-HMS. The study result of flood frequency analysis indicated that there may be peak flow increase in Weyb river watershed. This may have a positive as well has a negative implication to the socio-economic condition of the region. The increase in flow will help to harness a significant amount of water for agricultural purposes either for water supply or other purpose. However, it may also aggravate the recurrent flooding problems in the study area especially for those living in the downstream sides.

5.2 Recommendation

This research recommends the following:

- Based on the modeling work undertaken in the selected catchments of weyb watershed, better results were obtained. Therefore, the simulation results can be used directly or in conjunction with other software for different hydrological and environmental studies and for flow forecasting, future urbanization impact assessment, flood damage reduction, reservoir design studies, and overall systems operation.

- Data collection in Ethiopia is a time consuming process and the data obtained is often of poor quality. However, advances in scientific hydrology and practice of engineering hydrology depend on good, reliable and continuous measurements of hydrological variables. Model calibration more than anything relies on the quality of data available. Therefore, good quality data collection should always be encouraged. No model can be calibrated or even used without a good quality of data. The hydrology community should bridge the gap that is existing in the advancement of model development and the data acquisition. In addition to the traditional ground observation of hydro-meteorological variables derived from satellite images and radar technology can augment the data availability for water resources studies. Of course even theses recent technologies can achieve certain goals if and only if they are well calibrated by ground observations. Thus, advanced hydro-meteorological data acquisition shall be top on the agenda of the concerned bodies.

- The number of meteorological stations within and outside the basin should be more than used in this study to improve the model quality.
- If a further improvement of the simulation should be obtained, sub-daily precipitation measurements will become necessary. One possible way of gaining accurate and consistent data is by installing and maintaining an hourly rain gauge .As a result, hourly data measurement shall be promoted in the watershed.
- A careful Assessment of flood inundation and mapping should be carried out in the watershed so as to identify the area that is probably affected by historical flood and to give reasonable measurement in time.

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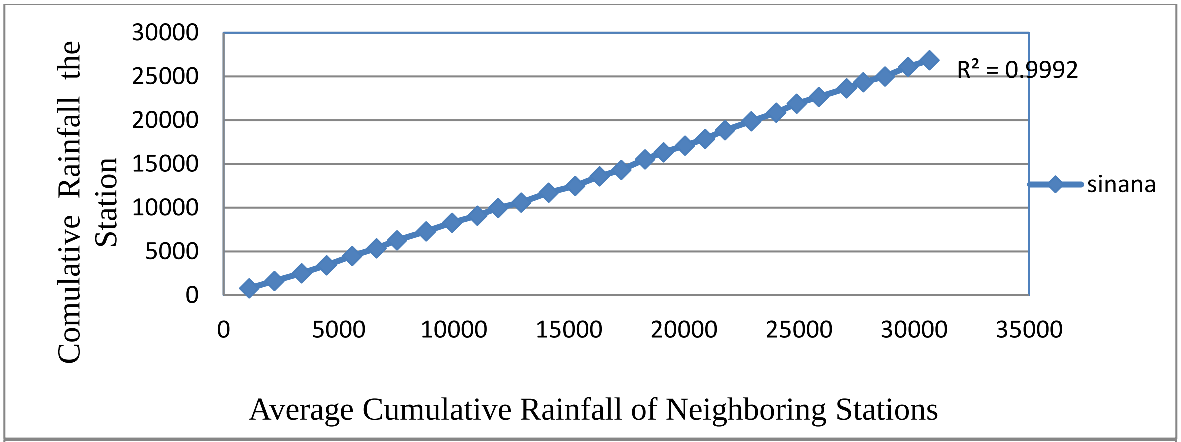
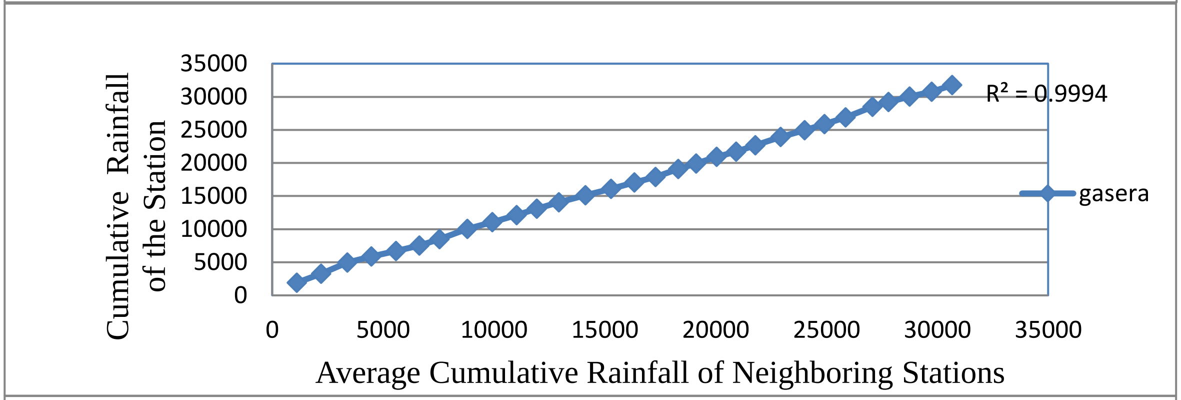
7. APENDIX

