JIMMA UNIVERSITY

SCHOOL OF POST GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

SIMULATION OF RAINFALL-RUNOFF PROCESS AND ANALYSIS BY USING HYDRAULIC ENGINEERING CENTER HYDROLOGIC MODELLING SYSTEM FOR HANGER WATERSHED, ABBAY BASIN, ETHIOPIA

BY: BIRITU DERECHA ITICHA

A THESIS SUBMITTED TO JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING, HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

MAY, 2021

JIMMA, ETHIOPIA

JIMMA UNIVERSITY

SCHOOL OF POST GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDROLOGIC ENGINEERING CHAIR

MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING

SIMULATION OF RAINFALL-RUNOFF PROCESS AND ANALYSIS BY USING HYDRAULIC ENGINEERING CENTER HYDROLOGIC MODELLING SYSTEM FOR HANGER WATERSHED, ABBAY BASIN, ETHIOPIA

BY: BIRITU DERECHA ITICHA

A THESIS SUBMITTED TO JIMMA UNIVERSITY, JIMMA INSTITUTE OF TECHNOLOGY, FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING, HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTERS OF SCIENCE IN HYDRAULIC ENGINEERING.

ADVISOR: MR. MAMUYE BUSIER (ASS.PROF)

CO-ADVISOR: MS. SARON TOKUME (MSC.)

MAY, 2021

JIMMA, ETHIOPIA

DECLARATION

I, declare that this thesis work entitled "**SIMULATION OF RAINFALL-RUNOFF PROCESS AND ANALYSIS BY USING HYDRAULIC ENGINEERING CENTER HYDROLOGIC MODELLING SYSTEM FOR HANGER WATERSHED, ABBAY BASIN, ETHIOPIA**" is my original work. It has not been submitted for similar or any other degree award in any other university. All the sources I have used or quoted have been indicated and knowledged by complete reference.

Biritu Derecha (BSc.):	________________	_____________
	Signature	date

This thesis has been submitted for examination with my approval as a University Supervisors.

Approved by:

Main Advisor: Mr. Mamuye Busier (Ass.Prof):	_____________	____________
	Signature	Date
Co- Advisor: Ms. Saron Tokume (MSc.):	_____________	____________
	Signature	Date

APPROVAL SHEET

The undersigned certifies that the thesis entitled "SIMULATION OF RAINFALL-RUNOFF PROCESS AND ANALYSIS BY USING HYDRAULIC ENGINEERING CENTER HYDROLOGIC MODELLING SYSTEM FOR HANGER WATERSHED, ABBAY BASIN, ETHIOPIA" is the work of Biritu Derecha. It has been accepted and submitted for examination with my approval as the university advisor in partial fulfillment of the requirements for the Degree of Master of Science in Hydraulic Engineering.

ADVISOR: MR. MAMUYE BUSIER (ASS.PROF):	____________	_________
	Signature	Date
CO-ADVISOR: MS. SARON TOKUME (MSC.):	____________	__________
	Signature	Date

As Member of Board of Examiners of the MSc. Thesis-Open Defense Examination, we certify that we have read, evaluated the thesis prepared by Biritu Derecha, and examined the candidate. We recommend that the thesis could be accepted as fulfilling the thesis requirement for the Degree of Master of Science in Hydraulic Engineering.

_______________	________________	_______________
External Examiner	Signature	Date
_______________	________________	______________
Internal Examiner	Signature	Date
______________	_________________	______________
Chair Holder	Signature	Date
_______________	_________________	_______________
Chair Person	Signature	Date

ABSTRACT

Water resource managers have undertaken comprehensive rainfall-runoff hydrologic studies to model the hydrological response in many regions around the world to meet different desirable needs with the goal of efficient and proper planning and management of water resources for present and future uses. However, such research does not pay enough attention to the Hanger watershed, Abbay basin, Ethiopia, which may be affected by water insecurity. Therefore, the main objective of this study was to simulate rainfall-runoff processes and analysis using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) for the Hanger watershed to see if the model works well in this study field. The input data used were the meteorological data, spatial data and, hydrological data obtained from the National Meteorological Service Agency and the Ministry of Water, Irrigation and Energy, respectively. The missing value of precipitation data was filled using the normal ratio method, and the consistency of data was checked using a double mass curve. Hydrologic Engineering Center-Geospatial Hydrologic Modeling System (HEC- GeoHMS) used for each sub-basin; the curve number was generated using DEM, land use land cover data, and soil data, and prepare basin model imported to HEC-HMS. The SCS-CN loss, SCS unit hydrograph, Constant monthly, and Muskingum methods are used to measure precipitation loss modeling, transform modeling, base flow modeling, and flood routing. For model calibration (1990-2009) and validation (2010-2014), hydro-meteorological data were used. The parameters used to evaluate the models' sensitivity were; curve number, initial abstraction, basin lag, Muskingum k, and Muskingum x. The results show that the model was most sensitive to Muskingum (K) and Muskingum (x), but Muskingum k is more sensitive than Muskingum x for this study. During the calibration and validation phase, the performance of the model was assessed by Nash-Sutcliffe Efficiency (NSE), Root means square error (RMSE), Coefficient of determination (R^2), Percent bias (PBIAS), Percent error in volume (PEV), and Percent error in peak flow (PEPF), indicating NSE (0.702), R^2 (0.7143), RMSE (0.5), PBIAS (-2.04%), PEV (2.035), and PEPF (8.764) and NSE (0.707), R^2 (0.743), RMSE (0.5), PBIAS (14.61%), PEV (14.58), and PEPF (8.15), respectively. The simulated and observed peak discharges differed by 91.2 m3/s in calibration time. This indicates that the peak discharge was well predicted. In the validation period, there was a difference of 79.9 m3/s between the observed and simulated peak discharge. This means that the peak discharge was slightly lower than expected. For this study, calibrated and validated model results showed that the model performed well. Flood prediction was conducted in the HEC-HMS using 24-hour rainfall depth of 2, 5,10, 25, 50,100, and 200 years return period and found to be 608.4 m^3/s, 967.2 m^3/s, 1225.2 m^3/s, 1565.9 m^3/s, 1830.6 m^3/s, 2103.2m^3/s, and 2382.7 m^3/s, respectively. Also using the General extreme value of the Statistical flood frequency analysis, the peak flow discharge for 2,5,10,25,50,100 and 200 year return period were 600.7m^3/s, 895.8 m^3/s, 1180.6 m^3/s, 1394.9 m^3/s, 1772.3 m^3/s, 1962.5 m^3/s, and 2243 m^3/s, respectively. The minimum and maximum peak flow records in HEC-HMS were 608.4 m^3/s and 2382.7 m^3/s, respectively. Therefore, these predicted values will aid future researchers in creating a flood inundation map and taking appropriate flood-control measures for the study area.

Keywords: *Calibration, Hanger Watershed, HEC-HMS, Rainfall-Runoff, Return Period, Validation.*

ACKNOWLEDGEMENT

First of all, I would like to thank almighty God who has given me the courage and strength to proceed with my research. And also I wish to express my deepest appreciation and gratitude to my main advisor Mr. Mamuye Busier (Ass. prof) and co-advisor Ms. Saron Tokume (M.Sc.) for their valuable guidance during this research preparation.

I would like gratefully to acknowledge the Ethiopian Ministry of Water, Irrigation, and Electricity (MOWIE) and the National Metrological Agency of Ethiopia (NMAE) for Providing me valuable input data for my thesis work.

I send my precious and honored full thanks to Jimma Institute of Technology, Civil and Environmental Engineering Faculty, Department of Hydrology and Hydraulic Engineering chair those who contribute the commencement of this thesis to the end.

Finally, my deepest gratitude and humble thanks go to my immediate parents particularly my lovely mother Jitu Cheka, and my brother Leta for their never-ending support in financial, encouragement, and motivation. I express my gratitude to all my friends whose names have not been mentioned individually but have helped me directly or indirectly in this work.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATION

AMC	Antecedent Moisture Condition
BCM	Billion Cubic Meter
DEM	Digital Elevation Model
DMC	Double Mass Curve
ESRI	Environmental System Research Institute
GIS	Geographic Information System
HEC-GEOHMS	Hydrologic Engineering Center-Geospatial Modeling System
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HR	Hour
HSG	Hydrological Soil Group
LU/LC	Landuse-Landcover
m.a.s.l.	meter above sea level
MOWIE	Ministry of Water Irrigation Energy
NMSA	National Meteorological Service Agency
NSE	Nash-Sutcliffe Efficiency
ONRS	Oromia National Regional State
PCT	Percent
R^2	Coefficient of Determination
RMSE	Root Mean Square Error
SCS-CN	Soil Conservation Service-Curve Number
UH	Unit Hydrograph
USACE	United State Army Corps of Engineers
USDA	United States Department of Agriculture

1. INTRODUCTION

1.1. Background of the study

Rainfall is a significant component of hydrologic cycles, and it is the primary source of water for runoff production over the land surface. Runoff is also one of the catchment's major hydrological responses, and it is connected to water conservation and soil degradation. When rain falls, runoff may or may not occur, depending on the soil's specific conditions and other factors such as rainfall. For integrated water resource management, accurate and reliable data on the volume and rate of runoff from the land surface into rivers is critical. This data is needed to investigate various watershed growth and management issues (Beven Keith and Freer Jim, 2001). Proper planning and management of water resources are vital for wise utilization and sustainable development of the resource. Water resource planning and management are important for the resource's wise use and long-term growth.

A watershed is a hydrologic unit that generates water as an end product by interacting rainfall with the ground surface (Shaikh *et al.,* 2018). The amount and intensity of rainfall and the nature of watershed management measure the water's quantity and quality provided by the watershed. As the study reports (Choudhari *et al.,* 2014), soil and water are the two most important natural resources for agricultural production in any country. Water is the most important natural resource for living things out of the two. Since the available amount of water is small, scarce, and not evenly distributed to meet the population's needs, careful management of water supplies is needed to meet current demands while also ensuring long-term sustainability.

However, in many situations, inadequate land-use planning and land management practices during rapid growth harm surface runoff quantities and quality, resulting in reduced land use land cover, nitrogen plant losses, degradation of river water quality, and an increase in surface impervious area (Supriya and Krishnaveni, 2016). According to (Zeberie 2019), Surface runoff is the most component in the hydrologic cycles. It is linked to various environmental issues, such as runoff excess causes soil erosion, water contamination, deterioration of land, floods, and loss of ecosystems (habitats). These factors are affected by the amount of rain, the rain's severity, and the infiltration potential. If the rainfall intensity falls below the equilibrium capacity, all of the water that reaches the land surface will infiltrate. Suppose the rainfall intensity exceeds the equilibrium infiltration capacity but falls below the initial infiltration capacity. In that case, all of the water will infiltrate at first, but when the infiltration capacity falls below the rainfall intensity, some of the water will remain on the ground surface. Finally, if the rainfall rate exceeds the initial penetration potential, some water can immediately stay on the land surface (Berhane *et al.*, 2013).

A simplified representation of a real-world structure is a hydrological model. The best model produces outcomes similar to the fact as possible by using the fewest parameters and templates. It is made up of various parameters that describe the model's characteristics and is primarily used to forecast system behavior and comprehend several hydrological processes (Sorooshian *et al.,*2008). Rainfall-runoff modeling is a crucial measure in water resource planning and development, and it is one of the most relevant topics in hydrology.

The relationship between rainfall and runoff is well understood as highly complex due to the spatial and temporal variability of watershed characteristics, precipitation heterogeneity, and various factors involved in runoff generation. Evaporation, infiltration, soil moisture, overland flow, and river flow are the most important components in converting rainfall to runoff (Beven, 2000). Therefore, modeling rainfall-runoff processing is a challenging challenge or complex task.

According to (Devi *et al*., 2015), hydrological models are now considered an effective and essential water and environmental resource management method. The two most critical inputs for all models are rainfall data and drainage area. Hydrologic modeling for runoff simulations requires accurate rainfall data as model input, but in many developing countries like Ethiopia, the rainfall observation network is relatively sparse. Hence, the quality of rainfall data plays a significant role in the reliability of simulation results, as basic input data for hydrological model simulations (Hailu, 2014).

Understanding the natural processes occurring at the watershed scale requires the use of hydrological models. Numerous computer-based models were created and made available for use in hydrologic modeling and water resource studies. It plays a critical role in hydrologic response prediction for the applications such as water resources management activities, flood control, and evaluation of water quality (Wagener and Wheater, 2006; Wagener and McIntyre, 2005).

Understanding the rainfall-runoff relationship is critical for hydrological modeling, ranging from simple unit hydrographs to more complex models based on fully dynamic flow equations that simulate time. Rainfall-runoff modeling is a simplified mathematical representation of hydrologic cycles that is best suited to depicting this complex and dynamic phase. On the other hand, runoff estimation is generally based on the rainfall-runoff method (Hirp, 2005; Ramly and Tahir, 2006; Berhane *et al*., 2013).

We need to model the rainfall-runoff process for several purposes. The key explanation is that hydrological calculation methods have limitations. As a result, the most difficult challenge remains accurate prediction of catchment runoff responses to rainfall events. Selecting a model with a clear structure, minimal input data specifications, and fair precision is critical. The use of effective hydrological models for the efficient management of watersheds and habitats is one viable solution and approach to this challenge (Choudhari *et al.,* 2014; Mccoll and Aggett, 2007; Singh, 2003; Johnson *et al.*, 2003; Majidi and Shahedi, 2012; Campling *et al.*, 2002; Beven 2001).

Hydrological models can be divided into two types: deterministic and stochastic. Stochastic models generate partly random outputs; deterministic models, on the other hand, do not produce randomness. Deterministic hydrologic models can be divided into three groups. First, there's the lumped model, which measures the catchment response solely at the outlet without accounting for individual sub-basin responses. Second, a semi-distributed model, in which the catchment is divided into several sub-basins and the catchment is partially allowed to shift in space. The final model is a distributed model, which allows its parameters to change in real-time at a resolution determined by the client (Tassew *et al*., 2019).

HEC-HMS is an example of a hydrological model that is still commonly used today. In recent years, it has been used in our country and Africa and international watershed studies. The HEC-HMS model is designed to simulate the surface runoff response of a watershed to precipitation by representing the catchment with interconnected hydrologic and hydraulic components, as described (Oleyiblo, James Oloche; Li, 2010).

(Rostaee *et al.*, 2018), also proposed that the HEC-HMS model was used to determine debit and runoff volume in two agricultural regions in the southeastern part of South Dakota, where the curve had high sensitivity and the initial loss had lower sensitivity to the change of the target function quantity in the HEC-HMS model. HEC-HMS, which has been used extensively in various studies, is one of the hydrologic models that meet these requirements.

In reality, the Hanger Watershed is one of the largest tributaries of the Didessa sub-basin of Ethiopia's upper Blue Nile. As a result, I had chosen for this study to use the Hydrologic Engineering Centers- Hydrologic Modeling System (HEC-HMS) model to simulate rainfall-runoff modeling and analysis for the Hanger watershed in Ethiopia's northwestern region. Since no more experiments using HEC-HMS models are being done for this watershed.

1.2. Statement of the problem

Water resources play a crucial role in the economic development of developing countries with plentiful water resources like Ethiopia. The region’s explosive population growth and resulting new demands on limited water resources require efficient management of existing water resources to meet the challenge. In the water resources management system, it is well known that to combat water shortage issues, maximizing water management efficiency based on runoff simulation was crucial (Legesse, 2009).

Abbay basin is one of the largest basins in Ethiopia which has a large volume of water resource and a source of life for several peoples living in the basin and for the downstream country. The rapidly increasing population, deforestation, over-cultivation, and other social, economic and political factors are the major problem in the basin and its tributaries.

Hanger watershed is one of the tributaries of this basin, which faces land and water resources degradation, which promote losses of soil fertility in most of the watersheds because of lack of effective land and rainwater management practices in the Abbay river basin, particularly in the Hanger watershed. 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).

Despite the different modelling activities are practiced in the basin, the HEC-HMS model was not tested, calibrated, and validated for Hanger Watershed. Therefore, considering watershed characteristics of the Hanger 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 general objective of this study is to simulate rainfall-runoff processes and analysis by using the HEC-HMS model in Hanger Watershed.

1.3.2. Specific objectives

To attain the general objective of the study, the following specific objectives were set out for major indicators of this study: -

1. To evaluate the performance of HEC-HMS in runoff simulation of the Hanger watershed
2. To estimate the runoff potential of the watershed
3. To predict the peak flood comparison for the different return period

1.4. Research questions

1. Does HEC-HMS perform well in Hanger Watershed?
2. How much is the potential of runoff in the watershed?
3. What is the comparison of peak flood discharge of the Hanger watershed for different return periods?

1.5. Scope of the study

This research is limited to the Hanger watershed, a tributary of the Didessa river basin. The set objectives can be met, and the research questions can be answered in the time allotted for this study. It was being assumed that the rainfall-runoff modeling will take place in the Hanger watershed.

1.6. Significance of the study

Modeling rainfall-runoff in the watershed can be used for sustainable water resources management in the catchment. This study is intended to assist concerned sectors in planning, implementing, and managing water resource projects in the study area and being input for those interested in further research in related fields and area of study.

1.7. Limitations of the Study

Though, the study has a significant role in provided the information about the status of rainfall-runoff process and flood prediction of the study area in order to plan and implement an environmental protection programs on time, it has also some limitations. Due to Limited time and cost, detail site investigation on moisture condition of the catchment will not be conducted for this study. Therefore, the average moisture condition of the catchment was considered during the determination spatial distribution of curve number in the catchment.

Moreover, the initial parameters of the models were not obtained directly from the field. They were computed from the theoretical knowledge of these parameters. The performance of the model was not checked by all the model parameters. The selected model parameters were those that affect the selected that affect the selected loss model baseflow model and routing model.

In most developing countries like Ethiopia, there are usually no plenty of recorded stream flow data. In Hanger watershed, there is no recorded stream flow data at the outlet of each sub-basin except only one stream flow gauging station near to the outlet of the study area (Uke Near Nekemte). Therefore, for all sub-basin the model was calibrated and validated using only uke stream flow.

2. LITERATURE REVIEW

2.1. Hydrological Cycle

The hydrologic cycle is a cyclic process that depicts the occurrence, distribution, and movement of water in the natural environment on a global scale. The hydrological cycle can be characterized as "the pathway of water as it moves in its various stages through the atmosphere to the earth, over and through the land, to the ocean, and back to the atmosphere," according to national studies from 1991. Because the total amount of water in the cycle is constant, it can be called a closed system for Earth (Azmat *et al.*, 2016).

According to the findings of (Tarboton, 2003) hydrologic cycles may have treated as systems whose components are precipitation, evaporation, infiltration, runoff, and other processes in the hydrologic cycle. Depending on the level of detail and purpose of the analysis, different components may be grouped into subsystems. Since the second half of the nineteenth century, scientists have been attempting to estimate the total amount of water on the planet and in the various processes of the hydrologic cycle. However, due to a lack of quantitative data, especially over the oceans, the quantities of water in the different components of the global hydrologic cycle are still unknown (Subramanya, 2008).

2.1.1. Rainfall

Precipitation is the water that falls to the ground from the atmosphere in the form of rain, snow, hail, frost, and dew. As a function of time and space, precipitation can be extremely variable. Rainfall is the most common type of precipitation that causes streamflow. The systematic averaging methods Thiessen polygon, isohyets, and reciprocal distance can be developed to account for variations in space to obtain a representation of areal precipitation values from point observation (Garg, 2005).

2.1.2. Runoff

The flow of precipitation from the catchment area through a surface channel is known as runoff. Before runoff can begin, the evapotranspiration, initial loss, infiltration, and detention storage requirements for a given precipitation must all be met. When these conditions are met, the excess precipitation moves across the land surface to smaller channels (Baharudin, 2007).

2.2. Rainfall-Runoff Relationship

The relationship between rainfall and runoff is one of the most commonly used events in hydrology. It calculates the runoff signal that leaves the watershed based on the rainfall signal that the basin receives. Rainfall is the most important factor in the generation of surface runoff. Surface runoff and rainfall have a unique and important relationship. It examines a portion of the hydrological cycle to convey catchment runoff as a function of rainfall and other catchment characteristics (Subramanya, 2008).

Precipitation is one of the inputs used to calculate runoff from a watershed and the resulting streamflow. Rainfall varies in space and time due to atmospheric circulation patterns and local variables such as topography. Water that falls into the stream flows through the channel by either flowing over the soil surface as surface runoff or infiltrating through the soil surface as subsurface flow. During rainy seasons, surface runoff is quick and contributes to flooding flow, while subsurface water moves slowly and contributes to sustained streamflow during dry seasons. The model processes are the intermediate steps that turn rainfall into runoff. It is self-evident that any modeling effort must first comprehend hydrological processes and their magnitude of impact on water abstraction from or addition to a catchment (Campling *et al.*, 2002).

The main factors that influence the rainfall-runoff process for a better understanding of the challenges of accurately forecasting the runoff amount resulting from a rainfall event. The types of soil are the most important factors that directly impact the volume and occurrence of runoff (Subramanya, 2008). Slope can also influence the generation of surface runoff (Shrestha *et al*., 2011). In the headwaters of drainage basins, steep slopes may produce more runoff than lowland areas; in mild slopes, water may temporarily pond and later infiltrate; and on mountainsides, water tends to move down more quickly.

According to (Campling *et al.*, 2002), there are various reasons why we need to model the rainfall-runoff process of hydrology. The main reasons for this are a limited number of hydrological measurement methods and a limited number of spatial and temporal measurements. We cannot measure everything about hydrological systems that we would like to know.

We only have a limited number of measuring methods and a limited number of spatial and temporal measurements. Most of the real-world complexity of rainfall-runoff correlation has been overcome by today's advanced rainfall-runoff computer software (Rathod *et al.*, 2015). As a result, even a complex phenomenon can be represented more accurately. Therefore, the current trend is to use mathematical models and geospatial analysis tools to study hydrological processes and responses to rainfall-runoff relationships (Shaikh *et al*., 2018).

The goal of hydrologic modeling, from its simplest form of unit hydrograph to more complex models based on fully dynamic flow equations, has always been to establish a rainfall-runoff relationship. The use of these models to simulate a catchment has become standard as computing capabilities have improved. To avoid the risk of rain on the catchments, it is necessary to predict the quantitative amount of rainfall and runoff. Models are commonly used in water resources to investigate the effects of human intervention in areas such as land-use change, deforestation, and other hydraulic structures like dams and reservoirs (Arekhi *et al*., 2016; Aytek, 2008).

(Devi *et al.*, 2015), stated that one of the challenges of water resources is improving rainfall-runoff relationships. Rainfall-runoff models were used to solve this problem. The general classification of the rainfall-runoff model into three categories empirical, conceptual, and physical model, is based on model input and parameters and the extent of physical principles applied in the model. Furthermore, lumped, semi-distributed, and distributed models can be categorized based on the model's catchment area's spatial and temporal knowledge. Because it includes many parameters, either physical features of the catchment or climatic parameters the rainfall-runoff relationship is a complex phenomenon to represent in mathematical form.

As with any real-world system, the rainfall-runoff process is influenced by the physical characteristics of the catchment. The most difficult task is to comprehend all of the catchment's physical features. This is due to a lack of hydrological parameters or dubious quality and consistency (Choudhari *et al*., 2014; Sanjay *et al*., 2010). Therefore, determining a clear relationship between rainfall and runoff for a watershed remains one of the most challenging tasks for hydrologists, engineers, and agriculturists (Singh, 2003; McColl and Aggett, 2007).

2.3. Hydrological Models

A mathematical model used to simulate river or stream flow and make water quality calculations is a hydrological model. Environmental laws in the United States and the United Kingdom drove the demand for numerical forecasting of water quality in the 1960s and 1970s, which led to the development of these models. Around this time, computers became more widely available and powerful enough to considerably aid modeling processes (Azmat *et al.*, 2016). In the broader sense, rainfall-runoff models are simplified conceptual representations of a part of the hydrologic cycle (Campling *et al.*, 2002).

Understanding the fundamental relationship between rainfall over the catchment and the resulting runoff is critical for determining the catchment's water resource potential and ensuring proper management of the catchment's water resources. Hydrologic models are preferred to capture the associated problems because the hydrologic cycle has many complex components. They are mostly used for hydrological forecasting, bettering our understanding of processes, and designing new or improved management strategies. When data is unavailable, hydrological models are critical for establishing baseline characteristics and determining long-term impacts that are difficult to quantify (Lenhart *et al.*, 2002; Beven, 2000; Spruill *et al.*, 2000).

According to (Beven 2001), the two essential components in every hydrological model are the runoff production component (determine how much of the rainfall became part of the storm hydrograph) and the runoff routing component (to take account of the distribution that runoff in time, to form the shape storm the hydrograph). The complexities and non-linearity of modeling in the flow generation process, according to practical experience, are much higher than in the routing process. Timestep, spatial scale, whether the model simulates single events or continuously, and how different hydrological components are computed are examples of differences in hydrological models. (Singh *et al.*, 2002), also state that watershed models can be categorized based on a variety of criteria, including process description, time scale, spatial scale, and solution technique.

However, understanding the complexity of hydrological processes is primarily based on knowing rainfall characteristics and watershed properties, and predicting future changes in runoff at the basin's outlet is one of the most challenging aspects of hydrology (Azmat *et al.*, 2016). According to (Moradkhani and Sorooshian, 2009; Soroosh Sorooshian *et al.*, 2008), models are representations of real-world systems that have been simplified. The best model produces a result that is as close to reality as possible while using the fewest parameters and model complexity. They are primarily used to forecast system behavior and comprehend different hydrological processes.

Hydrological models are becoming more important in terms of coverage and functionality (Moriasi *et al.*, 2007). A hydrological model is a common tool for estimating and evaluating the hydrological response of a basin due to precipitation. It allows for precise forecasts based on the hydrologic response to different watershed management practices, allowing for a better understanding of these practices' consequences (Choudhari *et al.*, 2014). HEC-HMS 3.5 was used by researchers all over the world, including (Gebre 2015), who used it to calibrate (from 1988 to 2000) and verify (from 2001 to 2005) the upper Blue Nile River Basin.

The inputs and outputs of a hydrologic model are measurable hydrologic variables, and the model's structure is a set of equations linking the inputs and outputs. To modeling rainfall-runoff, various hydrological models have been developed around the world. Rainfall, soil characteristics, topography, land use, land cover, and other physical parameters are among the inputs used by various models (Devi *et al.*, 2015).

According to (Seibert *et al.*, 2012), models should help us gain a quantitative understanding of hydrological factors and their relationships. Hydrological modeling is a more precise and time-consuming process, which saves users time and results in a better end product. The many activities required by river basin planning and management, ranging from a timely flood warning to the demarcation of areas at risk of flooding to the programming of water budget at the basin scale, according to national and regional laws in the field, encourage and sometimes even enforce the need for such a modeling system (Razi *et al.*, 2010; Halwatura and Najim, 2013).

According to (Beven 2012), hydrological modeling is important in studying water resources and water management, particularly in ungauged catchments. Furthermore, data is required for sustainable water resource planning and management to quantify water quality and quantity. A hydrologic model for a watershed is used to simulate hydrologic processes. It has been designed for various reasons and in a variety of forms, all of which are influenced by the hydrology of the watershed. As stated by (Singh *et al.*, 2002), the model structure and architecture are determined by the objective for which the model is constructed.

According to studies by (Mengistu 2009; Campling *et al.*, 2002; Demelesh Wondimagenewu, and Kassa Tadele, 2015), hydrological models are generally designed to satisfy one of two primary goals. One goal of watershed modeling is to understand better the hydrologic processes in a watershed and how these processes are affected by the watershed changes. The generation of synthetic hydrologic data sequences for facility design is the second goal. Therefore, a thorough understanding of the watershed's hydrological processes is required for effective water management and environmental restoration (Shaikh *et al*., 2018).

Rainfall-runoff modeling is defined as a set of equations that help estimate the amount of rainfall that turns into a runoff as a function of various parameters used to describe the watershed (Devi *et al*., 2015). Rainfall-runoff modeling is important for sustainable watershed growth and reliable estimates of the various hydrological parameters. Due to the spatial and temporal heterogeneity in soil properties, vegetation, and land-use practices, a hydrological cycle is a complex system. As a result, the current trend is to use mathematical models and geospatial analysis tools to study hydrological processes and reactions to rainfall-runoff relationships (Jain *et al.*, 2010).

Empirical methods, large-scale energy-water balance equations, conceptual rainfall-runoff models, landscape daily hydrological models, and fully distributed physically-based hydrological models that explicitly model hillslope and catchment processes are examples of hydrological model approaches that range from simple to complex (Vaze *et al.*, 2011). The physical model, also known as mechanistic models, is based on an understanding of the physics related to hydrological processes, according to (Pechlivanidis *et al.*, 2011). It employs measurable state variables that are functions of both time and space. VIC, SHE/MIKE SHE is two examples of physical models. Physical models are site-specific, require many parameters (tens to thousands), and are best used on a small scale with much data. The purpose of the modeling, the nature of the system to be modeled, the hydrological element(s) to be modeled, the availability of input data, the model's applicability, and the accuracy of the output all factor into the selection of an appropriate model (Vaze *et al.*, 2011).

(Yasmeen *et al*., 2016), used the hydrologic modeling system (HEC-HMS) to develop rainfall-runoff modeling and quantify surface runoff in the Tarbela catchment for flood damage mitigation. It helps to visualize what happens in water systems due to changes in past meteorological events, surfaces, and vegetation and better understand hydrologic phenomena and how changes affect the hydrological cycle (Kumar *et al.*, 2020).

Rainfall-runoff correlation is a problematic phenomenon to reflect mathematically. (Sardoii *et al.*, 2012), confirmed that rainfall-runoff modeling is a physical phenomenon that is difficult to study due to its sensitivity to various variables. Most of the real-world complexity of rainfall-runoff correlation has been overcome by today's advanced rainfall-runoff computer software (Rathod *et al.*, 2015). As a result, even a complex phenomenon can be represented more accurately.

2.4. Types of Hydrological Models

The capabilities, strengths, and limitations of hydrological models are generally described and discussed using a classification system. Models have been categorized in various ways depending on the criteria of interest because there is no universal method for categorizing hydrological models (Gupta *et al*., 2015). The best model produces results that are as close to reality as possible while using the fewest parameters and model complexity (Devi *et al*., 2015). All models have spatial and temporal limits to their discretization and description, which means that the "scale problem" remains unsolved (Silberstein, 2006).

Hydrologic models may be categorized as Deterministic hydrological models, Stochastic hydrological models, or hybrid models, depending on how they handle randomness, space, and time variability in hydrologic phenomena processes. Stochastic hydrological models allow for some randomness or uncertainty in the possible outcomes due to uncertainty in input variables, boundary conditions, or model parameters. Deterministic hydrological models do not consider randomness; a given input always produces the same output (Campling *et al.*, 2002; Chow *et al*., 1988). According to (Karamouz *et al*., 2013), a deterministic model makes forecasts while a stochastic model makes predictions. A hybrid model contains both deterministic and stochastic components. It is also known as a stochastic-deterministic model or a hybrid model (Moriasi *et al*., 2007).

The majority of the models are deterministic, and almost none are entirely stochastic. The degree of approximation of physical processes and their scale of representation by existing physical laws are used to categorize deterministic models (Cunderlik, 2003). Lumped models, distributed models, and semi-distributed models are the three types of deterministic models. The HEC-HMS model is a physically-based semi-distributed model that simulates rainfall-runoff processes in dendritic watershed systems (Scharffenberg *et al.*, 2010). The US Army Corps of Engineers designed the model.

HEC-HMS has been widely used to simulate and predict streamflow in wet, tropical, subtropical, and arid watersheds. All related hydrological processes, such as infiltration, evapotranspiration, surface runoff, and baseflow, are included in the model. HEC-HMS is concerned with the spatial distribution of basin features by subdividing a catchment into sub-basins that are treated as homogeneous in soil type, land use, and so on, and offers a wide range of modeling options, with the main emphasis being on determining runoff hydrographs from sub-basins and routing the hydrographs from the channels to the study area outlets. Different modeling methods were chosen based on the available data and the catchment's local characteristics; additionally, a spatial data set was created in a Geographical Information Systems (GIS) platform and directly imported into HEC-HMS using Geospatial Hydrologic Modelling Extension (HEC-GeoHMS).

2.4.1. Lumped Models

The hydrologic parameters in lumped models do not differ spatially within the basin, so basin response is only assessed at the outlet, without specifically accounting for the response of individual sub-basins (Cunderlik, 2003). The catchment area is treated as a single homogeneous unit in lumped models. In lumped models, catchment spatial variability is ignored (Soroosh Sorooshian *et al.*, 2008). They do not consider changes within a watershed or whether those changes impact the runoff process (Stefan, 2004). Mean soil storage and uniform precipitation quantities are used as averaged values across the catchment (Beven, 2012; Rinsema, 2014). The catchment characteristics are set to be the same across the board, which often leads to over-or under-parameterization (Rinsema, 2014).

2.4.2. Distributed Models

Distributed models allow all parameters to differ in space at a resolution that the user typically chooses. The distributed modeling approach combines data on the spatial distribution of parameter variations with computational algorithms to assess this distribution's impact on simulated precipitation-runoff behavior (Liew and Garbrecht, 2003). For parameterization in each grid cell, these models typically require large quantities of (often unavailable) data. It's the most difficult because it considers feedback and parameter spatial heterogeneity (Sitterson *et al*., 2017). Small elements or grid cells separate the model process is fully distributed, models. They are often organized in a physically-based model, making them more comparable to the actual hydrologic process (Muluken *et al.*, 2017).

Distributed models have the disadvantage of requiring distributed data and calibrated parameters for each grid cell (Parmar *et al*., 2009). Estimates using weighted averages are used to extrapolate data if the data are not fully distributed. The spatial resolution of distributed models is often constrained by the model resolution or the input grid size. Another flaw in distributed models is the time it takes to run a single simulation, ranging from a few minutes to several hours depending on the input data, catchment size, and computational constraints (Vaze *et al.*, 2011). Distributed models are not widely used because of these difficulties compared to lumped models (Rinsema, 2014).

2.4.3. Semi Distributed Models

semi-distributed hydrologic modeling is typically physical, taking into account average watershed physical parameters expressed in terms of a theoretically appropriate set of equations. They do, however, require some lumping because analytical solutions to the equations cannot be found, so estimate numerical solutions based on a finite-difference of space and time dimensions are used (Gautam, 2016). By dividing the basin into several smaller sub-basins, the model's parameters are allowed to differ partly in space in a semi-distributed model.

