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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

**FLOOD HAZARD MAPPING AND PROPOSE MITIGATION MEASURE:
A CASE OF WERA DISTRICT, IN HALABA ZONE, ETHIOPIA.**

A Thesis submitted to the School of Graduate Studies of Addis Ababa University,
Addis Ababa Institute of Technology in Partial Fulfillment of the Requirements for
the Degree of Masters of Science in Hydraulic Engineering

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FLOOD HAZARD MAPPING AND PROPOSE MITIGATION MEASURE: A CASE OF WERA DISTRICT, IN HALABA ZONE, ETHIOPIA

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**FLOOD HAZARD MAPPING AND PROPOSE MITIGATION MEASURE: A CASE
OF WERA DISTRICT, IN HALABA ZONE, ETHIOPIA**

CERTIFICATION

The undersigned certify that I have read the thesis entitled “**Flood Hazard Mapping and Propose Mitigation Measure: A case of Wera Woreda, in Halaba Zone, Ethiopia**” and I hereby recommend for acceptance by the Addis Ababa University institute of Technology in partial fulfillment of the requirement for the Degree of Masters of Science in Civil and Environmental Engineering Specialization in Hydraulic Engineering.



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Date

**FLOOD HAZARD MAPPING AND PROPOSE MITIGATION MEASURE: A CASE
OF WERA DISTRICT, IN HALABA ZONE, ETHIOPIA**

DECLARATION

I, **Martha Ersumo**, hereby present for consideration by Civil and Environmental Engineering School, my Thesis in partial fulfillment of the requirement for the Degree of Master in Civil Engineering (Hydraulic Engineering major), which entitled as “**Flood Hazard Mapping and Propose Mitigation Measure: a case of Wera District, in Halaba Zone, Ethiopia**”. I sincerely declare that this thesis is the product of my own efforts. The work has not been presented elsewhere for assessment. The materials that have been used from other sources are acknowledged or referred properly.

Name: - Martha Ersumo

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Date: -February, 2024

FLOOD HAZARD MAPPING AND PROPOSE MITIGATION MEASURE: A CASE OF WERA DISTRICT, IN HALABA ZONE, ETHIOPIA

ABSTRACT

For flood prone areas, identifying flood generating factors, mapping flood hazardous zones and propose flood eliminating methods can increase the knowledge, awareness and individual initiatives to prevent themselves and their properties from flood effects by using appropriate flood mitigation measures before and during flood events. Developing Flood Hazard Maps for flood prone area can be developed by integrating geo-spatial information on flood conditioning factors. Based on the AHP and GIS techniques, Flood Hazard Map for Wera District was develop by using Soil data, Lu/Lc data, Drainage Density, Slope, Rainfall and Topographic data of the Catchment. This study aims to map flood hazardous area and propose mitigation measures, for Wera Woreda in Bilate River sub-basin by using GIS, HEC-HMS, AHP, HEC-RAS and HEC – GeoRas software. Depending on the L-momentum Ratio diagram of the three distribution methods, Gumbel Distribution was used for this study to compute peak discharge. Thus, the final peak Discharges for 2,5,10, 25, 50 and 100 years was estimated 119.44, 189.18, 235.36, 293.70, 336.71 and 379.94m³/s respectively. HEC-Geo RAS Software was used to develop river geometry such as: the river centerline, river bank, flow path and cut cross-section for Bilate River. HEC-RAS, hydraulic analysis includes the computation of the water surface profiles.

Based on the degree to flooding, the importance of selected factors was ranked to five flood hazard category, namely very low, low, moderate, high and very high flooding. The weight coefficients were determined for each parameter by Analytical Hierarch Process (AHP) and overlay of ranked spatial information result the final flood hazard map of study areas. The flood hazard maps indicate that 60, 91, 93, 58, and 12.5km² corresponds with very high, high, moderate, low and very low hazard areas respectively for Wera Woreda. For this thesis work, I was try to compare construction of levee along the channel and channel modification as alternatives for remedial measures to protect the flood from study area. From two alternatives, construction of levee along the river was the best alternative for study area.

Key Words: APH, Flood Hazard, GIS, HEC-HMS, HEC-RAS, HEC-Geo RAS, Mitigation Measure

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LIST OF ABBREVIATION

DEM	Digital Elevation Model
GIS	Geographic Information System
GUI	Graphical User Interface
HEC-RAS	Hydraulic Engineering Center for River Analysis System
Hec-Georas	Hydraulic Engineering Center River geometry analysis system.
NMA	National Metrological Agency
SRTM	Shuttle Radar Topography Mission
TIN	Triangular Irregular Network
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
DPPA	Disaster Prevention and Preparedness Agency
FDPPA	Federal Disaster Prevention and Preparedness Agency
SCS-UH	Soil Conservation Service Unit hydrography
MoWE	Ministry of water resource
NSE	Nash-Sutcliffe coefficient of efficient
WMO	World Metrological Organization
GeoHMS	Geospatial Hydrological Modeling
HEC-HMS	Hydraulic Engineering Center-Hydrological Modeling System
NCGIA	National Center of Geographic Information Analysis
ADRC	Asian Disaster Preparedness Centre
FEMA	Federal Emergency Management Agency
FFEWS	Flood Forecasting and Early Warning System
IDF	Intensity Duration Frequency
TR	Technical Release
CN	Curve Number
TIN	Triangular Irregular Network

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DTM	Digital Terrain Model
CFCA	Canadian Foundation for Climatic and Atmospheric Sciences
UH	Unit Hydrography
UNESCO	United Nations Educational, Scientific and Cultural Organization
OCHA	Office for the Coordination of Humanitarian Affairs
NDRMC	National Disaster Risk Management Commission

1 INTRODUCTION

1.1. Background

Natural hazards are disasters caused by forces of nature that can have devastating effects on human populations in their vicinity, as well as on ecosystems and the environment in general. Examples of natural hazards include floods, Droughts, earthquakes, volcanic eruptions, and wildfires. Each of these disasters can cause serious damage on properties and even loss of life, yet they are often difficult to avoid completely. Though natural hazards are often unavoidable, it is possible to reduce their devastating consequences with improved disaster preparedness and risk management. By understanding the potential risks posed by these disasters and by taking preventive action, we can minimize the effects of these hazards.

The flood in Ethiopia is a devastating event that occurs almost every year. The floods have been a part of the country's history since ancient times and the severity of the floods has grown steadily over the last several hundred years. Ethiopia is a landlocked country with no external sources of water (does not have territory connected to an ocean), and so it relies on its own natural resources for sustenance. There are many factors that contribute to the floods in Ethiopia, from intense seasonal rainfall, land use or land cover, catchment slope, Soil texture, Drainage systems, topography...etc.

Flood is the accumulation of surface water flow that comes from intensity rain falling on the high land areas and accumulates in narrow range of valleys or overflow of the rivers and Stream banks that affect many parts of the world. In Ethiopia, the occurrence of the floods and its magnitude are due to a combination of natural and human-induced factors and are mainly caused by the intensity of the seasonal rains, climate change, and changes in vegetation, topography, and population. Each of these factors is part of a complex natural system, and despite the devastating effects of the floods, understanding their causes will help the nation develop sustainable approaches to managing the risks associated with them. Human -activities these the catchment has to be susceptible to flood occurrence are Removal of forests to build settlements (deforestation) resulting from population growth, lack of watershed management, land preparation/clearing for agriculture may increase the magnitude of flood which increases the damage to the properties and human life. The depth of

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rainfall and its frequency of occurrence plays the great role in the occurrence of the flooding. If heavy rainfall falls in a given catchment for longer period of time, even if the soil has high infiltration capacity, all the pore spaces of the soil will be held by water. The soil afterwards has no space to accept additional water, so that the remaining water becomes runoff depending on the topography or nature of the ground. Therefore, heavy rainfall indicates high flooding event resulting the area as highly flood prone area.

Topographically, Ethiopia is both a highland/mountainous and lowland country. The country experiences two types of floods: flash floods and river floods. Flash floods are the ones formed from excess rains falling on upstream watersheds and gush downstream with massive concentration, speed and force

Flash floods are frequently related to violent convection storms of a brief duration falling over a little area. Flash flooding can occur in almost any area where there are steep slopes but is commonest in mountain districts subject to frequent severe thunderstorms. Flash floods are often the result of heavy rains of short duration. This particular sort of flooding commonly washes away houses, roads, and bridges over small streams then features a critical impact on communities and transport in these often-remote areas. Flash flood is generally defined as a rapid onset of flood with a short duration and a relatively high peak discharge. These floods occur in lowland areas when excessive rains fall in adjacent highland areas. In Ethiopia, some parts of the country are also vulnerable to flash floods. Flash floods, which occur in lowlands when excessive rain falls in the highlands. Flash floods are very dangerous and destructive not only because of the force of the water, but also the crashing debris that is often swept up in the flow.

River flooding is happening over a good range of river and catchment systems. Floods in river valleys occur normally on floodable areas or wash lands as a result of flow generated by rainfall exceeding the holding capacity of the river or stream channels and spilling over the natural banks of artificial embankments. They take place when the river exceeds its storage capacity and the water excess overflows the banks and fills the adjacent low-lying lands, producing significant social, economic, and environmental impacts, including: loss of human life and negative effects on population, damage to the infrastructure and essential services, damage to crops and animals, spread of diseases, and contamination of the water supply. Flooding in Ethiopia is mainly related

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with heavy rainfall and the topography of the highland mountains and lowland plains with natural drainage systems formed by the principal river basins. In most cases floods occur in the country as a result of prolonged heavy rainfall causing rivers to overflow and inundate areas along the river banks in lowland plains. Flooding phenomenon cannot be completely avoided, but damages that may happen from severe flooding can be reduced or eliminated by implementing effective flood control measures (structural or non- structural) which include land use control, construct proper drainage systems, mapping of the flood prone areas, and develop flood hazard mapping techniques.

Generally, some areas in halaba zone are affected by both flash and River floods. So, it needs researches related with flood phenomenon. Wera woreda is one of the three woredas in halaba zone, it was selected for the fact that it is severely affected by the flood impacts because of Bilate River crosses it. The study area is one of the frequently flood affected woreda in Halaba Zone due to over flow of the Bilate river and flood runoff comes from highly elevated areas of Oromia region, Silte region and other elevated areas of the zone during rainy season. The main objective of the study was to develop flood Hazard map for Wera woreda in halaba zone flood prone area and propose appropriate mitigation measure to protect communities from recurrent flooding

Therefore, flood hazard mapping of Wera Woreda is essential for researchers, government officials, NGOs and other organizations simply to understand areas that affected by flood hazards and used as flood hazard zones identifying tools in planning and developing any water-related projects along the flood vulnerable catchments. Therefore, this study will help to fill the existing gap on available information and identify /specify the areas that might be frequently affected by flood hazard impacts.

1.2. Statement of the Problem

We know that consequences of flood impacts with in flood prone areas like damages of property, loss of human life, failures of infrastructure, and others are common in both the world and country level. Ethiopia is also one of the countries which affected both river and flash flood problem during rainy season at every year. It has been occurring at different regions and times with varying its magnitude. When the flood capacity become high, the intensive rainfall within the catchment,

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vegetation cover, Elevation of the watershed, slope steepness, less infiltration capacity of the soil types are main parameters to increase flood occurrences in the specific area.

Flood problem is probably the most devastating, widespread and frequent natural hazard for both developed and developing countries like Ethiopia. Flooding in Ethiopia is mainly related with the topography of the highland mountains and lowland plains with natural drainage systems formed by the major river basins. This show that most of drainage line in Ethiopia is started from high lands of the country toward the low lands. When there is excess rainfall is falling on the high land/mountain areas of the country the huge amount of flood may be generated in low land areas of the river basin, which may result damage to the low land population and properties. This problem is more difficult in highland areas like Ethiopia under strong environmental degradation due to population pressure. Although flood events are not new to Ethiopia, the country, in its main rainy season, especially from June to September has been susceptible by quite unprecedented flooding of abnormal/uncontrollable magnitude of the flood and its damages. Apparently, this is, for the large part due to heavy rains falling for long period of times on the upstream highlands, high amount of sediment accumulation take place in the River/channel plains (silt deposition takes place), which escalates the flooding problem by reducing the holding capacity of the river to overtops flood water to downstream/lowland areas.

In Ethiopia, there is a lot of areas under flood problems. Bilate River floodplain is one of the most repeatedly flood affected area and the river conveys high amount of runoff from upper catchments and local rainfall on the floodplain to resulting in flooding problems to low-lying areas. Normally, Halaba Zone is predominantly flat and many areas in this zone are vulnerable to flooding and frequently affected by flood impacts. According to 2018/19, Halaba zone Report, in Wera Dijo woreda 763 people were displeased due to flood, 18 homes are failed, 739 homes occupied by flood water, 829-hectare farm land covered by sediment deposing and 489 livestock are died. Similarly, (2020-2021) in this woreda 943 householders (4507) families are affected by flooding.

1.3. Objective of the Study

1.3.1. General Objective

The general objective of this study is developing flood hazard maps of Wera woreda in Halaba zone along the Bilate river floodplains and propose appropriate mitigation measures.

1.3.2. Specific Objective

- ❖ To identify flood prone areas of the woreda
- ❖ To identify factors controlling flood hazard in the study area
- ❖ To develop flood hazard map of the Wera woreda
- ❖ To suggest some mitigation measures or Controlling measures for the recurrent flood hazards

1.4. Research Question

What are the main flood generating factors in study area?

What is the highest flood peak discharge for different return period?

What is the appropriate mitigation measure for the study area?