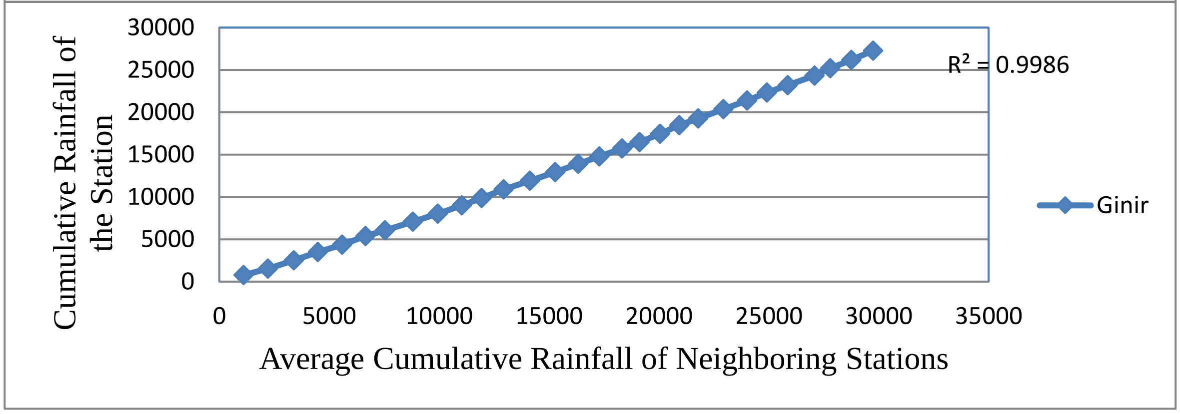
Appendix A

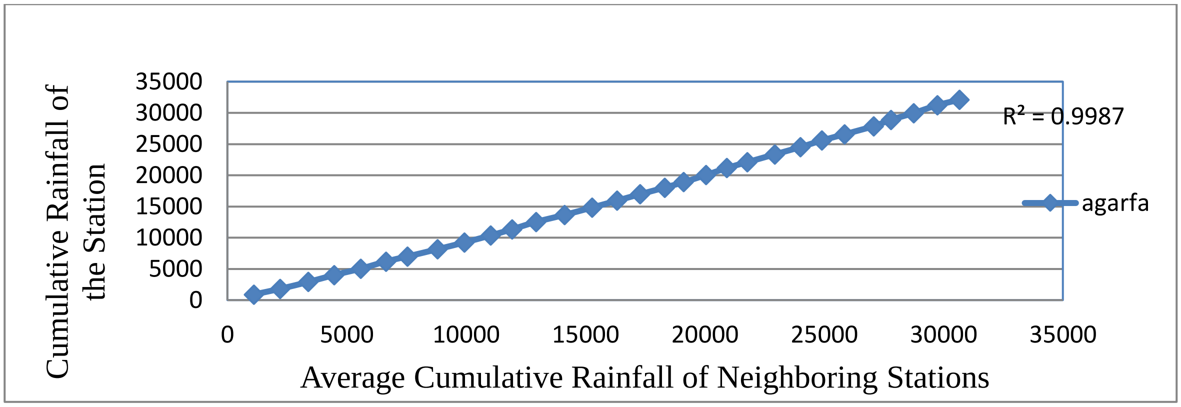
Table 7.1:DMC_Analysis

Year	Average Cumulative Of All Stations	Gasera	Sinana	Agarfa	Ginir	Robe	Dinsho
1985	1103.467	1909	790	902.4	766.4	666.4	946.4
1986	2206.633	3248.1	1645.6	1807.9	1535.9	1335.9	1895.9
1987	3387.45	4941.8	2526.8	2904.7	2496.7	2196.7	3036.7
1988	4470	5862.2	3440	4015.8	3471.8	3071.8	4191.8
1989	5584.967	6672.2	4482	5038.6	4358.6	3858.6	5258.6
1990	6636.333	7530.4	5372.8	6181.5	5365.5	4765.5	6445.5
1991	7535.683	8505.5	6269	6986.2	6034.2	5334.2	7294.2
1992	8800.067	10043.3	7320.4	8153.6	7065.6	6265.6	8505.6
1993	9924.9	11070.7	8273.4	9231.7	8007.7	7107.7	9627.7
1994	11020.8	12100.1	9107.4	10354.2	8994.2	7994.2	10794.2
1995	11927.98	13083.3	9971.7	11353.3	9857.3	8757.3	11837.3
1996	12928.12	14059.8	10603.9	12521	10889	9689	13049
1997	14128.65	15103.4	11744	13658.6	11890.6	10590.6	14230.6
1998	15270.82	16074.8	12484.1	14824.2	12920.2	11520.2	15440.2
1999	16327.47	17057.8	13609.8	15942.8	13902.8	12402.8	16602.8
2000	17280.15	17884.6	14330.1	16960.6	14784.6	13184.6	17664.6
2001	18312.3	19075.7	15524.3	18015.7	15703.7	14003.7	18763.7
2002	19114.18	19887.4	16348.5	18900.6	16452.6	14652.6	19692.6
2003	20045.18	20929.8	17100.9	20028	17444	15544	20864
2004	20920.48	21708.8	17888.8	21168.6	18448.6	16448.6	22048.6
2005	21780.47	22669.2	18842.6	22097	19241	17141	23021
2006	22927.77	23905	19870.2	23346.7	20354.7	18154.7	24314.7
2007	24009.03	24961.6	20853.6	24517.7	21389.7	19089.7	25529.7
2008	24905.53	25859.4	21889.3	25581.4	22317.4	19917.4	26637.4
2009	25853.43	26883	22659.9	26565.8	23165.8	20665.8	27665.8
2010	27075.2	28475.8	23636.1	27868.9	24332.9	21732.9	29012.9
2011	27789.75	29198.4	24327.9	28874.1	25202.1	22502.1	30062.1
2012	28742.38	30037.6	25005.1	29965.4	26157.4	23357.4	31197.4
2013	29733.95	30755	26081.4	31210.9	27266.9	24366.9	32486.9
2014	30665.53	31748.2	26849.1	32109.3	28029.3	25029.3	33429.3


Comulative Rainfall the Station
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
R² = 0.9992
sinana
Average Cumulative Rainfall of Neighboring Stations


Cumulative Rainfall of the Station
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
R² = 0.9994
gasera
Average Cumulative Rainfall of Neighboring Stations


Cumulative Rainfall of the Station
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
R² = 0.9986
Ginir
Average Cumulative Rainfall of Neighboring Stations


Cumulative Rainfall of the Station
35000
30000
25000
20000
15000
10000
5000
0
0
5000
10000
15000
20000
25000
30000
35000
R² = 0.9987
agarfa
Average Cumulative Rainfall of Neighboring Stations