Semi-distributed models have the advantage of having a more physically based structure than lumped models and requiring fewer input data than fully distributed models (Cunderlik, 2003). SWAT (Soil and Water Assessment Tool), HEC HMS (Hydrologic Engineering Center-Hydrologic Modeling System), Storm Water Management Model (SWMM), PRMS

(Precipitation-Runoff Modeling System), TOPMODEL, HBV, and others are examples of semi-distributed hydrologic models (Mengistu, 2009; Cunderlik, 2003).

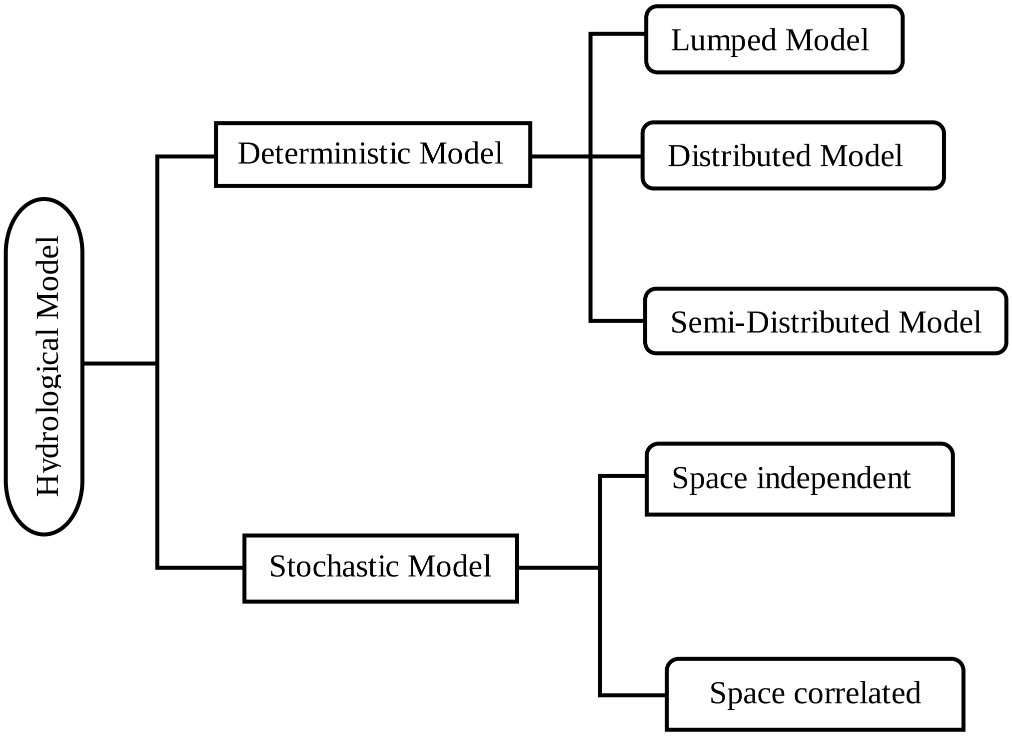


Figure 2. 1. Process distribution classification of hydrological models (Cunderlik, 2003).

2.5. Model Selection Criteria

In any research project, choosing the best and most appropriate model is critical. The function determines the type of hydrological model to use that the model must perform. There are a variety of hydrological models that simulate the hydrological process at various spatial and temporal scales. Although there are no hard and fast rules for choosing between models, some basic guidelines can be mentioned. There are several factors to consider when selecting the best model. According to (Cunderlik and Simonovic, 2007), the choice is primarily based on the research or project's requirements and needs in question. According to this, the selection model's criteria are as follows:

- Availability of input data
- Prices and availability of the model
- Both for study and future use in the model structure, the model must be easily and freely available.

In general, the reasons behind selecting the HEC-HMS model for this study are:

- It is the public domain for free and online access.
- It is a Physically based model: It is based on readily observed and measured information and it attempts to simulate many hydrological components.
- It was applied for land use and land cover change impact assessment in different parts of the world.
- It was compatible with the ArcGIS interface: for ease of database management.
- Easy linkage to sensitivity, calibration, and uncertainty analysis tools.

2.6. HEC-HMS Model Description

The US Army Corps of Engineers designed the computer program Hydrologic Engineering Center - Hydraulic Modeling System (HEC-HMS), available on the internet. The Hydrologic Engineering Center owns and controls the software. HEC-HMS is a program that simulates the precipitation-runoff processes in dendritic watersheds. It was used as a hydrologic model connected to a GIS and extracted geospatial input data using the HEC-GeoHMS extension (USCAE, 2013). It is suitable for both event-based and continuous-based hydrologic modeling, and it can be used in a wide range of geographic areas to solve a wide range of problems. These issues range from large-scale water supply and flood hydrographs to small-scale runoff analysis in urban or natural watersheds. Water availability, urban drainage, flow forecasts, future urbanization effect, reservoir spillway design, flood damage reduction, floodplain regulation, and system operation can all be studied using the model output in the form of runoff hydrographs (Karamouz *et al*., 2013).

As a result, a software system would need to be designed to choose suitable process models, with the possibility that some processes would be excluded entirely. The HEC-HMS software was created with the research process in mind that is commonly used in the Army's United States Engineer Corps (Scharffenberg *et al.*, 2010).

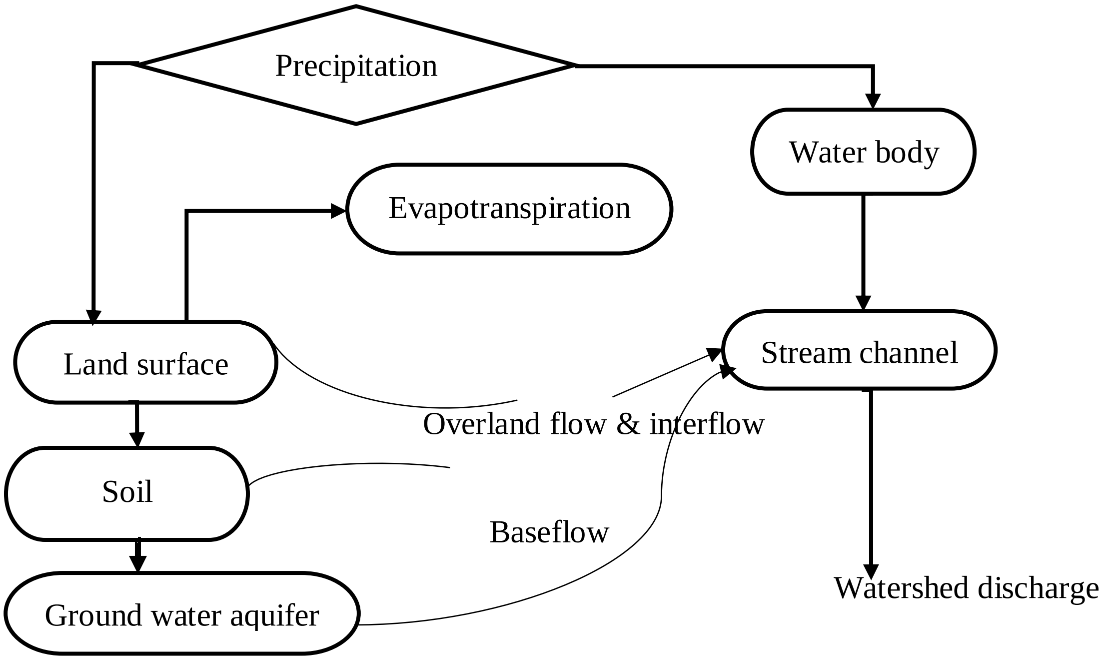


Figure 2. 2. HEC- HMS Runoff Representation (USCAE, 2013).

2.6.1. Relationship between Arc GIS, Hec-Geo HMS, and HEC-HMS Models

GIS (Geographic Information System) is a computer-based system for storing, retrieving, analyzing, and displaying geographical data. For data formatting, processing, and coordinate transformation, GIS is used. DEM, land use land cover, geographical names, digital graph line data, registered satellite, and land ownership are all possible components of a geographic information system (Saleh *et al*., 2011). Using Arc GIS, various spatial data are preprocessed and used as input data for the Hydraulic Engineering Centre- Hydrologic Modeling System (HEC-HMS). GIS can perform the same task much more quickly by using elevation data and geometric algorithms. To aid in the creation of basin models for such projects, a GIS companion product was created. The Geospatial Hydrologic Modeling Extension is its name (HEC-GeoHMS). It can be used to produce basin and meteorological models that can be used in conjunction with the program (Arekhi *et al*., 2011).

2.7. HEC-Geo HMS Model Description

The US Army Corps of Engineers created the computer program Hydrologic Engineering Center-Geospatial Hydrologic Modelling Extension (HEC-GeoHMS), which can be used with ArcView GIS to create a variety of hydrologic modeling inputs. It's a geospatial hydrological toolkit for engineers who don't have much experience with GIS (Fleming *et al.*, 2011). Users can visualize spatial data, document watershed characteristics, perform spatial analysis, delineate sub-basins and streams, create inputs to hydrologic models, and report preparation with this program, which is an extension of Arc GIS.

The basin's river network was derived from the DEM, and the basin's sub-basins were defined. The drainage routes and watershed borders are transformed into a hydrologic data structure that reflects the watershed response to precipitation by HEC-GeoHMS. The HEC-GeoHMS hydrological results are then imported into the HEC-HMS, where simulation is performed (Chelangat, 2014). The following diagram summarizes the relationship between ArcGIS, HEC-GeoHMS, and HEC-HMS.

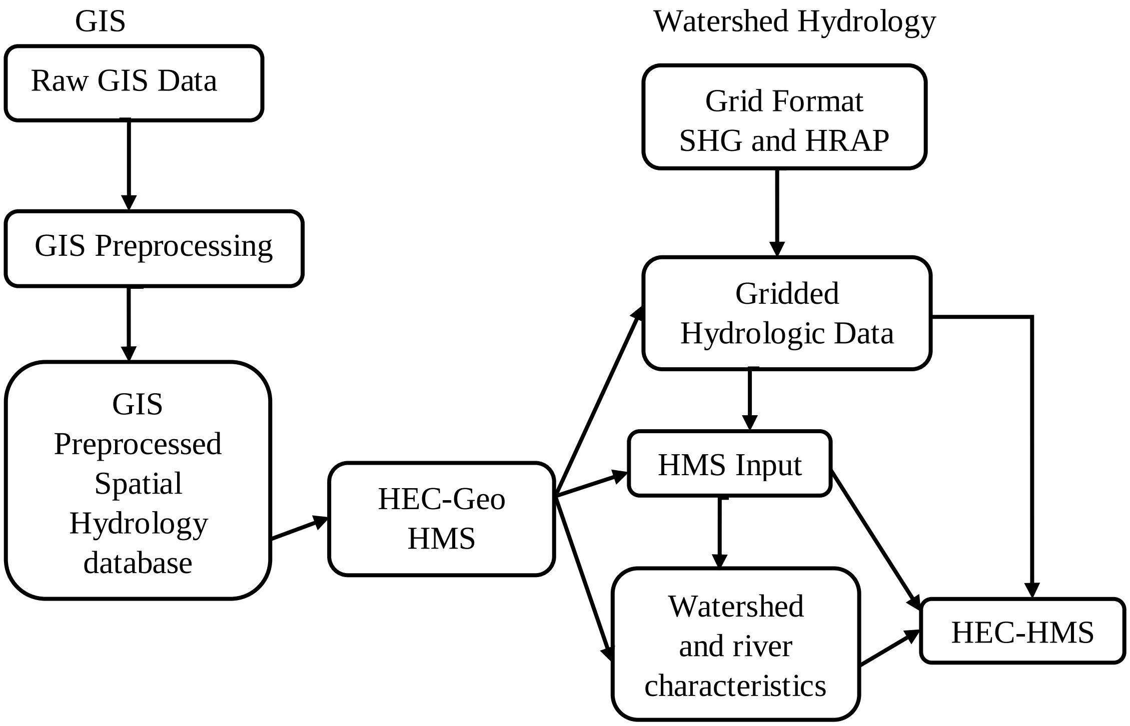


Figure 2. 3. Relationship between Arc GIS, HEC-GeoHMS and HEC-HMS (USCAE, 2013)

2.8. Flood Forecasting

Flood forecasting is the method of estimating and forecasting the severity, timing, and length of flooding based on established river basin characteristics, to prevent harm to human life, property, and the environment. Flood frequency analysis is used to measure statistical details such as mean, standard deviation, and skewness, which is then used to construct frequency distribution graphs, using annual peak flow data that is available for many years.

General extreme value, Gumbel Max, Normal, Log-normal, Lognormal (3p), and Log Pearson type-III are among the statistical distributions that can be selected as the best frequency distribution. Rainfall and the spatial analysis of the hydrologic cycle played the most significant role in runoff and flood modeling among these primary controlling flood variables. This is why rainfall prediction, which is also used for flood prediction, is heavily reliant on data availability, especially in the prediction of flood depths for short-term flood prediction (Moraise *et al.*, 2017).

The frequency analysis in this study was done using HEC-HMS and other well-fit probability distributions. The study was carried out using the calculated data for the study area from the available data on Era Drainage Manual (ERA, 2013) for region RR-A2 for the HEC-HMS model, and the data was used as input data for probability distributions.

2.9. Previous studies by HEC-HMS Model

There is no rainfall-runoff modeling using HEC-HMS conducted on the Hanger Watershed. However, there are little rainfall-runoff modeling that are conducted using HEC-HMS in the Upper Blue Nile Basin, Ethiopia. Some of them are described as follow:

(Gebre, 2015) , for runoff simulation of the upper Nile Blue Nile Basin, used HEC-HMS with a soil moisture accounting algorithm. The model was calibrated from 1988 to 2000, and from 2001 to 2005, it was validated. The outcome was satisfactory and acceptable for runoff simulation.

(Tassew *et al.*, 2019), applied HEC-HMS model for flow simulation in the Lake Tana Basin in Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia. The result showed that the model is appropriate for hydrological simulations in the Gilgel Abay Catchment.

(Legesse, 2009), developed rainfall- runoff relationship using HEC-HMS for the Anjeni Watershed in the Blue Nile Basin. The result of this study has shown that it could be possible to use a simple water balance model to reasonably predict river discharge and at the same time to indicate where and how runoff is generated to help dictate the selection of appropriate SWC.

3. MATERIALS AND METHODS

3.1. Description of the study area

3.1.1. Location

The Hangar River watershed is located in Oromia National Regional State (ONRS), Wollega Zone, in Ethiopia's northwestern region. The catchment is primarily located in Oromia National Regional State's East Wollega Zone, with a small portion in Benishangul Gumuz Regional State. The total drainage area is estimated to be 7,674.82 km^2, and the watershed is accessible via the main asphaltic road from Addis Ababa to Nekemte and gravel roads to Gida Ayana.

The main river Hangar is situated 40 kilometers north of Nekemte. The watershed highlands are higher in altitude, ranging from 1800 m.a.s.l. to 3210 m.a.s.l. In the western lowlands of the watershed, the lowlands have an altitude of less than 1200 m.a.s.l. The climatic condition varies depending up on the variation in elevation (Awulachew *et al.*, 2010). The majority of the study region has a wet tropical climate with heavy rainfall, with about 70% of the total annual rainfall falling during the Kiremt rainy season (June-September). The Hanger watershed is geographically located between 36^0 31' 41" to 37^0 06' 50" East longitude and 9^0 41'58" to 9^0 59' 56" North Latitude. For this study area, the dominant soil type is Haplic Alisols, with 27.45% of coverage area, and the dominant land use land cover is state farm with a percent coverage area is 41.52%.

3.1.2. Geology and Climate of the Study Area

The regional geology of the study area was developed from three types of geological terrains. These are Quaternary sediments, Paleozoic to Mesozoic rock, Precambrian rock (from youngest to oldest). Most of the study area is covered with intrusive Precambrian rocks mainly granite with coarse grained texture and massive in nature which is overlaid by thick black to brownish cotton soil (OWWDSE, 2015). The climatic condition varies depending up on the variation in elevation. According to Hurni (1986) description of Agro climatic zones of Ethiopia, the catchment consists of three agro-climatic zones “kola, weynadega and dega” with elevation variation of 500-1500, 1500-2300 and above 2300 m, respectively.

The maximum and minimum temperature at higher elevation “dega” of the study area is about 27.9oc and 12.2oc respectively. And maximum and minimum temperature at lower elevation (kola) of study area is 30.3oc and 14.7oc respectively (OWWDSE, 2015).

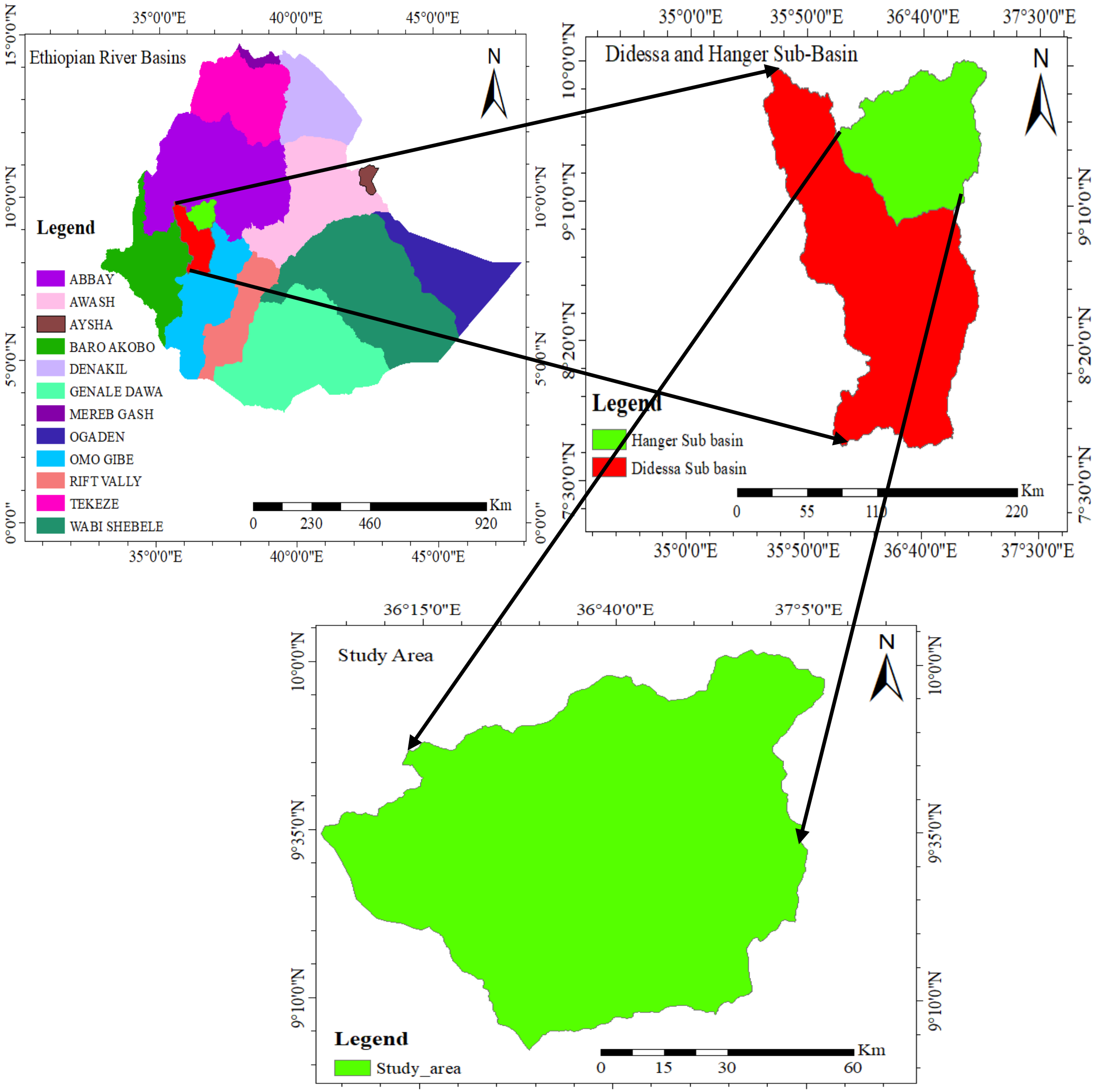


Figure 3. 1. Location and map of Hanger Watershed

3.2. Tools used for the study

The software was the tool that was used to conduct this research. The main software used for the study area was ArcGIS Version 10.1, HEC- GeoHMS Version 10.1, HEC-HMS 4.4.1, Rainbow software, and Microsoft Excel Sheet.

Arc GIS version 10.1 is the public domain software, it was developed by ESRI and released in June 2012. Because it was compatible with HEC-GeoHMS version 10.1, I chose Arc GIS version 10.1. It was used to demarcate/delineate/ watersheds. HEC-GeoHMS was developed by Hydrologic Engineering Center (HEC). Hydrologic Engineering Center (HEC) is an organization within the institute for water resources. The HEC-GeoHMS version 10.1 was tested, verified, and released by HEC. Except for HEC-GeoHMS version 10.2, the newer version of HEC-GeoHMS is not supported by HEC.

As a result, HEC-GeoHMS version 10.1 was chosen for this research. It was used to generate curve numbers (CN) and prepare basin models. For the simulation of rainfall-runoff, HEC-HMS version 4.4.1 was used. USACE developed HEC-HMS version 4.4.1, which was released in August 2019. It is the most recent edition. Additionally, software such as Microsoft Excel Sheets and Rain Bow is used to analyze time-series data and test the homogeneity of rainfall data.

3.3. Study Design

Data input, process, and analysis are the general processes for achieving the study's goals. The study's overall framework is shown in Figure 3.2.

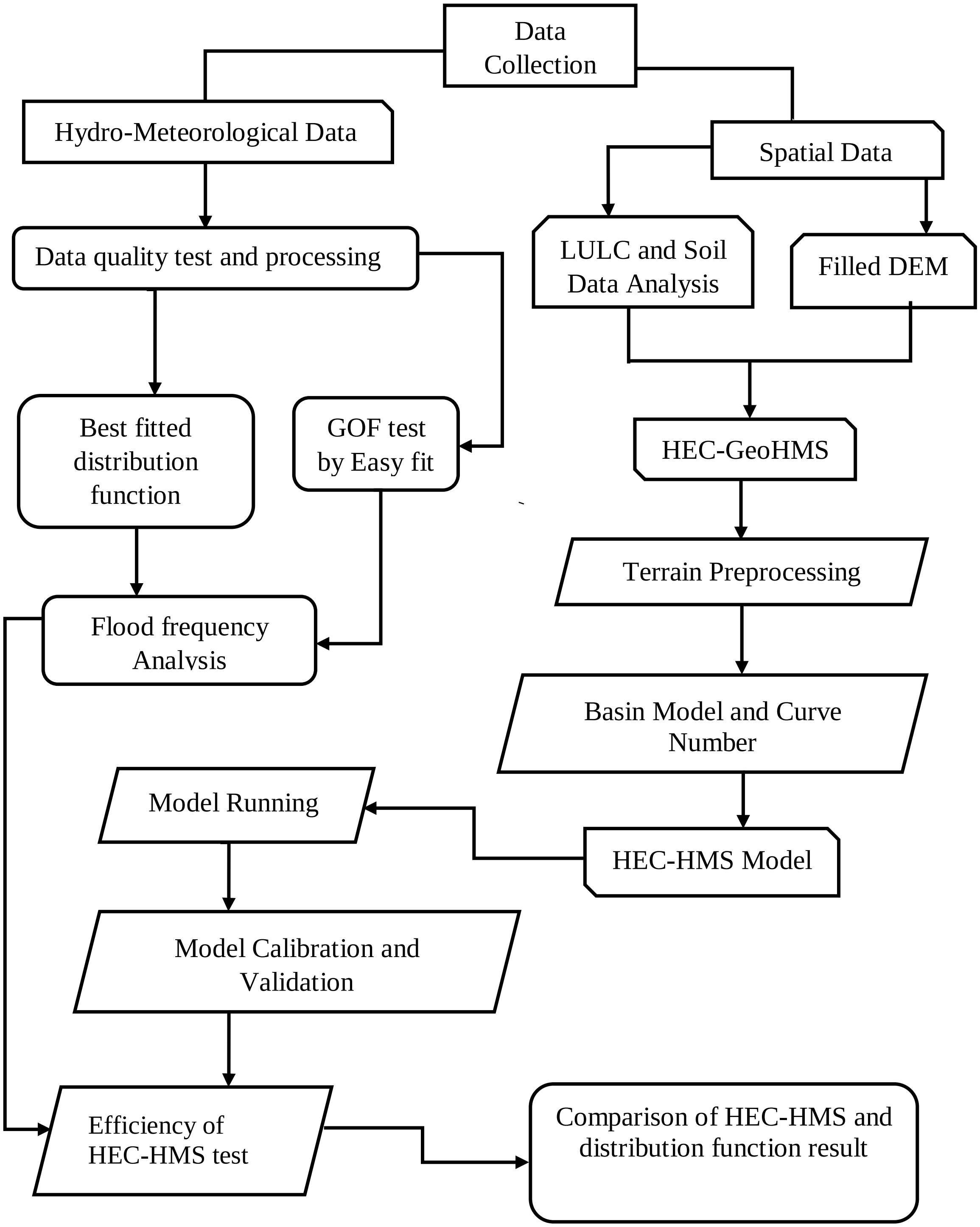


Figure 3. 2. The Overall Frame Work of the Study Area

3.4. Data collection and analysis

Spatial and physical data are the two most important factors in rainfall-runoff modeling with the HEC-HMS model. Soil data, Land Use, and Land cover (LULC) data, and Digital Elevation Model (DEM) are examples of spatial data, while meteorological (precipitation) and hydrological (streamflow or discharge) data are examples of physical data.

3.4.1. Meteorological data

Rainfall data was the first and most significant time-series data for this study. Daily rainfall data is needed as input data for the HEC-HMS model. Meteorological data (1990 to2014) obtained from National Meteorological Service Agency (NMSA). The chosen seven rainfall stations in and around the watershed are Alibo, Anger, Gelila, Gida Ayana, Kiramu, Nekemte, and Shambu. In the diagram below, the locations of all rainfall stations are depicted (shown).

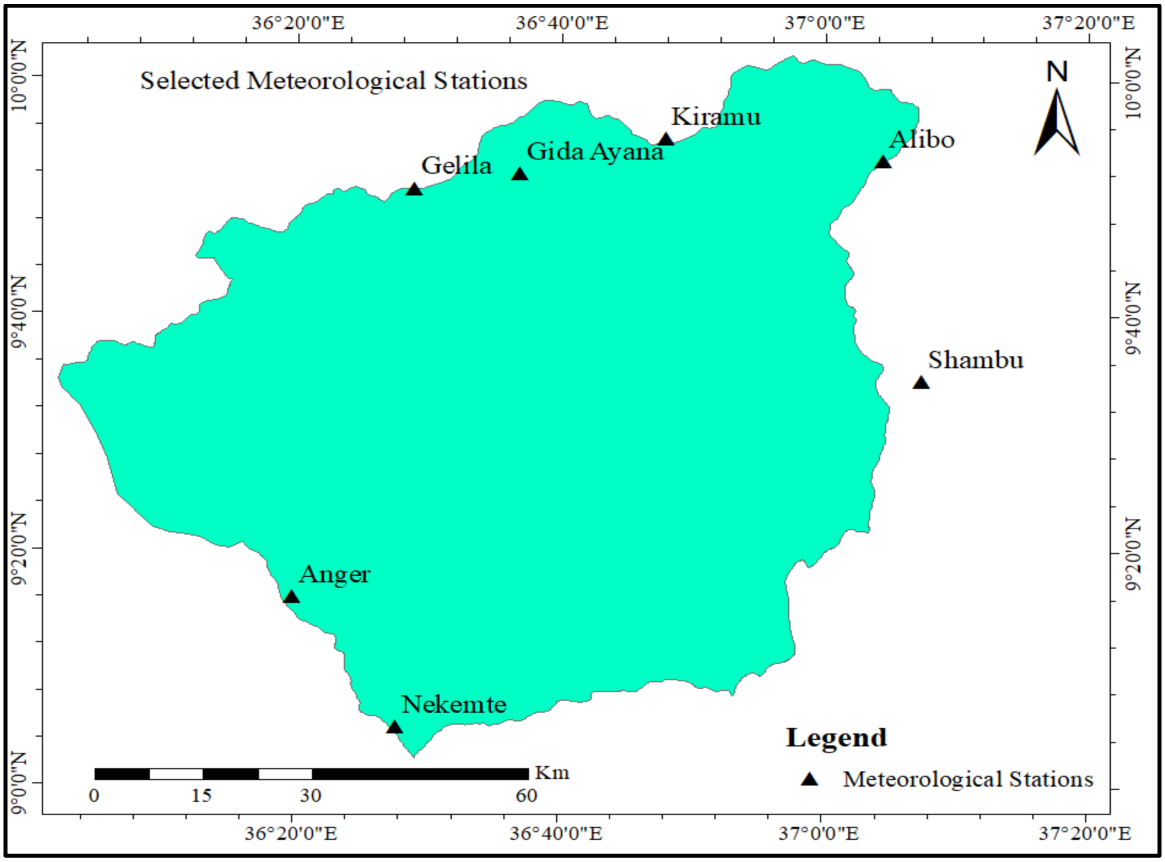


Figure 3. 3. Location of meteorological stations in and around the Hanger watershed

Table 3. 1. Precipitation gages, Elevation, location, and availability of data

S .No	Station Name	Lat.(degree)	Long.(degree)	Elev.(m)	Data used (years)
1	Anger	9.27	36.33	1350	1990-2014
2	Alibo	9.88	37.07	2513	1990-2014
3	Gelila	9.1	36.48	2178	1990-2014
4	Gida Ayana	9.86	36.62	1850	1990-2014
5	Kiramu	9.92	36.8	2040	1990-2014
6	Nekemte	9.08	36.46	2080	1990-2014
7	Shambu	9.575	37.1	2430	1990-2014

3.4.2. Hydrological data

In watershed modeling, the availability of streamflow data is critical. The hydrological data used in this study were daily streamflow data for model calibration and validation. Streamflow data Uke near Nekemte (near to the outlet) from 1990 to 2014 collected from MOWIE of GIS department was used.

3.4.3. Digital Elevation Model (DEM)

A DEM describes the elevation of any point in a given area at a particular spatial resolution, which is used to define topography. The Ministry of Water, Irrigation, and Energy supplied a DEM of the 30*30 Abbay Basin. However, when studying a basin's hydrological response, a higher resolution DEM is preferred. As a result, a DEM with a pixel size of 12.5mx12.5m was obtained from https://vertex.daac.asf.alaska.edu, which covered the entire study area. The DEM of the Hanger watershed derived from this site is shown in Figure 3.4.

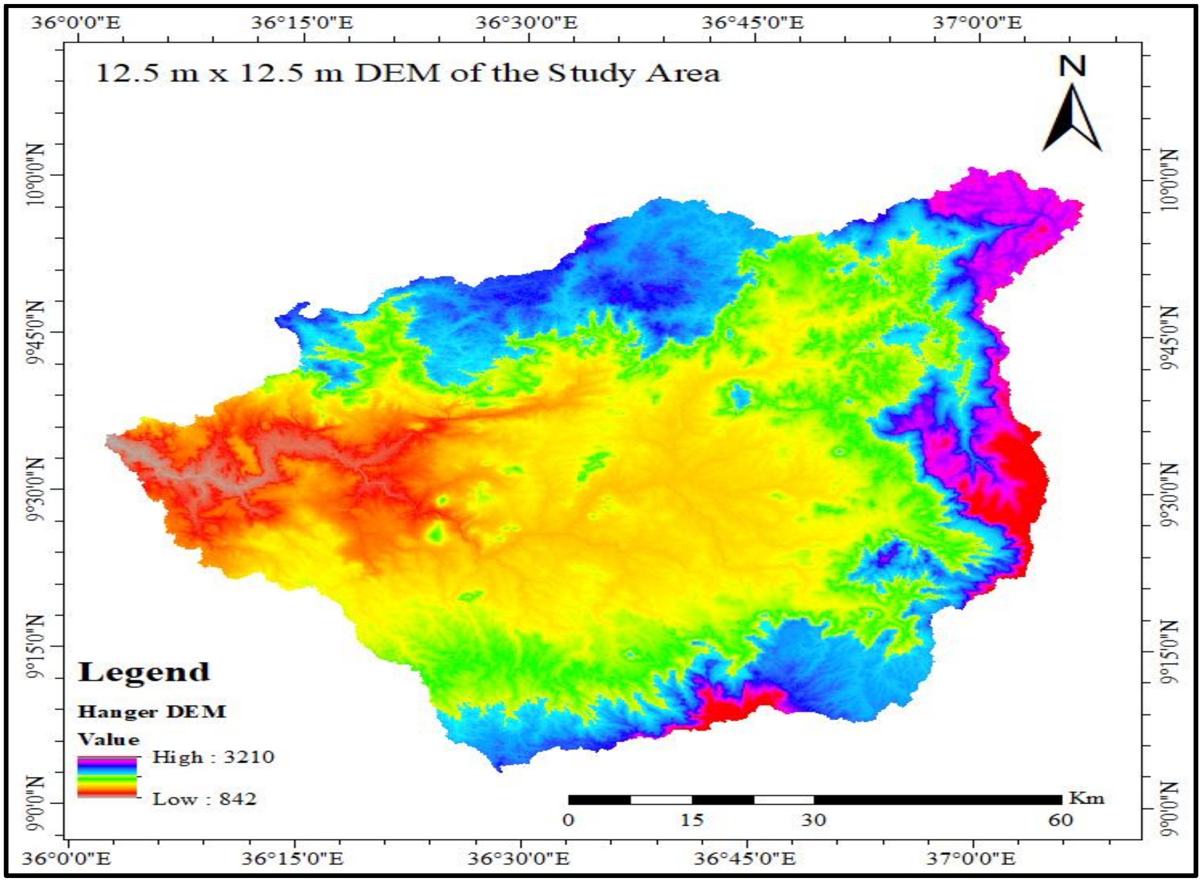


Figure 3. 4. DEM of Hanger Watershed

3.5. Data analysis

3.5.1. Hydro-Meteorological data analysis

3.5.1.1. Filling missing Meteorological and Stream Flow data

In hydrology, missing data is a common issue. Missed data, which may occur as a result of a lack of proper records, station relocation, or processing, is a serious issue because it leads to inconsistency and ambiguous results that may contradict the actual situation. It was necessary to check the data for consistency and continuity before using a station's rainfall records. Each of the seven stations' precipitation data has its own set of missing values. These missing values necessitated the estimation of records before further data analysis.