1.5. Significance of the Study

Know a day, flood is one of common unavoidable natural disaster that affect human life and property from worldwide to country level. A better understanding of the consequences of flood can be used to develop new strategies for protecting flood-prone areas. In the case of Ethiopia, some part of the country was suspected to negative impacts due to flood occurrences during rainy season (from June-September). Bilate River Basin is one of the flood prone area in our country. Since there is highest negative impact of the flood on the low-lying areas of the Bilate River sub-basin, especially Wera Woreda crossed by Bilate river that requires support from governmental institution /flood impact managing or decision maker. To manage, prevent, and minimize flood impacts and to take mitigation measures this study have significant. Therefore, this study is needed to understand or visualized flood hazardous areas within the Woreda on the map and recommend some appropriate flood mitigation measure in risk areas as soon as possible.

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Therefore, the government, the people and any concerned body living along particular flood hazard and inundation zones should have enough flood information to be ready, flood hazard awareness and take alternative measurement to prevent flood risk and damage consequences.

1.6. Scope of the Study

The depth of this study was bounded by the main objective of the study that aimed by flood hazard mapping and mitigation measures. The flood hazard mapping was accomplished by using ARC GIS 10.3 software package and by developing maps of flood generating factors such as Digital Elevation Model (DEM), slope, rainfall, drainage, soil type and land use/ land cover of the study area. These factors and their relative weight were used to develop flood hazard of the specific region. In addition to this the river cross-section and geometry using HEC-Geo RAS and HEC-RAS were used to simulated study area water surface profile.

1.7. Organization of the Thesis

This thesis was organized into six chapters. In the first chapter the background information, introduction, problem statement, general and specific objectives, Significance of the study and Scope of the study were discussed. In the second chapter, literature review about the subject matter was presented and it gives a scientific review of this study. In the third chapter Data collection and Analysis, Meteorological Data Availability and Processing, Estimation of Missing Precipitation Data, Checking Consistency and Homogeneity, Testing for Outliers, Areal precipitation/Average Rainfall Depth over an Area, and Flood frequency analysis from hydrologic data was presented in this chapter. The fourth chapter Material, Method and Procedure, Description of the Study Area, Flood problem in the study area, Research Methodologies, Hydrologic Analysis: HEC-HMS modelling, Model calibration and validation, HEC-GeoRAS: Hydraulic Modelling, preparing maps for Flood Hazard governing factors and determine relative weights for each factors, developing flood hazard map for wera woreda and finally propose mitigation measures.. The fifth chapter presents the results and discussion of the study. The sixth chapter summarizes the conclusion and recommendation for future study

2 LITERATURE REVIEW

2.1. Flood

Ethiopia is experiencing extreme weather variability with some areas experiencing drought, while others are impacted by flooding. Flood is an unusually high stage in a river, normally the level at which the river over flows its banks and inundates the adjoining area. Floods are known as the most frequent and destructive natural disasters in both developed and developing countries from the ancient age until now. According to Ethiopia, Topographical settlement is both a highland/mountainous and lowland due to this topography characteristics has made the country pretty vulnerable to floods and resulting destruction and damage to life, economic, livelihoods, infrastructure, services and health system (FDPPA, 2007). Floods are an extreme naturally occurring weather event that result in an overflowing of large amounts of surface water over land that is not always inundated ((Adeoye, 2009). It is considered to be the worst natural disaster in the world and it is responsible for a third of all-natural problems and half of damages on facilities around the globe.

Flood has become one of the most frequent natural occurrences in the last few decades (Jeb, 2008). It is becoming a common phenomenon around the world, caused by climate change and variability and land use change. Gradually floods are as a result of flow of water exceeding the capacity of the river channel, particularly at bends or meanders, or the unexpected drainage obstructions, or from combination of tidal sea surges in coastal areas or water in the lake or reservoir overflowing or breaking of levees or catastrophic event and flows onto the floodplain. In Ethiopia, flood area weather-related natural disaster and commonly two type's river flood and flash flood. Flash flood occurs in lowland areas when excessive rains fall in adjacent highland areas, ((NDRMC, 2017). Usually, flash floods in the country are caused by heavy rainfall falling on upstream river catchments and gush downstream with huge concentration, speed and force (Fekadu, 2018).

River Flood are characterized by gradual riverbank overflows caused by extensive rainfall over an extended period of time. The areas covered by river floods depend on the size of the river and the amount of rainfall. Common parameters that shows flood characteristics are amount of precipitation, depth of the flood water, the velocity of the flow, and duration of the rainfall event.

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Being one of the largest countries in East Africa, Ethiopia's topography characteristics has made the country pretty vulnerable to floods and resulting destruction and damage to life, economic, livelihoods, infrastructure, services and health system (FDPPA, 2007).

2.1.1. Flood prone Areas of Ethiopia

Ethiopia is a country located in the horn of the Africa and is known for its diverse land escapes such as mountains, valleys, and deserts. Ethiopia is a flood- prone country due to its topography and climate conditions. The major flood-prone areas in the Ethiopia are the low land and valley areas located near rivers and streams. Agricultural activities in our country are predominantly located in lowland areas, which exposes farmers to the risk of losing their crop products and livestock when floods occur. Flood prone area means that an area adjacent to the water courses or River that may inundated when water holding capacity of the River was less compare to that of the flood water.

Among the major river flood-prone areas are: parts of Oromia and Afar regions lying along the upper, middle and downstream plains of the Awash River; parts of Somali region along the Wabe Shebelle, Genale and Dawa Rivers; low-lying areas of Gambella along the Baro, Gilo, Alwero and Akobo Rivers; downstream areas along the Omo and Bilate Rivers in SNNPR and the extensive floodplains surrounding Lake Tana and the banks of Gumera, Rib and Megech Rivers in Amhara (The National Flood Task Force Alert report, 2015). Flood prone area maps show areas likely to be flooded by virtue of their proximity to a river, stream, lake, ocean, or other watercourse as determined from readily available information.

When we talk about flood problems in our county, we must consider both types of floods. Some Areas mostly affected by Flash floods are Central, Southern and Western Tigray region; North and South Wollo, West Gojjam and Oromia zones in Amhara region; North Shewa zone in Oromia region; Wolayita, Hadiya, Siltie, Guraghe and Sidama, and Halaba zones in SNNPR; Jigjiga Town in Somali region and Dire Dawa City Administration. This type of flood is characterized by sudden onset with little lead time for early warning and often resulting in considerable damage on lives, livelihoods, infrastructures and property. Therefore, such kinds of floods often result in a

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considerable toll; and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration.

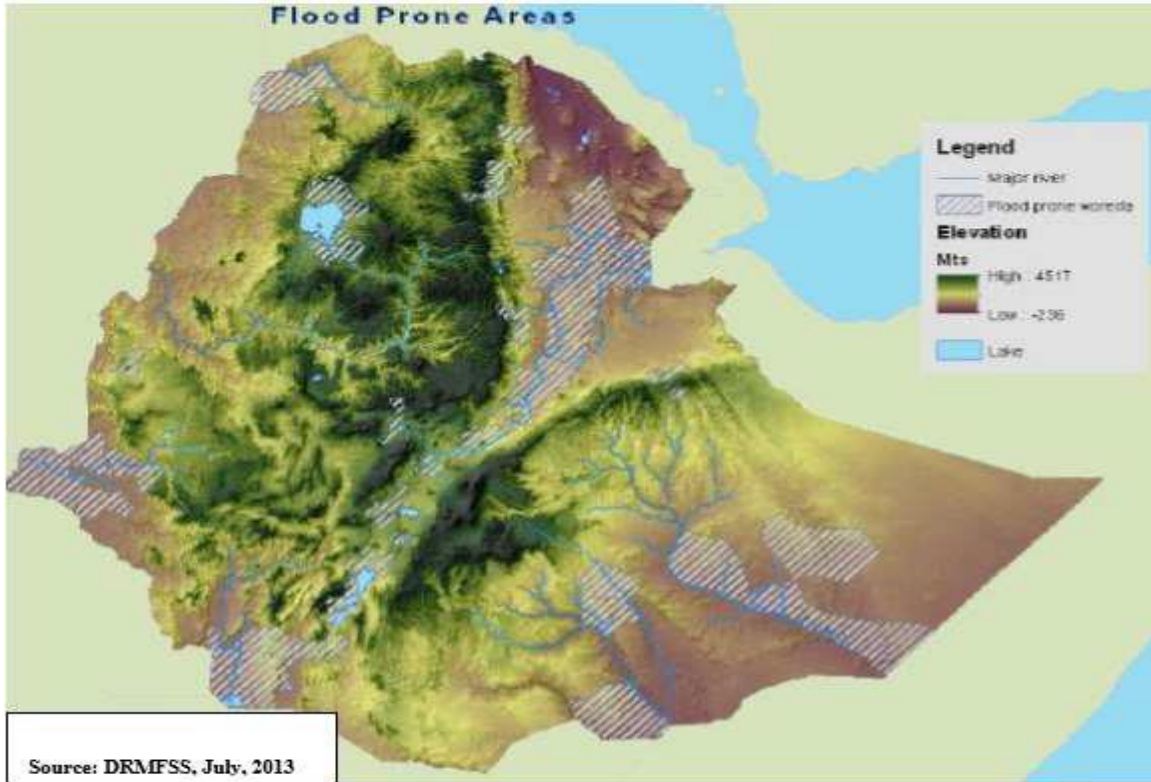


Figure 2:1 Flood Prone Areas of Ethiopia

Maps that show geographical distribution of these areas, and other relevant information on flood occurrence years and flood risk are incorporated on the above-mentioned document.

According to (DPPA, 2006) summer, a total of some 524,400 people was vulnerable to flood disaster throughout the country. Out of this population, 199,900 people are actually affected by flood disaster in various areas

Table 2:1 Regions and Population Affected/under Threat by Flood Disaster in the 2006 Rainy Season

No	Region	Vulnerable	Affected*
1	Afar	28000	4600
2	SNNP	106300	44000

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3	Amhara	47100	47100
4	Oromia	61300	21900
5	Tigray	122300	2600
6	Diredawa	10400	10400
7	Somalia	87000	43200
8	Gambela	62000	26100
	Total	524400	199900

**The affected number of populations includes 15 % contingency Source: (DPPA, 2006)*

According to DPPC, 1996, In Southern nation’s nationalities and people regions, for both flash and River flooding 252713 population, 79781 livestock are affected, and 4708683 property damaged in Birr.

2.1.2. Causes of Flooding in Ethiopia

Flooding is a devastating natural disaster that has the potential to wreak damage to ecosystems, economies, and even human lives. Although there are many causes of flooding, understanding the types and their respective impacts allows for better responses and prevention efforts. The country is mainly situated in the Horn of Africa, where there is a combination of numerous water sources, such as rivers, lakes, and groundwater formations. These bodies of water coupled with the country's topography, human activities, and climate change have contributed to the recurrent flooding in Ethiopia that has caused loss of life and property. One of the cause of flooding in Ethiopia is the country's topography. Ethiopia has highlands and lowlands, and the highlands are at risk of flooding during the rainy season. Heavy rainfall causes flash floods that collect away houses, crops, and fertile soil. The elevation of some parts of the country is not high enough to withstand the heavy rains, leading to floods that cause massive destruction. Another cause, Ethiopia has numerous water sources, such as rivers, lakes, and groundwater formations, which can cause floods. These water sources can overflow due to heavy rainfall, leading to floods that inundate homes and property.

2.1.2.1. Natural Cause

In terms of hydrologic flood causes, it is essential to study long-term weather forecasts and install early warning systems. This allows people to prepare for extreme weather conditions and/or evacuate as needed. Governments should also invest infrastructure, such as levees or embankments control floods, as well as ensure storm drainage systems are well-maintained and functioning properly.

Rainfall is the most common flood generating factor compare to other flood contributing factors. When heavy rain falls on a given catchment, the amount of precipitation that reaches the surface depends on the characteristics of the catchment, like its size, shape, and land use management activities. From the intense rainfall falling over highland catchments, the portion of rain water may infiltrated into the soil, some quantity of the water intercepted by vegetable and other buildings before reaches the ground surface, some the portion of rain water stored on the surface/evaporated, and remaining amount of the rainwater to be contributed to flood formulation and that may affect low-lying areas. These like natural phenomenon may not be avoided completely but may eliminated by using appropriate flood controlling mechanisms.

Wera Woreda was affected both river flood and flash floods. In the previous year that means March 20, 2022, in Halaba zone Wera woreda at least seven people died and pregnant woman was among the seven people due to flash flooding in southern part of the Ethiopia .The incident happened at night time as victims were returning back from the market and caught up by the flash flood (Halaba Zone Wera Woreda Polis Office, 2022). Flooding is common in the Ethiopia, mainly during the rainy season. Last year, a similar incident in the capital Addis Ababa had claimed the lives of at least seven people



Figure 2:2 Flood Incident in Wera Woreda (Halaba Zone), March 2022

2.1.2.2. Anthropogenic Causes

Human activities have also great contribution for the formation and magnitude of flood problems. Man-made activities within the a given specific catchment like deforestation of forests and cutting down of trees for firewood contribute to soil erosion, reducing its water absorption capacity and inadequate design and maintenance of drainage systems are increase the magnitude and occurrences of flood which resulting the damage to the properties and life. Intensive agricultural activities on steep slope areas of the catchment and its expansion decrease the abstraction of rainwater and thereby changed quickly to flood water (Brook and Boneya, 2020).

2.2. Rainfall-Runoff Process, Run off Hydrograph and Peak discharge

2.2.1. Rainfall- Runoff Process

An adequate knowledge of rainfall-runoff processes is vital to compute the amount of runoff produced with in the given catchment. Knowing the amount of runoff with in a given watershed is essential for sustainable water resources project planning, and management. The activities to

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estimate runoff volumes and flood peaks can be easily simplified by adopting a modelling concept and by understanding rainfall partitioning and the principal factors triggering runoff (Bitew, 2019). The type of the modelling approach normally depends on the purpose, data availability and ease of use. Rainfall-runoff models are often used as a tool for a wide range of tasks, such as the modelling of flood events, the monitoring of water levels during different water conditions or the prediction of floods (Bitew, 2019).