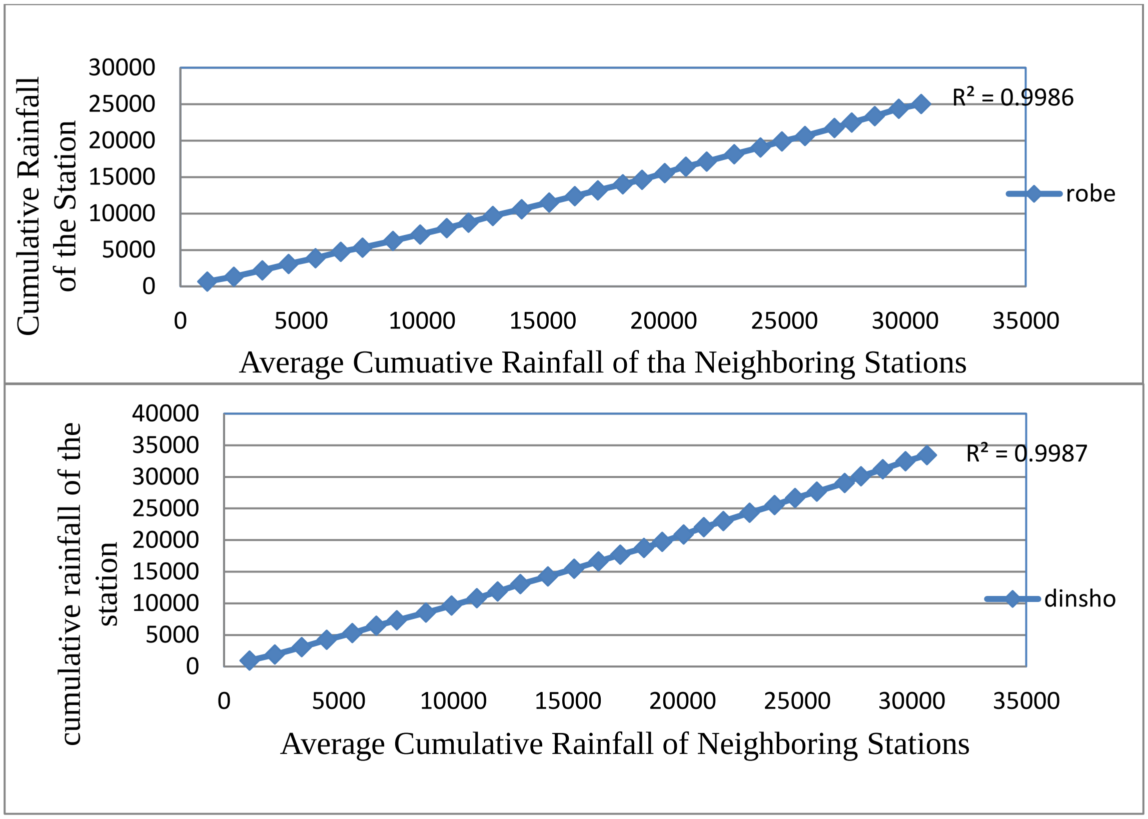
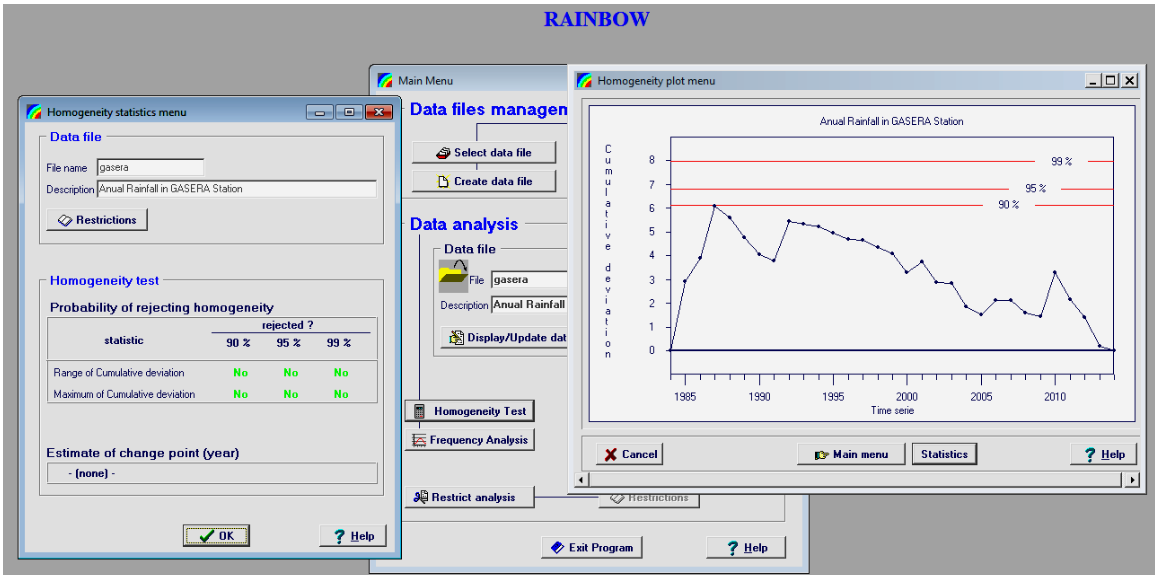


Figure 7.1: Double mass curve of different stations in the study are

Table 7.2: Table for Homogeneity Test Using Rainbow Software

Year	Cumulative Annual Rain Fall of each stations					
	Gasera	Sinana	Agarfa	Ginir	Robe	Dinsho
1985	1909	790	1183.8	755.8	666.4	1315.8
1986	1339.1	855.6	1371.1	764.8	669.5	1618.9
1987	1693.7	881.2	1142.8	908.5	860.8	1597.9
1988	920.4	913.2	1987.2	815.5	875.1	983.9
1989	810	1042	2358.9	911.3	786.8	780.8
1990	858.2	890.8	1868.4	889.7	906.9	894.2
1991	975.1	896.2	1442.1	772.9	568.7	741.1
1992	1537.8	1051.4	2328.7	706.6	931.4	1030.4
1993	1027.4	953	1895.2	1067.3	842.1	964
1994	1029.4	834	1885.3	917.9	886.5	1022.3
1995	983.2	864.3	1304.3	679.6	763.1	848.6
1996	976.5	632.2	1174.1	994.9	931.7	1291.4
1997	1043.6	1140.1	1483.5	1086.7	901.6	1547.7