Several methods for estimating missing rainfall data have been proposed. For this study the normal ratio method was selected, due to the annual precipitation of each gauging station varies by more than 10%. The normal ratio method was being expressed as;

$$P_X = \frac{NX}{N}\left[\frac{P1}{N1} + \frac{P2}{N1} + \frac{P3}{N3} + \cdots \frac{PN}{Nn}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where: P_X is missing value of precipitation to be computed, NX is average value of rainfall for the station in question for recording period, N1, N2………Nn is the average value of rainfall for the neighboring station, P1, P2...Pn are Rainfall of neighboring station during the missing period and N is the number of stations used in the computation.

Missing flow data record was filled by developing a correlation between the station with missing data and any of the adjacent stations with the same hydrological features and common data periods. The correlation equations used for Uke gauging station were filled by using linear correlation.

3.5.1.2. Checking the consistency of data

Consistency checks of time series data are just as important as infilling missing data for a good model result. One issue that hydrologists must address is estimating missing precipitation. Rainfall data reported by a station may not always be consistent throughout a rainfall record's observation period. A second issue (problem) arises when rainfall at rain gauges in the watershed varies over time, necessitating adjustments to the measured data to provide a consistent record. A consistency record is one whose characteristics have remained constant over time, whereas an inconsistency record is one whose characteristics have changed over time. This means that if their graph is straight, they are consistent; otherwise, the observed data must be adjusted. The consistency of rainfall records at a given station can be influenced by a variety of factors.

The double mass curve (DMC) was used to check the consistency of the data. For this study, the double mass curve was used to verify the consistency of seven rainfall stations. The double mass curves revealed that all of the stations were consistent and that no correction was required. As a result, all broadcasters have a reasonable level of consistency (similar or related data). The interpretation of the double mass curve graph of the study area of combined stations is shown in figure 3.5. But for each rainfall station the individual DMC graph was attached in Appendix-1(figure 1.1).

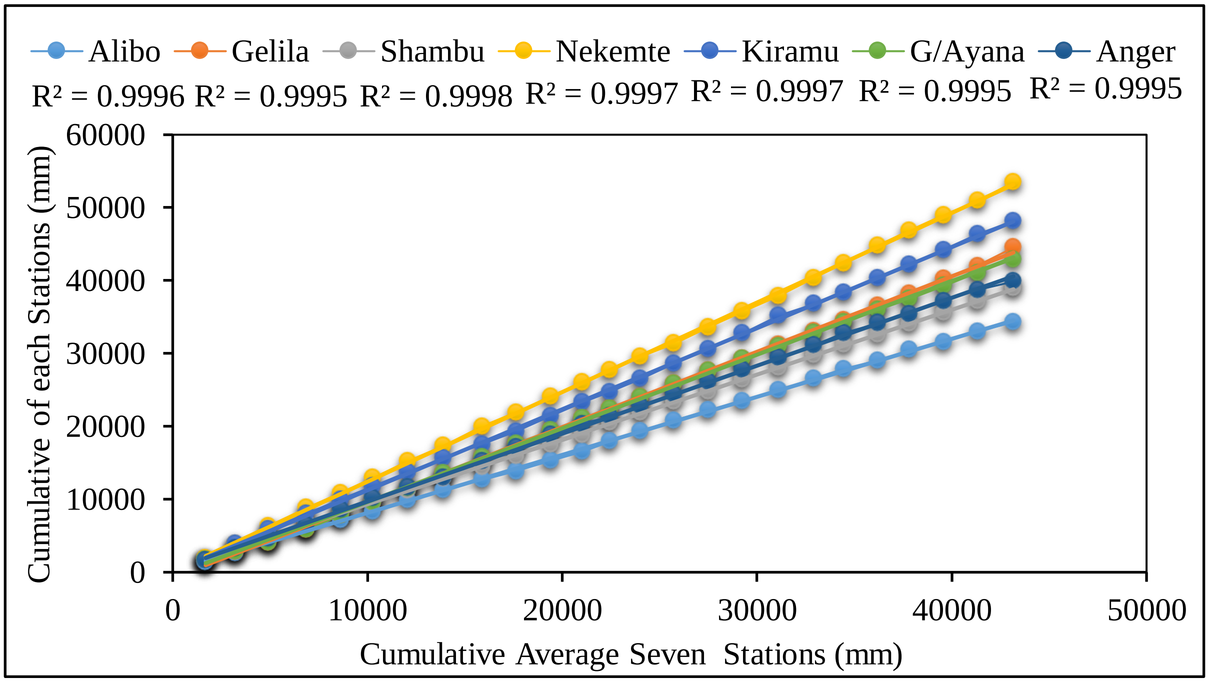


Figure 3. 5. Double Mass Curve of the stations

3.5.1.3. Rainfall Homogeneity Test

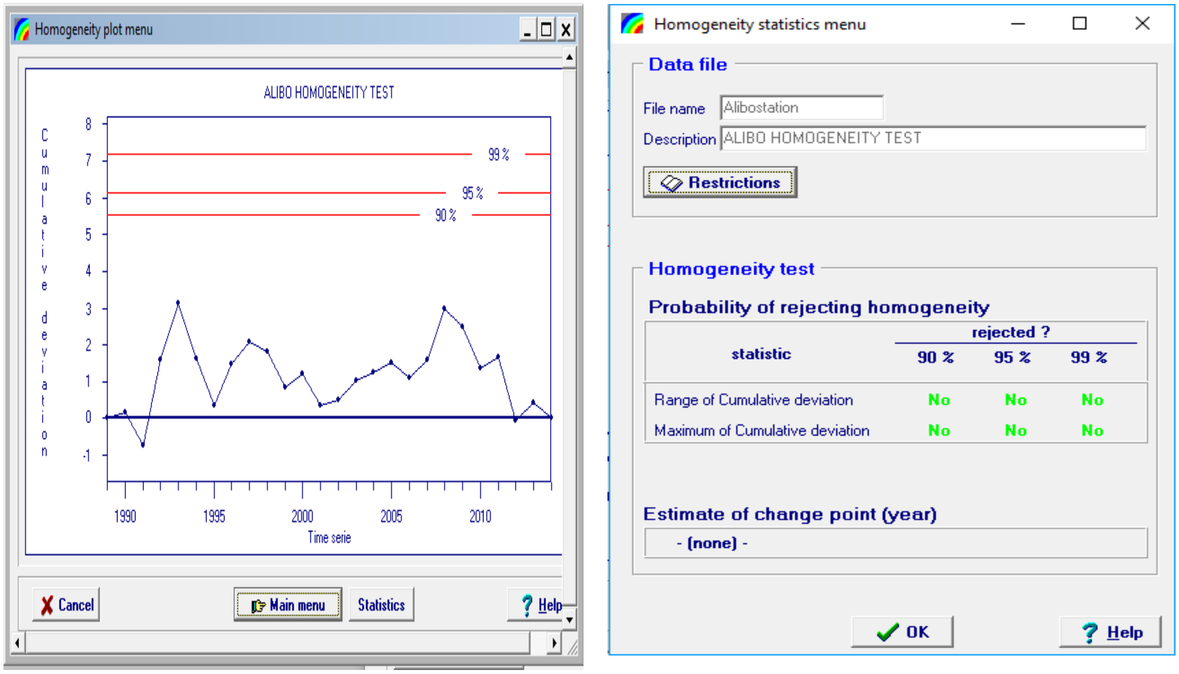
To fill missing rainfall data and select representative meteorological stations, the homogeneity of group stations must be checked. The homogeneity test is required to detect data variability. If the measurements were continuously done by the same technique, with the same instrumentation, in the same environment, at the same time and place, the gathered data were said to be homogeneous. The homogeneity of rainfall data is tested using a variety of techniques. For this study Rainbow Software was selected (measuring cumulative deviation from the mean).

According to (Raes *et al.*, 2015), if the range of cumulative deviation and maximum cumulative deviation of the data oscillates around zero lines the data are homogeneous. As a result, Rainbow software can be used to test the homogeneity of precipitation data in this study. The data used in this software for frequency analysis of precipitation should be homogeneous and independent. The homogeneity restriction ensures that the observations come from the same population. The equation of the homogeneity test can be calculated using the following equation:

$$S_k = \sum_{i=1}^{k}(X_i - \overline{X}) \quad \text{..........} 3.2$$

Where; K = 1,2,….n , Xi = time series precipitation data, $\bar{X}$ = average of precipitation data, S_k= cumulative deviation and K= number of years.

Changes in the averaged are easily detected when plotting the SKs (also known as a residual mass curve). Sk=i increases and decreases for a record, Xi above normal and Xi below normal, respectively. If the cumulative deviation crosses one of the horizontal lines, homogeneity of the data set is said to be dismissed (rejected) with 90%, 95%, and 100% probability. In the homogeneity statistics menu, the probabilities of rejecting the datasets homogeneity were calculated for this study. Figure 3.8. Shows the annual sum of the Alibo homogeneity test. The rest homogeneity test of the stations was attached in Appendix-2.



Data file

File name: Alibostation

Description: ALIBO HOMOGENEITY TEST

Homogeneity test

Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -

Figure 3. 6. Alibo homogeneity test

3.5.1.4. Conversion of Point Rainfall to Areal Rainfall

The input data required for HEC-HMS modeling is the areal rainfall as input data to convert it into runoff (USCAE, 2013). A rain gauge is a device that measures rainfall at a single location. The rainfall at this location has been converted to areal rainfall. It is one of the most important hydrological studies because it determined the average depth of rainfall over the study area. There are numerous methods for converting point rainfall into areal rainfall or average rainfall over a watershed. The method was selected based on the quality and nature of the data, as well as their significance, application, and necessary precision of the result. The Thiessen polygon method is the most popular of various methods for converting point rainfall to areal rainfall.

Therefore, for this study, the Thiessen polygon method was selected, for changing point rainfall into the areal rainfall. For this study, there are seven rainfall stations. From the seven rainfall stations, one rainfall station is outside of the watersheds. Due to this the Thiessen polygon method is required if the multiple rainfalls gauging stations near the watershed's boundary, as well as outside the watershed (Legesse, 2009). The following equation of the Thiessen polygons method is used to calculate the areal precipitation:

$$P_{total} = \frac{A1}{Atotal} * P1 + \frac{A2}{Atotal} * P2 + \cdots + \frac{An}{Atotal} * PN \ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where: A_{total} = total area, A1, A2……. An = Area of each station, P = Precipitation, P_{total}= the sum of precipitation for seven meteorological stations.

The area of a sub-basin that lies on a given polygon would take the polygon's areal rainfall in direct proportion to the sub- basin's area. The ratio of the area of the sub-basin that lies within the polygon to the area of the polygon will be used to calculate the gauge weight for each sub-basin. The gauge weight was multiplied by gauge precipitation for each sub-basin to obtain the sub-basin precipitation time series. Using Arc GIS version 10.1 software, the area of influence of each gauge is determined by constructing polygons determined by drawing perpendicular bisectors to the line connecting the gauges. Each gauge was given a weight that was proportional to the size of the polygon. To calculate the areal rainfall for each station, the individual weights were multiplied by the station observation. According to the Thiessen polygon method, the area's average rainfall, R_{area}l, can be calculated using equation;

$$R_{\mathrm{areal}} = \sum_{i=1}^{n} \frac{R_i A_i}{A_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where: R_{areal} = areal average of rainfall, R_i=rainfall of each sub-basin, and A_i=area of each sub-basin. Figure 3.7 and table 3.2 show different sub-basin that can get rainfall from different stations and the contributing gage weight value for each sub-basin from each meteorological station, respectively.

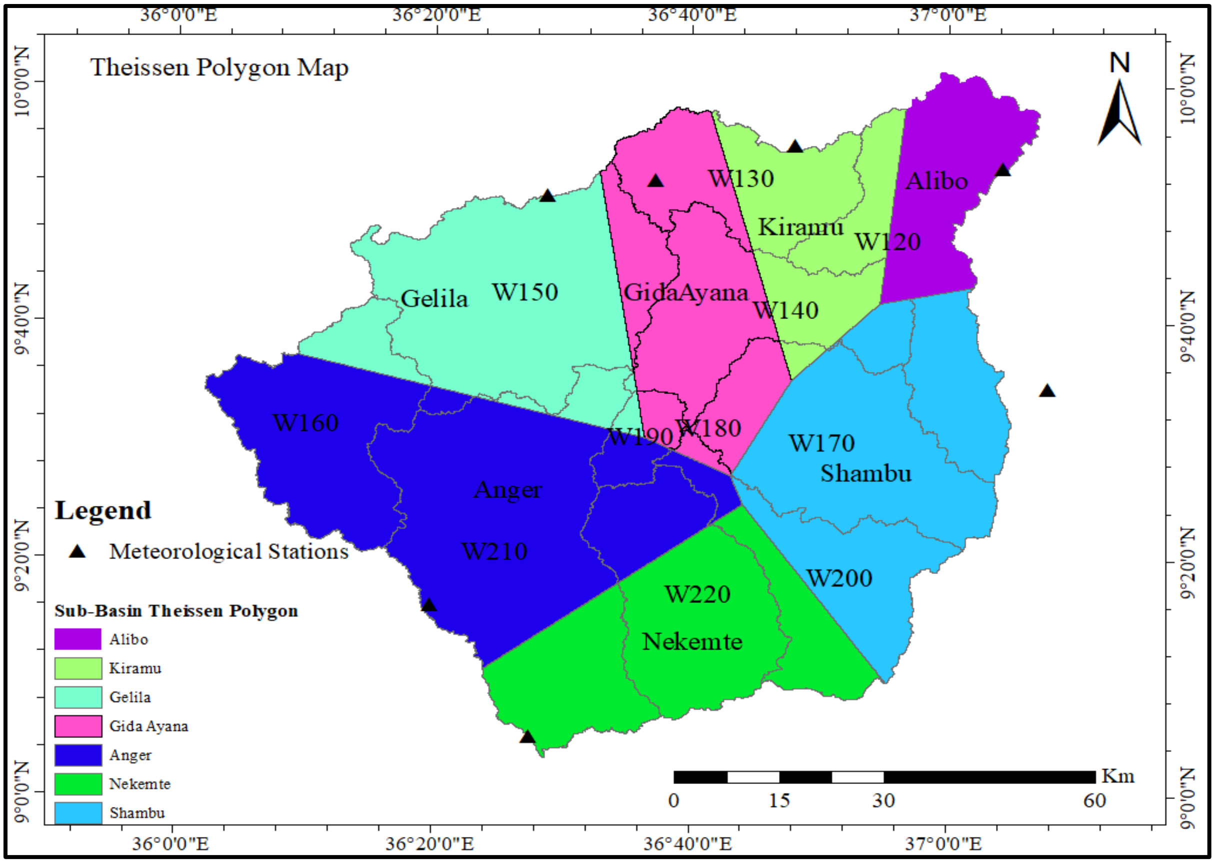


Figure 3. 7. Hanger watershed Thiessen polygon sub-basin

Table 3. 2. Distribution of Rainfall Station for each sub-basin

Subbasin name	Precipitation stations	Area weight (km2)	Gauge weight (%)
W120	Alibo	913.66	0.475
	Kiramu		0.2016
	Shambu		0.3234
W130	Gida Ayana	508.73	0.4582
	Kiramu		0.5418
W140	Alibo	671.52	0.027
	Gelila		0.0055
	Gida Ayana		0.5833
	Kiramu		0.2619
	Shambu		0.1223
W150	Anger	1113.27	0.0201
	Gelila		0.8456
	Gida Ayana		0.1343
W160	Anger	699.44	0.8302
	Gelila		0.1698
W170	Gida Ayana	839.72	0.1819
	Kiramu		0.0256
	Shambu		0.7925
W180	Gida Ayana	0.40	1.000
W190	Anger	133.54	0.502
	Gelila		0.1398
	Gida Ayana		0.3582
W200	Anger	659.60	0.0713
	Gida Ayana		0.0339
	Nekemte		0.3378
W210	Anger	1422.52	0.6866
	Gelila		0.0585
W220	Anger	712.42	0.2835

3.5.2. Spatial Data Analysis

3.5.2.1. Land Use Land Cover (LULC)

LULC is a spatial dataset in the model that defines the densities and types of land use found within a given area. During the image classification from the Ethiopian Ministry of Water, Irrigation, and Energy (MoWIE), the LULC is processed and prepared as a map. It is an important input in hydrological models because it has a significant impact on the water balance, primarily by affecting the evaporation, transpiration, interception, and surface processes. It is used to generate Curve numbers. LU/LC types of Hanger watershed were dominated by urban, state farm, woodland dense, and open, forest, moderately and dominantly cultivated, bushland and grassland. The LU/LC types of Hanger watershed was shown in Figure 3.5.

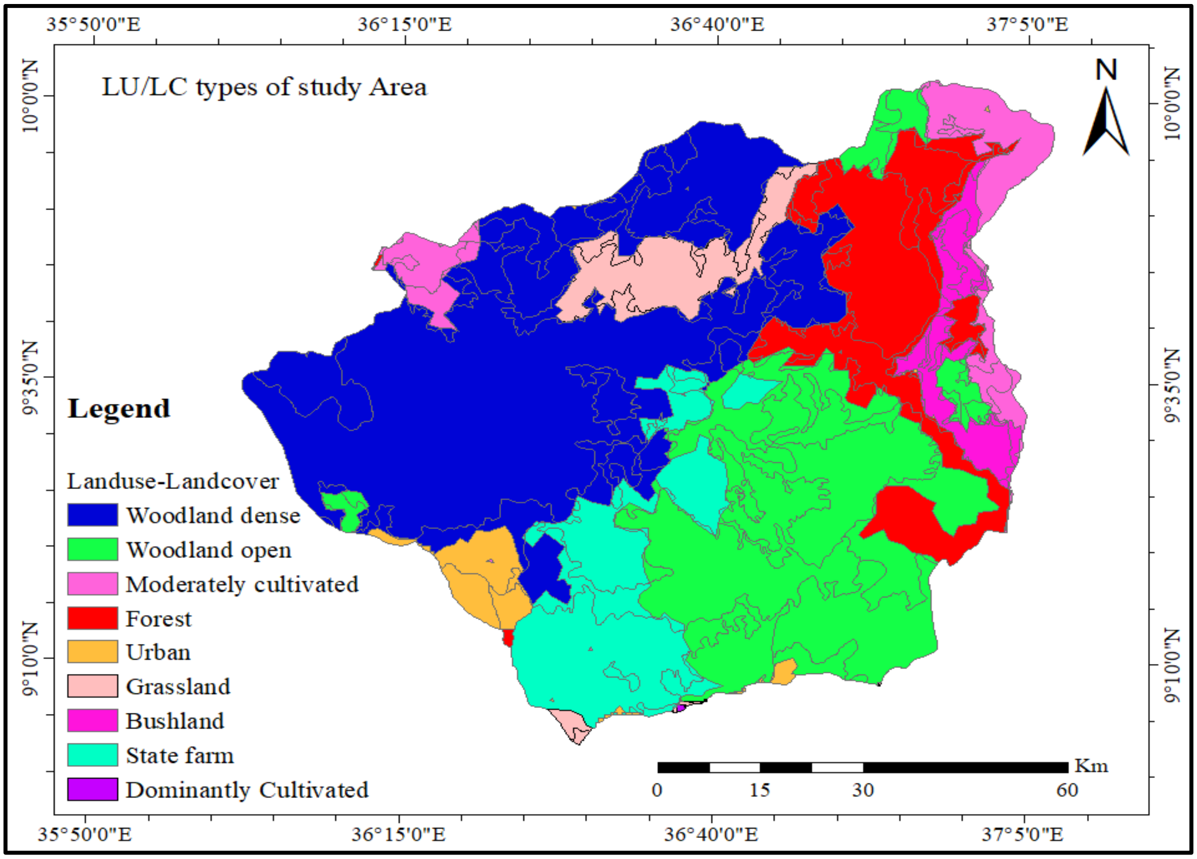


Figure 3. 8. Land use Land cover type of Hanger Watershed

Table 3. 3. LU/LC type of Hanger watershed

S.No	Land Use Land Cover Types	Covered Area (%)
1	Bush land	2.33
2	Dominantly cultivated	12.54
3	Moderately cultivated	25.63
4	Forest	4.99
5	Grassland	2.65
6	State farm	41.52
7	Urban	1.48
8	Woodland dense	3.65
9	Woodland open	5.21

3.5.2.2. Soil Types

Soil is the foundation for generating curve numbers (CN). It was derived from the GIS Department of the Ministry of Water, Irrigation, and Energy (MOWIE). The Hanger watershed was dominated by nine major types of soil groups; Haplic Alisols, Haplic Acirisols, Haplic Arenosols, Rahodic Nitisols, Dystric Leptosols, Haplic Nitisols, Eutric Vertisols, Eutric Leptosols, and Eutric Regosols. Haplic Alisols have the highest percent coverage area (27.45%), while the Haplic Arenosols have the lowest percent coverage area (1.96%).

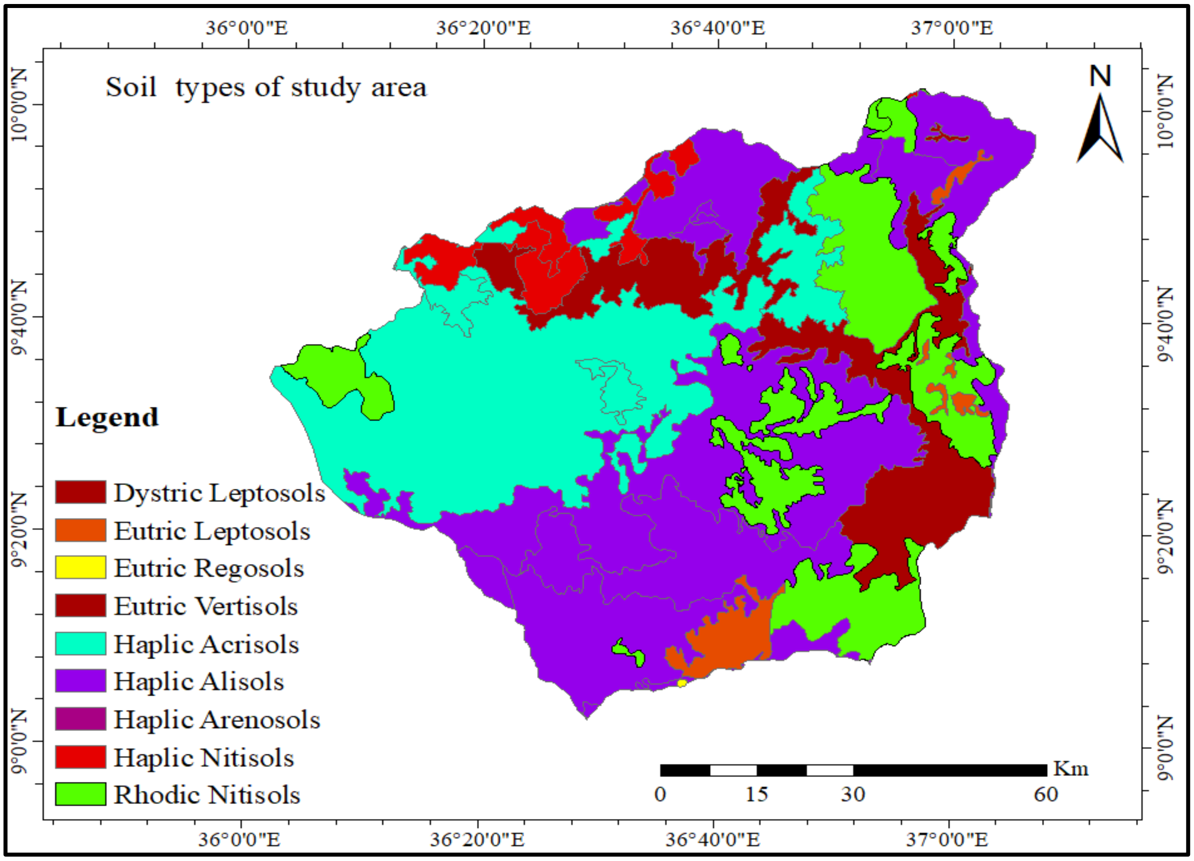


Figure 3. 9. Soil types of Hanger Watershed

Table 3. 4. Soil types of Hanger watershed

S .No	Soil Types	Covered Area(%)
1	Dystric Leptosols	5.88
2	Eutric Leptosols	11.77
3	Eutric Regosols	1.96
4	Eutric vertisols	3.92
5	Haplic Acrisols	11.76
6	Haplic Alisols	27.45
7	Haplic Arenosols	1.97
8	Haplic Nitisols	9.8
9	Rhodic Nitisols	25.5

3.6. Curve Number Generation

The United States Department of Agriculture created the Soil Conservation Service (SCS) model (USDA). To convert rainfall into run-off, the curve number acts as a coefficient between rainfall and run-off and it is determined by the soil group and land cover. Using tables and chart forms, a single curve number for a single land cover and soil type, as well as a weighted curve number for a wide range of soil and land cover, can be computed manually. Most of the input data needed to produce a CN grid map can be built using Arc- GIS (for filled DEM) and Hec-GeoHMS (for the union of soil and land use land cover polygon).

Therefore, the major processes used for the generation of curve number for this study was; soil polygon process, classified land use, and land cover process merging soil polygon and land use land cover and creating CN-LOOKUP table. These activities are carried out with the help of ArcGIS and HEC-GeoHMS.

3.6.1. Classified Land Use Land Cover

The terms land use and land/cover are frequently used interchangeably, even though there is a significant difference between the two. Land use refers to the type of economic activity carried out on the land, whereas land cover refers to the extent to which the earth's surface is covered. Original land use land cover data has several classes; it is required to reclassify the land use land cover type with a specific numerical value to facilitate the process by using ArcGIS version 10.1. Therefore, reclassified land use land cover polygon is the first step used for the assignment of curve number. Woodland dense, Woodland open, Urban, Forest, Bushland, moderately cultivated, dominantly cultivated, state farm, and Grassland are dominated the study area's cover and use.

3.6.2. Hydrological soil group

To compute Curve Number, soil data should contain information of hydrologic soil groups. Hydrologic soil groups are groups of soils having similar runoff potential under similar storms and conditions. Soil scientists assigned hydrological soil groups to the series based on their water transmission rate, texture, structure, and degree of swelling when saturated, all of which have comparable runoff reactions. The percentage of soil texture in each soil type study area, especially in the Hanger watershed, was used to assign HSG. The normal soil moisture condition was used to estimate the curve number due to a lack of detailed information on the moisture condition of the study region.

Soils were classified into various hydrological soil groups using the hydrological soil classification. The hydrological soil groups in the Hanger watershed were dominated by soil groups' C' and 'D'. Based on the properties and characteristics of the soils, Soil group 'C' are moist, they have a relatively high runoff potential and low infiltration rates, and Soil group 'D' has high runoff potential and very low infiltration rate. Because soil groups C and D are dominant, the occurrence of runoff is high in the watershed.

Table 3. 5. Hydrological soil group for each soil type

S.No	Soil Types	Hydrological Soil Group	Soil Texture	Covered Area (%)
1	Dystric Leptosols	C	Clay	5.88
2	Eutric Leptosols	D	Sandy Clay	11.77
3	Eutric Regosols	C	Clay	1.96
4	Eutric vertisols	C	Clay loam	3.92
5	Haplic Acrisols	D	Clay Loam	11.76
6	Haplic Alisols	D	Loam	27.45
7	Haplic Arenosols	C	Clay loam	1.97
8	Haplic Nitisols	C	Loam	9.8
9	Rhodic Nitisols	C	Sandy-Loam	25.5

3.6.3. Merging of soil and land use land cover polygon

After you've reclassified the land use land cover and assigned HSG to each soil type, use the union function to combine the soil and land use land cover polygons. The soil and land use land cover data were combined to produce one shapefile using the union procedure, and the resulting attribute table includes all A, B, C, and D soil types as well as the land use special value. When the soil and land use land cover were combined, a negative value appeared in the attribute table. The union table has been abolished due to a lack of union. Create an empty field with the name "Soil Code" for storing group soils. This field will be used to store HSG for each type of soil. The soil's attribute table and the land use land cover layer's attribute table have no field for storing these data. For these storing data, four field names can be generated, PctA, PctB, PctC, and PctD. Each polygon was assigned a soil group. Pct A = 100, Pct B = 0, Pct C = 0, and Pct D = 0 are the values for a polygon with soil group "A." Similarly, only Pct D = 100 and the rest of the Pcts are zero for the soil group D polygon. A field name can be created in the land cover soil union table that contains land use category information linked to "CNLOOKUP." HEC-GeoHMS searches the Land Use field for this information, which is stored in the GRID CODE field. The name of the field was added, and it was equated to GRID CODE.

Table 3. 6. Curve-Number values for various LU/LC and HSG combinations (Source: Subramanya, 2008).

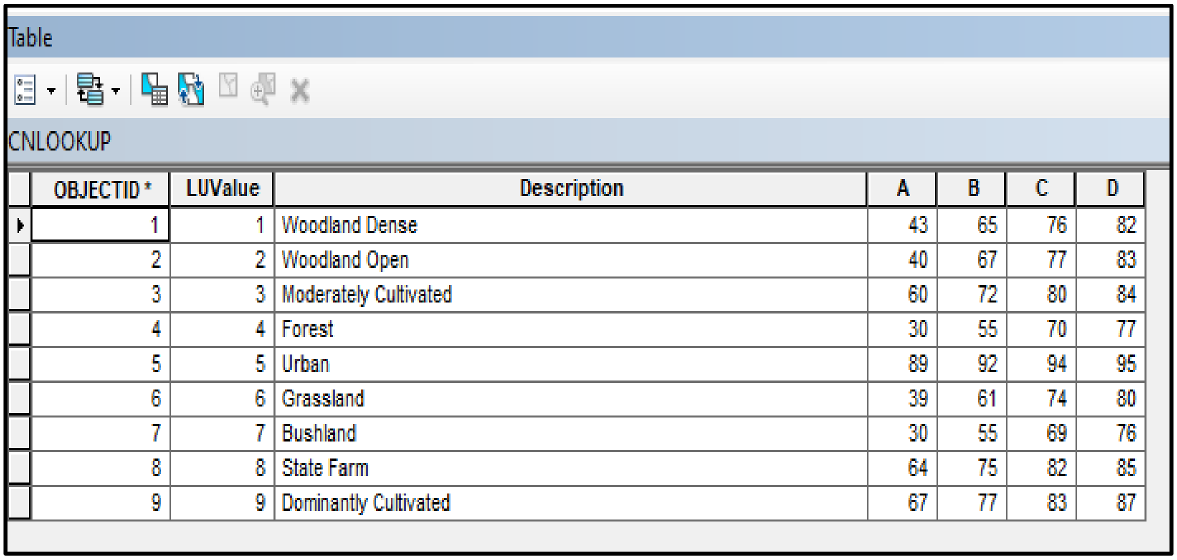
S.No	Types of LULC	Hydrological Soil Group (HSG)			
		A	B	C	D
1	Bushland	30	55	69	76
2	Dominantly cultivated	67	77	83	87
3	Forest	30	55	70	77
4	Grassland	39	61	74	80
5	Moderately cultivated	65	70	82	90
6	State farm	64	75	82	85
7	Urban	89	92	94	95
8	Woodland dense	43	65	76	82
9	Woodland open	40	67	77	83

3.6.4. Creating CN-LOOKUP Table

It is the most fundamental input table for Curve Number generation and created by using the ArcGIS tool to generate a CN Lookup Table with the columns LU value, A, B, C, and D. It was prepared based on Land use land cover (LULC), Hydrological Soil Group (HSG) and

Antecedent Moisture Condition (AMC). The columns contain a curve number that is unique to the land use and HSG combination.

Table 3. 7. CN-LOOKUP Table



OBJECTID *	LUValue	Description	A	B	C	D
1	1	Woodland Dense	43	65	76	82
2	2	Woodland Open	40	67	77	83
3	3	Moderately Cultivated	60	72	80	84
4	4	Forest	30	55	70	77
5	5	Urban	89	92	94	95
6	6	Grassland	39	61	74	80
7	7	Bushland	30	55	69	76
8	8	State Farm	64	75	82	85
9	9	Dominantly Cultivated	67	77	83	87

Finally, the curve number is a significant parameter that was calculated using the HEC-GeoHMS parameter estimation tool and the CN grid raster file. For each sub-basin, this tool derives the weighted curve number. The sub-basin attribute table was updated with the calculated curve number. The formula for calculating a weighted curve number is as follows:

$$CN = \sum_{i=30}^{n} \frac{C_i\, A_i}{A} \ldots\ldots\ldots 3.5$$

Where: CN = weighted curve number, C_i = curve number for the i^{th} polygon, A_i = area with curve number C_i.

Because the CN parameter has defined limits of 0 CN 100, it simplifies the rainfall-runoff relationship. If CN=0, S= ∞, the surface is entirely previous and all incoming precipitation is abstracted (low runoff and high infiltration rate), while if CN = 100, S=0, the surface is completely impervious and all incoming precipitation becomes runoff or surface water with no infiltration. Following the completion of the above curve number generation process, the generated curve number was shown in figure 3.11.