Simulation of rainfall-runoff or Runoff estimation process is very important in hydrological analysis like water resources management, river engineering, design flood control structures and both surface and groundwater utilization. Rainfall Runoff modeling is an important tool in the study of water resources and water management of the watersheds. Rainfall runoff models are mainly used for river flow forecasting for the management of the resource and to minimize the ill effects through early Warning measures. Due to existence of various hydrologic factors basin's response is very complex to the rainfall. Runoff depends on geomorphologic properties of a basin such as geometry, vegetative covering, soil type and climate characteristics such as rainfall, temperature, etc. The runoff generated by a watershed depends on the amount of precipitation (input function) occurring over a watershed. The rainfall hyetograph (graph of the distribution of rainfall over time) can be classified into three-time dependent parts - initial abstraction, losses (loss function), and rainfall excess (Brikowski, 2012).

When the rainfall retained on the land surface, losses take place before runoff begins. The initial abstraction is the portion of precipitation (interception, surface depression storage, evaporation, infiltration), which occurs before the start of the runoff. Interception is the part of rainfall captured /blocked temporarily by vegetation (leaves and stems). The portion of rainfall that enters the soil is known as infiltration. The surface depression storage is the part of rainfall that is stored by the puddles, lakes, and ponds. Evaporation is the portion of water that is evaporated from soils and open water bodies.

The initial abstraction is depth of rainfall that must fall before runoff begins, which has no contribution for the runoff. The value of initial abstraction depends on the type of soil of the drainage area being studied, land use and land cover. When the initial abstraction is satisfied, the excess rainfall become appears on the surface as direct runoff. Even if the direct runoff is start the

Losses never stop and this is called the loss function. A Unit Hydrograph can be used as a transfer function to transform rainfall excess into direct runoff. A Unit Hydrograph is the Direct Runoff Hydrograph that resulted from one unit (1 inch or 1cm) of excess rainfall falling uniformly over the watershed at a uniform rate during the specified period of time (Brikowski, 2012).

2.2.2. Runoff Hydrograph

Runoff: Gravity movement of water from a watershed on the surface of the land or Output from the catchment (difference between total precipitation and an initial abstraction) in a given period of time. A considerable portion of water from the hydrologic cycle after flowing on land is returned as stream flow, which is defined as the movement of water under the force of gravity through well-defined channels. Sometimes the water that moves in defined channel or all the rest over the land in undefined channel is termed as runoff, (Ven Te Chow, 1988). During precipitation, some of the rainfall is intercepted by vegetation before it reaches the land surface. This may later fall to the ground or evaporate. Meteoric water which is not intercepted by the vegetation cover falls on the ground surface, where it evaporates, infiltrates into pervious soils, lies in the ground depression or flows down giving rise to runoff. The runoff process is strongly influenced by infiltration capacity

2.2.2.1. Sources of Runoff

Formation of runoff is contributed by three components:

- Flow above the soil (overland flow): The overland flow, sometimes called Horton overland flow, occurs only when the rainfall intensity exceeds the infiltration capacity. In areas in which soils have a high infiltration capacity, this process may occur only during very intense storms or when the soil is saturated or frozen. This flow unable to be intercepted due to the high intensity rainfall and/or low value of infiltration capacity
- Interflow: Flow at the upper crusts of the soil that returns to the surface. It is also called through flow, subsurface storm flow, storm seepage etc. Interflow is the portion of the streamflow contributed by infiltrated water that moves laterally in the subsurface until it reaches a channel.

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- Flow deeply below the soil (Groundwater flow): Rainfall that infiltrates the catchment surface, percolates through the soil layer to the underlying groundwater and will eventually reach the main stream channels

A runoff hydrograph is a time sequence of river stage or discharge at a particular stream cross section for a particular storm. The runoff hydrograph can be separated into two parts direct runoff, and base flow (Brikowski, 2012).

2.2.3. Peak discharge

From the hydrological design perspective, there are several types of hydraulic structures that can be designed mainly depends on the peak discharge of an associated hydrograph. The peak flood flow is the maximum expected flow at a certain location for a given frequency. According to (Thompson, 1997), peak flood flows depend on the catchment area, the slope of the main channel, the basin shape factor, the hydrologic region, and the return period.

Potential extreme peak discharges are estimates of the highest peak discharges expected to occur at a certain location and, according to U. S. G. Survey, are explained mostly by the area of the corresponding catchment and by the hydrologic region where the catchment is located (Masoud, 2011).

2.3. Watershed Modeling

What is modeling?

Hydrologic engineers are called upon to provide information for activities for a variety of water resource studies, like Planning and designing new hydraulic-conveyance and water-control facilities, Operating and/or evaluating existing hydraulic-conveyance and water-control facilities, preparing for and responding to floods, Regulating floodplain activities ...etc.

In rare cases, the record of historical flow, stage or precipitation satisfies the information need. More commonly, watershed runoff must be predicted to provide the information. For example, a flood-damage reduction study may require an estimate of the increased volume of runoff for proposed changes to land use in a watershed. However, no record will be available to provide this information because the change has not yet taken place. Similarly, a forecast of reservoir inflow

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may be needed to determine releases if a tropical storm alters its course and moves over a watershed. Waiting to observe the flow is not acceptable. The alternative is to use a model to provide the information. A model relates something unknown (the output) to something known (the input). In the case of the models that are included in the program, the known input is precipitation and the unknown output is runoff, or the known input is upstream flow and the unknown output is downstream flow (Scharffenberg, 2010).

Why is Modeling?

There are many different reasons why we need to model the rainfall-Runoff process of hydrology. The main reason is however, a result of the limitations of hydrological measurement techniques. We are not able to measure everything we would like to know about hydrological systems. We have in fact, only a limited range of measurement techniques and limited range of measurements in space and time. Therefore, there is a means of extrapolating from those available measurements in both space and time. Particularly to ungauged catchments and into the future (where measurements are not possible) to assess the likely impact of future hydrological change, models of different types provide a means of quantitative extrapolation or prediction that will hopefully be helpful in decision making.

2.3.1. Hydrological Model description

Hydrological modeling is the use of physical or mathematical techniques to simulate the hydrologic cycle and its effect on watersheds. Hydrological modeling is a commonly used tool to estimate the basin's hydrological response due to precipitation. It allows to predict the hydrologic response to various watershed management practices and to have a better understanding of the impacts of these practices (Kadam, 2011). Hydrologic models are simplified, conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes.

2.3.2. Why Hydrological Models Are Needed?

No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists in replacing the parts of the universe under consideration by a

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model of similar but simpler structure. Models, formal or intellectual on the one hand, or material on the other, is thus a central necessity of scientific procedure.

Most hydrologic systems are extremely complex, and we cannot hope to understand them in all detail. Therefore, abstraction is necessary if we are to understand or control some aspects of their behavior. Indeed, man has found through experience that understanding and predicting the behavior of any significant part of his environment requires abstraction.

The catchment hydrologic models have been developed for many different reasons and therefore have many different forms. However, they are in general designed to meet one of the two primary objectives. The main objective of catchment modeling is to gain a better understanding of the hydrologic phenomena operating in a catchment and of how changes in the catchment may affect these phenomena, to generate useful information from limited data due to Limitation in hydrological measurement technique, Another objective of catchment modeling is the generation of synthetic sequences of hydrologic data for facility design or for use in forecasting. They are also providing valuable for studying the potential impacts of changes in land use or climate. The variety of uses and the rapid increase both in scientific understanding and in technical support, from data collection systems and computer technology, have produced an enormous range in levels of sophistication.

2.3.3. HEC-HMS Model

HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) is hydrologic modeling software developed by the US Army Corps of Engineers-Hydrologic Engineering Center (HEC), it is the physically based and conceptual semi distributed model designed to simulate the rainfall-runoff processes in a wide range of geographic areas such as large river basin water supply and flood hydrology to small urban and natural watershed runoff. Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. HEC-HMS is a popularly used for estimation of watershed model to simulate rainfall- runoff processes and peak discharge of specific catchment area with the input data are rainfall, land use, etc. for different return periods. This system is designed to simulate the precipitation-runoff processes by using different methods like losses, direct runoff and base flow methods for dendritic watershed systems and designed to

be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. HEC-HMS has become very popular and been adopted in many hydrological studies because of its ability in the simulation of runoff both in short and longtime events, its simplicity to operate, and use of common methods (Halwatura, 2013).

2.3.3.1. Components of HEC-HMS Model

HEC-HMS uses separate models to represent each component of the runoff process. Each model run combines a basin model, meteorological model, and control specifications with run options to obtain results. It contains four main components: (1) An analytical model to calculate overland flow runoff as well as channel routing, (2) an advanced graphical user interface illustrating hydrologic system components with interactive features, (3) a system for storing and managing data—specifically large, time variable data sets—and (4) a means for displaying and reporting model outputs (Brook and Boneya, 2020).

Basin Model represents the physical description of the watershed in a HEC-HMS process. The physical attributes of the model, such as basin areas, river reach connectivity, or reservoir data describes in this model. In addition to, including the physical description, a basin model also includes information on the mathematical methods (or equations) that will be used in simulating the hydrology of the basin, and the values for all the variables in those equations. The variables in all the equations are called parameters because by changing the values for these parameters we can change the output from the model.

Meteorological Model contains input data to the model (rainfall, evapo-transpiration) data of the watershed. Meteorological model contains meteorological information to drive the hydrologic simulation and calculates the precipitation input required by a sub basin element.

Control specification applied to specify the timing and the time interval for the model (time control during a simulation run). The control specification file basically tells HEC-HMS how long the simulation will last and the time step to continue the simulation (sets the time span and time interval of a simulation run) and

Time-series data component where the actual rainfall, discharge data are entered in tables as per the control specified

2.3.3.2. The Analytical Components of HEC-HMS

The HEC-HMS model is composed of several different modeling components that make up the entire watershed model including: infiltration loss method that calculates runoff, transform method for transforming excess precipitation into runoff, routing methods that accumulates modeled flow from each of the distributed sub basins, creating a stream flow hydrograph, meteorological model that handles precipitation inputs, watershed stream network and size and the time span of the simulation.

HEC-HMS consists of different models of the major hydrological processes and transports. It consists of runoff volume models, models of direct runoff (overland flow and interflow), base flow models; channel flow models. HEC-HMS gives flexibility to the user by providing each component with suit of models. Researcher or model user can select a suitable combination of models depending on the availability of data, the purpose of modeling and the required spatial and temporal scales

2.4. Runoff-Volume Models

HEC-HMS calculates amount of runoff by computing the quantity of water that is intercepted by vegetable leave and other buildings before reach the surface, infiltrated in to the soil, stored on the ground surface, evaporated /transpired and subtracting it from the total precipitation. In HEC-HMS program, Interception, infiltration, storage, evaporation, and transpiration collectively are considered as and documentation as losses. HEC-HMS considers that all land and water in a watershed can be categorized as either directly-connected impervious surface, or pervious surface. Directly connected impervious surface in a watershed is that portion of the watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses. Precipitation on the pervious surfaces is subject to losses. However, only some of the applicable methods used for the purpose of this research paper are described below.

2.4.1. Loss Model

The loss models in HEC-HMS program calculate the runoff volume by computing the volume of water that is intercepted by vegetable and other things before reach the ground, infiltrated, stored, evaporated, or transpired and subtracting it from the total amount of precipitation. Different methods are available to estimate losses in HEC-HMS program. In this study, the Soil Conservation Service Curve Number loss method was selected to calculate direct runoff from a specific or design rainfall. The Soil Conservation Service (SCS) curve number (CN) method is one of the most popular methods for computing the runoff volume from a rainstorm. It is popular because it is simple, easy to understand and apply, and stable, and accounts for most of the runoff producing watershed characteristics, such as soil type, land use, hydrologic condition, and antecedent moisture condition. The SCS-CN method was originally developed for its use on small agricultural watersheds and has since been extended and applied to rural, forest and urban watersheds. This method has several advantages compare to other methods in that: It is a simple conceptual method for the estimation of the direct runoff amount from a storm rainfall event, and is well supported by empirical data; it relies only on the curve number, which is a function of the soil type and land use/cover that are the major runoff-producing watershed characteristics.

2.4.2. Transform Model

After the losses are computed and subtracted it from rainfall to estimate runoff volume, the time distribution and magnitude of runoff is computed with a rainfall to runoff transform. The transform prediction models in HEC-HMS simulate the process of the direct runoff of excess precipitation on the watershed, and they transform the precipitation excess in point runoff. (Bitew, 2019). Commonly available methods for the transform model in HEC-HMS are: SCS- UH (Soil Conservation Service Unit Hydrograph Method, Clark or Snyder unit hydrographs, Kinematic wave, Mod-Clark and User specified unit hydrograph. During the analysis of the hydrological data, the SCS- UH model was suitable to transform the excess rainfall into runoff. Therefore, SCS unit hydrograph method was selected in this study work

2.4.2.1. Basic Concepts and Equations of SCS-UH Method

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The Soil Conservation Service (SCS) proposed a parametric UH model; this model is included in the Hydrologic Engineering Center’s Hydrologic Modeling System program. The model is based upon averages of UH derived from gaged rainfall and runoff for a large number of small agricultural watersheds throughout the United State. (SCS Technical Report 55 , 1986) And the (National Engineering Handbook , 1971) describe the UH in detail. At the heart of the SCS UH model is a dimensionless, single-peaked Unit hydrography. This dimensionless UH, expresses the UH discharge, U_t , as a ratio to the UH peak discharge, U_p , for any time t , a fraction of T_p , the time to UH peak. Research by the SCS suggests that the UH peak and time of UH peak are related by:

$$U_p = CA/T_p \dots\dots\dots \text{Equation 2.1}$$

in which A = watershed area; and C = conversion constant (2.08 in SI and 484 in foot-pound system). The time of peak (also known as the time of rise) is related to the duration of the unit of excess precipitation as:

$$T_p = \frac{\Delta t}{2} + t_{lag} \dots\dots\dots \text{Equation 2.2}$$

In which Δt = the excess precipitation duration (which is also the computational interval in HEC-HMS model); and t_{lag} the basin lag, defined as the time difference between the center of mass of rainfall excess and the peak of the UH. When the lag time is specified, HEC-HMS model solves Equation above to find the time of UH peak, and Equation of U_p to find the UH peak. With U_p and T_p known, the UH can be found from the dimensionless form, which is included in HEC-HMS.