1998	971.4	740.1	1444.8	911.7	929.6	1855.4
1999	983	1125.7	1232.2	725.9	882.6	1390.5
2000	826.8	720.3	1093.2	930.5	781.8	1363.5
2001	1191.1	1194.2	965.1	659.9	819.1	1363.5
2002	811.7	824.2	860.9	811.5	648.9	854.1
2003	1042.4	752.4	1174.6	713.6	891.4	1011.6
2004	779	787.9	895.7	840.6	904.6	1044
2005	960.4	953.8	903	913.6	692.4	736.7
2006	1235.8	1027.6	904.3	1417.3	1013.7	1285.1
2007	1056.6	983.4	1235.4	1249.1	935	1028.1
2008	897.8	1035.7	1040.6	755.3	827.7	821.9
2009	1023.6	770.6	771	1360.7	748.4	1013.1
2010	1592.8	976.2	1462.2	1700.6	1067.1	531.7
2011	722.6	691.8	456	1088.5	769.2	559.2
2012	839.2	677.2	1205.8	1243.5	855.3	894.8
2013	717.4	1076.3	1096.8	1450.1	1009.5	599.3
2014	993.2	767.7	1137.6	1373.3	662.4	655.3



File name: gasera
Description: Anual Rainfall in GASERA Station

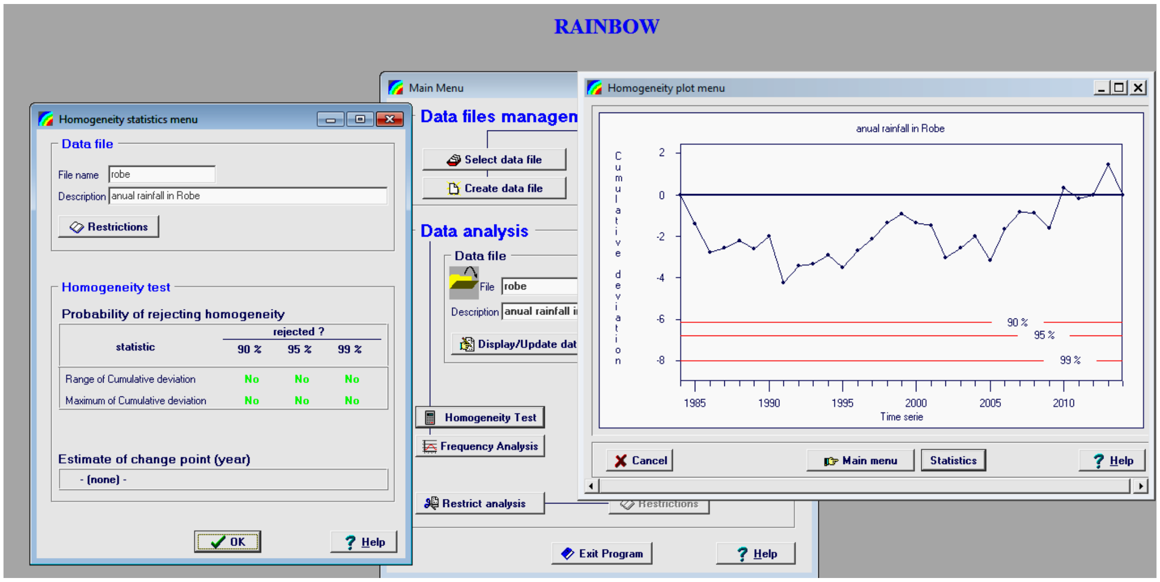
File: gasera
Description: Anual Rainfall

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) -

a)



File name: robe

Description: anual rainfall in Robe

File: robe

Description: anual rainfall i

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)

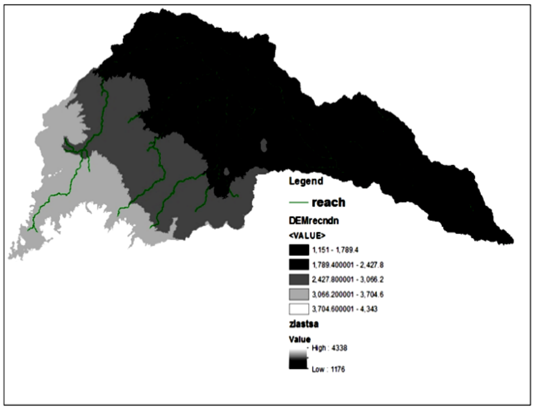
- (none) -

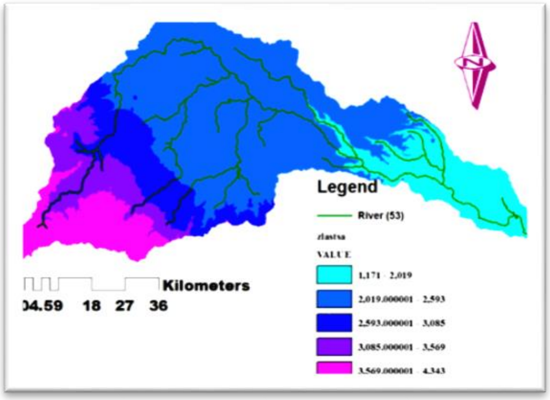
b)

Figure (a&b)7.2: Homogeneity test of the meteorological satiation

Appendix B:

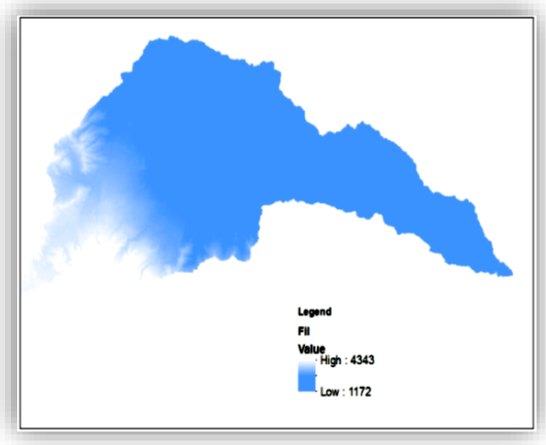
Some of Geo-HEC and HEC_ HMS_ Outputs

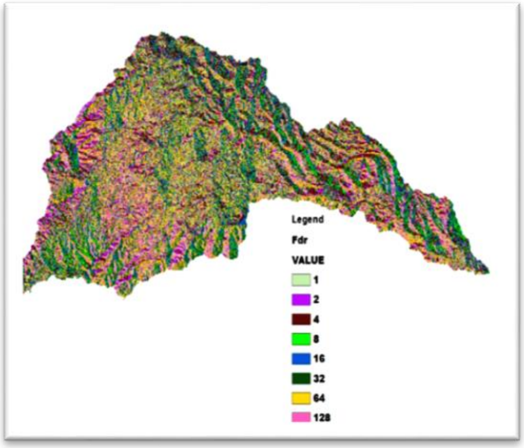




a) DEM (30x30)