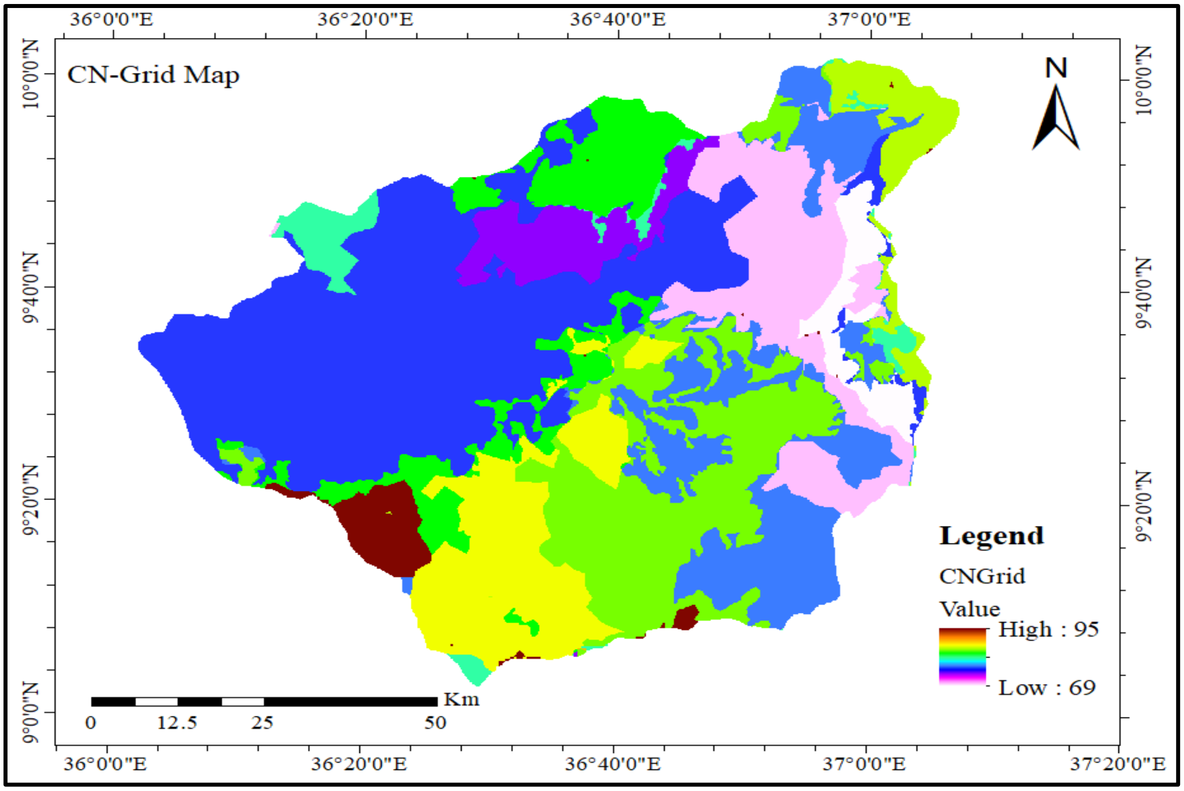


Figure 3. 10. Curve number grid map of Hanger watershed

3.7. Input requirements of HEC-HMS

The main methods for preparing HEC-HMS basin model input data include; terrain preprocessing, basin processing, Hec-GeoHMS project configuration, extraction of subbasin and river features, hydraulic parameter estimate, and hydraulic modeling system. However, for this study, HEC-GeoHMS tools were used for terrain preprocessing and basin processing, as well as HEC-HMS tools used for hydrologic processing.

3.7.1. Terrain Preprocessing by using HEC-GeoHMS

The first step in designing the basin model is terrain preprocessing, which is used to delineate the watershed using the DEM of the study area. HEC GeoHMS is a set of ArcGIS tools designed specifically to process geospatial data and generate input for the HEC-HMS. It establishes a connection for converting GIS spatial data into HEC-HMS model files. The following parameters were calculated using HEC-GeoHMS to process a DEM step by step.

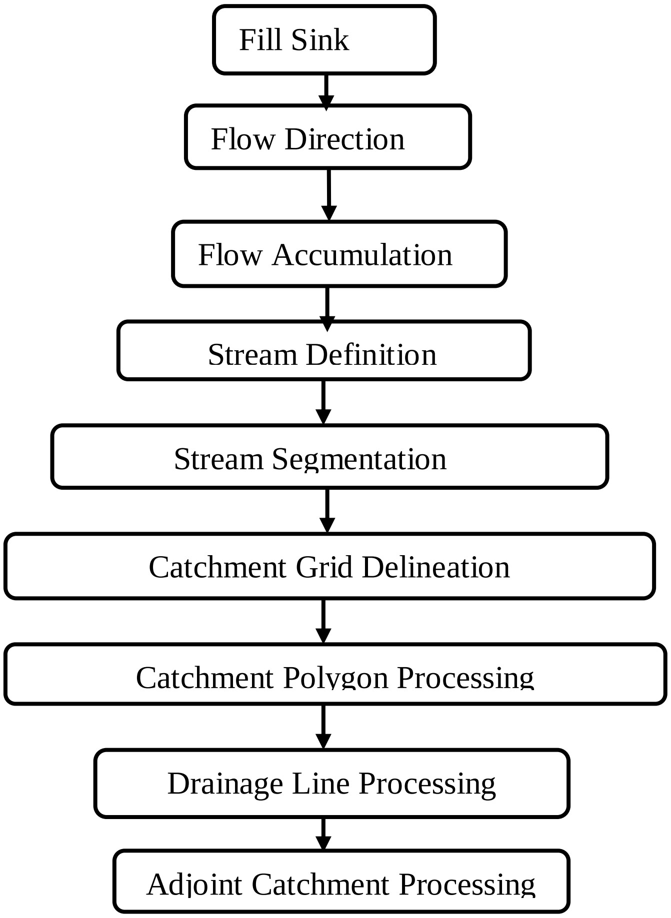


Figure 3. 11. Terrain preprocessing using Hec-GeoHMS

By using HEC-GeoHMS for the delineation of sub-basin and reach the network, the results of terrain preprocessing consist of raster and vector data. The final output of these preprocessing steps is a drainage line feature. The drainage line is shown in Figure 3.12. Appendix-4 contains the step-by-step findings of terrain preprocessing.

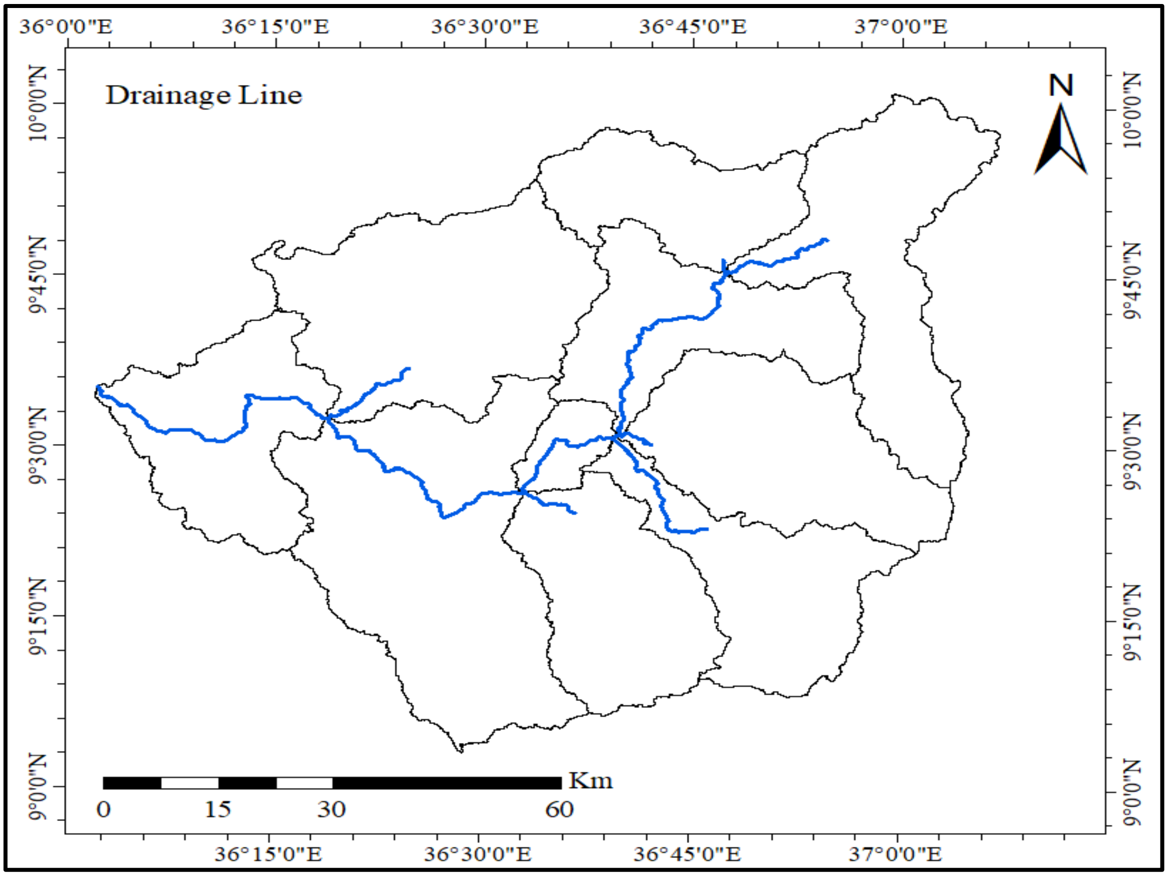


Figure 3. 12. Terrain preprocessing results using HEC-GeoHMS

3.7.2. Hydrologic Processing

HEC-HMS project configuration on the HEC-GeoHMS main view toolbar menu was used in hydrologic processing to collect data that was used to generate the necessary information to construct the HEC-HMS project. The extraction method included defining a control point at the downstream outlet, which serves as the HEC-HMS project's downstream boundary. HEC-GeoHMS copied all of the terrain preprocessing data for the region upstream of the outlet after identifying the downstream outlet. The sub-basin and stream delineations were then processed with HEC-GeoHMS, which was used to extract physical characteristics of sub-basins and streams, estimate model parameters, and prepare input files for HEC-HMS.

Computing basin processing, stream, and watershed features, and HMS model files were all done in the Arc GIS GUI (Graphical user interface) project view document. HMS basin schematic and legend, basin processing, computation of stream and sub-basin characteristics, and computation of lag-time for each sub-basin are all part of the hydrologic process.

According to Singh, 2003 , the SCS unit hydrograph method was used to compute lag time for each basin. It can be stated as follows:

$$T_{Lag} = \frac{L^{0.8}(S+1)^{0.7}}{1900y^{0.5}} \qquad 3.6$$

Where: T_{Lag} = basin lag time (minutes), L = length from sub-basin outlet to divide along longest drainage path (km), y = Y is the mean slope of the basin (%), S = Potential maximum retention after runoff begins. This S can be expressed in terms of average curve number as:

$$S(mm) = \frac{25400}{CN} - 254 \qquad 3.7$$

Where: CN = average curve number for each sub-basin. By substituting the above equation, it becomes;

$$T_{Lag} = \frac{L^{0.8}\left(\frac{25400}{CN} - 253\right)^{0.7}}{1900y^{0.5}} \qquad 3.8$$

Therefore, by using the above (equation 3.8), in HEC-GeoHMS the hydrologic parameter menu has assigned lag time for each sub-basin. In the attribute table menu bar, the calculated lag time was populated. Finally, the output of hydrologic processing is shown in figure 3.13.

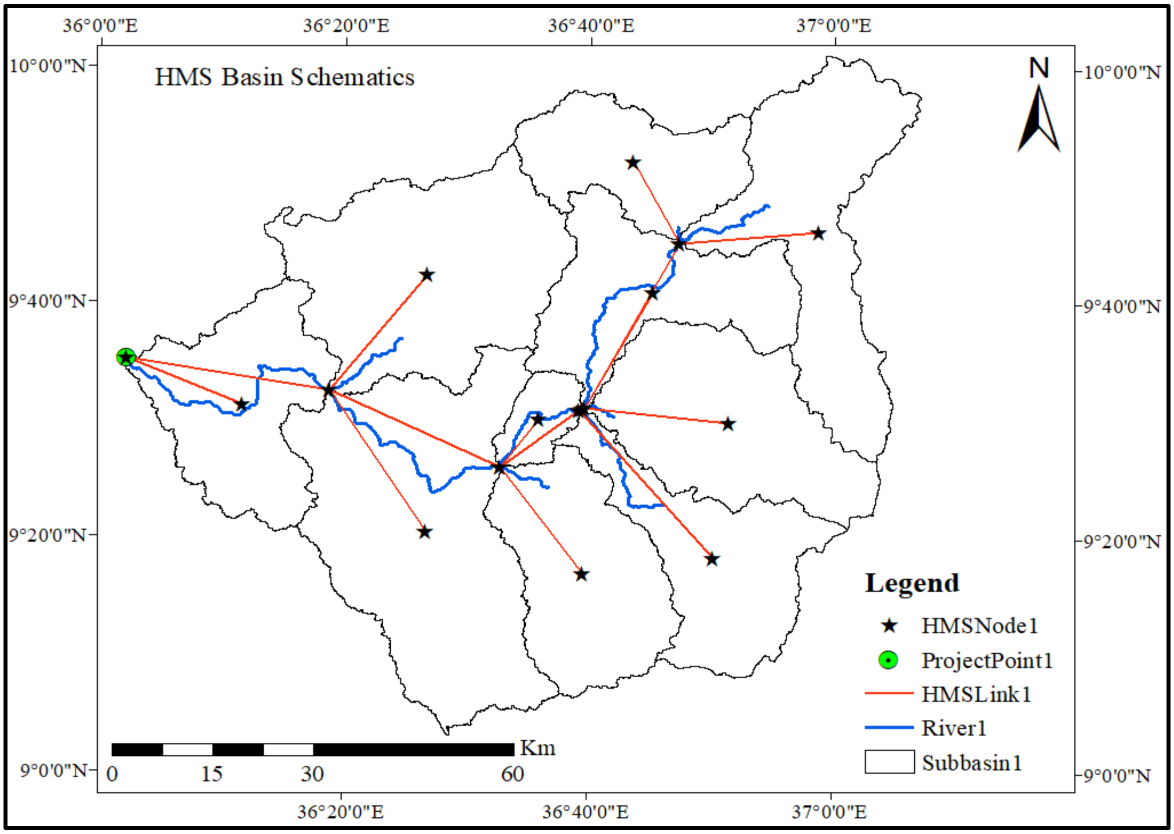


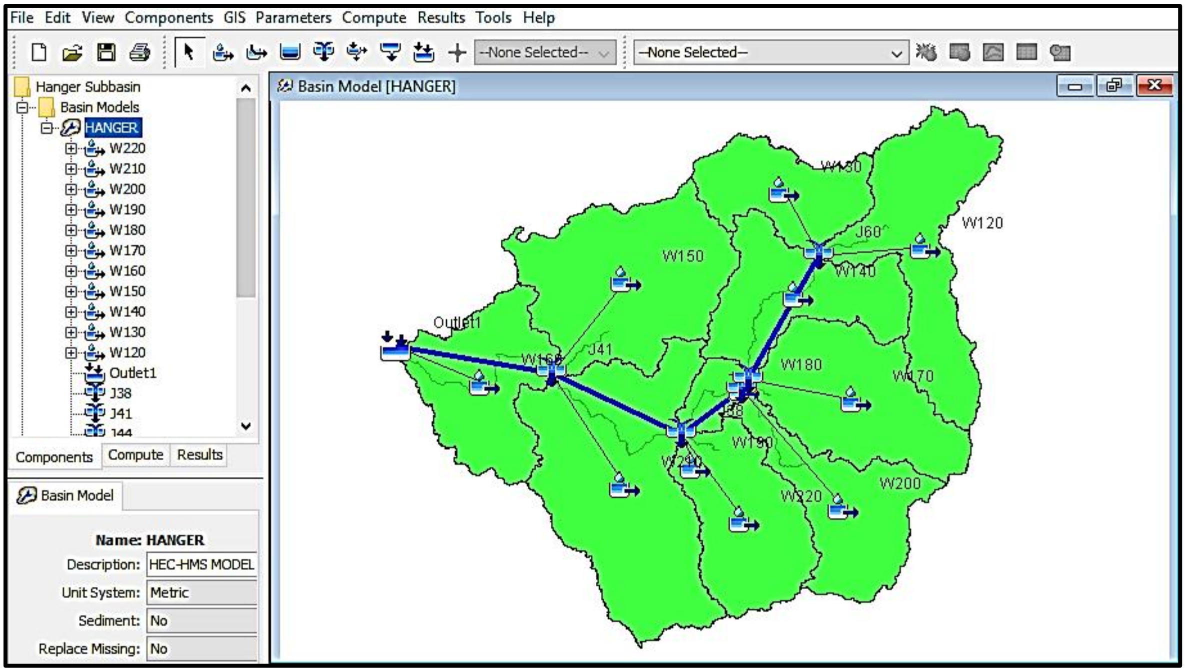
Figure 3. 13. The study area sub-basin schematics

3.8. HEC-HMS Model

HEC-HMS model consists of four main components. Meteorological model, Basin model, Control specification, and input (time series) data. Reach, junction, sub-basin, and sink or outlet are the four items in the basin model's schematics for this study. The properties and connectivity of the objects in the diagram are stored in the basin model. The meteorological component is also the first computational element that distributes precipitation input over the river basin spatially and temporally. Input data is needed as boundary conditions or as a parameter in a basin and meteorological models. Simulation properties such as duration and time step are defined by the Control specification model. The major components of the HEC-HMS model were discussed below:

3.8.1. Basin Model

The user can either develop the basin model in the HEC-HMS itself or else by feeding the DEM into the HEC-GeoHMS, which is an extension tool of ArcGIS software. In this particular study, the basin model was developed using the HEC-GeoHMS tool. For this study, the Hanger watershed was divided into 11- subbasins (see figure 3.14). The division of the watershed was based on land use land cover of the study area to get more accurate results. If the watershed division is below 11 - subbasins, the model was not fit the study area. Hence, it is not necessary to divide above 11- subbasins, because there is no variation of land use land cover. In this study, precipitation was defined by the specified hyetograph method. This was done by taking the proximity of the rain gauge to the sub-basin into account. The developed model was simulated in daily time steps. Baseflow, channel routing, infiltration (loss), and runoff surface are all described by these components. The figure below depicts the basin model's connectivity and hydrologic elements:



Basin Model

Name: HANGER
Description: HEC-HMS MODEL
Unit System: Metric
Sediment: No
Replace Missing: No

Figure 3. 14. The basin model's connectivity and hydrologic elements

Four main hydrological model processes can be categorized as basin models. SCS-CN loss method, Transform method, Baseflow method, and Routing method.

3.8.1.1. SCS-CN Loss method

The amount of rainfall infiltrated into the soil is referred to as loss. Loss methods are typically used in the HEC-HMS model to calculate runoff volume by subtracting the volume of water intercepted, infiltrated, stored, evaporated, or transpired from the precipitation. Various loss methods are available in the HEC-HMS model. The Soil Conservation Service -Curve Number (SCS-CN) loss method was chosen for this study, to estimate direct runoff from particular rainfall. According to (Sardoii *et al.*, 2012), the SCS-CN loss method was chosen for the analysis of HEC-HMS because it is widely used in various settings and produces better results than other loss rates. The fact that only a few factors need to be estimated based on hydrologic soil group, land use land cover, and slope maps, as well as its simplicity, makes it easier to calculate. The curve number, which ranges from 0 to 100, is a function of the soil's ability to infiltrate water. The following is the general equation for the curve number method:

$$Q = \frac{(P-Ia)^2}{(P-Ia+s)} \quad \text{3.9}$$

Where: Q = runoff (mm), P = depth of rainfall (mm), Ia = initial abstraction, S = maximum potential retention (mm).

All losses that occur before runoff begin are included in the initial abstraction (Ia). It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. Ia is a highly variable parameter that is normally correlated with soil and cover parameters and can be calculated using the equation:

$$Ia = 0.2S \quad \text{3.10}$$

Substituting Ia in equation 3.9 gives a combination of S and P to produce a unique runoff amount. The equation of rainfall relationships becomes:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)}, \quad \text{If } P>0.2S \text{ and } Q = 0, \text{ If } P<0.2S \quad \text{3.11}$$

The potential maximum retention S (mm) can vary in the range of $0 \leq S \leq \infty$, and related to the soil and cover conditions of the watershed through the curve number by the equation;

$$S = \frac{25400}{CN} - 254 \quad \text{3.12}$$

Where: CN = which is a function of LULC, soil type, hydrologic soil group, and antecedent moisture condition (AMC) is a key factor of the SCS-CN method.

3.8.1.2. Transform Method

SCS-UH, Snyder synthetic UH, and Clark Synthetic hydrograph techniques are widely used in HEC-HMS models (Scharffenberg *et al.*, 2010). For this research, the SCS-unit hydrograph was selected. The primary criteria for selecting the SCS unit hydrograph are; the suitability of the model's assumptions, their prior application and it also outperforms the other methods for modeling direct runoff. With the HEC-HMS, the purpose of SCS-UH is to produce hydrographs for storms during hydrologic events periods.

The only input needed for the SCS-UH method is the lag time for each sub-basin. The lag time is the interval between the centroid of the precipitation mass and the peak flow of the resulting hydrograph. The unit runoff percentage was not evenly distributed across the sub-basins. Therefore, the watershed's ground slope, flow length, and other properties changed (USCAE, 2013).

3.8.1.3. Base Flow method

The subsurface model is represented by a base flow model, which interacts with the infiltration and surface runoff processes. For this study, from the various base flow method in the HEC-HMS model, the constant monthly varying method was selected. It only requires streamflow data and it allows you to specify a fixed base flow for each month of the year.

3.8.1.4. Routing method

Routing is used to model channel flow from the upstream to the basin outlet (downstream). Different flood routing methods are available in the HEC-HMS model. These are Kinematic wave, Lag, Modified pulse, Muskingum, and Muskingum-Cunge method. The selection of flood routing method depends on several factors including channel slope, availability of observed streamflow data, and the significance of backwater effects, among others. For this study, the Muskingum routing model was selected. This method requires Muskingum “k” (the time travel pass through the reach) and Muskingum “x” (weighting coefficient of discharge).

According to (Subramanya, 2008), the storage in the channel reach, can be represented as follows:

$$S = K\,(x\,I^{m} + (1-x)\,Q^{m}) \quad \text{……………………………………………………………} 3.13$$

Where K and x are coefficients, and m is a constant exponent. The value of m has been found to range from 0.6 for rectangular channels to 1.0 for natural channels. Equation (3.13) is reduced to a linear relationship when m = 1 is used for natural channels. For S in terms of I and Q as;

$$S = K (x I + (1-x) Q \quad \text{………………………………………………………………………}3.14$$

x is a parameter that takes a value between 0 and 0.5. When x = 0, the storage is a function of discharge only, while when x=0.5, both the inflow and outflow play an equal role in deciding the storage. Mathematically, k is given by the following equation:

$$K = \frac{L}{V} \text{……………………………………………………………………………………}3.15$$

Where v is allowable flow velocity, L is the length of the reach.

From the theoretical background, the permissible velocity of water passing through a natural channel without erosion and sediment deposition is 1.5 m/s. As a result, for the first experiment, a minimum channel velocity of 1.5 m/s was assumed by treating the channel as natural. HEC-GeoHMS was used to calculate the river length for each sub-basin. The river's minimum and maximum lengths were 1289.18 meters and 26795.71 meters, respectively. By calculating using the above (equation 3.16), the minimum and maximum initial values of Muskingum k were 0.143 hr and 4.586 hr, respectively. Similarly, the initial value of Muskingum k for other sub-basins was calculated. The weighted coefficient of discharge (x) ranges between 0 and 0.5. As a consequence, by taking the average value of x, 0.25 was initially assumed.

In general, the following equation is used to estimate the final routing model of a given reach (Subramanya, 2008).

$$Q_t = \left[\frac{\Delta_t - 2kx}{2k(1-k)+\Delta t}\right] \Delta_t + \left[\frac{\Delta_t - 2kx}{2k(1-k)+\Delta t}\right] \Delta_{t-1} + \left[\frac{(-\Delta_t + 2k - 2kx)}{2k(1-k)+\Delta t}\right] Q_{t-1} \text{…………………}3.16$$

Where: Δt denotes the time interval between each successive inflow, k is the travel time of the flood wave through routing reach, St is the storage in the channel at time t, It is the inflow to the channel at time t, Qt is the outflow from the channel at time t and x is the weighting factor.

3.8.2. Meteorological Model

Precipitation for runoff modeling is the meteorological model used in this study in HEC-HMS (USCAE, 2013). The sub-basin meteorological model can be matched with the sub-basin in the basin model by using the name of the sub-basin. Precipitation is the most important component in a meteorological model. It is the driving factor for watershed responses; as a result, a substantial effort was expended to compute the meteorological model to obtain spatially and temporally distributed precipitation input data. The gauge weight of the sub-basin is equal to the area of the sub-basin that passes through the polygon divided by the area of the polygon. Sub-basin precipitation time series data can be obtained by multiplying the gauge weight by gauge precipitation for each sub-basin.

3.8.3. Time Series Data Entry Model

HEC-HMS model requires precipitation gage and discharge gage time series data for simulation of runoff. After the rainfall-runoff model was set up, the observed runoff data was entered into the discharge Gage to be compared to the simulated runoff data. The observed flow can be fed into this model for model calibration and simulation. For time-series flow calibration (January 1, 1990, to December 31, 2009) and validation (January 1, 2010, to December 31, 2014), Alibo, Anger, Gelila, Gida Ayana, Kiramu, Nekemte, and Shambu are seven-time series precipitation data that can be used to make a precipitation gauge. The depicted weight for each rainfall station in the Hanger watershed was divided using Thiessen's Polygon method. The average rainfall for each subbasin was calculated using Thiessen's Polygon Method and entered it into the precipitation data.

3.8.4. Control Specification Model

Control specification is used to control when the simulation starts and stops, as well as what time interval is used in the simulation, even though it does not contain much parameter data.

3.8.5. Simulation Runoff

The results of the hydrological model can be computed using the simulation run. It is required to complete the process in HEC-HMS. One meteorological model, one basin model, and one set of control specifications make up the simulation run. It simulates the hydrologic response by combining watershed and meteorology data. Through the basin map or the watershed explorer, the simulation results can be visualized as graphs, summary tables, and time series tables.

3.9. Flood prediction

Flood prediction is a crucial mathematical technique for determining the extent and severity of a river's peak discharge. This approach is useful for predicting floods and ensuring that public and government resources are not harmed. Flood forecasting can be done in a variety of ways.

3.9.1. Flood Prediction by HEC-HMS Model

The HEC-HMS frequency storm system is a meteorological method for estimating flood frequency from statistical precipitation data in meteorological models. Probability, intensity length, storm duration, intensity duration, storm area, and rainfall depth are all required by the method. To measure peak flood frequency, flood frequency analysis was performed using rainfall depths of 2, 5, 10, 25, 50, 100, 200, and 500 years return periods. The Ethiopian Roads Authority (ERA) divided the country into eight meteorological regions based on rainfall pattern similarity and established Intensity Duration Frequency (IDF) curves for each meteorological region's 24-hour rainfall depth. According to (ERA, 2013), the Hanger Watershed is located in Rainfall Region-Two (RR-A2). Figure 3.15 shows the locations.

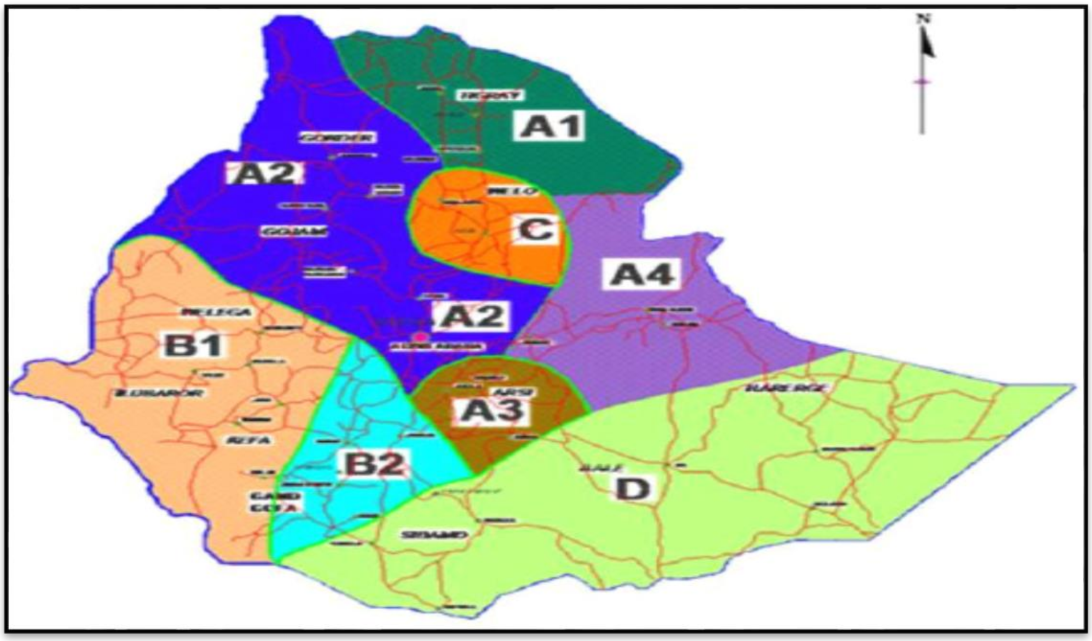


Figure 3. 15. Ethiopian Rainfall Regions

The ERA, drainage manual also provided the rainfall depth for each return period for the selected time interval of this study was calculated using the equation (3.17) below, which took the 24 hr maximum rainfall depth given for RR-A2 in Table 3.8.

Table 3. 8. Rainfall Depth (mm) vs return period (yr) (Source: ERA, 2013)

Return period Years	24 hr Rainfall depth (mm) vs frequency (yr)							
	2	5	10	25	50	100	200	500
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.38
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
Note: RR-Rainfall Region								

The above table 3.8 of the 24-hr rainfall depth with rainfall duration was used to developed ERA equation in can be expressed as;

$$R_{Rt} = \frac{t(b+24)^n}{24(b+t)^n} \tag{3.17}$$

Where: RRt= Rainfall depth ratio Rt: R24, Rt = Rainfall depth in a given duration 't', R24= 24hr Rainfall depth, b and n are constant coefficient in which b = 0.3 and n = (0.78 – 1.09) and t = Rainfall duration. For this study the value n = 1 used, to calculate the 24-hr depth for each return period.

3.9.2. Flood Prediction by Probability Distribution Function

There are a variety of statistical distribution functions that can be used to predict floods caused by extreme events. There is currently no universally accepted frequency distribution model for frequency analysis of extreme floods (Topaloglu, 2002). Using the Easy-Fit software edition, the best-fit statistical distribution function was calculated. Easy Fit is a data analyzer and simulation program that allows you to fit probabilistic distributions to given data by selecting the best-fitting probability function and putting the results into practice.

According to (Pakgohar, 2014), easy fit software is used as a windows compatible application and as an Excel add-on. It assigns the rank of each statistical distribution based on the maximum annual streamflow results. As a result, the maximum daily streamflow data of the Hanger watershed was used for 25 years (1990-2014). For this study, Easy Fit software is used to evaluate the General Extreme Value (GEV), Log Pearson type-III, Gumbel max, Normal, Lognormal, and Lognormal (3P) probability distributions. Because of their simplicity, suitability, and efficiency, these statistical distributions were selected.

The Selection of best-fit probability distribution was based on the offered rank by all goodness of fit tests Kolmogorov Smirnov, Anderson Darling, and Chi-Squared. Based on the rank of the goodness of fit tests in (table 3.9), Kolmogorov-Smirnov test (KS), and Anderson-Darling Test (AD) the statistical value of Gen. Extreme value distribution provides a good fit to the yearly maximum discharge data at the outlet of the study area while using Kolmogorov Smirnov test (D), Anderson-Darling Test (AD) and Chi-squared test (X^2) it was observed that the log Pearson type-III is the second goodness of distribution at the downstream (outlet) of the Hanger watershed.

Table 3. 9. Professional and Ranks of Fitting Statistical Distributions Easy Fit 5.6 Output.

S No	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Static	Rank	Static	Rank	Static	Rank
1	Gen. Extreme Value	0.09619	1	0.32038	1	1.3385	2
2	Gumbel Max	0.20687	6	2.5571	6	5.3752	6
3	Log-Pearson 3	0.11535	2	0.56996	2	0.59128	1
4	Lognormal	0.16476	5	1.1744	5	1.4944	3
5	Lognormal (3P)	0.15041	4	0.90954	4	1.5757	5
6	Normal	0.14664	3	0.83556	3	1.5647	4

Therefore, the General Extreme value and Log Pearson Type-II distribution functions were used to calculating the peak floods for 2, 5,10, 25, 50, 100, and 200-year return periods using table 3.10 of the selected statistical parameters, and the results were compared to those of the HEC-HMS model. The selected statistical parameters were given in table 3.10.

Table 3. 10. Statistical Parameters for selected distribution methods

No	Distribution	Parameters
1	Gen. Extreme Value	k=-0.66543 σ=158.01 μ=837.63
2	Gumbel Max	σ=108.86 μ=797.93
3	Log-Pearson 3	α=4.6568 β=-0.08108 γ=7.1215
4	Lognormal	σ=0.17143 μ=6.7439
5	Lognormal (3P)	σ=0.0301 μ=8.4301 γ=-3723.3
6	Normal	σ=139.62 μ=860.77

According to (H.Hamed, 2000), General Extreme value and Log Pearson Type-II distribution functions were determined by equations 3.18 and 3.22.

General Extreme Value (GEV) distribution method

The recurrent period flood computation of GEV given by: -

$$X_T = \mu - \frac{\delta}{k}\left[1 - \left\{log\left(1 - \frac{1}{T}\right)^{-K}\right\}\right] \tag{3.18}$$

Log Pearson Type-III distribution method

The equation of recurrence period flood distribution of Log Pearson Type-III is expressed as: -

$$Z_T = logX_T = \mu_Z + K_T\delta_Z \tag{3.19}$$

$$K_T = \frac{2}{C_s}\left[\left\{\frac{C_s}{6}\left(u - \frac{C_s}{6}\right) + 1\right\}^3 - 1\right] \tag{3.20}$$

$$C_s = \frac{2}{\sqrt{\beta}} \tag{3.21}$$

The equation 3.20 becomes: -

$$Z_T = e^{Z_T} = e^{\mu_Z + K_T\delta_Z} \tag{3.22}$$

Where:$Z_T\ and\ X_T$ = recurrent period of flood distribution, T = return period, $\mu_Z, \sqrt{\beta}, \delta_Z, \mu$, δ, and k are the statistical parameters used for the selected distribution methods from easy fit 5.6 software.

3.10. Performance Evaluation

The performance of a model must be evaluated on the extent of its accuracy, consistency, and adaptability (Abushandi, 2013). The criteria used to evaluate the performance of the models are the overall agreement between predicted and measured runoff discharges, and the models' ability to predict the time and magnitude of hydrograph peaks, and runoff volume. There are six criteria for model evaluation adopted for this study. Those are; Nash-Sutcliffe efficiency (NSE), Coefficient of determination or correlation (R2), Root mean square error (RMSE), Percent bias (PBIAS), the Percentage error in simulated volume (PEV), and Percentage error in simulated peak (PEP).