SCS unit hydrograph method was selected due to its availability of information for parameter estimation, appropriateness of the assumption inherent in the model, and user preference and experience (Feldman, 2000). In HEC-HMS, it requires only lag time between rainfall and runoff for each sub-basin, this helps in simplifying the model simulation.

2.5. Routing

Once excess precipitation has been transformed into overland runoff and routed to the outlet of a sub watershed, it enters the stream at that point and is added to stream flow routed from upstream. There are several methods available in HMS model for stream flow routing including Kinematic

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Wave, Lag, Modified Puls, Muskingum, Muskingum-Cunge, and Straddle Stagger. As mentioned above, Muskingum method was selected for this process. This method requires two parameters K, and X. Muskingum X is the weighting between inflow and outflow influence; it ranges from 0.0 up to 0.5. Muskingum K the travel time through the reach and it was determined through calibration depends on catchment characteristics. The values of the X parameter affect attenuation travel time through reaches of stream flow volume. Therefore, parameters can be estimated with the help of observed inflow and outflow hydrographs. Parameter K estimated as the interval between similar points on the inflow and outflow hydrographs.

2.6. Hydraulic Modeling

The purpose of hydraulic modelling is to simulate flow conditions and to understand flood phenomenon of the location based on the hydrologic model that gives catchment flows. A hydraulic model is a collection of mathematical equations that give a simple representation of reality. They estimate: flow, water level and velocity in river channels and pipe networks. Hydraulic models take a known flow amount (typically the output of a hydrologic model) and provide information about flow height, location, velocity, direction and pressure.

2.6.1 HEC-RAS Model

HEC-RAS (Hydrologic Engineering Center - Analysis System River) is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S Army Corps of Engineers. From many hydrologic software, HEC-RAS (Hydrologic Engineering Center - River Analysis System) is a good choice for one -dimensional (1D) flood plain modelling. The model is fully available from the web and copes with a variety of problems as rainfall-runoff modelling, river and civil works hydraulics, and the mapping of hydraulic hazard. Its ArcGIS application companion HEC-GeoRAS makes it easier to gather physical data required by the model from a high-resolution DEM (Tabyaoui, 1997).The extension allows users to create an HEC- RAS import file containing geometric data from an existing digital terrain model and complementary data sets.

2.7. Software's used for Flood Hazard Mapping

2.7.1. Geographic Information System (GIS)

Water resource managers and hydrologists are always use geographic information system (GIS) technology to visualize and analyze hydrologic data for different tasks such as assessing water quality, estimating water availability, planning flood prevention, understanding the natural environment, and managing water resources. According to National Center of Geographic Information Analysis, Geographic Information System is a computer-based system that used to capture, store, manipulate, analyze, and display of geo-referenced data to solve complex problems (NCGIA, 1990).

Geographic Information System (GIS) is the best assemblage of computer equipment and a set of computer programs for the entry and editing, storage, query and retrieval, transformation, analysis and display of the factors affecting flood hazard. Geographic Information Systems (GIS) are successfully used to visualize the extent of flooding and also to analyze the flood maps to produce flood damage estimation maps and flood hazard map (Vahdettin, 2015). Nowadays GIS is emerging as a powerful tool for the assessment of risk and management of Natural Hazards. Due to these techniques, natural hazard mapping can be prepared now to delineate flood prone areas on the map. Such kind of maps will help the civil authorities for quick assessment of potential impact of a natural hazard and initiation of appropriate measures for reducing the impact. Such data will help the planners and decision-makers to take positive and in time steps during pre-disaster situation. It will also help them during post disaster activities for the assessment of damages and losses occur due to flooding (Woubet, 2007).

2.7.2. Arc-hydro

Arc hydro software, which works as extension on ArcGIS and used to delineate the watershed for which flood hazard analysis was done. Arc-Hydro is the common GIS based tool to process DEM (Digital Elevation Model) to delineate watershed, sub-watersheds, and stream network systems. It is used to manipulate (assign) key attributes in the Arc-Hydro data mode land provide some core functionality often used in water resources applications includes DEM-based watershed delineation, network generation, and attribute-based tracing.

2.7.3. HEC-HMS

HEC-HMS is hydrologic modeling software program developed by the US Army Corps of Engineers-Hydrologic Engineering Center (HEC). HEC-HMS model is designed to simulate the rainfall-runoff processes in a wide range of geographic areas such as large river basin water supply and flood hydrology to small urban and natural watershed runoff. The system encompasses losses, runoff transform, open channel routing, and analysis of meteorological data, rainfall-runoff simulation and parameter estimation. HEC-HMS uses separate models to represent each component of the runoff process, including models that compute runoff volume, models of direct runoff, and models of base flow. Each model run combines a basin model, meteorological model and control specifications with run options to obtain results.

2.7.4. HEC- GEORAS

According to (USACE,, 2010), HEC-GeoRAS (Geospatial Hydrologic Modeling Extension) is a set of ArcGIS tools specifically design to process geospatial data for use with the Hydrologic Engineering Center - Analysis System. HEC-GeoRAS is a GIS extension that provides the user with a set of procedures, tools, and utilities for the processing or preparation of geospatial data in ArcGIS using a graphical user interface (GUI) for import into HEC-RAS and generation of GIS data from RAS output. The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. HEC-GeoHMS used to transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation.

The Geospatial Hydrologic Modeling Extension has been developed as a geospatial hydrology toolkit and used as an instrument for engineers and hydrologists with limited GIS experience.

HEC-GeoHMS uses ArcGIS and the Spatial Analyst extension to develop a number of hydrologic modeling inputs for the Hydrologic Engineering Center's Hydrologic Modeling System, HEC-HMS. In ArcGIS using a graphical user interface (GUI). The extension allows users with limited GIS experience to create an HEC-RAS import file containing geometric attribute data from an existing digital terrain model (DTM) and complementary data etc. The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported

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from HEC-RAS. The user creates a series of line themes pertinent to developing geometric data for HEC- RAS. The themes created are the Stream Centerline, Flow Path Centerlines (optional), Main Channel Banks (optional), and Cross Section Cut Lines referred to as the RAS Themes. Additional RAS Themes may be used to extract additional geometric data for imports in HEC-RAS these themes include Land Use, Levee Alignment, Ineffective Flow Areas, and Storage Areas. Water surface profile data and velocity data exported from HEC-RAS simulations may be processed by Hec-Georas for GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness.

2.7.5. HEC-RAS

HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the United State Army Corps of Engineers (USACE). Hydrologic Engineering Center's River Analysis System (HEC-RAS) like the other software's, it can be downloaded free of charge from the Hydrologic Engineering Center's and predominately used in the field of hydraulic analysis /model hydraulic structures for floodplain delineation, for 1D food plain modeling, modelling open-channel flow systems (rivers),mapping of hydraulic hazard and generating water surface profiles which are the main components to apply flood mitigation measures because it shows more accurately where to focus for future mitigation activities. The HEC-RAS program allows the user to generate water surface profile and elevation using one dimensional steady and unsteady flow computational methods.

HEC-RAS is intended for one-dimensional steady flow water surface profile computations, unsteady flow simulation, and movable boundary sediment transport calculations. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendritic system, or a single river reach. The model results are typically applied in floodplain management and flood insurance studies to evaluate floodway encroachments.

2.7.5.1. HEC-RAS Parameters

HEC-RAS program uses a number of input parameters for hydraulic analysis of the stream channel. There are two types of data required for computing water surface profile of river reach

are River geometry and water flow data. These parameters are used to generate a series of channel cross sections along the direction of the stream. The River channel cross section is divided into segments of left flood Flow path, main channel, and right flood flow path.

At every River cross-section, HEC-RAS assumes that energy is constant and that the velocity vector is perpendicular to that cross section. After defining the stream geometry, flow values for each reach within the river system are entered. The channel geometric description and flow rate values are the primary model inputs for the hydraulic computations.

2.7.5.2. Water Surface Profile Estimation

Hydraulic model software program is intended for generating water surface profiles for steady gradually varied flow in natural and man-made channels and designed for application in flood plain management and flood insurance studies to evaluate flood way encroachment. For steady, gradually varied flow, the main important procedure for computing water surface profiles between cross sections is called the standard step method. The basic computational procedure is based on the iterative solution of the energy equation. Given the flow and water surface elevation at one cross section, the goal of the standard step method is to compute the water surface elevation at the adjacent upstream or downstream cross section, depending on the flow regime.

2.7.5.2.1 Basic Data Requirements

The data needed for HEC-RAS program to perform water surface profile computations are both geometric and steady flow data.

(1) Geometric data includes

➤ River Cross section Data

The river bottom points characterize the properties of each river cross section. In HEC-RAS, these points are called stations. The points are defined by the horizontal distance from the left riverbank and the bottom elevation above some datum. The cross sections should be normal to the direction of the flow and required at representative locations throughout the stream and at locations where changes occur in discharge, slope, shape, roughness, and at hydraulic structures. According to (Dewberry & Davis LLC, 2002), the

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required information for a cross-section includes: Stream centerlines, Bank lines, River cross-sections and Flow lines of the river.

➤ Reach Length

In this application, the distance between two cross sections is called reach length. A reach length is required for the main channels as well as for the over banks.

➤ Manning's Roughness Coefficient

Manning's roughness, n : depends on the surface roughness, vegetation, channel irregularities, channel alignment, obstructions of the channel, size and shape of the channel, and others. In practice, the roughness coefficient of the overbank areas is usually chosen higher than that of the channel, due to the abundance of obstructions such as grasses, bushes, and trees.

Manning's Roughness values for channels and flood plains should be determined separately (Cowan's, 1956). Thus, the physical shape and vegetation of a flood plain can be quite different from those of a channel. For surface flow, increased roughness delays the runoff and increase the potential for infiltration, reduces flow velocities associated with increased roughness and this should also decrease the amount of erosion. The "n" values were assigned based on the characteristics of River channel and information obtained from floodplain area. The roughness coefficient for flood plains is determined by selecting a base value for natural base soil surface of the flood plain and adding adjustment factors due to surface irregularity, obstructions and vegetation (Cowan's, 1956).

➤ Contraction and Expansion Coefficients

Contraction and Expansion of the flow is due to variation of channel cross-section because of energy loss between sections.

According (USACE, 2010) the contraction and expansion coefficient for natural channel which has gradual change in cross-section is estimated to be 0.1 and 0.3 respectively.

(2) Flow data: To enter the steady flow data, from the main program window Edit and then Steady Flow Data were selected. It is required to enter information about the number of profile, the boundary conditions and the Flow data.

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(a) Boundary conditions

After all of the flow data have been entered into the table form, the next step is to enter any boundary conditions that may be required. To enter boundary conditions data, press the boundary conditions button at the top right of the steady flow editor. Boundary conditions are necessary to establish the starting water surface at the ends of the river system (upstream and downstream).

There are four external boundary conditions available for steady flow analysis •

- ❖ **Known Water Surface Elevations** - For this boundary condition the known water surface for each of the profiles to be computed.
- ❖ **Critical Depth** - When this type of boundary condition is selected, the user is not required to enter any further information. The program will calculate critical depth for each of the profiles and use that as the boundary condition.
- ❖ **Normal Depth** - For this type of boundary condition, the energy slope that will be used in calculating normal depth (Manning's equation) at that location. A normal depth will be calculated for each profile based on the user-entered slope.
- ❖ **Rating Curve** - When this type of boundary condition is selected, a pop up window appears allowing the user to enter an elevation versus flow rating curve. For each profile, the elevation is interpolated from the rating curve given the flow.

(b) Discharge

The discharge is also other boundary conditions required at the upstream end of a reach and it is assumed to be the same downstream until a new discharge is entered.

2.8. Flood prone area maps

Flood prone area maps show areas likely to be affected by flood at several times due to over flow of the river, stream, bay, ocean, or other watercourse as determined from readily available information. Flood prone area maps for the study area used to identify affected areas in the watershed, this information was also important for planners and decision makers will prepare themselves to minimize impacts caused by flood by using either structural or non-structural measures as soon as possible. For example, starting from land use planning to mitigation measures to be taken to protect the people live in flood plain areas and their property from flood hazards. .

2.9. Data used to create Flood Hazard Map of the Study Area by using AHP and GIS

Techniques

❖ *Rainfall intensity (precipitation)*

Precipitation plays a significant role in Hydrological studies or analysis to (i) identifying precipitation characteristics and variability (ii) statistical modeling and forecasting of precipitation and (iii) resolving the problems such as floods, droughts, landslides, etc. The rainfall pattern and intensity greatly influence the runoff. Precipitation is one of the critical factors which affect the occurrence and magnitude of flood is rainfall as discussed in (Muse et al., 2018). The depth of rainfall and its frequency of occurrence plays the great role in the occurrence of the flooding. If heavy rainfall falls in a specific area for longer period of time, even if the soil has high infiltration capacity, all the pore spaces of the soil will be held by water. The soil afterwards has no space to accept additional rainfall water, so that the water becomes starts to generate runoff depending on the slope of the ground or elevation. Therefore, heavy rainfall indicates high flooding event resulting the area as highly flood prone area. This indicates that magnitude of rainfall or the amount of precipitation and occurrence of flooding events have direct relationship.

❖ *Drainage Density*

Drainage density of a given watershed tells about the degree of runoff. High drainage density category indicates low infiltration capacity and steep slope in that particular area. This means the runoff capacity is very high, so that the probability of flood occurrence in that area is minimum. This shows infiltration and flooding events have inverse relationship (Muse et al., 2018)). The drainage density map of the watershed (study area) is generated using Spatial Analyst tool (Density-line density) from DEM data and Stream order feature of the study area.in ArcGIS software Drainage Density of the catchment should be calculated simply the total length of catchment divided by the area.