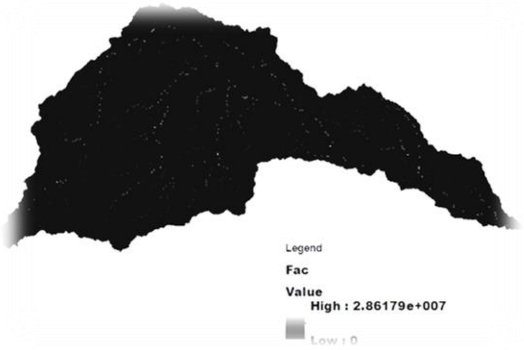
b) DEM reconditioning

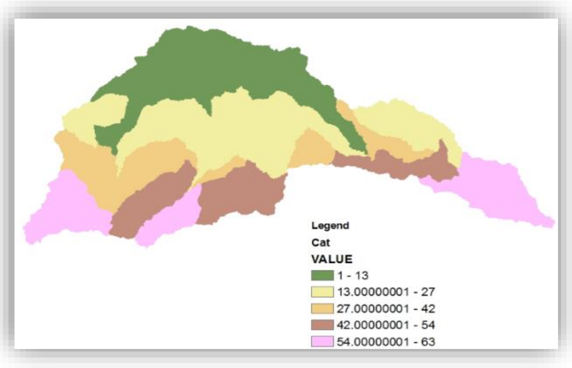




c) Fill sink

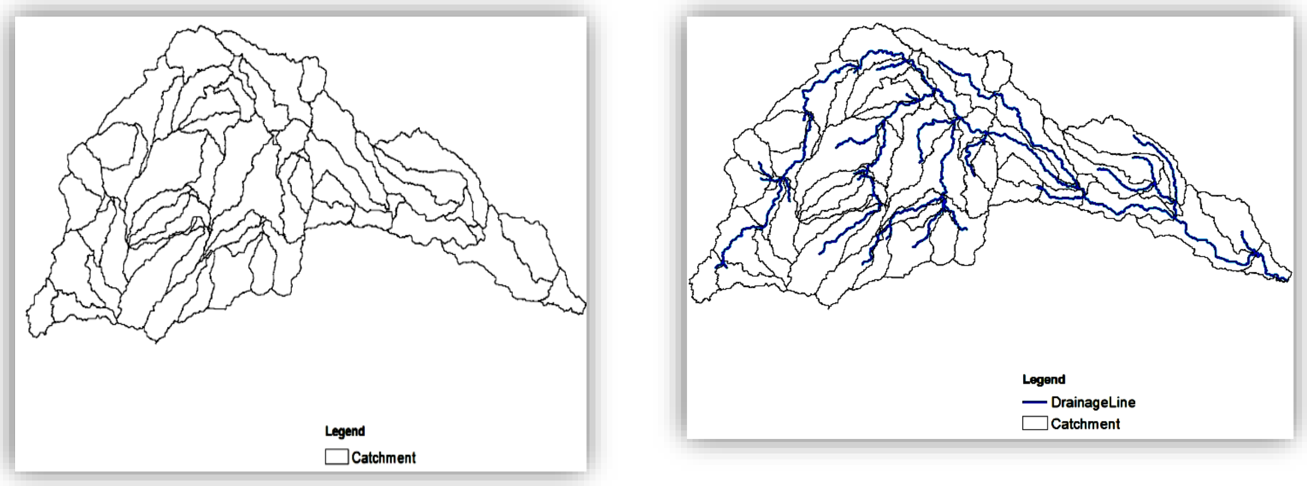
d) flow direction



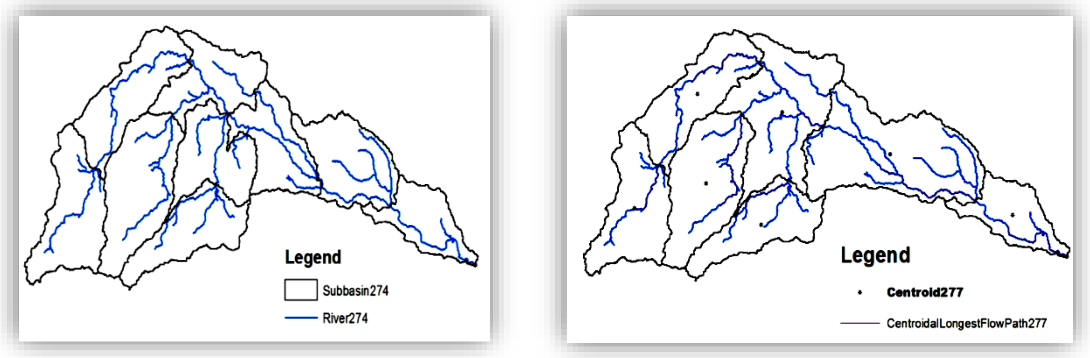


e) Flow accumulation

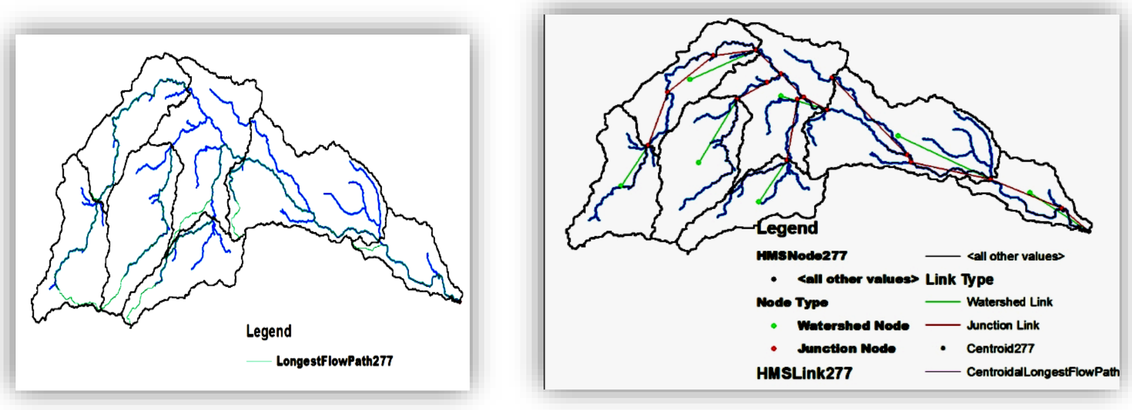
f) catchment



g) Catchment polygon h) drainage line processing



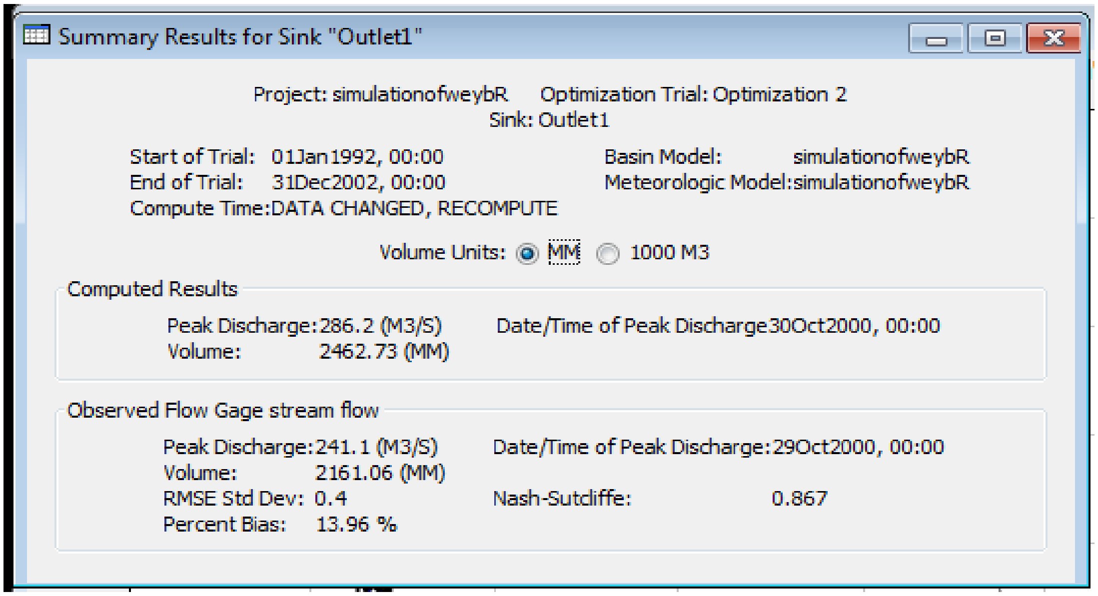
i) Basin merges j) Centroid and centroidallongest flow path



k) Longest flow path L) HMS schematic

Figure 7.3:HEC-GeoHMS Process Maps

Table 7.5: Summery Of the Model Simulation during Calibration(above) and Validation (Below)


Summary Results for Sink "Outlet1"

Project: simulationofweybR Optimization Trial: Optimization 2
Sink: Outlet1

Start of Trial: 01Jan1992, 00:00 Basin Model: simulationofweybR
End of Trial: 31Dec2002, 00:00 Meteorologic Model:simulationofweybR
Compute Time:DATA CHANGED, RECOMPUTE

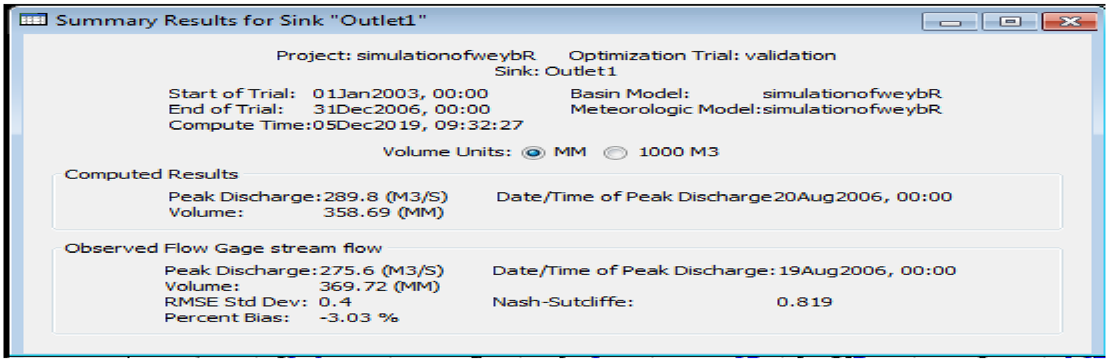
Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge:286.2 (M3/S) Date/Time of Peak Discharge30Oct2000, 00:00
Volume: 2462.73 (MM)

Observed Flow Gage stream flow

Peak Discharge:241.1 (M3/S) Date/Time of Peak Discharge:29Oct2000, 00:00
Volume: 2161.06 (MM)
RMSE Std Dev: 0.4 Nash-Sutcliffe: 0.867
Percent Bias: 13.96 %


Summary Results for Sink "Outlet1"

Project: simulationofweybR Optimization Trial: validation
Sink: Outlet1

Start of Trial: 01Jan2003, 00:00 Basin Model: simulationofweybR
End of Trial: 31Dec2006, 00:00 Meteorologic Model:simulationofweybR
Compute Time:05Dec2019, 09:32:27