Nash-Sutcliffe efficiency (NSE)

Nash-Sutcliffe efficiency (NSE) is used to assess the overall agreement of the shape of the simulated and observed streamflow time series. It calculates the model's effectiveness by comparing the simulated data's goodness of fit to the variance of the measured data. In general, if the NSE value is 1, the modeled daily stream flows are identical to the observed daily stream flows (or a perfect fit), while if the NSE value is less than zero, the model simulations are poorer than merely using the mean observed daily streamflow as the streamflow estimate for each day. NSE can be expressed as;

$$\mathrm{NSE} = 1 - \frac{\sum_{i=1}^{n} (Q_{obs} - Q_{sim})^2}{\sum_{i=1}^{n} (Q_{obs} - \overline{Q}_{obs})^2} \quad \text{..} 3.23$$

Coefficient of Determination (R^2)

It describes the proportion of the variance in measured and simulated data. R^2 has a value range of 0 to 1. The 0 values mean that the simulation model's ability is good and that the error of variance is low. R^2 has been widely used for model evaluation, expressed as;

$$R^2 = \left\{ \frac{\sum_{i=1}^{n} (Q_{obs} - \overline{Q}_{obs})(Q_{sim} - \overline{Q}_{sim})}{\left(\sum_{i=1}^{n} [Q_{obs} - \overline{Q}_{obs}]^2\right)^{1/2} \left(\sum_{i=1}^{n} [Q_{sim} - \overline{Q}_{sim}]^2\right)^{1/2}} \right\}^2 \quad \text{...} 3.24$$

Root Mean Square Error (RMSE)

The average error between observed and simulated discharges is measured by the RMSE (Root Mean Square Error). The model's performance improves as the RMSE value approaches zero. Residues are the individual differences between observed and predicted values. It can be expressed as the following equation:

$$RMSE = \sqrt{\frac{\sum_{i}^{n}(Q_{obs}-Q_{sim})^2}{n}} \tag{3.25}$$

According to (Singhie *et al.*, 2004), the Root mean square error is always greater than zero, and closer to the values to zero better model performance.

Percent error in peak flow (*PEPF*)

The percentage error in peak flow only measures considers the magnitude of the computed peak flow, but it does not account for the time of peak or total volume.

$$PEPF = 100\left[\frac{Q_{obs}-Q_{sim}}{Q_{obs}}\right] \tag{3.26}$$

Percent error in volume (*PEV*)

It considers the inverse of PEPF. Percent error in volume only considers the computed volume and does not account for the magnitude or timing of the peak flow. It expressed as;

$$PEV = 100\left[\frac{V_{obs}-V_{sim}}{V_{obs}}\right] \tag{3.27}$$

Percent Bias (PBIAS)

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

$$PBIAS = \left[\frac{\sum_{i=1}^{n} Q_{obs}-Q_{sim}}{\sum_{i=1}^{n} Q_{obs}}\right] \tag{3.28}$$

Where: Q_{obs} = Observed flow peak, Q_{sim} = simulated flow peak**,** V_{obs} = volume of observed flow and V_{sim} = volume of simulated flow peak, i = time step, and n = the number of observations.

Table 3. 11. Model performance rating guidelines of RMSE, NSE, R^2, PEV, and PEPF (Source: Moriasi *et al.*, 2007)

Performance rating	Very good	Good	Satisfactory	Unsatisfactory
NSE	$0.75 \leq NSE \leq 1$	$0.65 \leq NSE \leq 0.75$	$0.5 \leq NSE \leq 0.65$	$NSE < 0.5$
R2	$0.85 \leq R^2 \leq 1$	$0.7 \leq R^2 \leq 0.85$	$0.6 \leq R2 \leq 0.$	$R^2 < 0.6$
RMSE	$RMSE < 0.5$	$0.5 < RMSE \leq 0.6$	$0.6 < RMSE \leq 0.7$	$RMSE > 0.7$
PEV	$< \pm 10\%$	$\pm 10\%$ -15%	$\pm 15\%$-$\pm 25\%$	$\geq \pm 25\%$
PEPF	<15%	15%-30%	30%-40%	>40%
PBIAS	$PBIAS \leq \pm 10\%$	$\pm 10 PBIAS < \pm 15$	$\pm 15 PBIAS < \pm 25$	$PBIAS \geq \pm 25$

3.10.1. Sensitivity Analysis

Sensitivity analysis (SA) is a technique for determining which model parameters have the greatest influence on the model's output. It assigns a ranking to model parameters based on their contribution to the overall model prediction error. The five parameters curve number, initial abstraction, lag-time, Muskingum k, and Muskingum x are used for this study. Sensitivity analysis was carried out for these 5 parameters. The method used to determine the dominant hydrological parameters and to reduce the number of model parameters that will be used in calibration.

However, parameters that had been not evaluated during sensitivity analysis have to be modified during calibration so that the simulated flow model parameters fit that of the observed streamflow parameters. Modifying parameters other than those identified during sensitivity analysis was carried out by investigating the type of error that occurs in simulated variables. Therefore, sensitivity analysis as an instrument for the assessment of the input parameters for their impact on model output is useful for model calibration and validation model, and also reduction of uncertainty (Lenhart *et al.*, 2002).

Finally, the sensitivity analyses were run at the outlet of the Hanger watershed. In the analysis, the sensitive parameters of the streamflow of the basin were identified. The parameters, which resulted from the study, were ranked according to the magnitudes of response variable sensitivity to each of the model parameters, which divide most and more sensitivities.

3.10.2. HEC-HMS Model Calibration

Calibration is the process of modifying model parameters within recommended ranges and optimizing the model output until the observed set of data matches the predicted set of data. By comparing the produced hydrograph to the measured hydrograph, the software computes the index of goodness-of-fit. The successful application of the hydrologic model depends upon how well the model is calibrated which in turn depends on the technical capability of the hydrological model as well as the quality of the input data (Vaze *et al*., 2011).

The objective function, also known as the algorithm, looks for model parameters that produce the best value for the index (USCAE, 2000). During optimization from the objective functions, peak weighted root means square error (PWRMSE) was selected because, it is a measure of the comparison of the magnitudes of the peak, volume, and time of the peak of the simulated and measured hydrograph. Two search methods are available in the HEC-HMS model for minimizing the objective functions. These are:

Univariate Gradient Method (UG)

It is the best method for calibration of the models and it was used to minimize the PWRMSE by identifying the most reasonable parameter values that will yield the best fit of computed to the reference hydrograph (USCAE, 2000). This method evaluates and adjusts one parameter at a time while holding other parameters constant.

Simplex (Nelder and Mead Method)

In this method, the parameter space is searched using a geometric figure called simplex having several vertices one greater than the number of the parameters. Under this method, it is difficult to know the most sensitive parameters because the parameters are adjusted simultaneously.

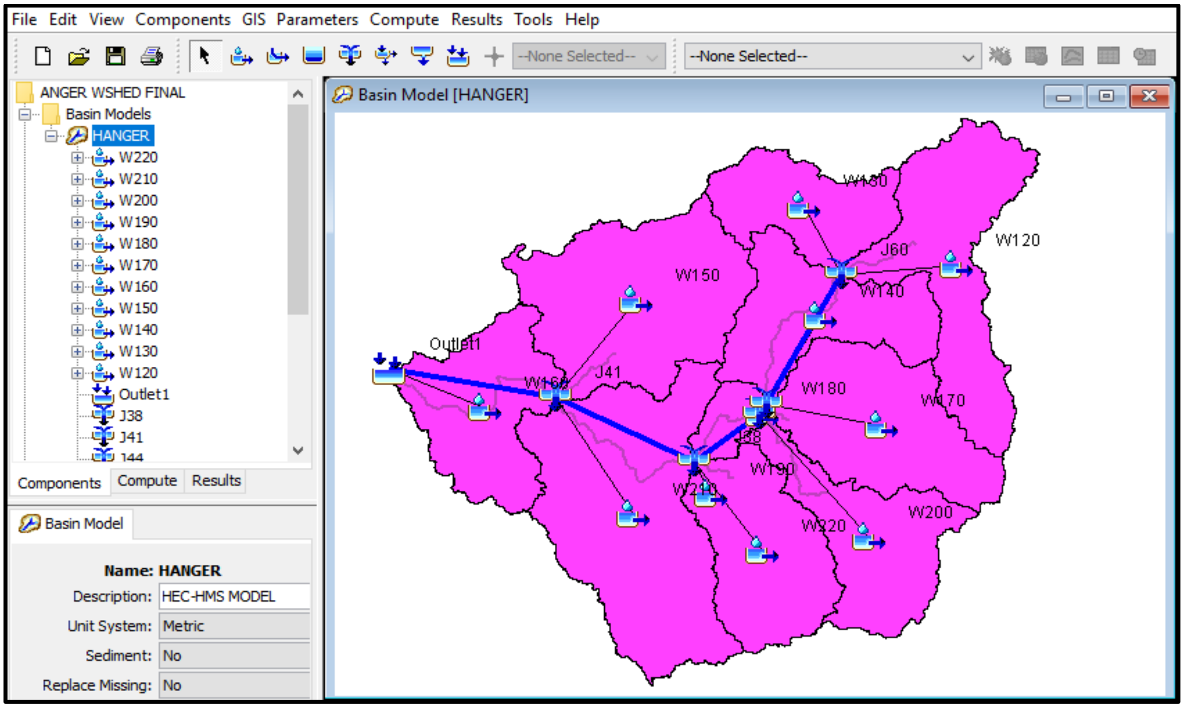
3.10.3. HEC-HMS Model Validation

It is the process of determining the degree to which a model is an accurate representation of the observed set of data from the perspective of the intended uses of the model. During the validation process, the model was calibrated using the calibration data set for the validation period without changing the model parameters. For validation, the simulated data as predicted by the model must be computed and compared with the observed data and statistical tests of error functions must be carried on.

4. RESULT AND DISCUSSION

4.1. Physiographic Characteristics of the Watershed

The background map file represents the physical watershed under consideration. For this study, a background map file that contains about 11 Sub-watersheds with 5 reaches and 5 junctions was generated using HEC-Geo HMS in Arc GIS (Figure 4.1). It encompasses Basin model file, Meteorological model file, and Gage model file later used as input in HEC-HMS during simulation of rainfall-runoff. The basin model file contains sub-watersheds, reaches, junctions, and outlet with methods for precipitation loss modeling, excess precipitation transforming, base flow modeling, and channel routing methods.



Name: HANGER
Description: HEC-HMS MODEL
Unit System: Metric
Sediment: No
Replace Missing: No

Figure 4. 1. Background map file of the Hanger Watershed

As discussed under the methodology part, the important watershed characteristics like, Curve number, lag time, watershed area, and the initial abstraction from watershed were determined using HEC-GeoHMS extension in Arc-GIS. The basin model of the hanger watershed and the parameters of each sub-watershed were imported from HEC-GeoHMS for HEC-HMS processing. Curve number and initial abstraction were used to determine the SCS-CN loss method, the lag time used for transformation, and flood routing for Muskingum k and x. To transform rainfall to runoff, the SCS-UH method and for channel routing, the Muskingum method was used. In HEC-HMS under time-series data, precipitation, and observed streamflow for each sub-watershed from 1990 to 2014 were entered to precipitation gage and discharge gage, respectively. All the above parameters are used to simulate rainfall-runoff for the Hanger watershed.

4.2. Simulation Results of the HEC-HMS Model

4.2.1. Sensitivity Analysis

Sensitivity analysis was carried out by selecting one parameter at a time holding the other parameters constant. The goal was to reduce the number of parameters calculated through optimization. The simulation time interval was selected based on the time interval of available data for both model calibration and validation, the bulk of the data was used to calibrate the model. HEC-HMS model was calibrated (1990-2009) and validated (2010-2014) using a total of 25 years with a one-day time interval for this study. Using the procedures described above in table 4.1 the basin model was created in the HEC-HMS by using 11 sub-basins and five routing reaches which were imported from the HEC-GeoHMS model. To begin the simulation task, calculated and assumed initial values for the sensitive parameter of the sub-watershed shown in Table 4.1and Table 4.2 was first used in the HEC-HMS model

Table 4. 1. Initial and optimized values of watershed parameters

Sub-watershed			Curve Number		Ia (mm)		Lag time (min)	
	Area (km2)	River Length (m)	Initial value	Optimized value	Initial value	Optimized value	Initial value	Optimized value
W220	712.4	3117	83	81	10.3	13.7	370	9914
W210	1422.5	19459	82	57	11.0	14.6	515	14649
W200	659.6	17542	78	45	14.2	18.9	598	17088
W190	133.5	41183	80	41	12.6	16.8	270	7694
W180	0.4	1289	83	41	10.4	13.9	23	642
W170	839.7	46645	78	42	14.2	19.0	633	17693
W160	699.4	6119	76	49	15.7	20.9	638	16680
W150	1113.3	20777	76	64	15.7	20.9	880	29998
W140	671.5	9597	75	51	16.8	22.4	949	25459
W130	508.7	41271	78	58	14.7	19.6	977	21387
W120	913.66	26796	76	66	16.3	21.7	1827	24465

After many iterations, it was found that the travel time through the reach (Muskingum-k), and weighted discharge coefficient (Muskingum x) was the most sensitive parameters. Calibration was done by using these parameters.

Table 4. 2. Initial and optimized values of k and x parameters in the routing reach element.

Reaches	Muskingum k, K(hr)		Muskingum x	
	Initial	Optimized	Initial	Optimized
R40	8.25	12.45	0.25	0.49
R50	5.43	7.86	0.25	0.13
R60	9.38	15.17	0.25	0.28
R80	6.34	7.92	0.25	0.13
R100	7.85	9.56	0.25	0.002

4.2.2. Model Calibration

Parameter optimization is a method of systematically changing model parameter values until the calculated model results agree with the observed data. Optimization of the parameter values was carried out within the allowable ranges recommended by the US Army corps of Engineers Hydrologic Engineering Center (USCAE, 2000). The objective function is a quantitative measure of the goodness of fit between the measured result from the model and the observed flow. The calibrated parameters are adjusted to fit observed data for better output (Beven, 2012). A search method for modifying parameters to minimize objective function value and find optimum parameter value is the secret to automated parameter estimation. Minimum objective function is obtained when the parameter values best able to reproduce the observed hydrograph are found. Based on model sensitivity Muskingum k and Muskingum x were the most sensitive parameters. The optimization result of the minimum and maximum optimized values of these parameters shown in table 4.3.

Table 4. 3. The minimum and maximum optimized value of Muskingum k and x.

Model parameter	Minimum Optimized value	Maximum Optimized Value
Muskingum k	7.86	15.17
Muskingum x	0.002	0.49

After optimization, the disparity between the observed and simulated runoff hydrographs was reduced as shown in Figure 4.2, with maximum values of 1040.6m3/s and 949.4m3/s, respectively. This means that during model calibration, the peak discharge was accurately predicted. The objective function Nash Sutcliff efficiency (0.702), Coefficient of determination (0.714), Root Mean Square Error (0.5), and Percent bias (-2.04%) are recorded. As studies reported by (Arnold *et al*., 2007; Dawson, 2007), the HEC-HMS result showed that NSE and R2 values should between 0.7 to 1.0, the RMSE value should be 0 to 0.5 and PBIAS should be ≤±10%, a model to be quite good. Therefore, for this study, all of the applied statistical error tests were found to be within appropriate ranges, indicating that the expected calibration result was confirmed.

(Legesse, 2009), also recommended that the HEC-HMS model shows a good and very good agreement between simulated and observed flow during model calibration and validation on the study of Blue Nile Basin. With (NSE and R2 found to be above 0.7, while RMSE found to be 0 to 0.5) for both in model calibration and validation periods. Hence, for this study, the value of NSE, R2, and RMSE was 0.702, 0.7143, and 0.5 during model calibration and 0.707, 0.743, and 0.5 during model validation, respectively. Therefore, the simulated and observed flow of model calibration and validation period was a good agreement relationship in terms of NSE, and R2), and very good agreement relationship in terms of RMSE. Therefore, the HEC-HMS model was well performed on the Hanger watershed.

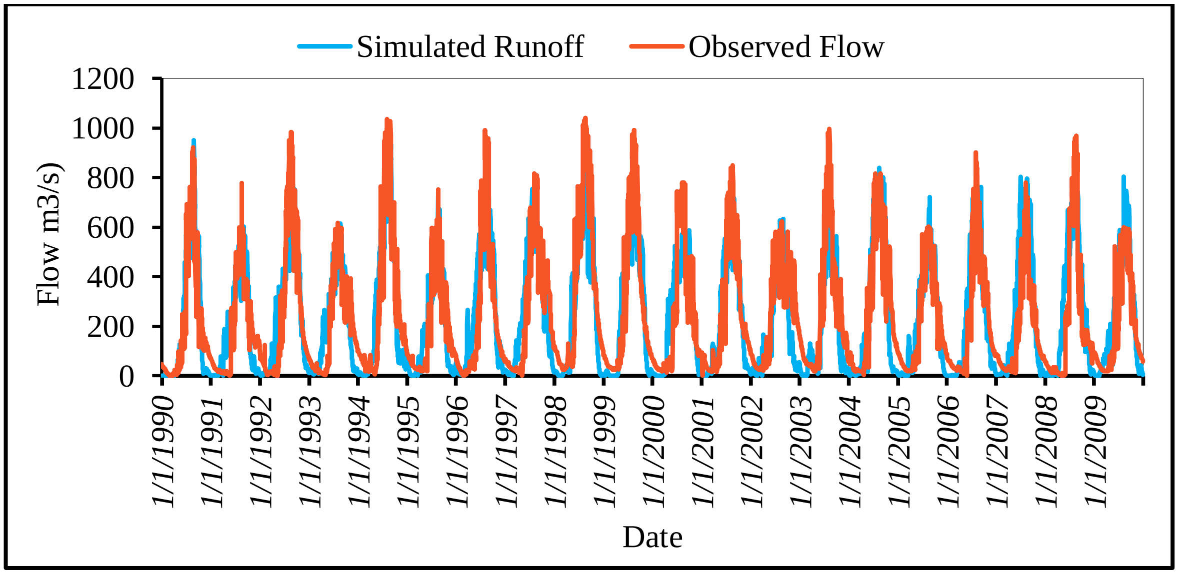


Figure 4. 2. Simulated and observed runoff hydrograph after calibration

Table 4. 4. The objective function result of model calibration

Objective functions	Values (%)
Nash Sutcliff efficiency (NSE)	70.2
Coefficient of determination (R2)	71.43
Root Mean Square Error (RMSE)	50
Percent bias (PBIAS)	-2.04

Figure 4.3 shows, there is good collinearity between observed and simulated runoff.

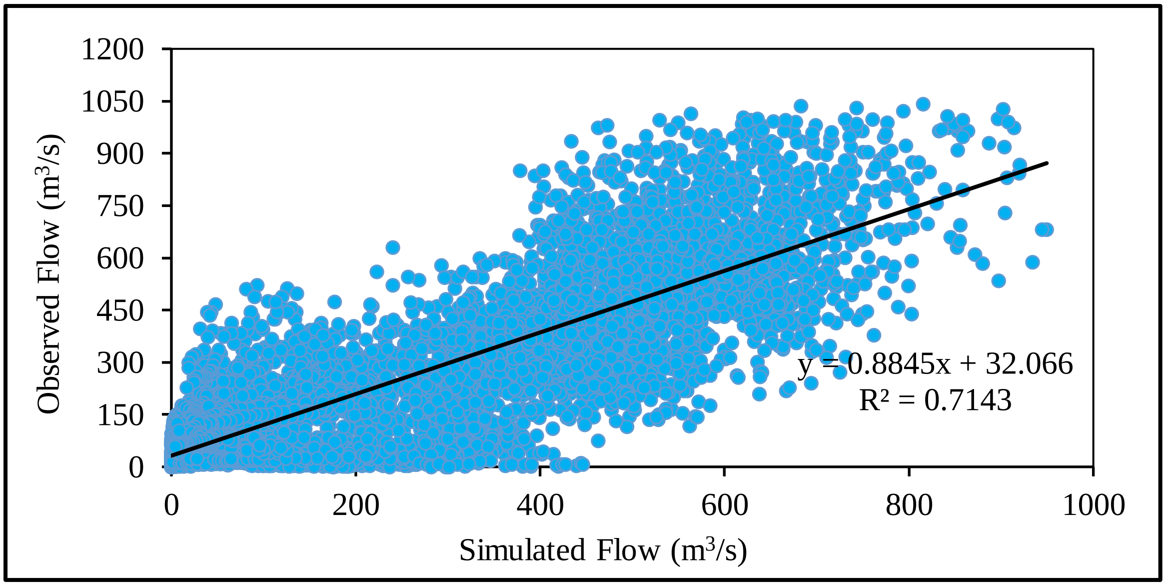


Figure 4. 3. Coefficient of determination of observed and simulated value after calibration

4.2.3. Model validation

After the calibration was completed and all model parameters were updated, the simulated runoff should be compared to the observed runoff using the same parameters that were used for model calibration during model validation. The model is validated directly using the parameter values obtained from model calibrations. The recently observed flow data from January 1, 2010, to December 31, 2014, was used for model validation in this study.

The validation period was chosen based on the availability of recorded data as well as the sample's freshness. During model validation, the observed and simulated peak flows were 980.3 m^3/s and 900.4 m^3/s, respectively. Therefore, the observed and simulated peak discharge were separated by 79.9m^3/s. This suggests that the peak discharge was significantly lower than the model expected. The simulated and observed runoff hydrographs show little difference, as shown in figure 4.4.

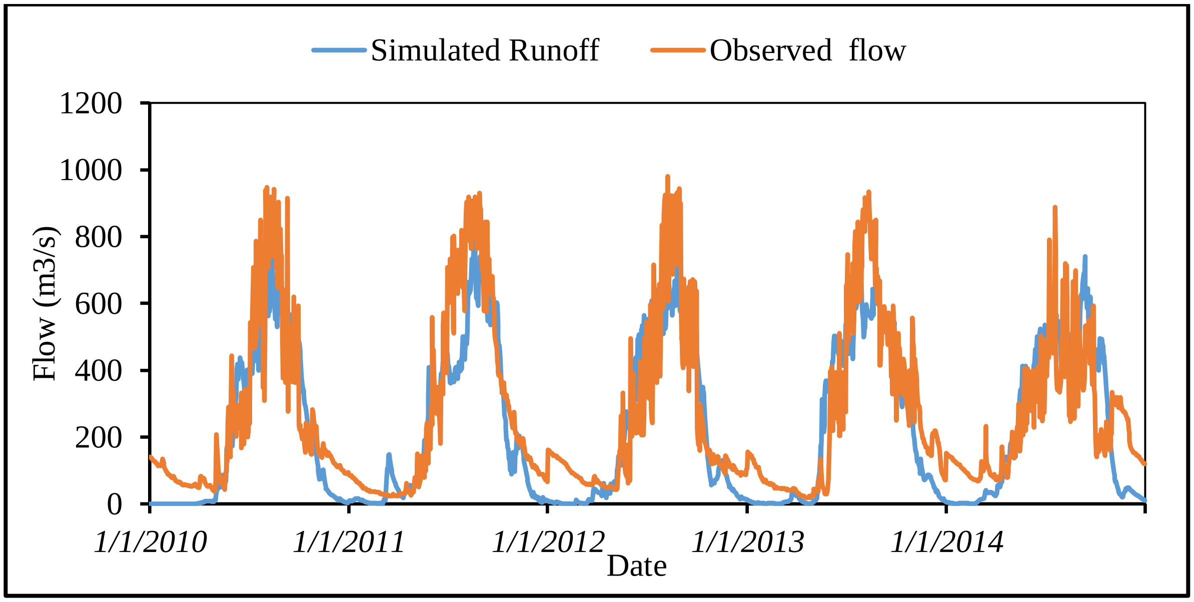


Figure 4. 4. Simulated and observed runoff hydrographs after Validation

Table 4. 5. The objective function results of model validation

Objective functions	Values (%)
Nash Sutcliff efficiency (NSE)	70.7
Coefficient of determination (R2)	74.3
Root Mean Square Error (RMSE)	50
Percent bias (PBIAS)	-14.61

According to (Moriasi *et al*., 2007), a model's performance rating is rated as good if the NSE and R2 values during calibration and validation are between 0.7 and 1 and RMSE 0 to 0.5. A similar result was obtained by (Ghrib *et al*., 2007) when they used the ModClark model to evaluate the simulation of the rainfall-runoff in the Tangrah watershed, Iran. Hence, Table 4.4. of the objective function results shows, the model performance was found to be within appropriate ranges, indicating that the expected validation result was confirmed.

Therefore, statistical tests of error functions affirm the validity of the HEC-HMS model for the Hanger watershed runoff simulation. The co-linearity between the observed and simulated runoff is shown in Figure 4.5.

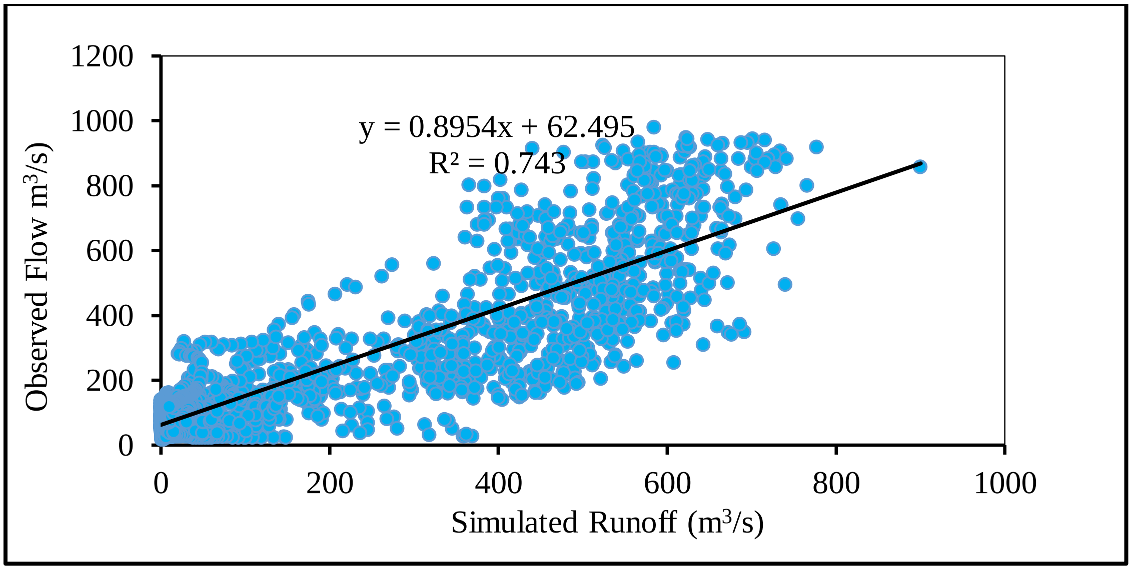


Figure 4. 5. Coefficient of determination of observed and simulated value after validation

4.3. Performance Evaluation

For this study, the performance evaluation criteria during calibration and validation model were Nash Sutcliff efficiency (NSE), Coefficient of determination (R^2), Root mean square error (RMSE), Percent bias (PBIAS), Percent error in peak flow (PEPF), and Percent error in volume (PEV). (Arnold *et al.*, 2015) investigated model evaluation criteria for systematic quantification of accuracy in Watershed simulations, concluding that for a model to be successful and very successful, the NSE and R^2 values to be between 0.7 to 1, the RMSE value to be 0 to 0.5, and PBIAS is between the range of ≤±10%, respectively. Hence, the NSE and R^2 values in this study were 0.702 and 0.7143, and 0.707 and 0.743, during the calibration and validation periods, while also in terms of RMSE and PBIAS, the value of RMSE (0.5) and PBIAS (-2.04% and -14.61%) during model calibration and validation. Therefore, the HEC-HMS model's output rating was rated as successful (good) and very successful (very good) based on these statistical error test parameters. The result obtained concludes that the model worked well based on the critical values.

Table 4. 6. Summary of Performance Evaluation Model

Performance Evaluators	After calibration	After validation	Remarks
Nash Sutcliff efficiency (NSE)	0.702	0.707	Good
Coefficient of determination (R2)	0.714	0.743	Good
Root mean square error (RMSE)	0.5	0.5	Very good
Percent error in peak flow (PEPF)	8.764	8.15	Very good
Percent error in volume (PEV)	2.035	9.585	Very good

As the study reported by (Roy *et al.*, 2013), the NSE, R2, RMSE, PEV, and PEPF were used for performance evaluation, have been found to range from (0.7-0.84), (0.7-1.0), (0-0.5), (4.39-19.47%), (1.9 to 19%), respectively, indicating the good performance of the model for simulation of streamflow and thereby quantification of available water. For this study, the performance evaluation criteria's found to be within the recommended ranges, based on these statistical test error parameters, and the model was well predicted for both calibration and validation.

The observed and simulated streamflow values were relatively similar to each other, as shown by the calibration and validation results, which indicates a good relationship. As a result, the concept of the Rainfall-Runoff simulation for the Hanger Watershed was completed. All of the performance assessment parameters prove that the simulation is within the recommended ranges, which contributes to the modeling goal. In general, the model's performance evaluation revealed a good correlation between the simulated and observed flows, indicating that the model worked well for the Hanger watershed.

4.4. Daily Runoff Potential of the Watershed

The first step in estimating the watershed runoff yield on a daily, weekly, or annual basis is to test the efficiency or performance of any runoff hydrological model. The quantity of runoff from a watershed must be determined before hydraulic structures such as storm sewers, ditches, culverts, dams, weirs, and retention basins at the watershed's outlet can be built. The normal watershed runoff was created after HEC-HMS model calibration and validation from January 1, 1990, to December 31, 2014.

The validated HEC-HMS model was used to measure the maximum peak discharge for various hydrologic elements such as the watershed, reach, junction, and outlet. We know the maximum and minimum values of the watershed's runoff potential after calibrating and validating the HEC-HMS model. The average of the watershed's daily runoff potential was estimated using an Excel sheet by adding all of the watershed's daily runoff potential and dividing by the number of years. Therefore, the watershed's average daily runoff capacity was 233.51 m^3/s.

Figure 4.6. depicted that the maximum runoff potential of the watershed occurred in August month of the year 1990 (949.4 m^3/s),1994 (934 m^3/s), 1998 (919.3 m^3/s), and 2004 (938.8 m^3/s), as well as the minimum values of the runoff potential of the watershed, was on October 2, 2000 (585.8m^3/s) and September 2, 1991 (601 m^3/s). Generally, as seen from figure 4.6 one year increased the next decreased, and so on. Site observations at various times and years, as well as land use land cover information collected from various sources, revealed that the study area of land use land cover was changed, having a significant impact on runoff.

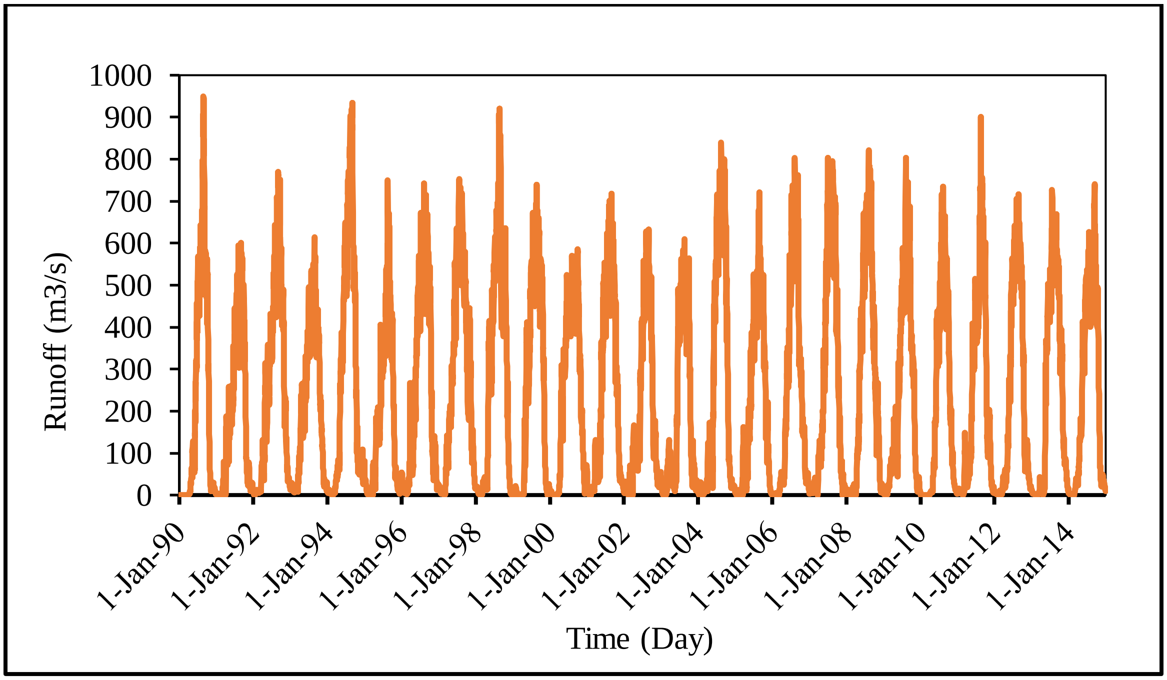


Figure 4. 6. Daily runoff potential of the watershed.

4.5. Frequency Storm Method Analysis

The 0.083hr, 0.25hr,1hr,2hr,6hr,12hr, and 24hr duration rainfall depth for the corresponding return period was (equation 3.17 and table 4.7) computed from the ERA drainage manual. As it can be seen from table 4.7, every return period under consideration has maximum rainfall depth during the 24hr.

Table 4. 7. Rainfall depth (mm) vs Return period (yr) for the Hanger watershed

Rainfall intensity duration	Rainfall depth (mm) versus return periods (yr)						
	2	5	10	25	50	100	200
0.083	5.8	14.4	16.3	18.8	20.6	22.5	24.3
0.25	15.7	30.2	34.3	39.4	43.3	47.2	51.0
1	40.44	51.0	58.0	66.7	73.3	79.8	86.4
2	45.71	57.7	65.5	75.5	82.8	90.2	97.6
3	47.79	60.3	68.5	78.9	86.6	94.3	102.1
6	50.07	63.2	71.8	82.6	90.7	98.8	106.9
12	51.29	64.7	73.5	84.7	92.9	101.2	109.6
24	51.9	65.5	74.5	85.7	94.1	102.5	110.9

The computed rainfall depth for each rainfall duration corresponding to the return period was used in HEC-HMS to generate peak discharge for each return period. After model setup was adjusted using different parameters and model validation was carried out using daily time series data a 0.083hr, 0.25hr, 1hr, 2hr, 3hr, 6hr, 12hr, and 24hr rainfall depth provided on (Table 4.8) was inserted into HEC-HMS for the computation of 2,5, 10, 25, 50,100, and 200 year return period peak flood.