❖ *Land use /land cover data*

The land uses simply defined as the technique/system in which land is used by people in a specific area to produce what is needed by the people for use through the involvement of labor, capital, and available technology. Land cover is physically appearing or observing coverage on the ground surface either by an artificial (manmade) or a natural entity Land use /land cover data was collected

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form MWE and used for both curve number generation and land suitability analysis of the study area.

❖ *Soil data*

Soil type is important in flood study since it affects the infiltration rate directly and the runoff indirectly (Wong., 1990). The higher the infiltration capacity of the soil, the lower will be the vulnerability to flood. In soil types which have low infiltration rate, the rainfall will accumulate on the top surface and increase vulnerability to flood.

2.10. Estimation of Missing Precipitation Data

For any Hydrological analysis, incomplete data is a common challenge for researcher or hydrologists as it poses a serious problem for many statistical approaches in hydrology which needs complete data sources since missing data is often harmful beyond reducing statistical power. Before starting any hydrological analysis, it is necessary to make sure that data are homogenous, correct, sufficient, and complete with no missing values. After collecting the necessary data, filling the missing precipitation data and check the quality of the hydro-meteorological data (Stream-Rainfall) data is necessary step. When undertaking an analysis of precipitation data from gauging stations where daily observations are made, it is often to find days when no observations are recorded at one or more gauges. In order to compute precipitation totals and averages, one must estimate the missing values. Sometimes a rain falls amount of certain rain gauge station for a certain time may be missed due to lack of an appropriate records, shifting of station location, absence of observation data may be due to flood problems and instrumental failure takes place and processing are serious because they lead inconsistency and ambiguous results that may contradict to the actual situation.

Necessity of estimating missing precipitation data is essential to minimizing errors that may occur in our final outputs. Data from surrounding gauging stations are used to estimate the missing data. In such a case it might be needed to estimate the missing rain fall data by approximating the value from the data of the nearest rain gauge stations.

2.11 Flood Hazard Analysis

According to (Saaty's, 1977,1978) context, decision-making process known as the Analytical Hierarchy Process (AHP) techniques used pair wise comparisons matrixes. The Analytical Hierarchy Process (AHP) is the most commonly used and effective method in multi-criteria Decision-making (MCDM) process to assign the relative importance of each criterion/factors considered in study area. According to Saaty's, procedures that can be used to assign relative weight factors for the parameters. First step, assigning the relative importance of a value ranging from One to Nine (1-9) intensity of importance of each factor to construct the pair -wise comparison matrix:

- ❖ 1= Equal importance means both factors contribute equally to the object.
- ❖ 3=Moderate importance of one factor over other
- ❖ 5=Strong importance
- ❖ 7=over strong importance
- ❖ 9=Extreme importance
- ❖ 2, 4, 6 and 8 are intermediate values between the two adjacent judgments.

Second step Prepare normalized pair-wise matrix table. Normalized pair-wise matrix table can be prepared by dividing each value in the column in pair-wise comparison by sum of the column.

Third step, Compute Relative weight for each selected factor. The weight of each criterion can be computed by dividing the sum row in normalized pair-wise comparison matrix table by the number of the factors.

2.12. Flood Hazard Mapping

2.12.1. Flood Hazard

Flood Hazard is a common natural disaster that occurs through the world .it is caused by the overflow of water on to areas that are normally dry land. Flood hazard can be created by variety of natural occurrences such as heavy rain fall, snowmelt, or the over flow of rivers and streams. The water can accumulate quickly, leading to flash flooding, which can be highly unpredictable and fast moving. On the other hand, human activities are also another factor to contribute flood

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hazards like change land use, soil erosion or deforestation. These activities can result in changes to the natural land scape and can cause the water to accumulate and flood areas more easily.

Flood Hazard is a potentially damaging physical event, phenomenon that may cause the loss of life, property damage, and environmental degradation, social and economic disruption. Flood hazard derived from topographical, land cover, geomorphic and population related data. All data are finally integrated in a GIS environment to prepare a final flood hazard map (Tesfaye H.A, 2018) .

According to (Zein., 2009) defines hazard as “the extreme natural events which may affect different places single or combination at different times over a varying return period”. On the other hand, according to Asian Disaster Preparedness Centre (ADRC) “hazard is an event or that has a potential for causing injuries to life and damaging property and the environment”.

Flood hazard mapping is a powerful tool for understanding, mitigating and preparing for the dangers posed by flooding. Utilizing multiple data sources and technologies, flood hazard maps offer a comprehensive view of potential areas of risk. Additionally, GIS technology can be used to analyze these maps and assess the potential damage that could be caused by a flood event. Through an understanding of the data and models used to create these maps, decision-makers can be better informed of potential risks and prepare accordingly.

Flood hazard mapping is a process by which areas are identified as being at risk for flooding. Utilizing various data sources, hydrologic models, and to overcome all important parameters geographic information system (GIS) technologies employed. Flood hazard mapping can be used to generate maps with the purpose of providing a better understanding of the nature and extent of a potential flood hazard. This can then be used to inform decision-making in land use, water resources management, and disaster preparedness. Flood Hazard Mapping is flood map identifying or shows the flood hazard events on the map that is the intensity of flood situations and their associated exceedance probability a specific flood affected area. Hazards associated with flooding can be divided into primary hazards that occur due to contact with flood water, secondary effects that occur because of the flooding, such as disruption of services, health impacts such as famine and disease, and tertiary effects such as changes in the position of river channels.

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Flood Hazard Maps are engineering maps that display the results of hydrologic and hydraulic investigations, including the extent of a regulatory design flood. These maps are used for regulatory planning purposes related to land use planning and flood mitigation purposes. Usually, flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth and distribution of flow velocity (Selina, 2007). Flood hazard maps also useful tools to raise people's awareness and comprise important input for emergency management, i.e. for planning the response to the flood event. The hazard aspect of the flood risk is related to the hydraulic and the hydrological parameters. Hazard level may be defined by the parameters like flood depth, flood velocity and flood duration. For this the weighted coexistence model facilitates the analysis by ranking of the hazard level (very high, high, medium, low and very low) based on the final output values of the flood hazard map of the studied area.

The role of flood hazard mapping for communities that may affected by flood impact is essential to understand how to protect themselves and their property from flood hazard events and how to eliminate flood effects by using flood controlling mechanisms (structural or non-structural measures) for the future times. To develop Flood hazard map of the flood prone area first consider flood generating factors. The main flood generating factors in the study area are, rainfall, Elevation, Drainage density, Slope, Soil type and Land use/land cover. Flood hazard maps show the extent of inundation as determined from a thorough technical study of flooding at a given location. Flood hazard maps are commonly used in floodplain information reports and require updating when changes have occurred in the channels, on the floodplains, and in upstream areas. These changes include structural modifications and channel or floodplain modifications in upstream areas. Development of new buildings on the floodplain, obstructions, or other land use changes can affect the stream discharges, water surface elevation, and flow velocities, thereby changing the elevation profile defining the floodplain.

2.13. Flood Hazard mitigation measures

According to US Federal Emergency Management Agency (FEMA) defines mitigation as “a sustained action taken to reduce or eliminate the long-term risk to human life and property from natural hazards and their effects”. Mitigation is the least visible concept, but it plays an important role in protecting communities from disaster, reduces direct damage to property, helps to create

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more prepared community and reduces human casualties or homeless. Mitigation refer to any activity or procedure that is implemented before and during a flood, so that the impact of or loss caused by the event can be predicted and avoided or reduced (Elisabetta G and Thomas T, 2020). Flood mitigation reduces the overall risk of structure experiencing flood damage, and also reduces the severity of flood damage when it occurs. According to (Kapucu et al, 2013) stated there are three main goals of mitigation strategy. First, mitigation involved efforts to change the natural of threat. Second, mitigation targets to decrease community vulnerability to damage brought upon by disaster. Third, mitigation aims to reduce the exposure to the threat of possible disaster. Actually, all goals have the same target which is to minimize risk of life and property due to flooding.

A good mitigation strategy is able to withstand disaster and reduce the damage, loss of affected community. For minimizing the losses due to floods, various flood control measures are adopted. The flood control measures which should more correctly be termed as ‘flood management’ can be planed either through structural engineering measures or non-structural measure. Wise application of engineering science has afforded ways of mitigating the ravages/destroy due to floods and providing reasonable measure of protection to life and property. Such measure comprises multipurpose reservoirs and retarding structures which stores flood waters, Channel improvements which increase flood carrying capacity of the river, embankments and levees which keep the water away from flood prone areas, detention basin which retard and absorb some flood water, floodways which divert flood flows from one channels to another channel and aver all improvement in the drainage system.

2.13.1. Forms of flood mitigation measures

For flood prone areas, appropriate mitigation measures are recommended/proposed to prevent people who are located in flood prone areas and their properties from flood hazards. The main purpose of flood mitigation is to minimize the problems raised from flood disasters in the flood affected area. According to (Mohit, 2013)Flood mitigation approaches used to eliminate flood hazards by reducing flood volume and frequency are classified into two categories: structural and non-structural

2.12.1.1. Structural mitigation Measures

Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. It also explained as the engineering approach or any mitigation measures involving physical construction of some hydraulic structures to minimize possible impacts of hazards these occurs due to flooding. Structural mitigation Measures are used to control flood impacts by using engineering structures like a levee, Dykes, dam, Diversion channel, channel modification (Brody, 2010). Most of time this method important to prevent flood hazards by implying the construction and maintenance of existing structures like levees, dams, sand bags and floodwalls, removing obstacles from flood plains, restricting construction, and controlling the design of the physical spaces in flood-prone areas.

According to (Brody, 2010), Analyzed structural mitigation can be classified into three groups which are modification of built environment, channel phrase and land phrase. Modifications of built environment involve the building of fills, floodwall and levees. Example of structural method in channel phrase is reducing bed roughness and deepening, dykes, dam, reservoirs. For structural method in land phrase is slope stabilization, re-vegetation, and soil conservation and so on. Structural approaches are based on engineering technique such as building revetments, channels, levees, seawalls to control flood.

2.13.1.2 Non-structural mitigation measures

Any measures not involving physical construction to reduce possible impacts of hazards. Non-structural measures rather it focuses on policy and legal-related works. It includes activities like land-use planning laws and their enforcement, research and assessment, information resources and public awareness programs and flood forecasting. Non-structural measures alter the impact or consequences of flooding and have little to no impact on the characteristics of the flood. These methods can simply be applied by improving the performance of the channel. Non-structural approaches can be performed by local government such as emergency and recovery politics, training and education, land use planning tool and insurance as flood programs. Non-structural

measures apply knowledge, practices, agreements, and/or policies to mitigate flood hazards land use planning, insurance, and improvements to resistance to the effects of flooding

2.13.1.3 Comparison between Structural and Non-Structural Flood Mitigation Measures

Structural mitigation measures are generally technology-based solutions and used in a more restricted sense to mean just the load-bearing structure to mitigate flood impacts by construction and designing of new flood control structures or maintaining existing structures to make them more resistant to flood hazards/effects. Structural measures are consuming more costs (not economical), but provide a better level of protection to the community. When we compare both flood mitigation measures, structural method is more advantageous according to flood plain protection physically, but their disadvantage expensive (not economical). Regarding the urgent requirement of resolving the flood hazard to residential areas, the structural measures were proposed as the main strategy. Structural measures to mitigate flood hazards often imply the construction and maintenance of levees, dams, mobile elements such as sand bags and mobile floodwalls, removing obstacles from flood plains, restricting construction, and controlling the design of the physical spaces in flood-prone areas. Common Structural mitigation measures consists

- **River Improvement:** that is fundamental measure for flood mitigation and includes works for channel normalization, dike, bank protection and flood diversion,
- **Flood Diversion:** The flood diversion work includes construction of floodway and intercepting channel to lead flood water away from the area to be protected,
- **Flood Runoff Retention:** Flood control dam and flood retardation pond are conceivable to retain floodwater so as to lower the flood peak in the lower reaches

Non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and education. Non-structural mitigations are they work with the forces of nature, through acquisition and relocation of people and properties away from risk areas or out of hazard zones. Non-structural measures actually cost less or economically efficient and environmentally friendly, but the intent is to remove or decrease human development in a

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hazard-prone zone. The non-structural measures, such as flood warning system, retarding basin, land use planning and integrated watershed management, should be adopted as supplements to strengthen flood hazard mitigation.

Non-structural measures activities like:

- **Watershed Management:** these activities include Afforestation, Conservation of existing forest, and Regulation of deforestation, Conservation of natural flood retardation areas, and Guidance to local people for appropriate forest use and conservation of mountain slope. To manage flood prone watershed area so as to retain rainwater in the catchment area and alleviate or eliminate flood impact and sediment runoff to the lower basin.
- **Flood Plain Management:** Used to manage flood plain area so as to reduce and avoid partially or completely the occurrence of flood damages and to support and guide the community people who located in the flood prone area by providing land use adjustment to reduce damageable properties in flood vulnerable areas, Encouragement of peoples' water-proofing activities, Establishment of flood forecasting and warning system, and Promotion of flood fighting activities by community organization.

2.14. Sensitivity Analysis for HEC-HMS Model

Sensitivity analysis involves investigating the behavior of the performance of a model in respect of one or more parameters which might be highly sensitive or insensitive to changes in values. A parameter which is insensitive to changes in values, may be kept at a fixed value while carrying out optimization to reduce the effective number of parameters to be optimized, thereby ensuring better convergence to optimum value of the objective function. Parameter sensitivity analysis is a necessary background for any deeper analysis and helps to improve the understanding of the model's behavior. Its goal is to explore the change in model output resulting from a change in model parameters or model inputs and to separate influential from non-influential parameters. Sensitivity analysis investigates the sensitivity of a parameter with respect to the simulation results at a certain parameter value (Héctor A. et al., 2020). SA, the most commonly essential component of hydrologic modeling, helps to simplify the complexities and understand the physical processes of complex hydrologic systems in a comprehensive way

Sensitivity analysis was performed on HEC-HMS model to determine which input parameters have the greatest influence on simulation results. The sensitivity analysis was performed for each calibration event by varying each of the above parameters by adjusting separate simulations, and then calculating the percent change in output parameters.