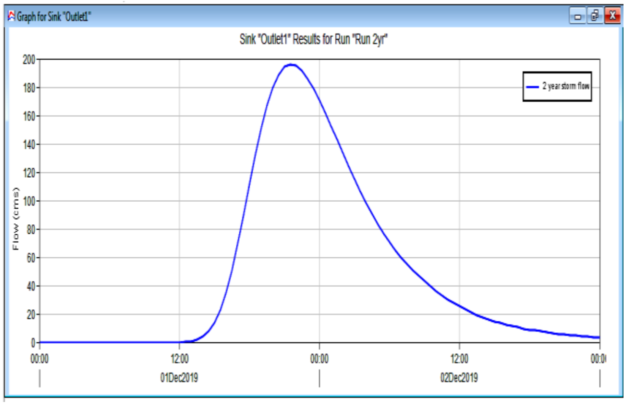
Volume Units: ● MM ○ 1000 M3

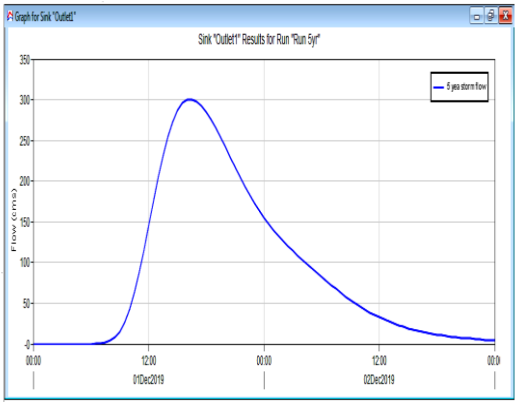
Computed Results

Peak Discharge:289.8 (M3/S) Date/Time of Peak Discharge20Aug2006, 00:00
Volume: 358.69 (MM)

Observed Flow Gage stream flow

Peak Discharge:275.6 (M3/S) Date/Time of Peak Discharge:19Aug2006, 00:00
Volume: 369.72 (MM)
RMSE Std Dev: 0.4 Nash-Sutcliffe: 0.819
Percent Bias: -3.03 %





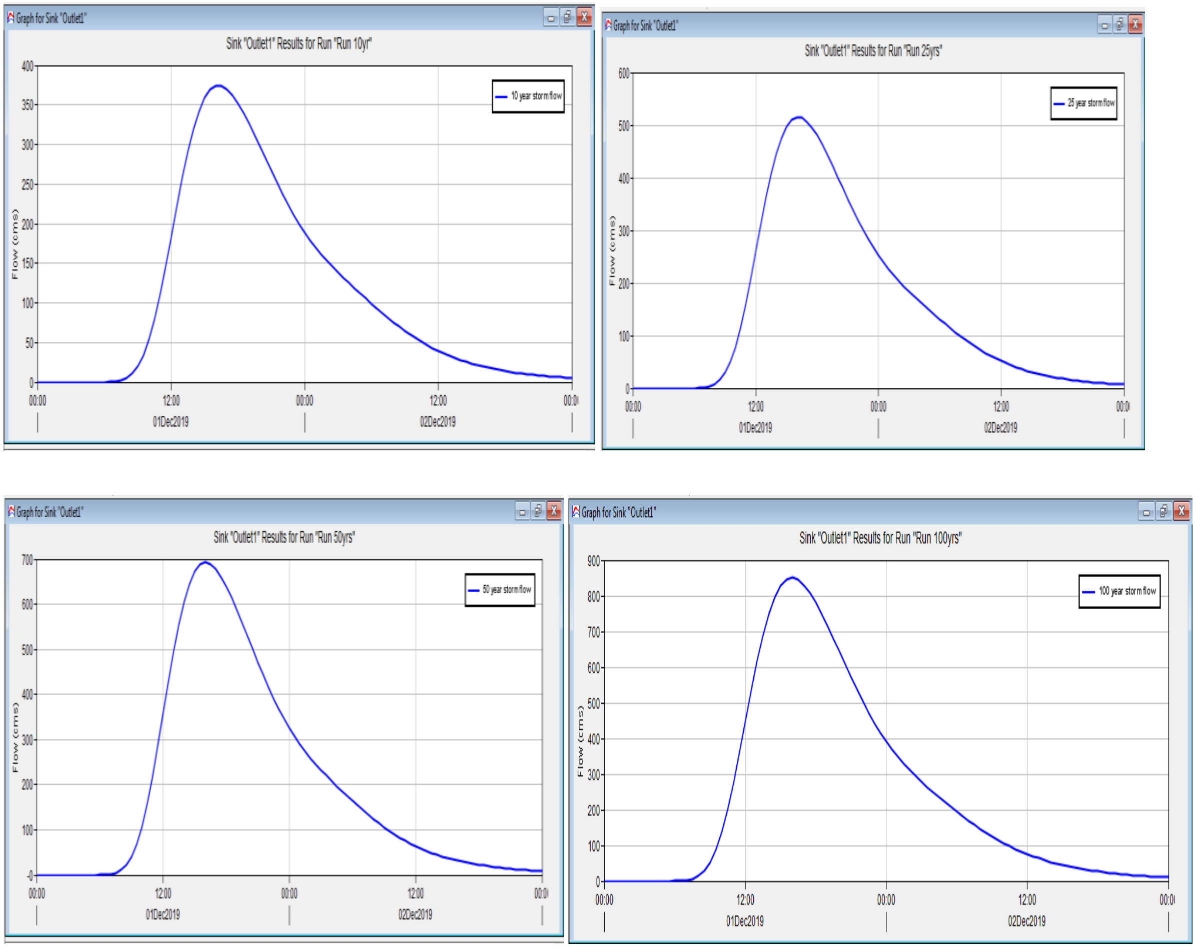
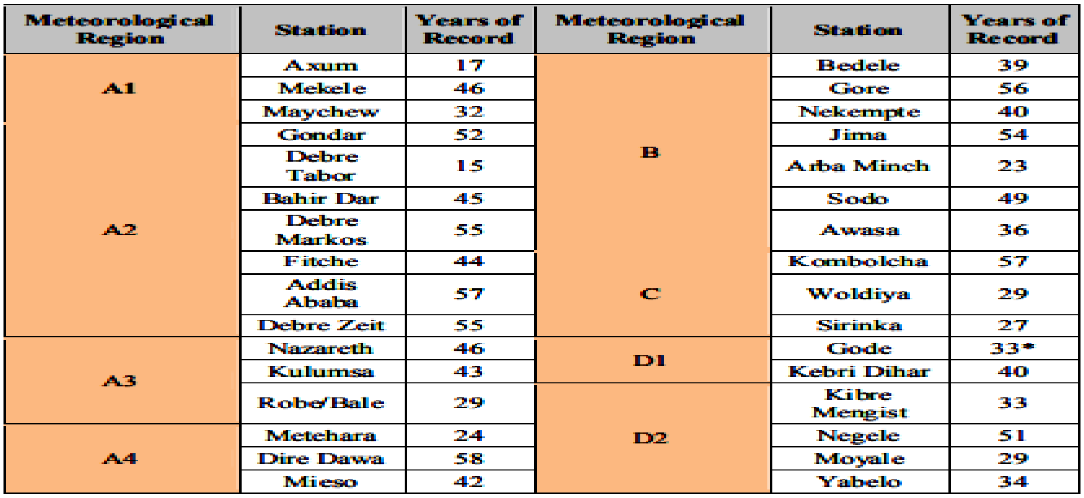