Table 4. 8. HEC-HMS Result of Peak Discharge Obtained for Different Return Period

s/no	Return period (yr)	Peak flow (m^3/s)
1	2	608.4
2	5	967.2
3	10	1225.2
4	25	1565.9
5	50	1830.6
6	100	2103.2
7	200	2382.7

From table 4.8 result the minimum and maximum peak flow for the Hanger watershed occurred in a 2-year return period and 200-year return period for 24-hour storm duration were 608.4 m^3/s, and 2382.7 m^3/s, respectively. Using the HEC-HMS model the graph of storm flow hydrograph for 2-year return period and 200-year return period shown in figure 4.7 and figure 4.8 are as the sample. The remaining graphs of 5-year, 10-year, 25-year, 50-year, and 100-year flood storm are shown in Appendix-5 (figure 5.3).

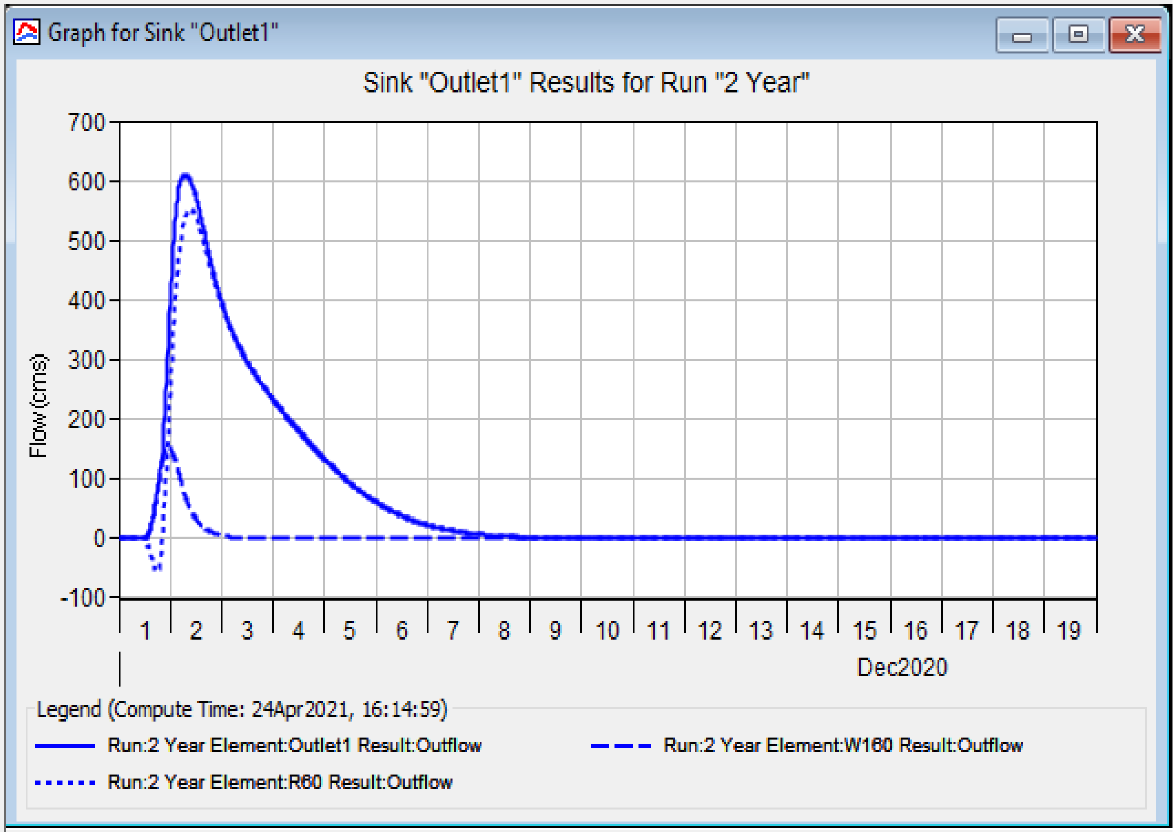


Figure 4. 7. 2-Year Storm Flow Hydrograph of Hanger Watershed

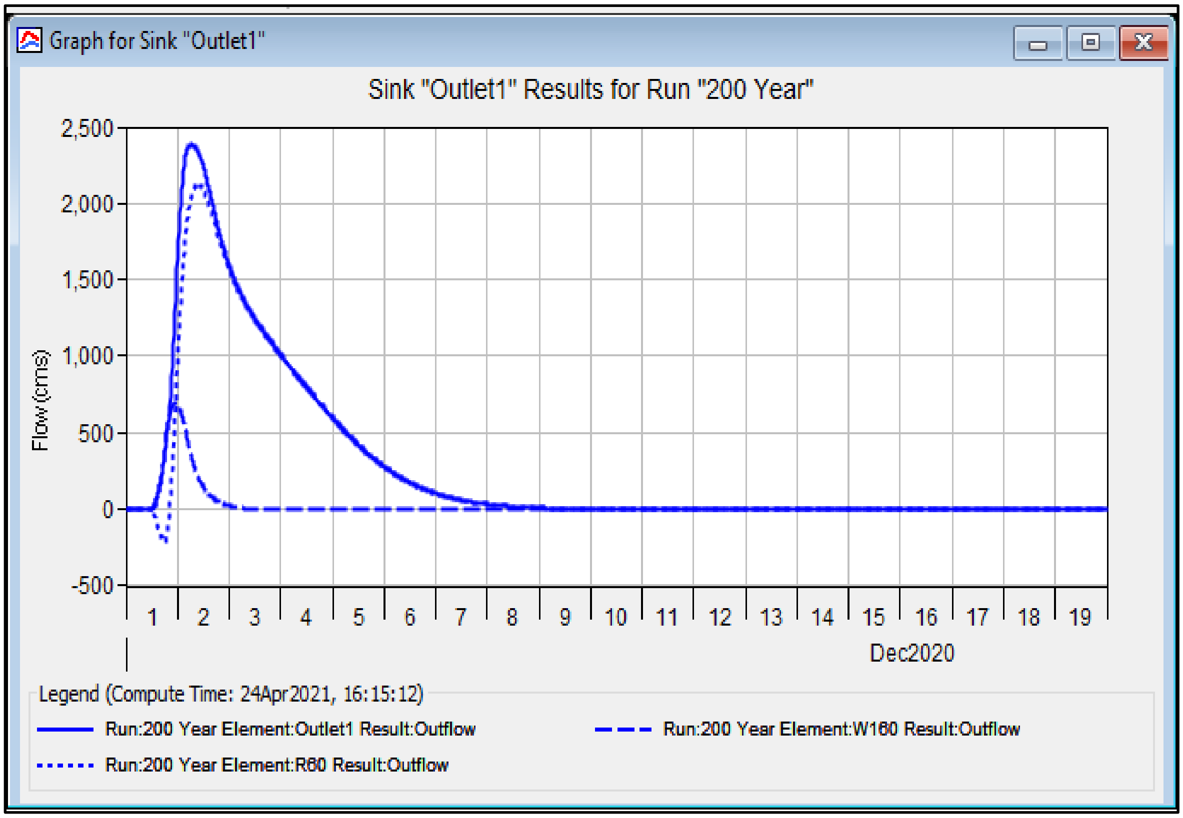


Figure 4. 8. 200-Year Storm Flow Hydrograph of Hanger Watershed

As can be seen from figure 4.8 and table 4.8 the frequency of storms estimated to be occurring in the coming 200 years is very big compared to the discharges obtained from other years. So it is recommended that, the design of the hydraulic structure that will be constructed across the river should consider this maximum flood, to minimize the negative impact that comes from the flood.

Finally, using the parameters obtained from the daily basis the model results in peak flows for different return period, the output peak streamflow from the HEC-HMS provides from the daily basis of rainfall depth of 24-hour the model predicts peak flows for the return periods of 2-year, 5-Year, 10-year, 25-year, 50-year, 100-year, and 200-year, and the analyzed flow values are shown in (figure 4.9).

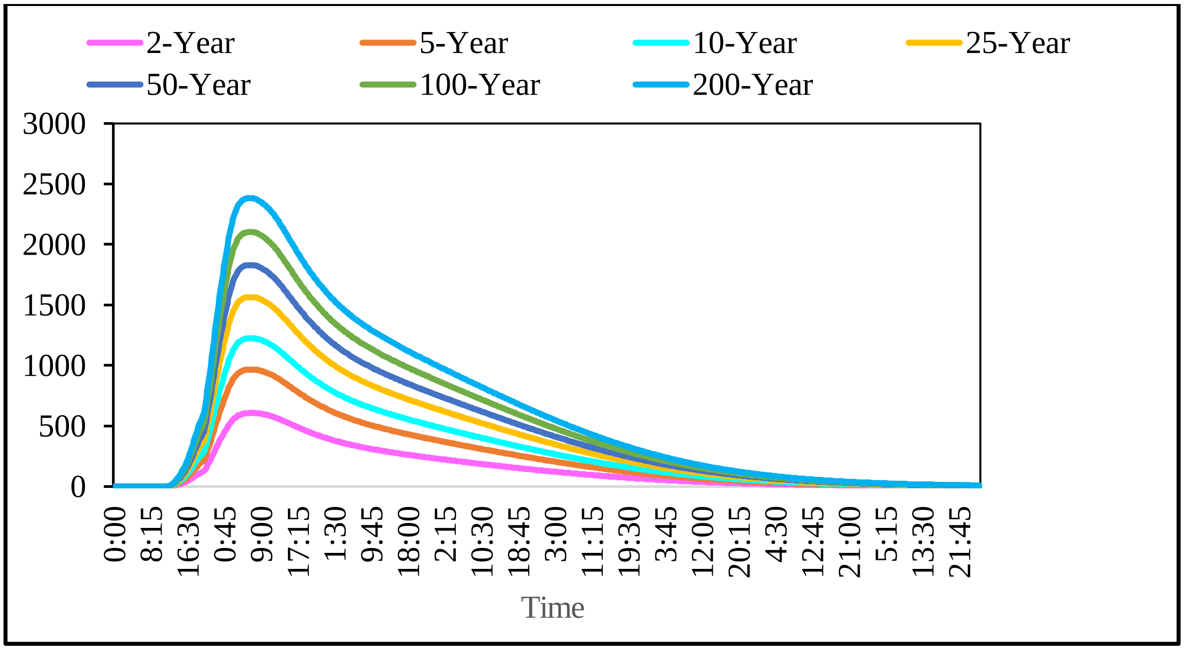


Figure 4. 9. Analysis of Peak Flood by HEC-HMS.

4.5.1. Comparison of HEC-HMS Result with other Frequency Analysis Methods

The HEC- HMS result found is compared with different techniques of frequency analysis like General Extreme Value, and Log Pearson Type 3 are selected for this study, based on the statistical distribution methods using easy fit software discussed under the methodology section. Therefore, the peak discharge for each return period for the selected distribution methods was compared with HEC-HMS frequency analysis methods in table 4.9.

Table 4. 9. Flood frequency analysis and results of HEC-HMS comparison

Return period	Discharge (m3/s)		
	HEC-HMS	Gen.Extreme Value	Log Pearson-III
2	608.4	600.7	559.6
5	967.2	895.8	738.9
10	1225.2	1180.6	956.4
25	1565.9	1394.9	1193.2
50	1830.6	1772.3	1286.4
100	2103.2	1962.5	1582.5
200	2382.7	2243.8	1708.9

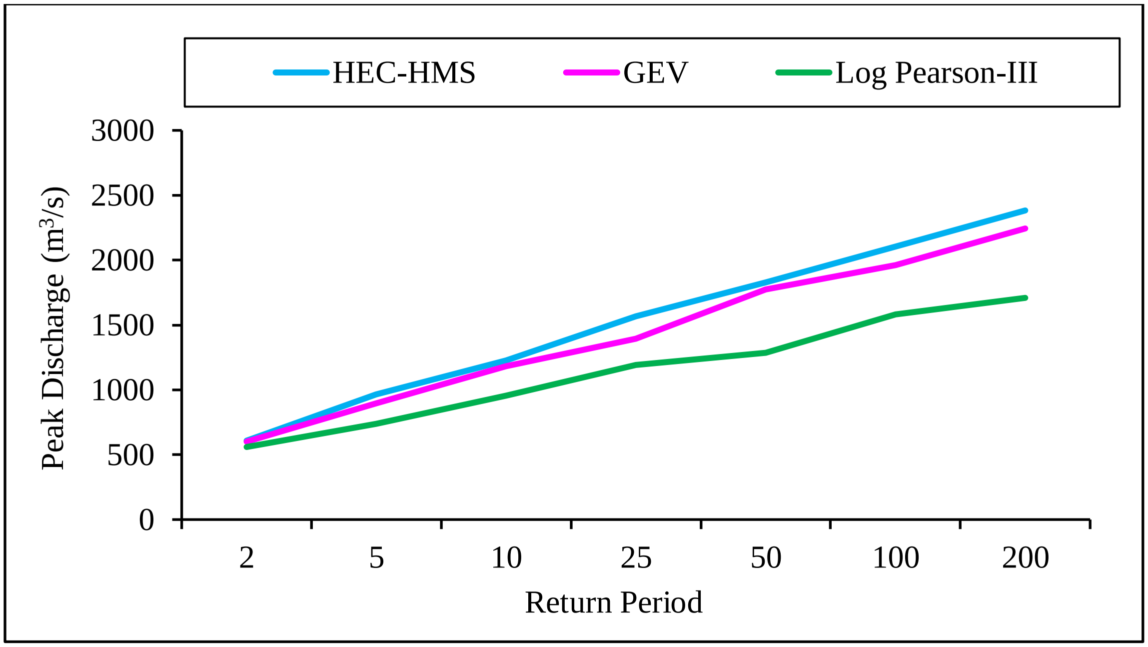


Figure 4. 10. HEC-HMS and flood frequency methods comparison analysis

As it is seen from table 4.11 and figure 4.10 the frequency discharge value derived using General Extreme Value method show high similarity than the Log Pearson type-III distribution method. This implies the HEC-HMS model shows the good performance of Frequency analysis for the Hanger watershed. However, the peak flood predicted by HEC-HMS was greater than the peak flood computed by the General Extreme Value method. This indicates that the simulated peak discharge by the HEC-HMS model can further used for flood mapping and mitigation measures.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

HEC-HMS model was used to simulate rainfall-runoff for the Hanger watershed of Abbay basin, Ethiopia. In addition to streamflow and precipitation data, curve number, initial abstraction, basin lag, maximum potential retention, Muskingum k, and Muskingum x were used as input data for rainfall-runoff simulation in the Hanger watershed.

HEC-Geo HMS was used to produce a curve number and a basin lag time. The Soil Conservation Service Curve Number (SCS-CN), Soil Conservation Service Unit Hydrograph (SCS-UH), constant monthly, and Muskingum method were used to compute the rainfall loss component, runoff component, base flow modeling, and channel routing, respectively.

To know the most influential parameter in the simulation, a sensitivity analysis was carried out and the results showed that Muskingum k and Muskingum x were the most sensitive. The model was calibrated using 20 years (1990-2009) and validated using 5 years (2010-2014) daily streamflow data, respectively. The Statistical test of error functions for rainfall-runoff simulation in the Hanger watershed like Nash-Sutcliffe efficiency (NSE), Coefficient of determination (R^2), Root mean square error (RMSE), Percent bias (PBIAS), Percent error in volume (PEV), and Percent error in peak flow (PEPF) were used to check the model performance in HEC-HMS by graphical and visual interpretation and found to be 0.702, 0.714, 0.5, -2.04%, 2.035, and 8.764, respectively during calibration and 0.707,0.743, 0.5, -14.61%, 14.585 and 8.15, respectively in the validation period.

The flood discharge of different return periods of 2, 5, 10, 25, 50, 100, and 200 years was calculated using different statistical methods such as General Extreme Value and Log Pearson Type-III, and compared to HEC-HMS result, with General Extreme Value (GEV) showing a high degree of similarity to HEC-HMS. According to the findings of the flood frequency analysis, the peak flow in the Hanger watershed may increase. This could have both positive and negative implications for the region's socio-economic situation. The increased flow would aid in the capture of a considerable amount of water for agricultural purposes, whether for irrigation or other purposes. However, it may exacerbate the study area's recurring flooding problems, especially for those who live on the downstream sides.

5.2. Recommendation

Even if the best simulation result is obtained from each model, it is necessary to investigate the performance of other hydrologic models to compare catchment behavior and impact statistics. The quality of data available is more important than anything else in model calibration and to improve the model consistency, the number of meteorological stations inside and outside the basin should be increased.

The HEC-HMS models were extremely difficult to implement, and a lack of appropriate data was one of the most pressing concerns throughout. The model implementation is extremely difficult without adequate data. For developing countries like Ethiopia, new data collection techniques should be considered so that local and regional authorities can engage in integrated and organized data compilation. The HEC-HMS model performance for the study area should be checked by selecting a different combination of direct runoff losses, base flow, and routing methods other than the methods considered in this study. Then it can be used for runoff estimation of other catchment or at a basin level with similar physical characteristics of the study area. Effective watershed management strategies should be implemented to minimize the effect of man-made activities and natural phenomena on daily watershed runoff.

In the watershed, a thorough assessment of flood inundation and mapping should be carried out to determine the region that is likely to be impacted by historical floods and to provide accurate time measurements.

REFERENCES

Abushandi, E. (2013) Modelling rainfall-runoff relations using HEC-HMS and IHACRES for a single rain event in an arid region of Jordan.

Arekhi Saleh, R. G. and R. N. (2016) Evaluation of HEC-HMS methods in surface runoff simulation

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., Santhi, C., Harmel, R. D., M. K. (2015). HEC-HMS: Model use Calibration, and Validation. American Society of Agricultural and Biological Engineering, 55(4), 1491–1508.

Awulachew, Seleshi Bekele; Ahmed, A. A. et al. (2010) 'CPWF Project Report', CPWF Project Report.

Aytek, A., Asce, M. and Alp, M. (2008) An application of artificial intelligence for rainfall-runoff modeling, (2), pp. 145–155.

Azmat, M. et al. (2016) Hydrological modeling to simulate streamflow under changing climate in a scarcely gauged cryosphere catchment, Environmental Earth Sciences. Springer Berlin Heidelberg.

Baharudin (2007) A Study on Rainfall-Runoff Characteristics of Urban Catchment of Sungai Kerayong By Fauzi Bin Baharudin

Berhane, Solomon; Zemadim, Birhanu; M.Melesse, A. (2013) Rainfall-Runoff Processes, and Modeling: The Case of Meja Watershed in the Upper Blue Nile Basin of Ethiopia, pp. 183-206.

Beven (2000) Rainfall-Runoff modeling Book 2nd edition.

Beven, K. (2012) Rainfall-Runoff Modelling.

Beven Keith and Freer Jim (2001) A dynamic TOPMODEL, 15, pp. 1993–2011.

Campling, P. et al. (2002) 'Rainfall-runoff modeling of a humid tropical catchment: The TOPMODEL approach, Hydrological Processes, 16(2), pp. 231–253.

Chelangat, G. (2014) Applicability of the HEC-HMS Model in Poorly Gauged Catchments: Study of the Upper Mara River Basin, Kenya, Szent István University, Pp. 1–80.

Choudhari, Kishor;panigrahi Balram; paul, Jagadish, C. (2014) Simulation of the rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India, International Journal of Geomatics and Geosciences, 5(2), pp. 253–265.

Chow Te VE, Maidment, David R, Mays, L. (1988) Applied_Hydrology.

Cunderlik, J. M. (2003) Hydrologic model selection for the CFCAS project: Assessment of water resources risk and vulnerability to changing climatic conditions, Water Resources Research Report.

Cunderlik, J. M. and Simonovic, S. P. (2007) Hydrologic Models for Inverse Climate Change Impact Modeling, pp. 1–9.

Dawson, 2007. A web-based toolbox of evaluation metrics for the standardized assessment of hydrological forecasts. In: See LM. Hydro Test: Environ Model Software, p. 1034–1052.

Demelesh Wondimagenewu and Kassa Tadele (2015) Evaluation of climate change impact on Blue Nile Basin Cascade Reservoir operation – case study of proposed reservoirs in the Main Blue Nile River Basin , Ethiopia, p. 5194.

Devi, G. K., PB, Ganasri, G. S. and Dwarakish (2015) ‘A Review on Hydrological Models, 4(Icwrcoe), pp. 1001–1007.

ERA, 2013. ERA Drainage Design manual. Addis Ababa: Ethiopian Roads Authority.

Fetene, Fikadu; Awulachew, Seleshi, Bekele ; Teklie, N. (2008) Development of Rainfall-Runoff-Sediment Discharge Relationship in the Blue Nile Basin,

Fleming, M.J., Gibson, S.A., Pak, J. H. (2011) Modeling Watershed and Riverine Sediment Processes with HEC-HMS and HEC-RAS, pp. 1340–1349.

Gharib, M.; Motamedvaziri, B.; Ghermezcheshmeh, B.; Ahmadi, H. Evaluation of ModClark Model for Simulating Rainfall-Runoff in Tangrah Watershed, Iran.Appl. Ecol. Env. Res.2018, 16, 1053–1068.

Garg (2005) Garg _Irriagtion Engineering & Hydraulic Structures.

Gautam, N. P. (2016) Assessment of the Flow at the Chatara on Koshi River Basin using Semi Distributed Model, Journal of the Institute of Engineering, 12(1), pp. 184–198.

Gebre, S. L. (2015) Application of the HEC-HMS Model for Runoff Simulation of Upper Blue Nile

River Basin, Journal of Waste Water Treatment & Analysis, 06(02).

Gupta, S. K., and Gunwant, Sharma; Tyagi Jaivir, A. S. J. and Gupta naveer kumara (2015) A critical review of hydrological models.

Hailu, Y. A. and D. (2014) Assessment of the use of Remotely Sensed Rainfall Products for Runoff Simulation in the Upper Blue Nile Basin of Ethiopia

Halwatura, D. and Najim, M. M. M. (2013) Application of the HEC-HMS model for runoff simulation in a tropical catchment, Environmental Modelling, and Software, 46, pp. 155–162.

Hirp, Y. H. (2005) Regionalization of Parameters of a Conceptual Rainfall-Runoff Model, Institut für Wasserbau der Universität Stuttgart.

Tarboton, Istanbulluoglu, E., D. G. and Pack, R. T. (2003) A sediment transport model for incision of gullies on steep topography, 39(4), pp. 1–15.

Jain, Sanjay K; Tyagi, Jaivir and Singh, V. (2010) Simulation of Runoff and Sediment Yield for a Himalayan Watershed Using SWAT Model.

Johnson, M. S. et al. (2003) Application of two hydrologic models with different runoff mechanisms to a hillslope dominated watershed in the northeastern US : A comparison of HSPF and SMR, 284, pp. 57–76.

Karamouz, M. and Szidarovszky, Ferenc and Zahraie, B. (2013) Water Resources.

Kumar, R. et al. (2020) Land use and land cover change and its resultant erosion susceptible level.

Legesse, E. S. (2009) Modeling Rainfall-Runoff Relationships For The Anjeni Watershed in The Blue Nile Basin, Cornell University.

Lemenih, M., Feleke, S. & Tadesse, W., 2006. Constraints to smallholder production of frankincense in Metema district, North-western Ethiopia.

Lenhart, T. et al. (2002) Comparison of two different approaches of sensitivity analysis, 27, pp. 645–654.

Liew, M. W. Van, and Garbrecht, J. (2003) Hydrologic Simulation of The Little Washita River Experimental Watershed Using SWAT, Journal of the American Water Resources Association, 2(39), Pp. 413–426.

Majidi, A. and Shahedi, K. (2012) Simulation of Rainfall-Runoff Process Using Green-Ampt Method and HEC-HMS Model (Case Study: Abnama Watershed, Iran), International Journal of Hydraulic, 1(1), pp. 5–9.

Mccoll, C. and Aggett, G. (2007) Land-use forecasting and hydrologic model integration for improved land-use decision support, 84, pp. 494–512.

Mengistu, K. T. (2009) Watershed Hydrological Responses to Changes in Land Use and Land Cover, and Management Practices at Hare Watershed, Ethiopia.

Moradkhani, H. and Sorooshian, S. (2009) General Review of Rainfall-Runoff Modeling : Model Calibration, Data Assimilation, and Uncertainty Analysis, pp. 1–24.

Moriasi, D. N, Arnold, J . G; Liew, M W Van, Bingner, R L; Harmel, R D and Veith, T. L. (2007) 50(3), pp. 885–900.

Oleyiblo, James Oloche;Li, Z.-J. (2010) Application of HEC-HMS for flood forecasting in Misai and Wan'an catchments in China', Water Science and Engineering, 3(1), pp. 14–22.

OWWDSE, (2015) Orochan medium scale irrigation project Design material

Pakgohar, A. (2014) Using Easy Fit Software for Goodness-of-Fit Test and Data Generation. International Journal of Mathematical Archive-5 (1), 7(118-124).

Pechlivanidis, I. G. et al. (2011) Catchment Scale Hydrological Modelling : A Review Of Model Types, Calibration Approaches And Uncertainty Analysis Methods in the Context of Recent Developments in Technology, 13(3), pp. 193–214.

Raes, D., Willems, P. and Gbaguidi, F. (2015). RAINBOW–A software package for hydro-meteorological frequency analysis and testing the homogeneity of historical data sets. In Proceedings of the 4th International Workshop on Sustainable management of marginal drylands. Islamabad, Pakistan (Vol. 2731).

Ramly, S. and Tahir, W. (2006) Application of HEC-GeoHMS and HEC-HMS as Rainfall-Runoff Model for Flood Simulation.

Rathod, P. et al. (2015a) Simulation of Rainfall-Runoff Process Using HEC-HMS (Case Study : Tapi River, India)

Razi, M.A.M; Tahir, Ariffin.M and Arish, N. A. (2010) Flood Estimation Studies using Hydrologic

Modeling System (HEC- HMS) for Johor River, Malaysia.

Rinsema, J. G. (2014) Comparison of rainfall-runoff models for the Florentine Catchment Comparison of rainfall-runoff models.

Rostaee, S. et al. (2018) Rainfall and Runoff Estimation Using HEC HMS Models and RSGIS Techniques for Nekaroud Basin, North Iran.

Roy S. B., S. Ghosh, and S. Jana. (2013). Calibration and Validation of HEC-HMS Model for A River Basin in Eastern India. ARPN Journal of Engineering and Applied Sciences, Vol.8.

Saleh, Arekhi; Ghobad, Rostamized, and Rostami, N. (2011) Evaluation of HEC-HMS methods in surface runoff simulation (Case study : Kan Watershed, Iran), Advances in Environmental Biology, 5(6).

Sardoii, E. R. et al. (2012) Calibration of loss estimation methods in HEC-HMS for simulation of surface runoff (Case Study: Amirkabir Dam Watershed, Iran), 6(1), pp. 343–348.

Singhie., J.H., Knapp, V. & Demises, M., 2004. Hydrologic modeling of the Iroquois River watershed using HSPF and SWAT. ISWS CR 2004-08. Champaign, Ill.: Illinois State Water Survey. Available at. [Online].

Scharffenberg, W. et al. (2010) Hydrologic Modeling System (Hec-Hms): Physically-Based Simulation Components, 2nd Joint Federal Interagency Conference, p. 8.

Seibert, Jan, and Vis, M. J. P. (2012) software package Teaching hydrological modeling with a user-friendly catchment-runoff-model software package.

Shaikh, M. P. and Yadav, Vipinkumar G and Yadav, S. M. (2018) Simulation of Rainfall-Runoff Event Using HEC-HMS Model For Rel Sub-Basin, Gujarat, India, Journal of Emerging Technologies And Innovative Research, 5(4), pp. 402–407.

Shrestha, M.S; Artan, G.A, Bajracharya, S.R; Guatam, D.K, Tokar, S. . (2011) Bias - adjusted satellite-based rainfall estimates for predicting floods : Narayani Basin, pp. 2016–2030.

Silberstein, R. P. (2006) Hydrological models are so good, do we still need data? Environmental Modelling and Software, 21(9), pp. 1340–1352.

Singh, M. and (2003) Soil conservation service curve number (SCS-CN) methodology.

Singh, V. P. et al. (2002) Mathematical Modeling of Watershed Hydrology, pp. 270–292.

Sitterson, Jan, Knights, Chris , Parmar, rajbil, Wolfe, Kurt, Muluken, M. (2017) An Overview of Rainfall-Runoff Model Types, United States Environmental Protection Agency(EPA), 14(152).

Soroosh Sorooshian ; Kuo-Lin Hsu; Erika Coppola ; Barbara Tomassetti ; Marco Verdecchia and Guido Visconti (2008) Hydrological modeling and the water cycle: Coupling the Atmospheric and Hydrological Models.

Spruill, C. A. and Workman, Stephen R, Taraba, J. (2000) Simulation of Daily and Monthly Stream Discharge from Small Watersheds Using the SWAT Model'.

Stefan; U. and Nils, R. S. andTilch (2004) 'Hydrological process representation at the mesoscale : the potential of a distributed , conceptual catchment model', 291, pp. 278–296.

Subramanya, K. (2008) Engineering Hydrology Book.

Supriya, P. and Krishnaveni, M. (2016) Comparing the Performance of Rainfall-Runoff Models For Chinnar And Anaivari Odai Sub-Basins.

Tassew, Bitew G; Belete, M. A. ; K. M. (2019) Application of HEC-HMS Model for Flow Simulation in the Lake Tana Basin: The Case of Gilgel Abay Catchment, Upper Blue Nile Basin, Ethiopia, Journal of Hydrology.

USCAE, 2000. Hydrologic Modeling System HEC-HMS. Technical Reference Manual. US Army Corps of Engineers (USACE), Hydrologic Engineering Center, HEC. Davis, CA, USA.

USCAE (2013) Hydrologic Modeling System, US Army Corps of Engineers Hydrologic Engineering Center.

Vaze, J. et al. (2011) Calibration Info eWater.

Wagener, T. and McIntyre, N. (2005) Identification of rainfall-runoff models for operational applications, Hydrological Sciences Journal, 50(5), pp. 735–751.

Wagener, T. and Wheater, H. S. (2006) Parameter estimation and regionalization for continuous rainfall-runoff models including uncertainty', 320, pp. 132–154.

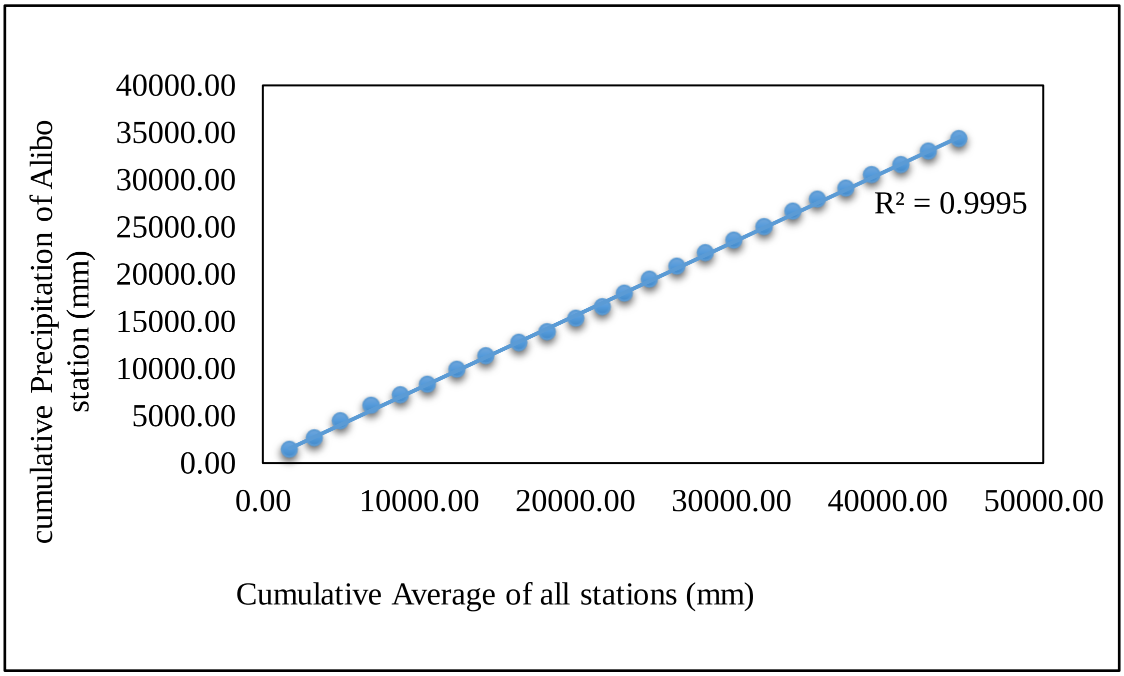
Yasmeen, Z, A. Zaidi, M. A. (2016) Rainfall-Runoff Modeling using Geospatial Techniques in

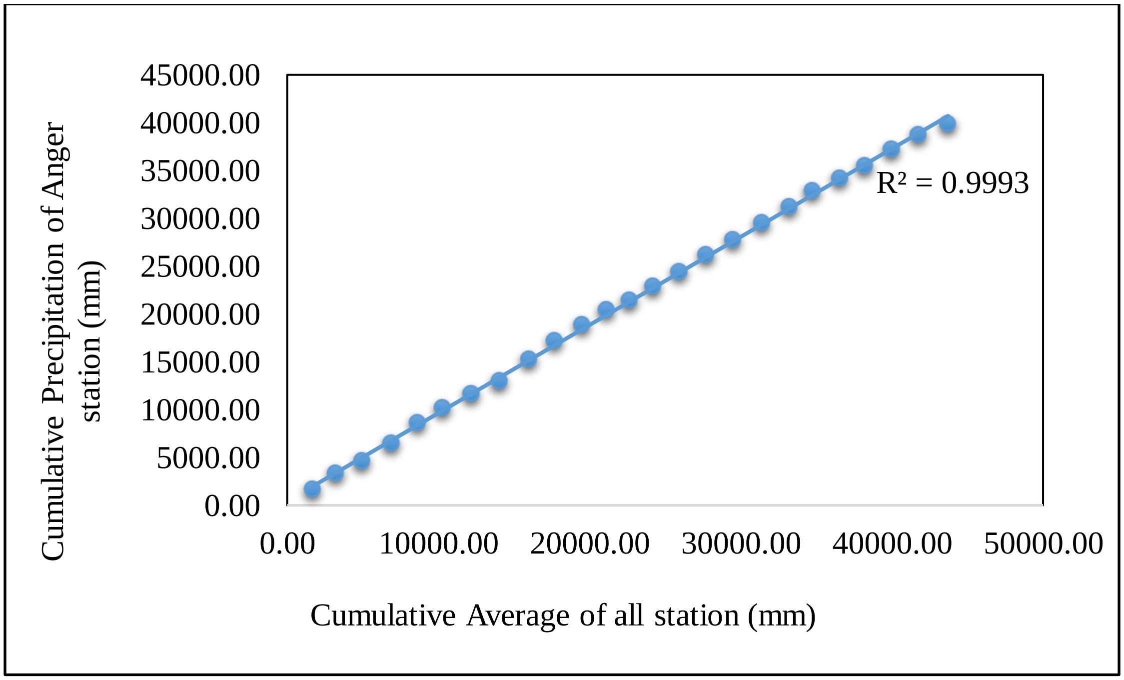
Tarbela Sub-catchment, 12(24), pp. 1–13.