The sensitivity analysis tool is helpful to model users in identifying parameters that are most influential in governing stream flow response. HEC-HMS model has an embedded tool to perform sensitivity analysis and provides recommended ranges of parameter change. The most sensitive parameter corresponds to greater change in output response. To improve simulation result and thus understand the behavior of hydrologic system in Bilate River sub basin, sensitivity analyses will be conducted using the entire flow parameters for HEC-HMS model. Therefore, sensitivity analysis as an instrument for the assessment of the input parameters with respect to their impact on model output is useful not only for model development, but also for model validation and reduction of uncertainty (M. E. M. El-Sayed and K. W. Zumwalt, 1991).

2.14.1. Methods for Sensitivity analysis in HEC-HMS model

In order to understand the model parameter behavior with respect to the model outcome (i.e. Model hydrograph) a sensitivity analysis was performed. The main idea of sensitivity analysis is to select the most effective model parameter for model calibration and validation. Sensitivity analysis was performed by adding 20%, 40% and 60% etc. in the right side of the original calibrated model parameters and its inverse to the left side by changing the value of one model parameter at a time (M. E. M. El-Sayed and K. W. Zumwalt, 1991). The effect of each model parameters was analyzed based on objective functions (model performance) NSE and RVE visualization. Those model parameters having steep slope (having high variation between intervals in NSE and RVE) are considered as most sensitive while those having moderate to gentle slopes (having low variation between intervals in NSE and RVE) are considered as less sensitive

2.15. Calibration and validation of the HEC-HMS model

Calibration is the process of adjusting model input parameters to increase the predictive accuracy of a model. Model parameters are changed in a systematic way and the model is run repeatedly until the simulated values approximately similar with measured values within a range that is

considered acceptable. Model calibration is the method of defining the optimal standards of model factors that will contribute the smallest variance among the measured and the simulated values.

Validation is the process of comparing the model and its behavior to the real system and its behavior. Model Validation is the method of analysis of the model capacity to simulate measured data other than those used for the calibration within standard exactness.

The successful application of the hydrologic watershed model depends upon how well the model is calibrated which in turn depends on the technical capability of the hydrological model as well as the quality of the input data. HEC-HMS watershed model is calibrated for the event-based simulation. The objective of the model calibration is to match observed simulated runoff volumes, runoff peaks and timing of hydrographs with the observed ones

2.15.1. Model Performance Evaluation

Model must be evaluated on the extent of its accuracy, consistency and adaptability. A forecast efficiency criterion is therefore necessary to judge the performance of the model. Assessing performance of a hydrologic model requires subjective and/or objective estimates of the closeness of the simulated behavior of the model to observations (Nash, 1970). Performance of the HEC-HMS model was evaluated in a subjective way by following the basic approach of assessing model efficiency by visual inspection. In model calibration, the model parameters have to be adjusted until the observed natural system output/data and the simulated model output show approximately acceptable level of agreement. The goodness of fit is always evaluated through an objective function which is selected based on several criteria. These criteria should be selected properly to evaluate different aspects of the hydrograph. There are many statistics used to evaluate model performance evaluation. Some of the statistical criteria that were considered in selecting the objective function are as follows:

Nash-Sutcliffe efficiency: The Nash-Sutcliffe efficiency (NSE) is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. NSE measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. NSE can be defined according to the following equation:

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$$NSE = 1 - \frac{\sum_{i=1}^n ((Q_{obs} - Q_{sim})^2)}{\sum_{i=1}^n ((Q_{obs} - Q_{obsavg})^2)} \dots\dots\dots \text{Equation 2.4}$$

Where: NSE = the Nash-Sutcliffe coefficient,

Q_{obs} = observed stream flow data

Q_{sim} = simulated stream flow data and

Q_{obsavg}: is the average observed value.

This objective function can vary between 1 and $-\infty$ and performs best when a value of 1 is generated. Besides, due to frequent use of this objective function, it is known that when values between 0.60 and 0.80 are generated, the model performs reasonably well. Values between 0.80 and 0.90 indicate that the model performs very well and values between 0.90 and 1 indicate that the model performs extremely well (Deckers, 2006).

Coefficient of determination (R²): it expresses the measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. The range of values for **r²** is 1.0 (best) to 0.0. R² can be defined according to the following

equation: $R^2 = \left[\frac{\sum_{i=1}^n (q_{iobs} - q_{iavgobs})(q_{isim} - q_{iavgsim})}{\sqrt{\sum_{i=1}^n (q_{iobs} - q_{iavgobs})^2} \sqrt{\sum_{i=1}^n (q_{isim} - q_{iavgsim})^2}} \right]^2 \dots\dots \text{Equation 2.5}$

Where: q_{sim} is the simulated value

q_{obs} is the observed values

q_{avgsim} is the average simulated value

q_{avg obs} is the average observed value

3 DATA COLLECTION AND ANALYSIS

3.1. Data Used and Sources

Table 3:1 Data types, their sources and Function

Data Types	Sources	Purpose
DEM 30 m	(https://earthexplorer.usgs.gov/)	To analysis: Slope Drainage Density map of study area To extract basin characteristics in HEC-HMS and HEC-RAS.
Rain fall data	From National Meteorological Agency	Used as input for model calibration and Validation
Gauged Flow Data	From Ministry of Water and Energy	For HEC-HMS model Simulation
Land use/ land cover Data	From Water and Land Resource center	Used as input data for flood hazard mapping and for Curve Number generation
Soil Data	From Ethio –GIS	For curve number generation and Used as input data for Flood hazard mapping
River Cross-Section Data	During Field Inspection	Used to run the HEC-RAS hydraulic model for the computation of water surface Elevation.

The main essential information to processes rainfall–runoff modelling in HEC-HMS model are meteorological and hydrological (streamflow) data. Stream flow and precipitation data are the most important parameters in the hydrological rainfall-runoff modeling processes. Collecting reliable data over time and space was an essential step before modeling the rainfall-runoff processes.

❖ *Hydrological Data*

The daily streamflow data were obtained from the Ministry of Water and Energy. The gage station used for the hydrological modeling of Wera district was near Halaba kulito.

❖ *Meteorological Data*

The only source of raw meteorological data in Ethiopia is the National Meteorological services Agency (NMA) of Ethiopia. Meteorological data for

selected meteorological stations was collected from National Meteorological Agency.

❖ *Topographic Data*

Topography is defined by a DEM (Digital Elevation Model) that describes the elevation of any point in a given area at a specific spatial resolution. ASTER-DEM was downloaded from the USGS open source website which is the world-class source of free satellite data. DEM SRTM 30 × 30 DEM data of the study area was used to derive slope maps and other related spatial data that may use to delineate study area. Digital Elevation Model (DEM), is used to estimate basin/sub-basins boundaries and area, drainage (stream) networks, reach length, and reach and basin slope.

❖ *Slope data*

For a given rainfall become to runoff (Rainfall-Runoff processes), slope of the catchment is one of the critical factors. Slope affects the infiltration capacity of the soil. The slope become steeper; the runoff generation will be higher since the soil will not get time to infiltrate the water through its pore spaces. The relationship between slope and flood vulnerability is inverse in such a way that steeper slope results high runoff and low flood vulnerability level in that area. Whereas, in flat areas the runoff generation rate is low resulting high residence time of water on the ground and results high flood vulnerability level.

3.2. Meteorological Data Availability and Processing

Normally hydrological studies require extensive analysis of meteorological, hydrological and spatial data to represent the actual processes taking place on the environment and better estimation of quantities out of it. Precipitation is the source of all waters which enters the land. Hydrologists need to understand how the amount, rate, duration, and quality of precipitation are distributed in space and time in order to assess, predict, and forecast hydrologic responses of a catchment. Before beginning any hydrological analysis, it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Generally, data should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques.

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Basically, a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. For this particular research work Meteorological, Hydrological, and Digital Elevation Model (DEM) data setting was undertaken for Wera woreda and the corresponding flood prone areas of the Woreda.

Table 2:2 Metrological Stations Used in Study Area

Name of Stations	Longitude in (deg)	Latitude in (deg)	Elevation in (m)	Data used in Years (1990-2014)
Halaba	38.1	7.33	1772	(1990-2014)
Angacha	37.917	7.35	2317	(1990-2014)
Durame	37.95	7.2	2116	(1990-2014)

Table 3:3 Wera Woreda Gauging Stations

Station Name	Longitude (deg)	Latitude (deg)	Year of Data Used	Station Number
Nr. Halaba Kulito	38.10 E	7.330 N	(1990-2014)	082008

3.3. Estimating Missed Precipitation Data

Incomplete data is a common challenge during data analysis for research or other hydrological studies. Several imputation methods commonly used to compute the missed precipitation data are: Arithmetic mean method, Normal Ratio method, Inverse Distance Weighting method, and Regression method.

3.3.1. Arithmetic mean method

The arithmetic average (AA) method is the simplest method which is commonly used to complete the missing Rainfall (meteorological) and Stream flow (hydrological) data. The missing data of rainfall and stream flow are estimated by the average of selected nearby stations around the nearest (target) station or the date on the same day with different years

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If the normal annual precipitation at various stations are within 10% of normal precipitation at station 'x'. Then missing precipitation P_x , at station 'x' can be determined using simple arithmetic mean method. The missing precipitation 'Px' is given as

$$P_x = \frac{1}{N} [\sum_{i=1}^n P_i] \dots \dots \dots \text{Equation 3.4}$$

Where 'Px' Missing value of precipitation to be computed

'N' Number of stations used in the computation and

'Pi' is precipitation at ith station

3.3.2. The Normal ratio method:

Normal ratio method (NRM) is used when the normal annual precipitation at any of the index station differs from that of the interpolation station by more than 10%. Normal ratio method is used in this research Work. The method is used when the normal annual precipitation of the index stations differs by more than 10% of the missing stations. In this method, the precipitation amounts at the index stations are weighted by the ratios of their normal annual precipitation data in a relationship of the form:

$$P_x = \frac{N_x}{n} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \frac{P_3}{N_3} \dots \dots \dots + \frac{P_n}{N_n} \right] \dots \dots \dots \text{Equation 3.5}$$

Where N_x , the normal annual precipitation of missing station,

$N_1, N_2, N_3 \dots \dots \dots N_n$ are Average value of rainfall for the neighboring station stations

$P_1, P_2, P_3 \dots \dots P_n$ Rainfall of neighboring station during missing period.

Generally, three (3) meteorological stations were used for my study area. Those stations were Halaba, Angacha, and Durame. First I try to compute Normal annual Precipitation data for each stations by counting non-missed years and their total precipitation data from all non-missed station divided by number of years. After computing NA data, 10% of the targate station normal annual data (Halaba station) identify minimum value($NAP_{value} - 10\% \text{ of } N_{Avalue}$) and maximum($NAP_{value} + 10\% \text{ of } N_{Avalue}$), then check for the the rest stations whether they are with in the rangeor

out the range. In my case, normal annual stations was out of the range, so it leads to use a Normal Ratio method to fill the missed data on Bilate Nr. Halaba station.

3.4. Checking Consistency and Homogeneity

There are two methods commonly used to check our data before using it for any hydrological studies/analysis like project works, research works, and etc.

3.4.1. Checking the Consistency of Data (Test for Consistency of Record)

The Rainfall data recording of the gauging stations has undergone a significant change during the period of record with different reasons; at that time recording rain fall data of the station may be inconsistent. A record would be consistent, when the characteristics of the record has not changed with time. If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency can be differentiated from the time the significant change took place. Inconsistency problem occurs when the catchment rainfall at rain gages is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record. Inconsistency may result from: change in gauge location, exposure, instrumentation, or an observational procedure is not real and on time. Some of the common causes for inconsistency of record are.

- Shifting of rain gauge station to a new location
- The neighboring hood of the station undergoing a marked change
- Change in the ecosystem due to calamities, such as forest fires, land slide and
- Occurrence of observational error from a certain date

Double Mass curve is a plotted on arithmetic graph paper, of cumulative precipitation collected at a gauge where measurement conditions may have changed significantly against the average of the cumulative precipitation for the same period of record collected at several gauges in the same region. The data is arranged in the reverse order, i.e., the latest record as the first entry and the oldest record as the last entry in the list. A change in proportionality between the measurements at the suspect station and those in the region is reflected in a change in the slope of the trend of the plotted points.

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If a significant variation in the regime of the curve is observed, it should be corrected and the stations used in this study have undergone significant change during the baseline period (1990-2014) of the study. So, the adjustment required for the recorded rainfall data set. The accumulated total of the individual station is compared with the surrounding totals for the Neighborhood the nearby gauging stations. If a decided change in the regime of the curve is observed it should be corrected by the following equation.

$$P_{cx} = P_x * \frac{M_c}{M_a} \dots\dots\dots \text{Equation 3.6}$$

Where P_{cx} : -is corrected precipitation at station x

P_x : - Uncorrected recorded precipitation at station x

M_c : - is Corrected slope of the double mass curve, and

M_a : - is original the slope of the double mass curve.