Figure 7.4: Storm Flow Hydrograph of 2, 5, 10, 25, 50 And 100 Year respectively

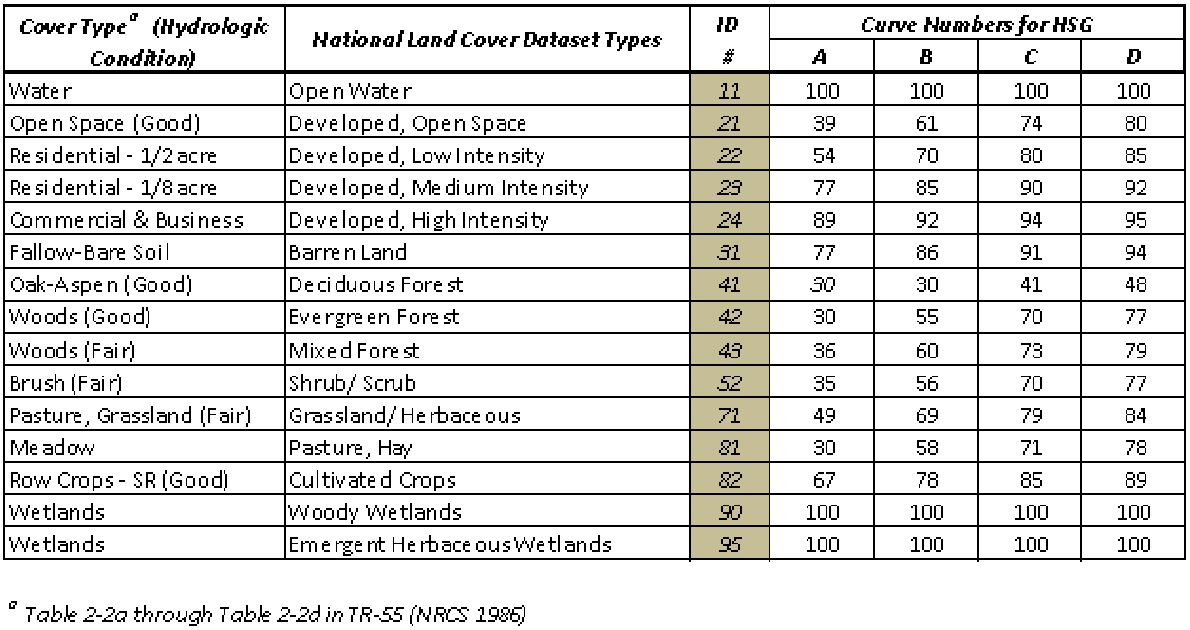
Table 7.6: Meteorological Stations (years of record through 2010)



Meteorological Region	Station	Years of Record	Meteorological Region	Station	Years of Record
A1	Axum	17	B	Bedele	39
	Mekele	46		Gore	56
	Maychew	32		Nekempte	40
A2	Gondar	52		Jima	54
	Debre Tabor	15		Arba Minch	23
	Bahir Dar	45		Sodo	49
	Debre Markos	55		Awasa	36
	Fitche	44	C	Kombolcha	57
	Addis Ababa	57		Woldiya	29
	Debre Zeit	55		Sirinka	27
A3	Nazareth	46	D1	Gode	33*
	Kulumsa	43		Kebri Dihar	40
	Robe/Bale	29	D2	Kibre Mengist	33
A4	Metehara	24		Negele	51
	Dire Dawa	58		Moyale	29
	Mieso	42		Yabelo	34

Source: ERA Drainage manual, 2013

Table 7.7: Lu/Lc Classification and their HSG



Cover Type[a] (Hydrologic Condition)	National Land Cover Dataset Types	ID #	Curve Numbers for HSG			
			A	B	C	D
Water	Open Water	11	100	100	100	100
Open Space (Good)	Developed, Open Space	21	39	61	74	80
Residential - 1/2 acre	Developed, Low Intensity	22	54	70	80	85
Residential - 1/8 acre	Developed, Medium Intensity	23	77	85	90	92
Commercial & Business	Developed, High Intensity	24	89	92	94	95
Fallow-Bare Soil	Barren Land	31	77	86	91	94
Oak-Aspen (Good)	Deciduous Forest	41	30	30	41	48
Woods (Good)	Evergreen Forest	42	30	55	70	77
Woods (Fair)	Mixed Forest	43	36	60	73	79
Brush (Fair)	Shrub/ Scrub	52	35	56	70	77
Pasture, Grassland (Fair)	Grassland/ Herbaceous	71	49	69	79	84
Meadow	Pasture, Hay	81	30	58	71	78
Row Crops - SR (Good)	Cultivated Crops	82	67	78	85	89
Wetlands	Woody Wetlands	90	100	100	100	100
Wetlands	Emergent Herbaceous Wetlands	95	100	100	100	100

[a] *Table 2-2a through Table 2-2d in TR-55 (NRCS 1986)*