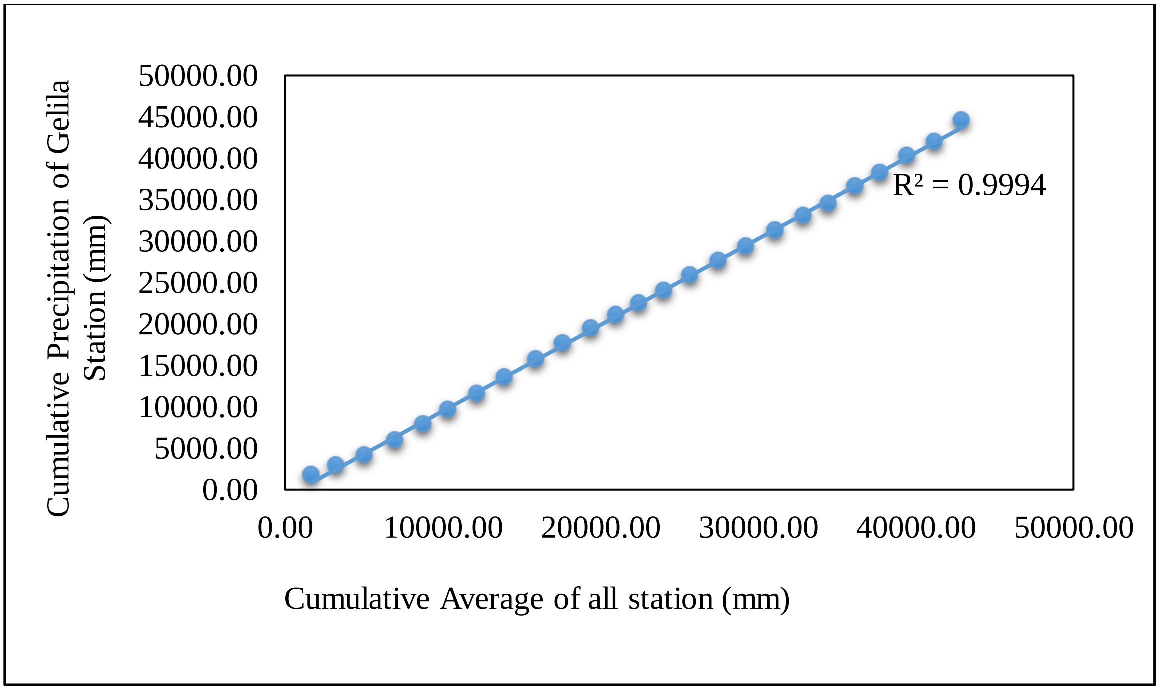
Zeberie, W. (2019) Modelling of Rainfall-Runoff Relationship in Big-Akaki Watershed, Upper Awash Basin , World News of Natural Science, 27, pp. 108–120.

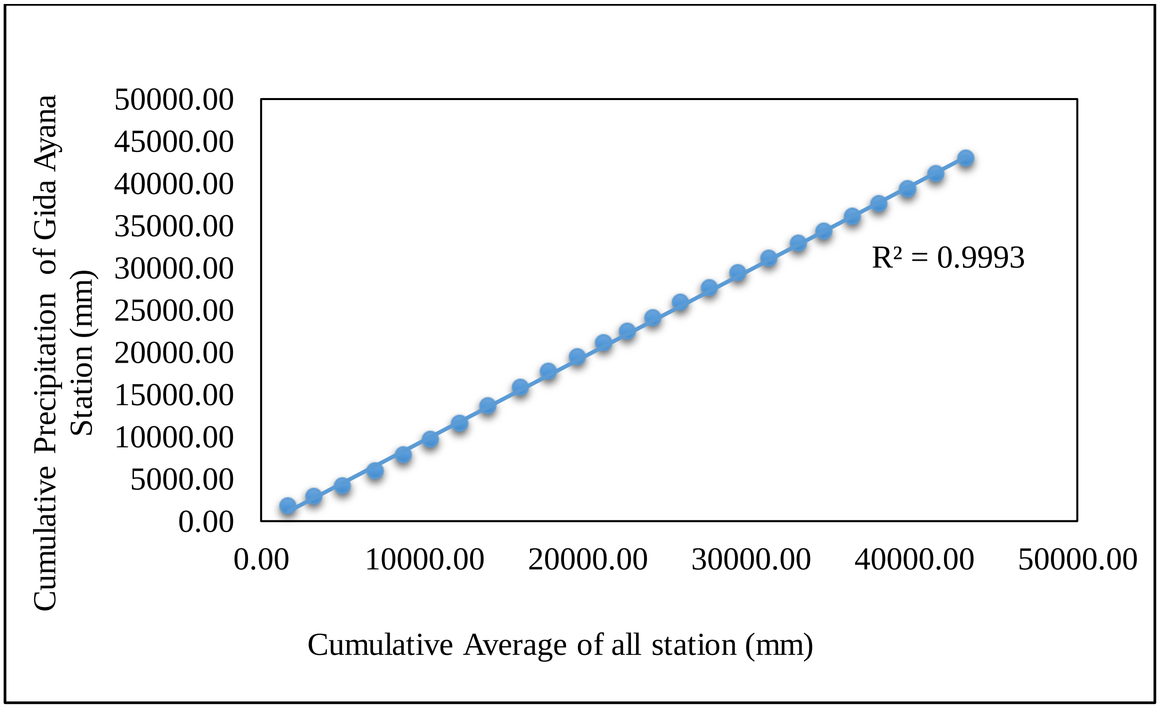
APPENDIXES

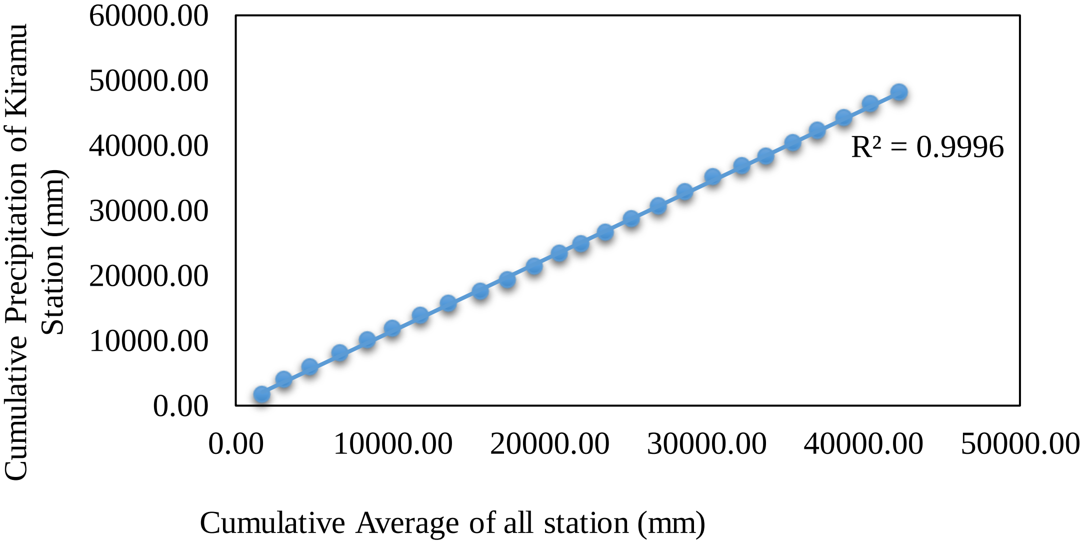
APPENDIX-1: RESULTS OF CONSISTENCY CHECK

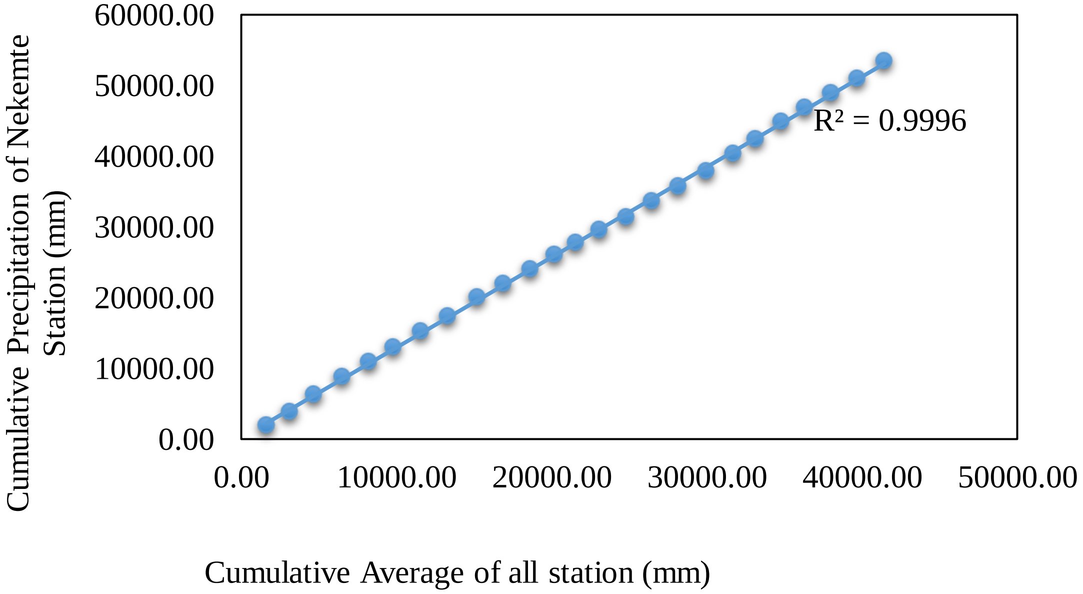





Cumulative Precipitation of Gelila Station (mm)
50000.00
45000.00
40000.00
35000.00
30000.00
25000.00
20000.00
15000.00
10000.00
5000.00
0.00
R² = 0.9994
0.00
10000.00
20000.00
30000.00
40000.00
50000.00
Cumulative Average of all station (mm)


Cumulative Precipitation of Gida Ayana Station (mm)
50000.00
45000.00
40000.00
35000.00
30000.00
25000.00
20000.00
15000.00
10000.00
5000.00
0.00
R² = 0.9993
0.00
10000.00
20000.00
30000.00
40000.00
50000.00
Cumulative Average of all station (mm)


Cumulative Precipitation of Kiramu Station (mm)
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
0.00
10000.00
20000.00
30000.00
40000.00
50000.00
Cumulative Average of all station (mm)
R² = 0.9996


Cumulative Precipitation of Nekemte Station (mm)
60000.00
50000.00
40000.00
30000.00
20000.00
10000.00
0.00
0.00
10000.00
20000.00
30000.00
40000.00
50000.00
Cumulative Average of all station (mm)
R² = 0.9996

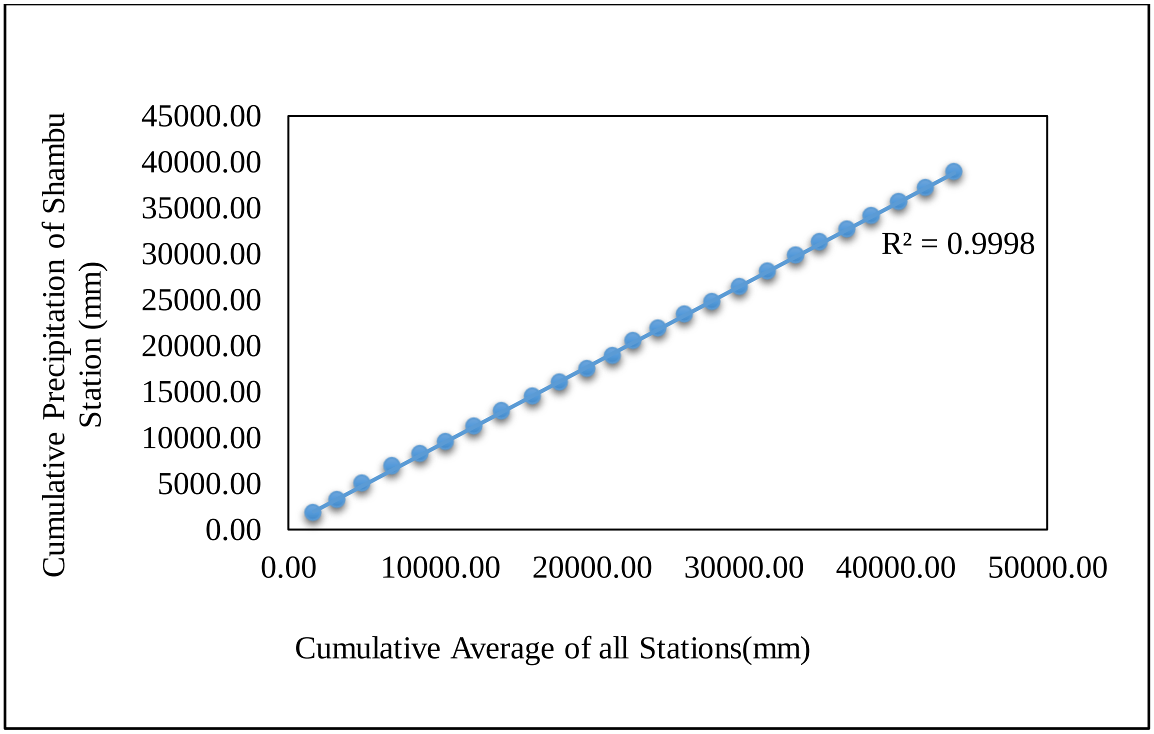
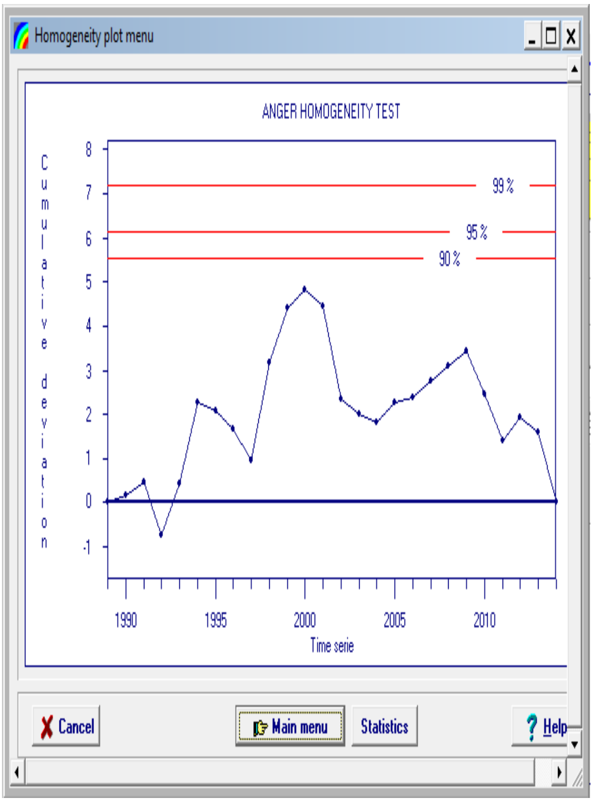
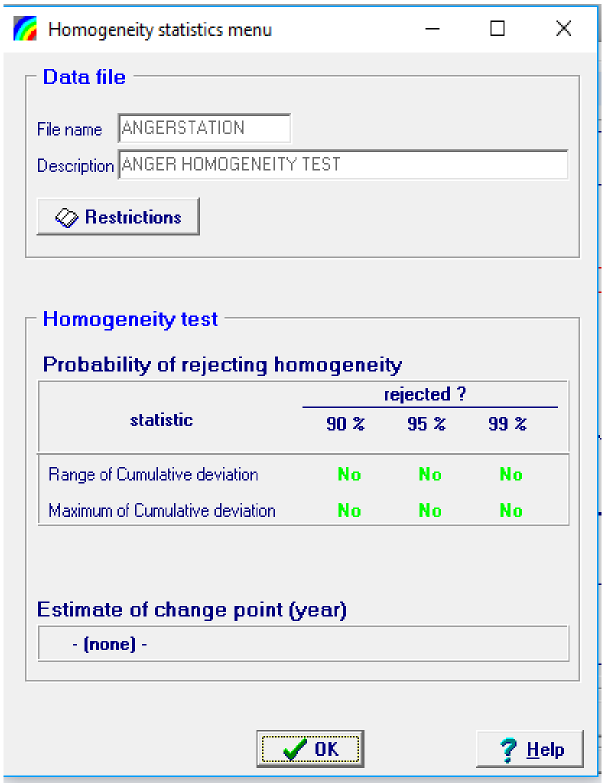


Figure 1.1. Consistency Check Results of Alibo, Anger, Gelila, Gida Ayana, Kiramu, Nekemte, and Shambu Stations, respectively.

APPENDIX-2: RESULTS OF HOMOGENEITY TESTS





Data file

File name: ANGERSTATION

Description: ANGER HOMOGENEITY TEST

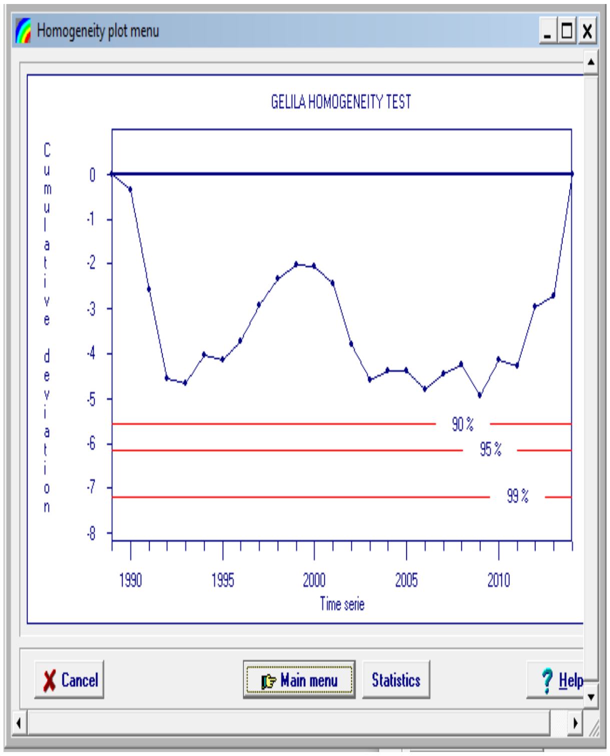
Homogeneity test

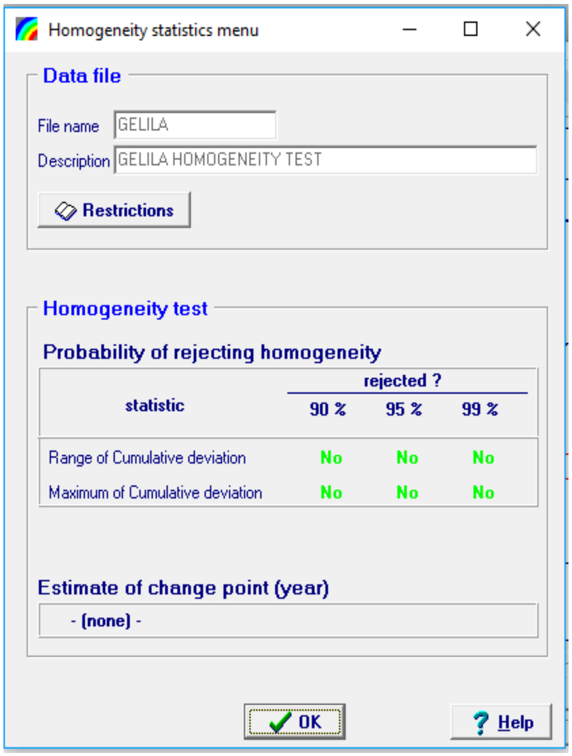
Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -





Data file

File name: GELILA

Description: GELILA HOMOGENEITY TEST

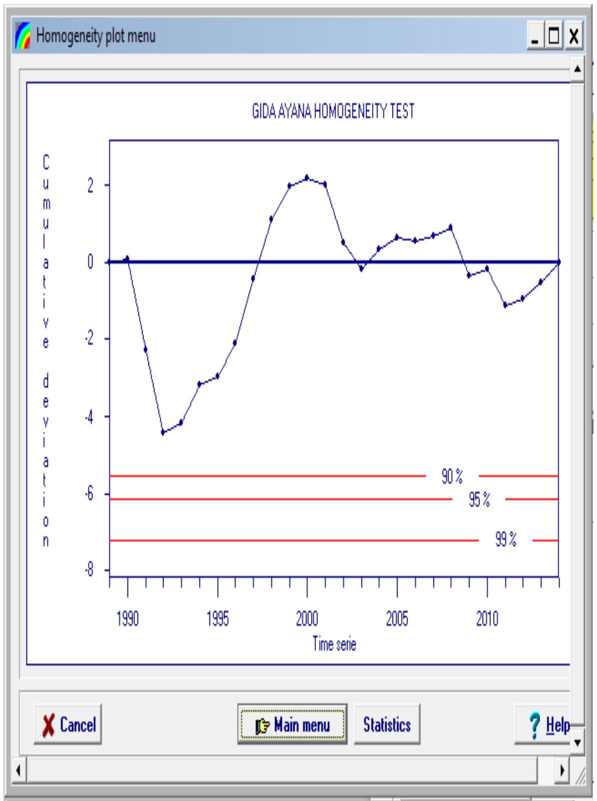
Homogeneity test

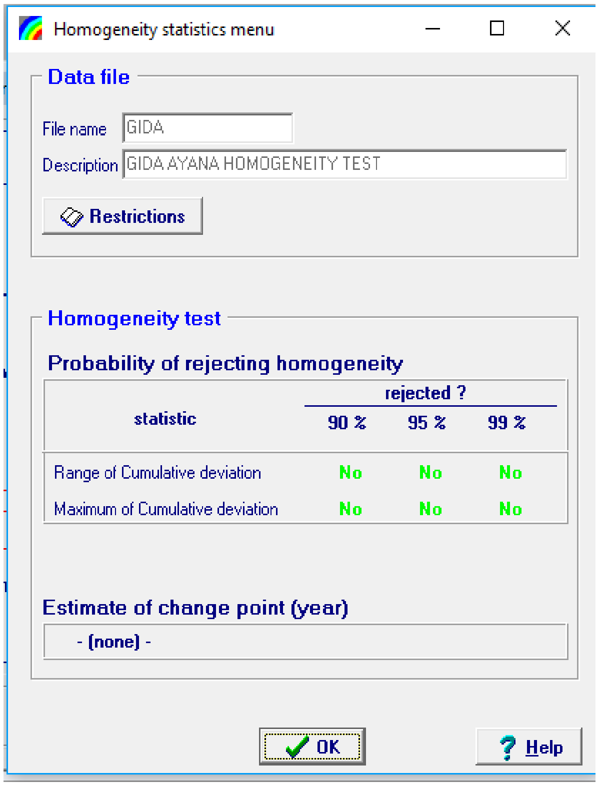
Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -





Data file

File name: GIDA

Description: GIDA AYANA HOMOGENEITY TEST

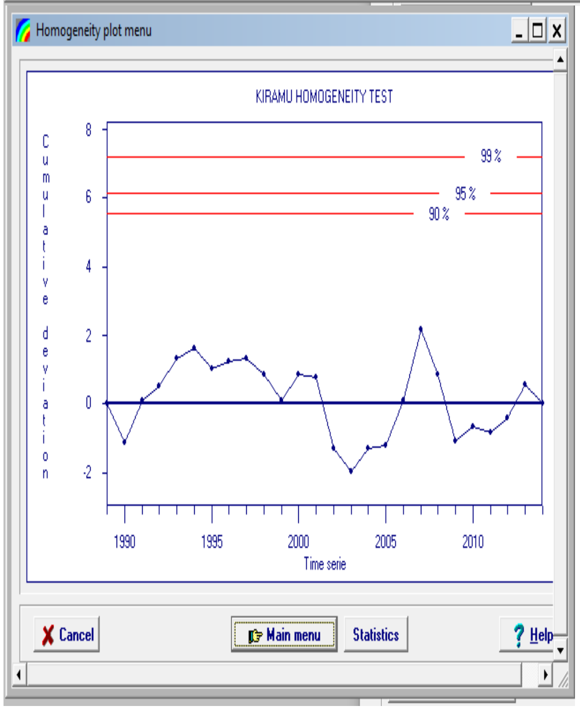
Homogeneity test

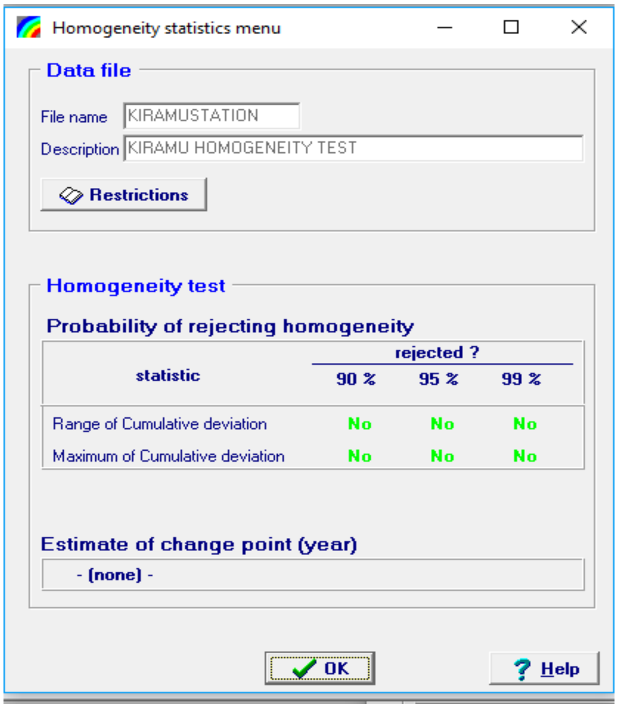
Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -





Data file

File name: KIRAMUSTATION

Description: KIRAMU HOMOGENEITY TEST

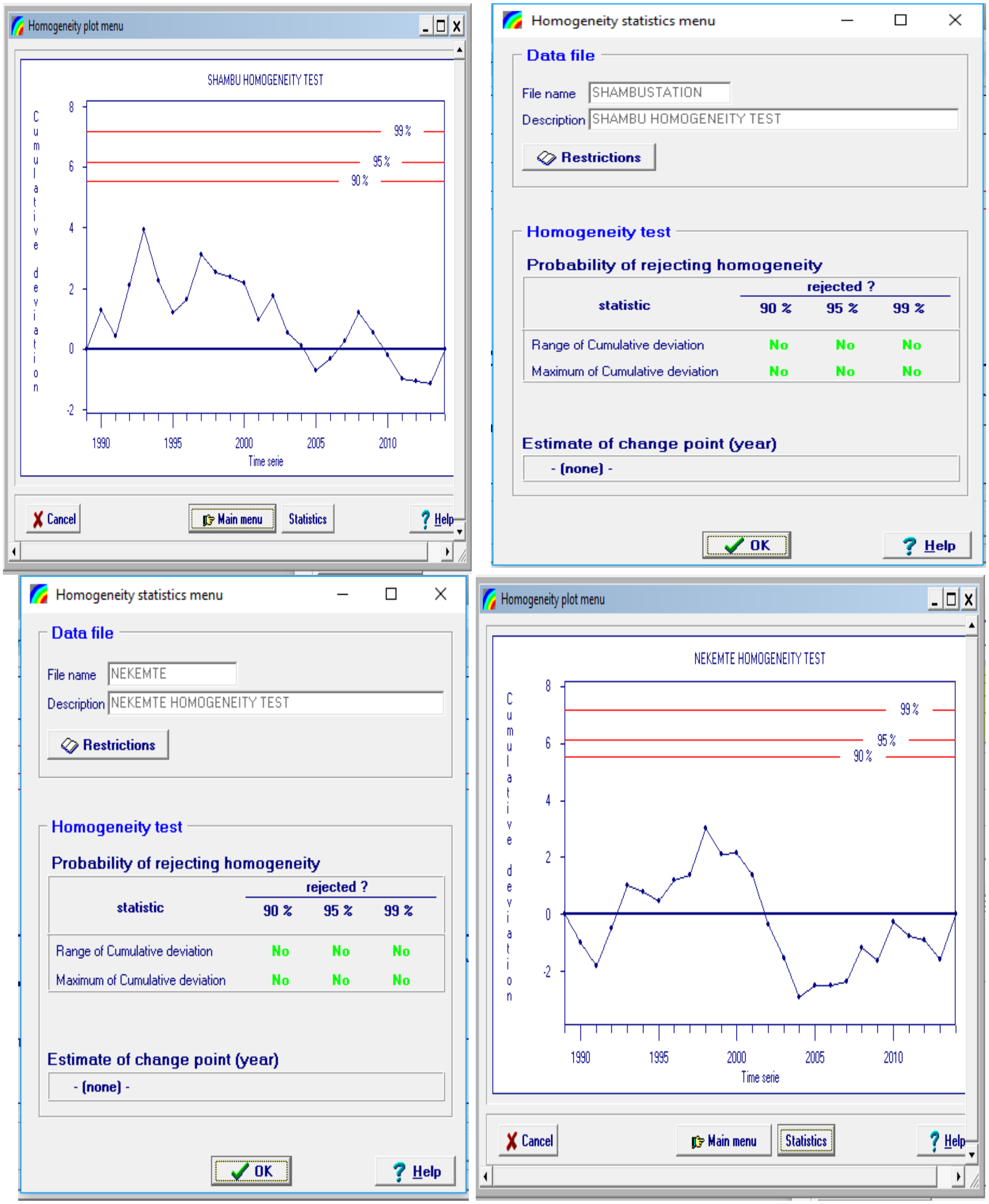
Homogeneity test

Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -



Homogeneity statistics menu

Data file

File name: SHAMBUSTATION

Description: SHAMBU HOMOGENEITY TEST

Restrictions

Homogeneity test

Probability of rejecting homogeneity

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

Estimate of change point (year)

- (none) -

OK Help

Homogeneity statistics menu

Data file

File name: NEKEMTE

Description: NEKEMTE HOMOGENEITY TEST

Restrictions

Homogeneity test

Probability of rejecting homogeneity

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

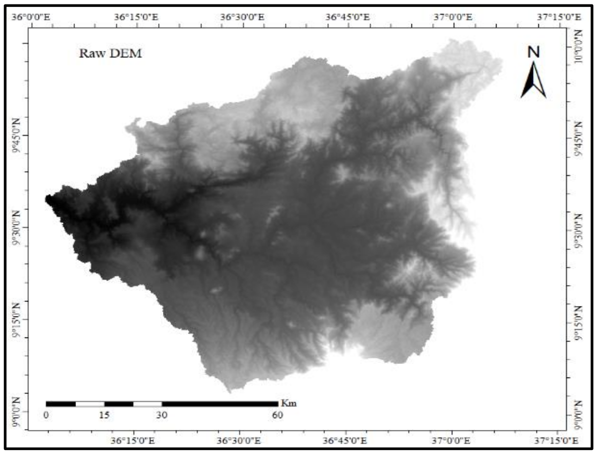
Estimate of change point (year)

- (none) -

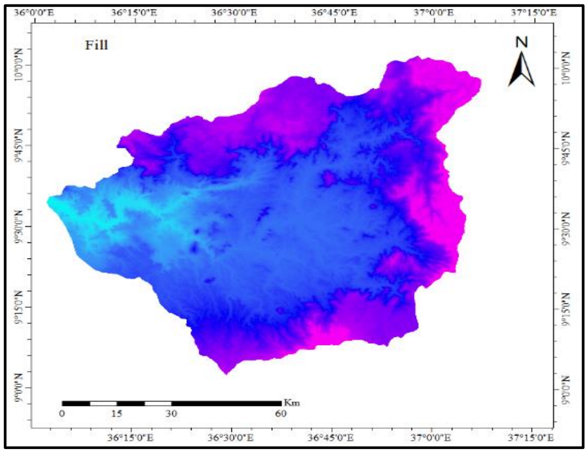
OK Help

Figure 2.1: Homogeneity test results of Anger, Gelila, Gida Ayana, Kiramu, Nekemte, and Shambu Stations, respectively.