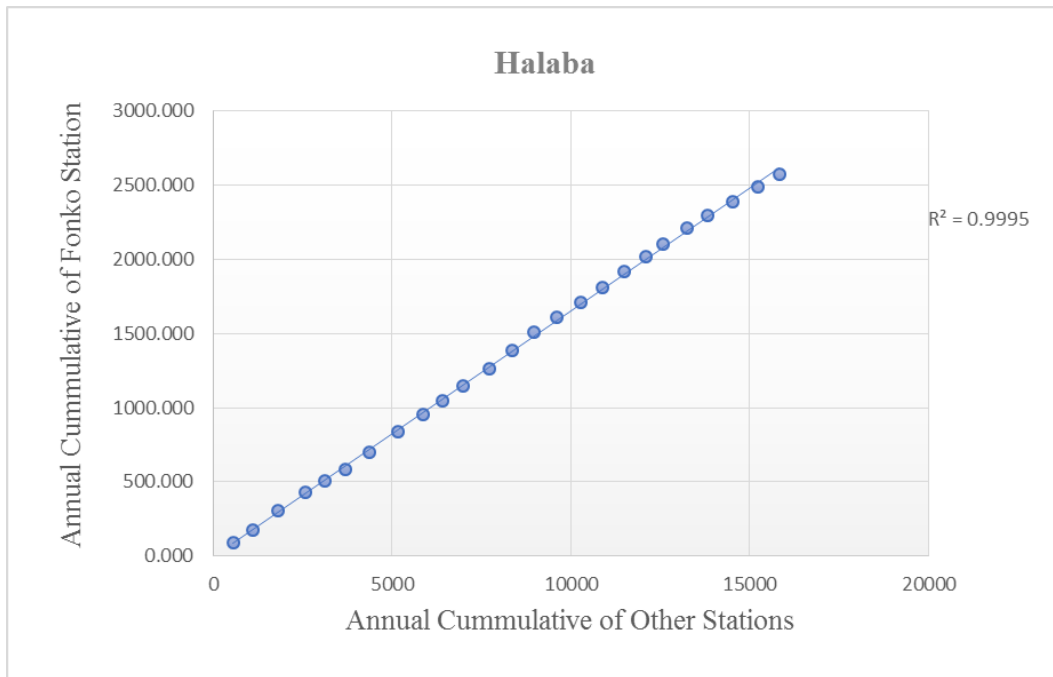


Figure 3:1 Double Mass Curve for Halaba Station

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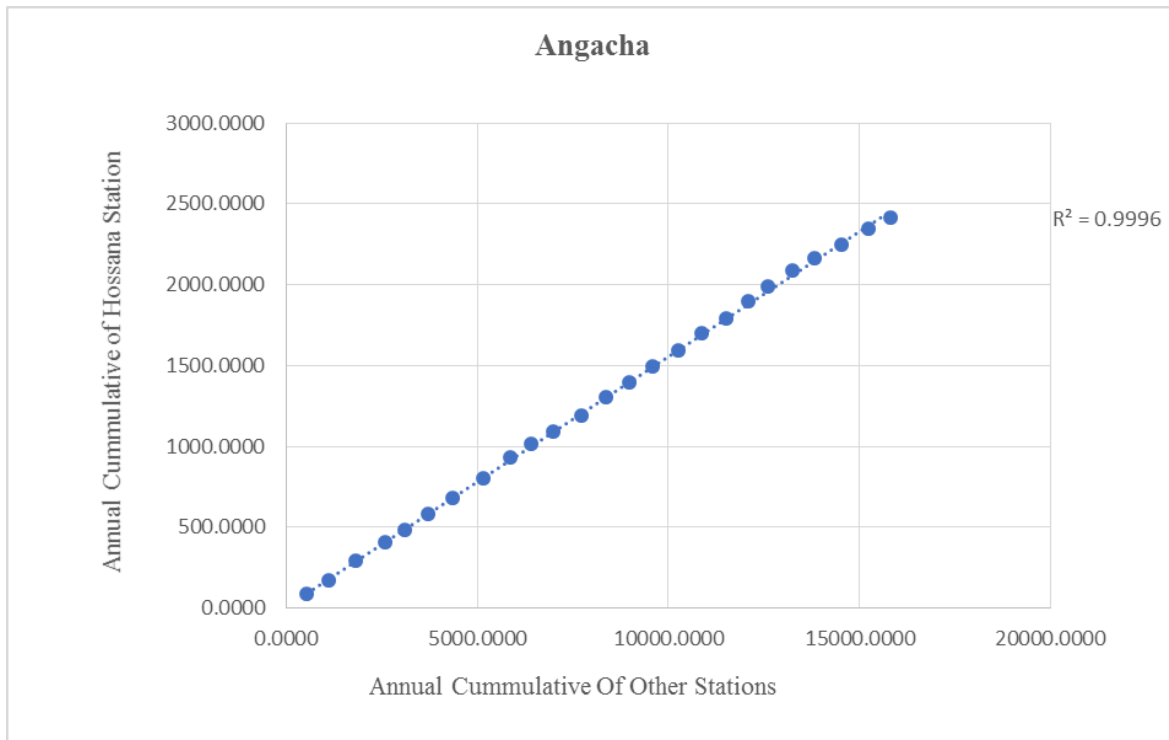


Figure 3:2 Double Mass Curve for Angacha Station

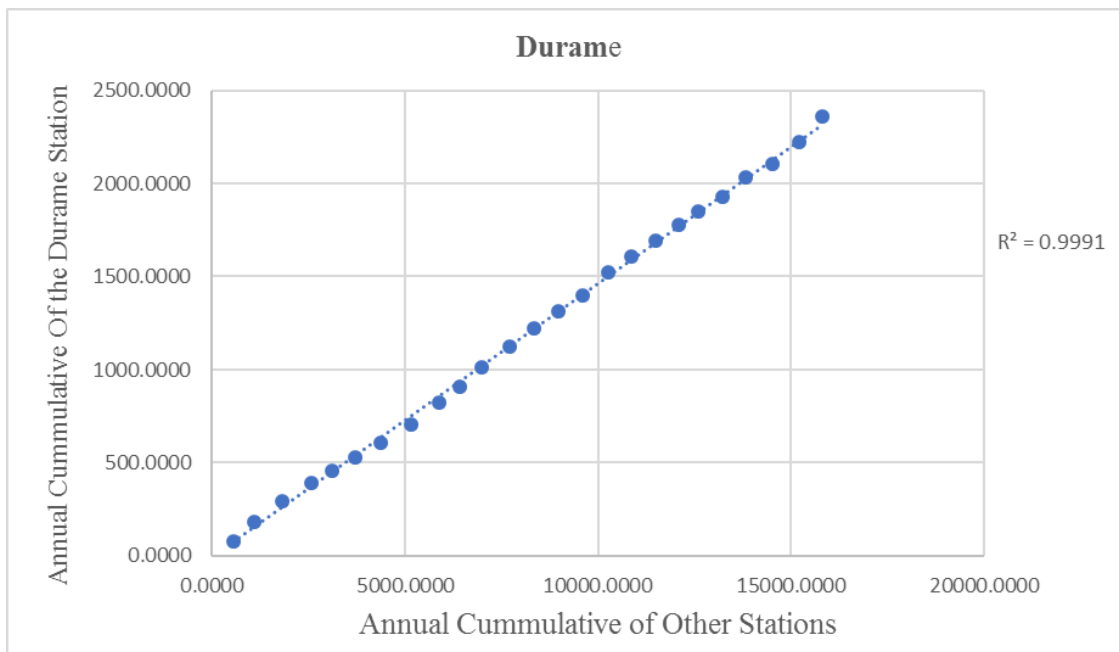


Figure 3:3 Double Mass Curve for Durame Station

3.4.2. Checking Homogeneity

The homogeneity of our data used for thesis/ research work was checked by graphically representing of time series monthly rainfall data of the selected stations. We said our data was homogeneity, when periodic pattern of all selected stations has shown similar. Graphical representation of the rainfall data of the selected stations done by creating time-series plotting of monthly rainfall data showed that the three stations show a similar periodic pattern of records.

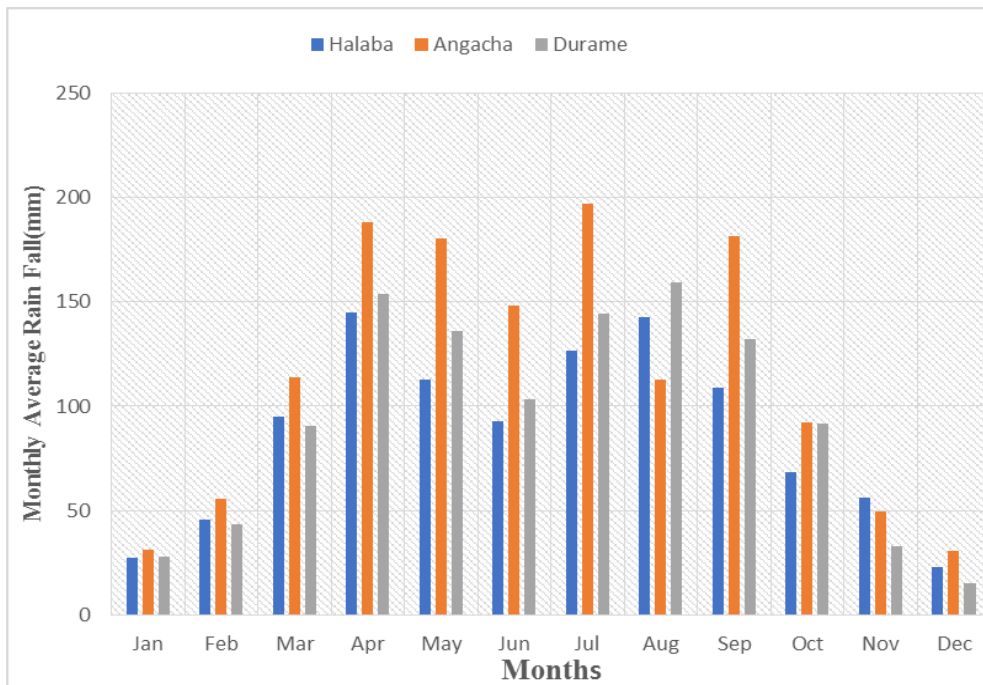


Figure 3:4 Homogeneity Test of Rain fall Data for Selected Stations

3.5. Testing for Outliers

3.5.1. Outlier Test for Rainfall Data

An outlier is a data point that differs significantly from other observations. An outlier may be due to variability in the measurement or it may indicate experimental error; the latter are sometimes excluded from the data set. An outlier can cause serious problems in statistical analyses. Outliers can occur by chance in any distribution, but they often indicate either measurement error or that the population has a heavy-tailed distribution. Outliers are data points that depart significantly from the trend of the remaining data. The retention or deletion of this outlier can significantly

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affect the magnitude of statistical parameters computed from the data; especially for small samples procedures for trending outliers require judgment involving both mathematical and hydrological considerations. There are two types of Outliers (Higher outliers and Lower outliers) were detected by using the following frequency equations respectively.

$$Y_H = Y_{\text{average}} + KnSd \quad \dots\dots\dots \text{Equation 3.7}$$

Where Y_H : is Logarithmic high - outlier test threshold,

K: -10- percent significance- level critical value for outlier test statistic for samples of size N from the normal distribution (Appendix B).

Sd: the standard deviation of data

If the logarithms of values in a sample are greater than X_H in the above equations, then they are considered high outliers. Accordingly, the information that indicates a high outlier is a maximum over an extended period, the outlier is treated as historic flood data and excluded from the analysis. If the record does not contain enough information to correct for high outliers, they shall be retained as part of the systematic record.

$$Y_L = Y_{\text{average}} - KnSd \quad \dots\dots\dots \text{Equation 3.8}$$

Where Y_L : - logarithmic low- outlier test threshold

The outlier test for basic stations has been done and tests for both high and low outliers were applied and the following results were obtained.

Table 4:4 Rainfall outlier test for Halaba Station

Year	Maximum Rain Fall of Halaba	Y=Log(P)	Higher outlier	Lower outlier
1990	68	1.83250891	2.0	1.5
1991	56.4	1.7512791	2.0	1.5
1992	74.7	1.8733206	2.0	1.5
1993	71.8	1.85612444	2.0	1.5
1994	37.9	1.57863921	2.0	1.5

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1995	52.4	1.71933129	2.0	1.5
1996	51.3	1.71011737	2.0	1.5
1997	75.4	1.87737135	2.0	1.5
1998	48.2	1.68304704	2.0	1.5
1999	59	1.77085201	2.0	1.5
2000	45.4	1.65705585	2.0	1.5
2001	57	1.75587486	2.0	1.5
2002	48.4	1.68484536	2.0	1.5
2003	55.4	1.74350976	2.0	1.5
2004	55	1.74036269	2.0	1.5
2005	55.7	1.7458552	2.0	1.5
2006	37.8	1.5774918	2.0	1.5
2007	56.7	1.75358306	2.0	1.5
2008	73.7	1.86746749	2.0	1.5
2009	41.4	1.61700034	2.0	1.5
2010	55.7	1.7458552	2.0	1.5
2011	53.8	1.73078228	2.0	1.5
2012	34.8	1.54157924	2.0	1.5
2013	51.4	1.71096312	2.0	1.5
2014	86	1.93449845	2.0	1.5
	Yaveg	1.73837264		
	Sd	0.09930082		
	N	25		
	K	2.485366		
	YH	2.0		
	YL	1.5		

The outlier test result shows that the largest recorded value ($Y = 1.934498451$) does not exceed high outlier test thresh-hold value which is ($YH = 2.0$) and the smallest recorded value ($Y =$

1.541579244) is not low outlier test threshold value which is $YL = 1.50$. So, both high and low outliers were not detected.

3.6. Areal precipitation/Average Rainfall Depth over an Area

Rain gauges represent only point measurements. In practice however, hydrological analysis requires knowledge of the precipitation over an area. Several approaches/methods have been used to work out mean rain fall/ areal precipitation from point measurements. The Arithmetic mean, the Thiessen polygon and the Isohyet method are some commonly used approaches to convert point rain fall to areal rain fall. The arithmetic mean method is the simplest method compare to others and give good results if the precipitation measured at the various stations in a catchment show little variation (gauges are distributed uniformly over the area). In the arithmetic mean method, the average depth of rainfall (\bar{P}) over an area is taken as the arithmetic mean of the rainfall depths of all stations. It is obtained by dividing the sum of the depths of rainfall recorded at all the rain gauge stations by the number of stations.

$$\bar{P} = \left(\sum_{i=1}^N \frac{P_i}{N} \right) \dots\dots\dots \text{Equation 3.9}$$

Where: P_i = the station i ,

N = the total number of rain gauges in and around the watershed.