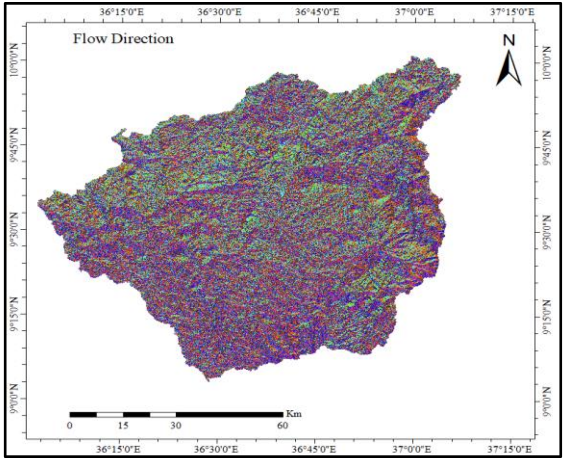
APPENDIX 3: RESULTS OF TERRAIN PREPROCESSING AND STREAM AND WATERSHED CHARACTERISTICS



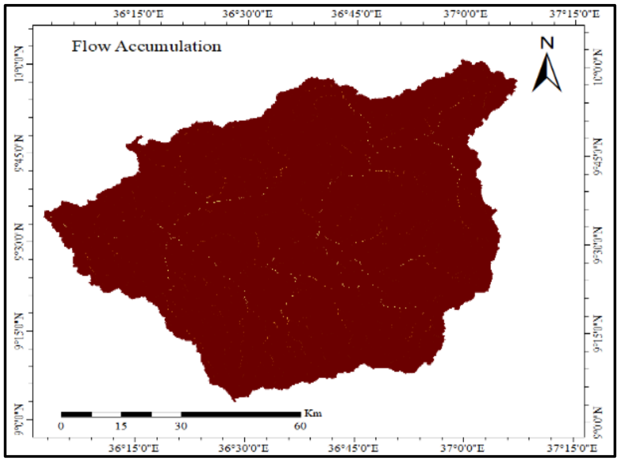
A)



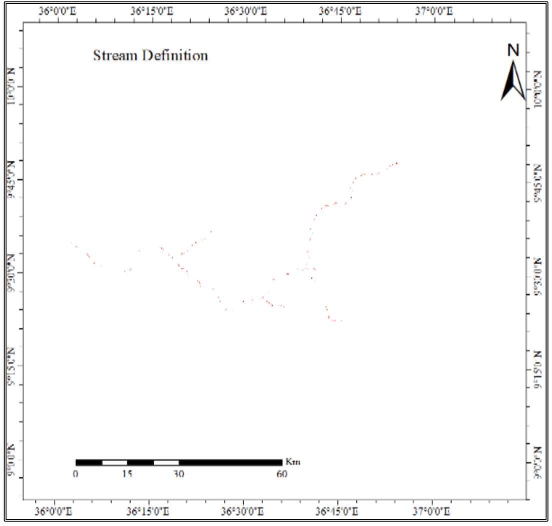
B)



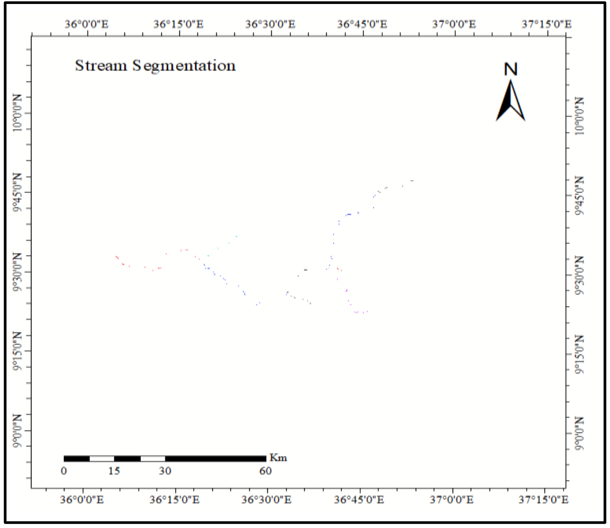
C)



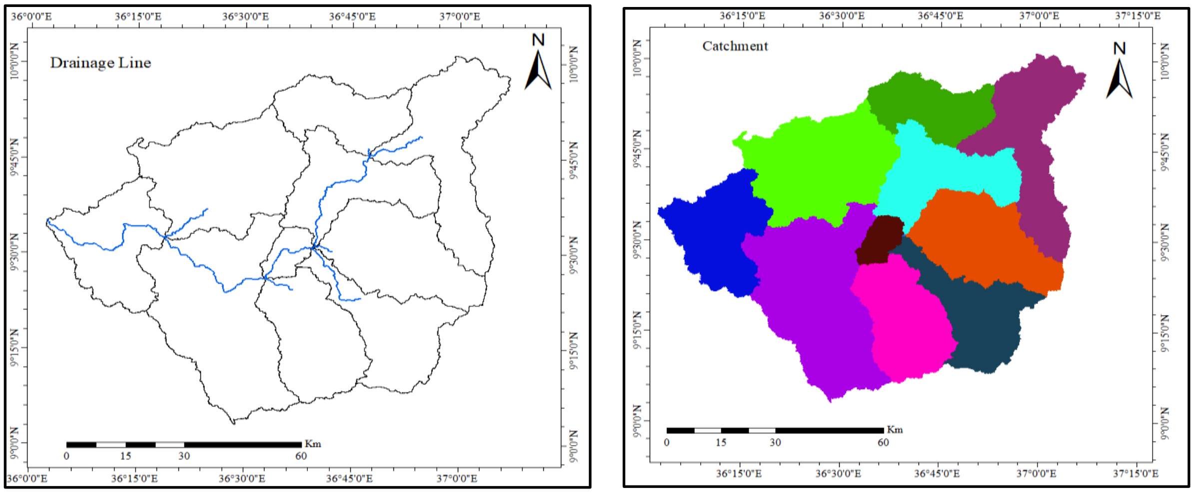
D)



E)

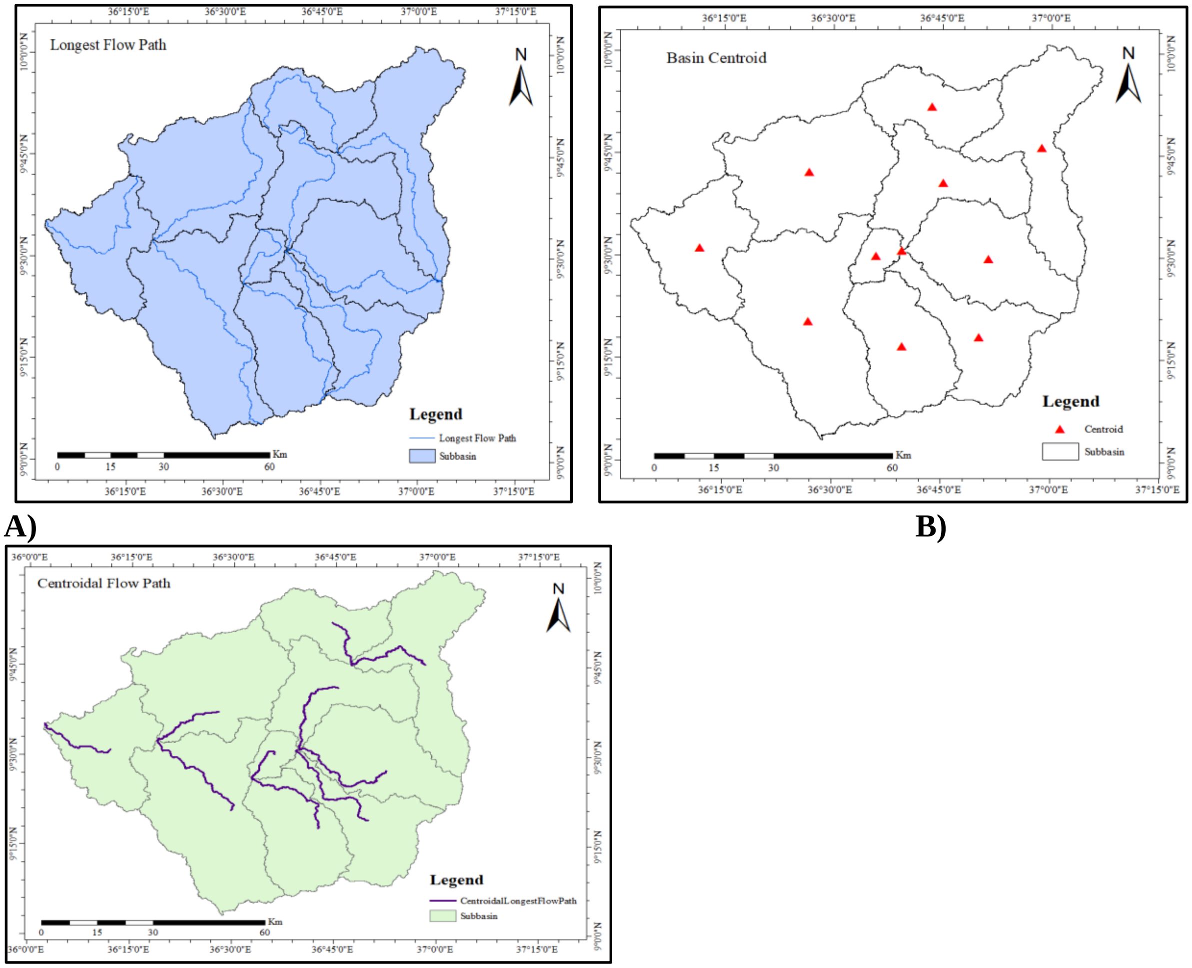


F)



G) H)

Figure 3.1: The steps and results of Terrain preprocessing



A) B)

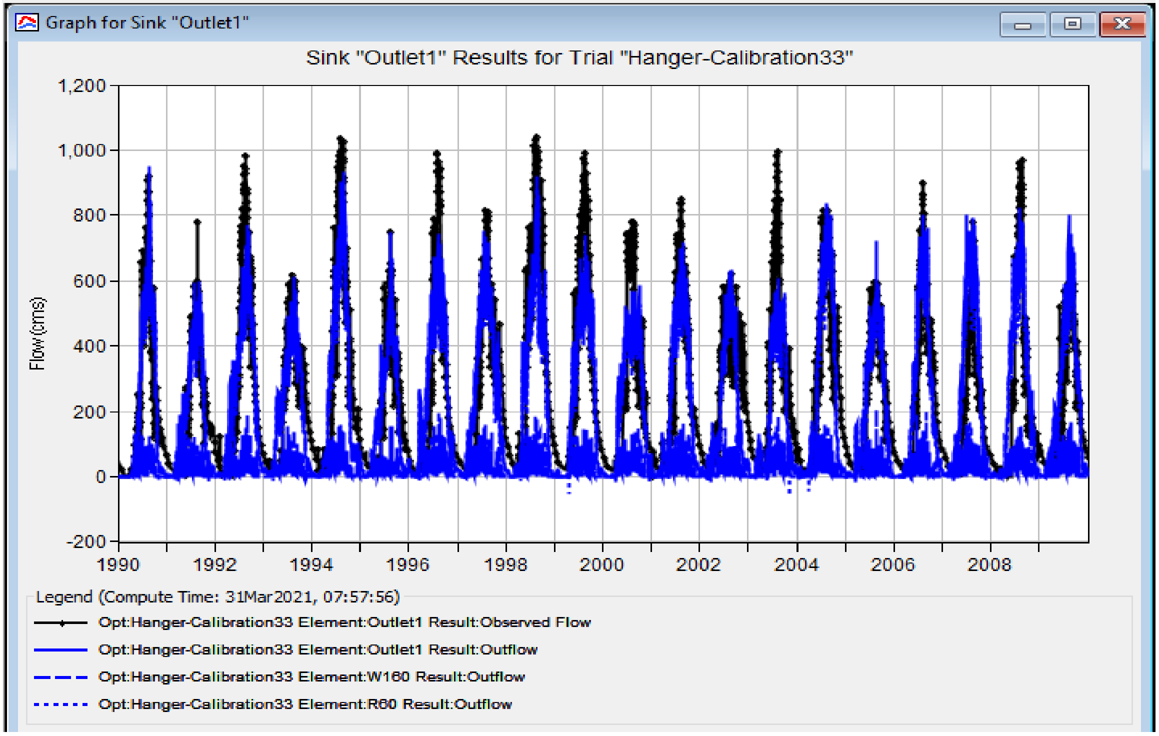
Figure 3.2: The computed process of stream and watershed characteristics

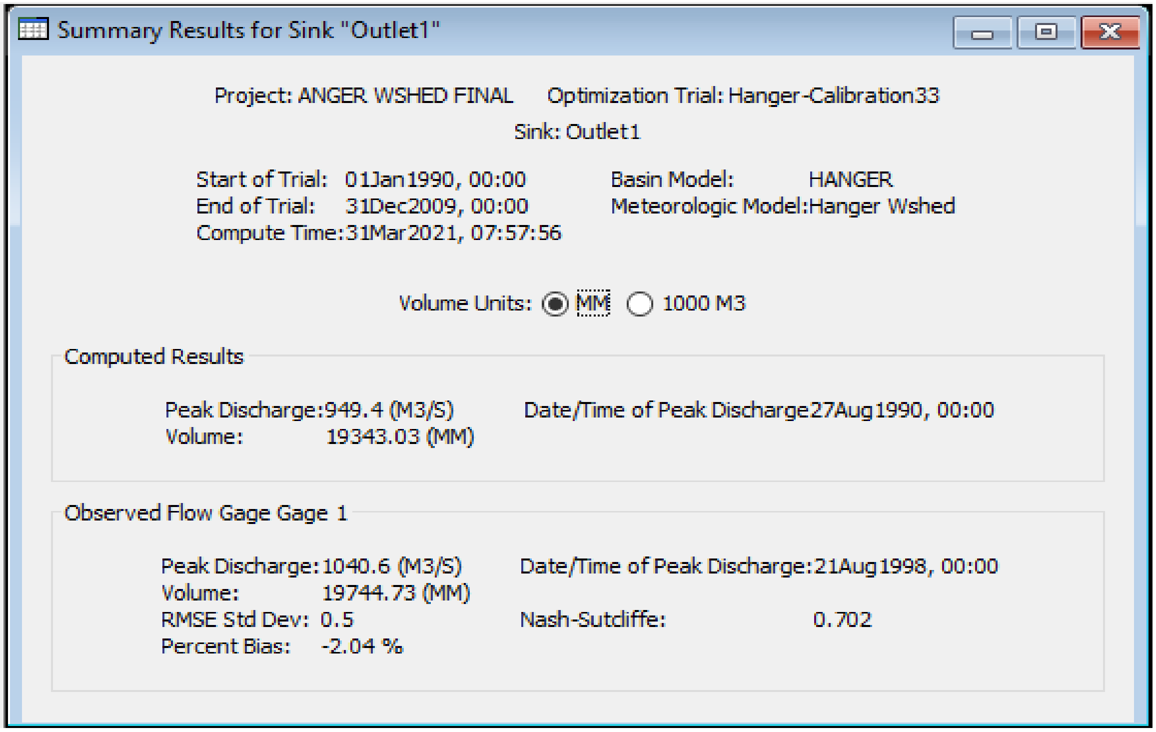
APPENDIX 4: CONVERSION OF POINT RAINFALL TO AREAL RAINFALL

Table 6.1: Gauge Weight for Each Sub-Watershed

Stations	Alibo	Anger	Gelila	G/Ayana	Kiramu	Nekemte	Shambu
GW1	0.475				0.202		0.323
GW2				0.458	0.542		
GW3	0.027		0.006	0.583	0.262		0.122
GW4		0.020	0.846	0.134			
GW5		0.830	0.169				
GW6				0.182	0.026	0.793	
GW7				1			
GW8		0.502	0.139	0.358			
GW9		0.071		0.034		0.3378	
GW10		0.687	0.059	0			
GW11		0.284				0.7165	

APPENDIX-5: HEC-HMS OUTPUT RESULTS





Project: ANGER WSHED FINAL   Optimization Trial: Hanger-Calibration33

Sink: Outlet1

Start of Trial: 01Jan1990, 00:00
End of Trial: 31Dec2009, 00:00
Compute Time: 31Mar2021, 07:57:56

Basin Model: HANGER
Meteorologic Model: Hanger Wshed

Volume Units: ● MM ○ 1000 M3

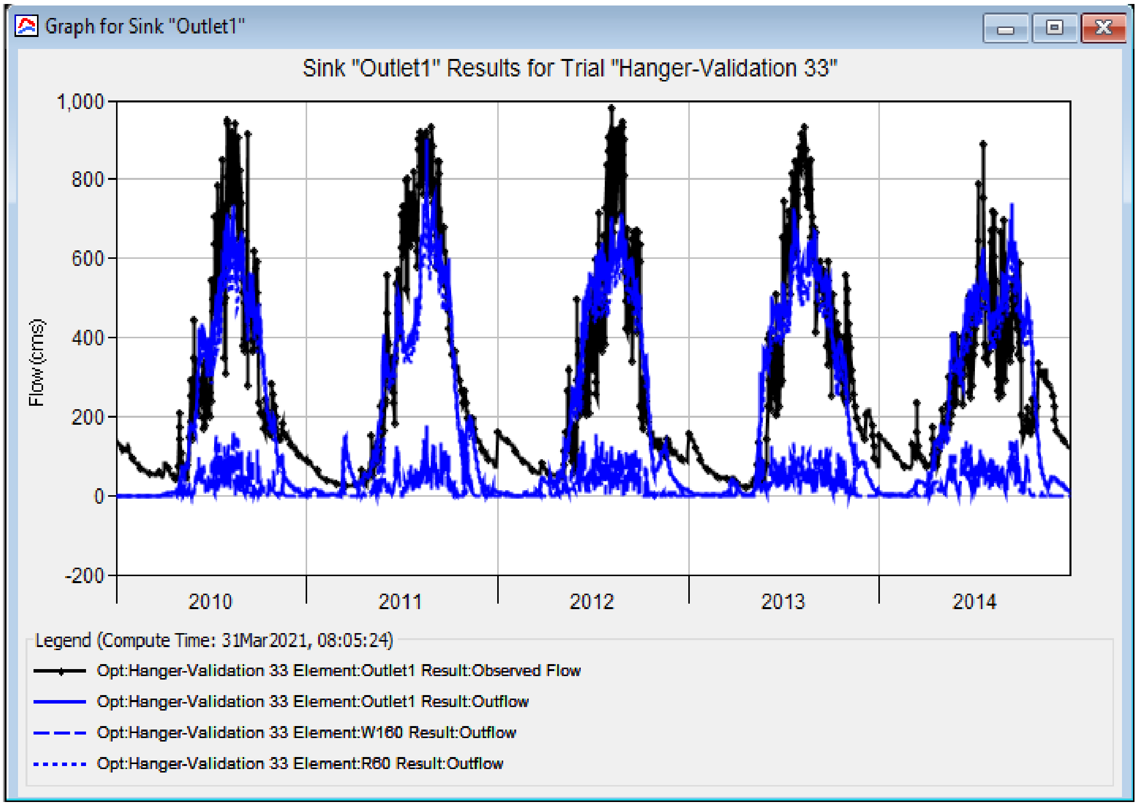
Computed Results

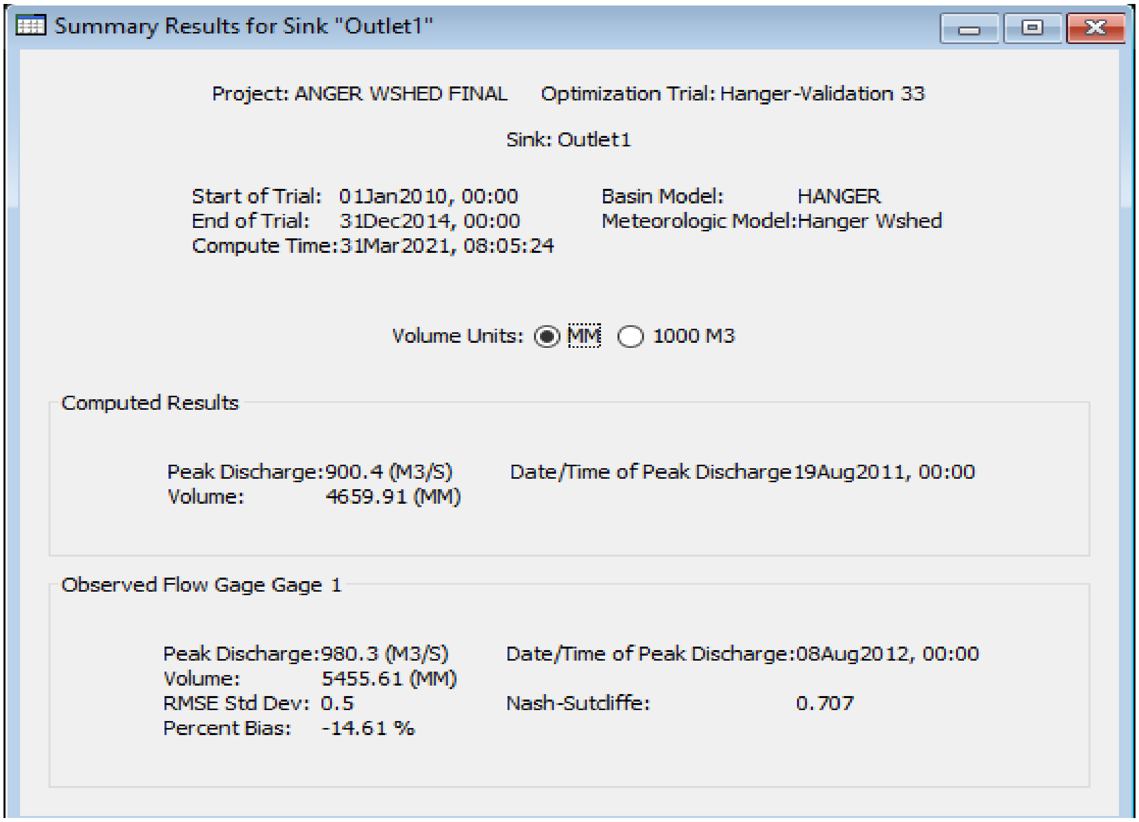
Peak Discharge: 949.4 (M3/S)
Volume: 19343.03 (MM)
Date/Time of Peak Discharge 27Aug1990, 00:00

Observed Flow Gage Gage 1

Peak Discharge: 1040.6 (M3/S)
Volume: 19744.73 (MM)
RMSE Std Dev: 0.5
Percent Bias: -2.04 %
Date/Time of Peak Discharge: 21Aug1998, 00:00
Nash-Sutcliffe: 0.702

Figure 5.1: Calibration Results of Simulated and Observed Streamflow Hydrograph





Project: ANGER WSHED FINAL Optimization Trial: Hanger-Validation 33

Sink: Outlet1

Start of Trial: 01Jan2010, 00:00 Basin Model: HANGER
End of Trial: 31Dec2014, 00:00 Meteorologic Model:Hanger Wshed
Compute Time:31Mar2021, 08:05:24

Volume Units: ● MM ○ 1000 M3

Computed Results

Peak Discharge:900.4 (M3/S) Date/Time of Peak Discharge 19Aug2011, 00:00
Volume: 4659.91 (MM)

Observed Flow Gage Gage 1

Peak Discharge:980.3 (M3/S) Date/Time of Peak Discharge:08Aug2012, 00:00
Volume: 5455.61 (MM)
RMSE Std Dev: 0.5 Nash-Sutcliffe: 0.707
Percent Bias: -14.61 %

Figure 5.2: Validation Result of Simulated and observed Streamflow Hydrograph

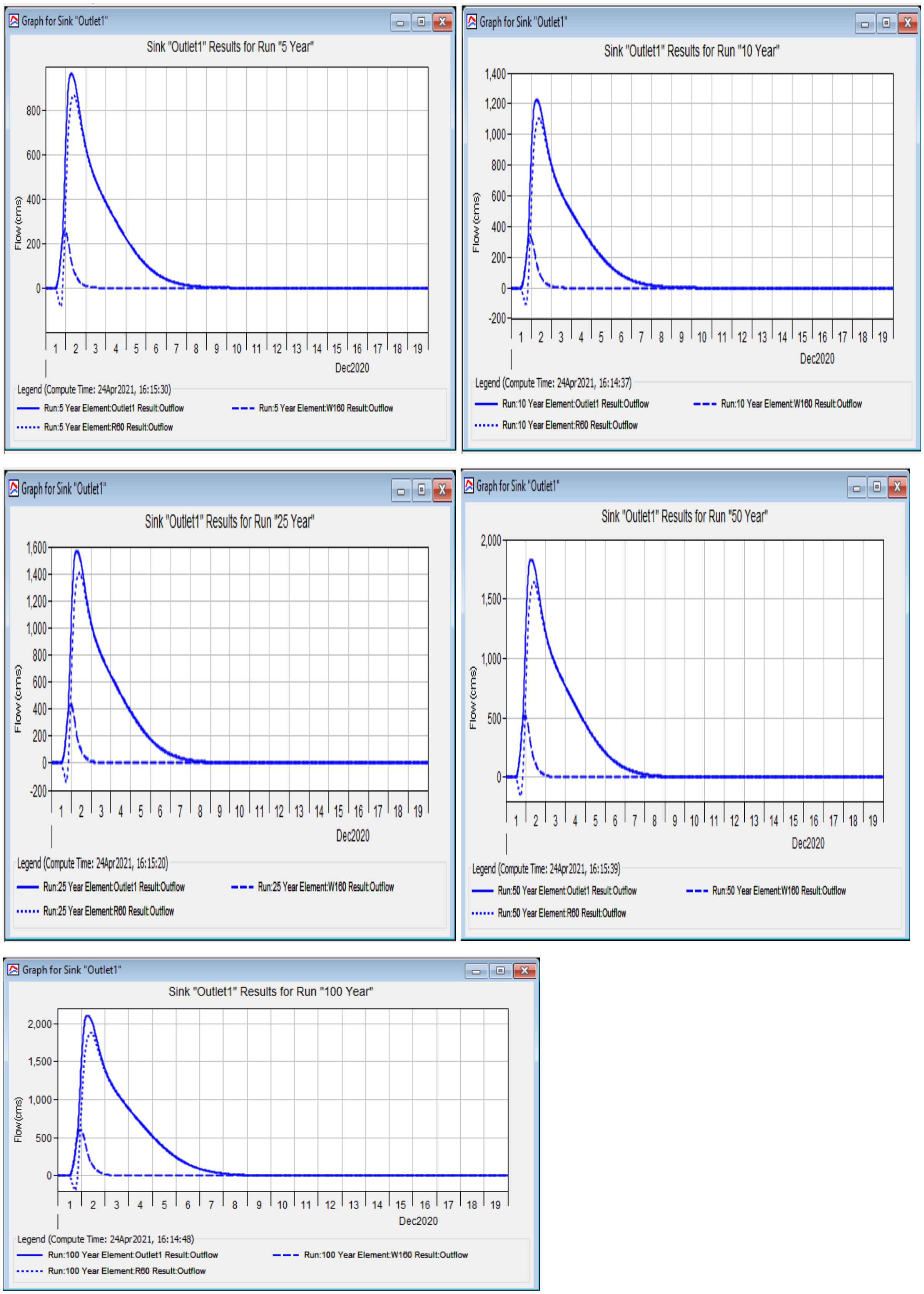
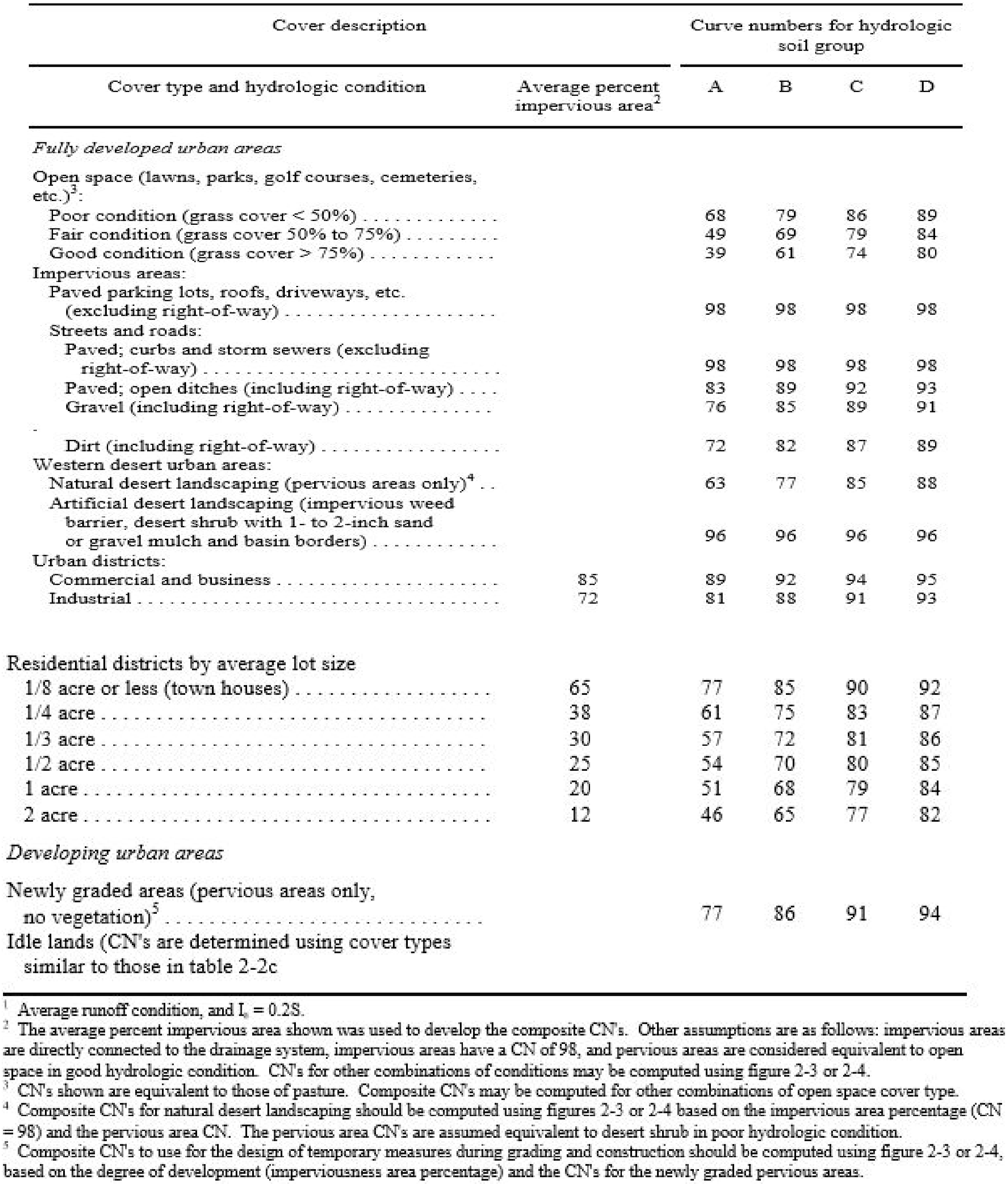


Figure 5.3. The Peak Flood of 5,10, 25, 50, and 100-Years, respectively

ANNEXES

Annex- 1: SCS –CN for different LU/LC and hydrologic soil group

Table 1.1: Runoff curve number for urban area



Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas					
Open space (lawns, parks, golf courses, cemeteries, etc.)[3]:					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only)[4] . .		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acre	12	46	65	77	82
Developing urban areas					
Newly graded areas (pervious areas only, no vegetation)[5]		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c					

---

[1] Average runoff condition, and $I_a = 0.2S$.

[2] The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

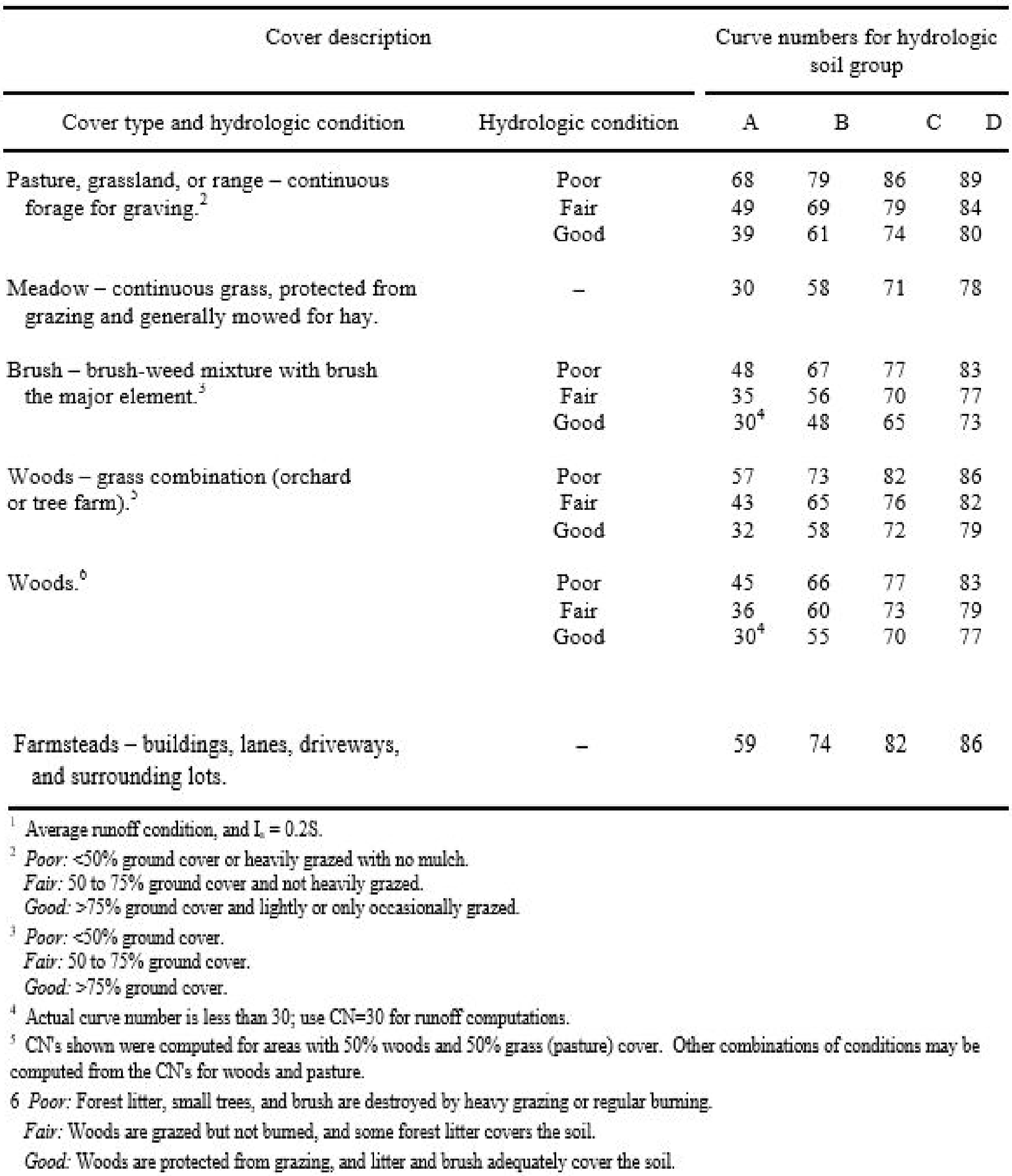
[3] CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

[4] Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

[5] Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4, based on the degree of development (imperviousness area percentage) and the CN's for the newly graded pervious areas.

(Subramanya, 2008)

Table 1.3: Runoff curve number for another agricultural area



Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Hydrologic condition	A	B	C	D
Pasture, grassland, or range – continuous forage for graving.[2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow – continuous grass, protected from grazing and generally mowed for hay.	–	30	58	71	78
Brush – brush-weed mixture with brush the major element.[3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30[4]	48	65	73
Woods – grass combination (orchard or tree farm).[5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods.[6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30[4]	55	70	77
Farmsteads – buildings, lanes, driveways, and surrounding lots.	–	59	74	82	86

[1] Average runoff condition, and $I_a = 0.2S$.

[2] *Poor:* <50% ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: >75% ground cover and lightly or only occasionally grazed.

[3] *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.

[4] Actual curve number is less than 30; use CN=30 for runoff computations.

[5] CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

(Subramanya, 2008)