In the Thiessen polygon method, the rainfall recorded at each station is given a weightage on the basis of an area closest to the station. The average rainfall over the catchment is computed by considering the precipitation from each gauge multiplied by the percentage of enclosed area by the Thiessen polygon. The total average areal rainfall is the summation averages from all the stations. The Thiessen polygon method gives more accurate estimation than the simple arithmetic mean estimation as the method introduces a weighting factor on rational basis. Furthermore, rain gauge stations in and outside the catchment area can be considered effectively by this method and was used in this research paper. In this procedure, areas and lines between adjacent stations were drawn on a map of the area by using Arc GIS 10.3 software with Arc tool box extension

$$\bar{P} = \frac{\sum_{i=1}^n A_i P_i}{\sum_{i=1}^n A_i} \dots\dots\dots 3.10$$

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Where: A_i = the area of polygon j in the watershed (km²)

P_i = rainfall amount in polygon j (mm)

\bar{P} = average rainfall (mm)

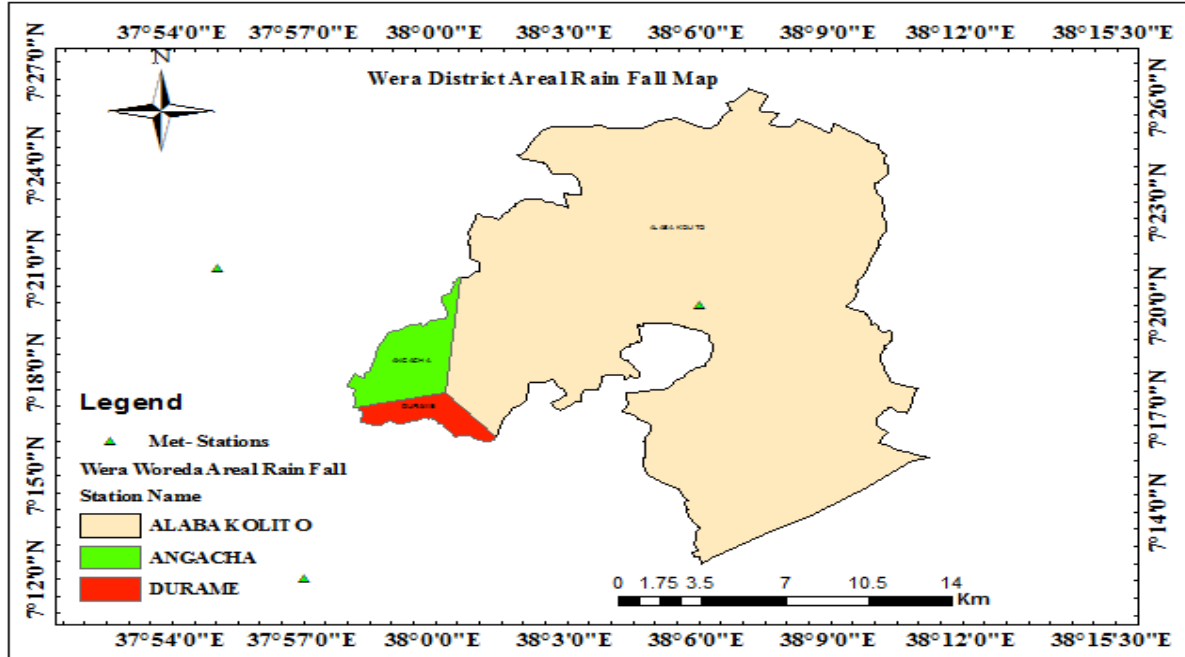


Figure 3:5 Thiessen polygon created from stations in and around Wera Woreda

Table 5:5 Areal Weight distribution for selected stations

Contributing Rainfall Stations	Contributing Area (km ²)	Weight by Area
Halaba Kulito	297.193437	0.93312533
Angacha	14.474467	0.045446804
Durame	6.824615	0.021427866
Total	318.492519	1

3.7. Flow data

The daily discharge of the study area is collected from the Ministry of Water and Energy. Unlike the daily precipitation, the daily discharge has full data composition for the considered stations to represent the study area.

3.7.1. Flood frequency analysis from hydrologic data

Hydrologists and engineers are familiar with flood frequency analysis in the world wide for estimating flood peak quantities for a set of non-exceedance probabilities. Frequency analysis is the hydrologic term used to describe the probability of occurrence of a particular hydrologic event (e.g. rainfall, flood, drought, etc.). Therefore, basic knowledge about probability (e.g. distribution functions) and statistics (e.g. measure of location, measure of spread, measure of skewness, etc) is essential. Frequency analysis usually requires recorded hydrological data. The aim of Flood frequency analysis is to compute the flood magnitude and occurrences in different return periods of Floods of 2-year return period, Floods of 5-year return period, Floods of 10 years return period, Floods of 50-year return period, etc. Data observed over an extended period of time in a river system are analyzed in frequency analysis. The data are assumed to be independent and identically distributed. The flood data are considered to be stochastic and may even be assumed to be space and time independent. Flood frequency analysis is a statistical measure/approach of the probable occurrence of the flood of a given magnitude. The probability of occurrence for the large and destructive floods is low compared to small and less destructive ones. Moreover, the accuracy of the flood susceptibility mapping greatly relies on the accuracy of previous flood events (Merz et al, 2014). The selection of flood frequency methods was based on two cogent reasons. The first is the lack of appropriate river runoff data, which makes it inevitable to utilize the most ecologically and hydrologically fit measure. Understanding about the magnitude and probable frequency of recurrence of the flood is necessary for: Economical planning and safe design of Hydraulic structures, managing flood plains and flood defense effectively, to estimate the frequency with which floods of a certain magnitude may occur etc. Final output of the flood flow frequency Analysis can be used for some engineering works like planning and design of hydraulic structures (Dams, culverts and flood control structures), delineate flood prone/plains, etc. Some of the

commonly used flood frequency functions: 1. Gumbel's extreme-value distribution (Extreme-Value type I) 2. Log-Pearson type III distribution and.3. Log-Normal distribution.

3.7.2. Extreme-Value Type I Distribution (Gumbel’s Method)

This extreme value distribution was introduced by (Gumbel, 1941) and is commonly known as Gumbel's distribution. Gumbel distribution method is the most common and widely known probability analysis, especially in meteorological and hydrological studies related to flood predictions. Gumbel defined flood as the largest of the 365 daily flows. The annual series of flood flows constitute a chain of the largest values of flows. In this study, an attempt was made to compute water levels at 2, 5, 10, 25, 50, and 100 return periods. Practically used Gumbel’s equation is given as:

$$X_T = X_{mean} + K * STDV \dots\dots\dots \text{Equation 3.11}$$

Where X_T stands for the value of variate with a return period or recurrence interval ‘T’, X_{mean} for average of the variate, $STDV$ for standard deviation of the sample, K for frequency factor expressed as:

$$K = (Y_T - Y_n) / S_n \dots\dots\dots \text{Equation 3.12}$$

With Y_T reduced variate of a given return period ‘T’ given by

$$Y_T = -[\ln. \ln \frac{T}{T-1}] \text{ Or } Y_T = -[0.834 + 2.303 \log \log \frac{T}{T-1}] \dots\dots\dots \text{Equation 3.13}$$

Where Y_n : reduced mean in Gumbel’s extreme distribution of a function of sample size N
 S_n : reduced standard deviation, a function of sample size N read from table (Appendix C)

3.7.3. Log–Pearson type III Distribution

Log-Pearson type III distribution, first proposed by Foster in 1924 and revised later in 1967 by U.S. In this distribution the variate is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. The distribution is a three-parameter gamma function with a logarithmic transform of the variable. The log-Pearson Type III distribution differs from most other distribution methods in that the three parameters mean (Z_a), standard deviation ($STDV$), and

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the coefficient of skew (K) are necessary to describe the distribution. For X variate of a random hydrologic series, Z variates calculated by using the formula logarithm of Z

($Z = \text{Log}X$). For any recurrence interval T, the values obtained by using the following formula

$$Z_T = Z_a + K_z * STDV \dots\dots\dots \text{Equation 3.14}$$

Where K_z is frequency factor taken from table with coefficient of skew values “Cs” at recurrence interval “T,” $STDV$ Standard Deviation of the “Z” variate sample and Z_a mean of the “ZT” variate.

$$STDV = \sqrt{\sum \frac{(Z-Z_{avg})^2}{N-1}} \dots\dots\dots \text{Equation 3.15}$$

$$Cs = \frac{(N \sum (Z-Z_{avg})^3)}{(N-1)(N-2)(\sigma)^3} \dots\dots\dots \text{Equation 3.16}$$

Where Cs is coefficient of skew of variate “Z,” N sample size i.e., number of years of record.

The variations of the K_z is the function of Cs and T i.e. $K_z=f(Cs,T)$ which is given on the table (Appendix D).

After finding Z_a with the equation above, the corresponding value of X_T is obtained as Antilog of Z_T .

3.7.3. Log-Normal distribution

Application of normal logarithmic method requires converting rainfall values to logarithmic values (i.e. logarithm values of the statistical variables). This distribution follows the same procedure of the Log Pearson type III distribution but the Log normal distribution used KT by Gumbel method.

$$Q_T = X_T = \text{antilog}(Y_T) \dots\dots\dots \text{Equation 3.17}$$

$$Y_T = \bar{Y} + K_T * STDEV \quad \text{And} \quad \bar{Y} = \frac{\sum Y}{N} \dots\dots\dots \text{Equation 3.18}$$

$$Y = \log Q_{\max} \quad STDEV = \sqrt{\sum \frac{(Y-\bar{Y})^2}{N-1}} \dots\dots\dots \text{Equation 3.19}$$

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$$P = \frac{1}{T}, \text{ Where } T \text{ is the return period and } P \text{ is probability}$$

$$W = [\ln \frac{1}{p^2}]^{0.5} \dots \dots \dots \text{Equation 3.20}$$

$$Z = KT = w - \frac{2.515517+0.802852W+0.010328W^2}{1+1.1432788W^2+0.189269W^2+0.001308W^3} \dots \dots \text{Equation 3.21}$$

3.8. Compare Distribution Result for Selection of the Best

The L-moments (standardized moments.) ratio diagram can be used to compare the L-skewness--L-kurtosis relations of different distributions and data samples. This gives a visual indication of which distribution may be expected to give a good fit to a data sample or samples. Depending on the result obtained from the L-Moment ratio diagram, type of the flood frequency analysis of distribution method is selected. The section was done using Easy-fit statistics software. This method of selecting and evaluating the best fit distribution specified based on the diagram that shows the Best-Fit distribution for the collected stream flow data.

Table 6:6 Estimation of Peak discharge using different distribution Methods

Recurrent Time(T)	Log-Normal (m3/s)	GEV I (m3/s)	Log-Pearson Type III
2	106.4676026	119.446707	116.0542184
10	205.372114	235.3608297	218.5518329
25	252.0827764	293.7063978	276.468847
50	301.3204775	336.7147198	321.8137802
100	345.460864	379.9436079	368.8386013

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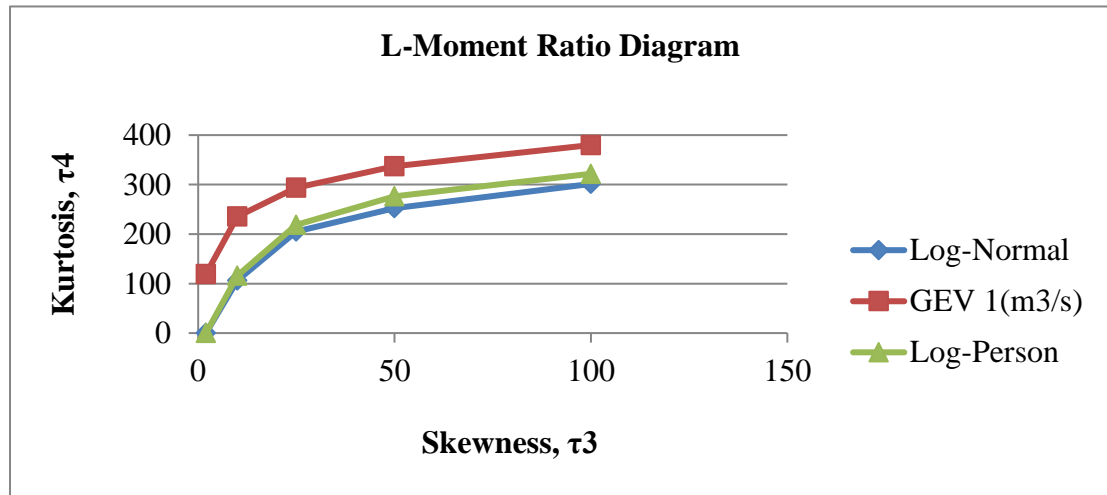


Figure 3:6 Data checking for select Best Distribution

From Data checking by using L-Moment ratio diagram, General Extreme Value I (Gumbel's) was the best-fit distribution method for the available hydrological data of Wera woreda. So based on the flood frequency analysis, the following peak discharges were summarized with their respective return period.

Table 7:7 Peak discharge using General Extreme Value I distribution Method

Recurrent Time(T)	2	5	10	25	50	100
$Q_{peak}(m^3/s)$	119.44	189.18	235.36	293.70	336.71	379.94

4 MATERIAL, METHOD AND METHODOLOGY

4.1. Description of the Study Area

4.1.1. Bilate River Sub- basin catchment Overview

Bilate River catchment is located in South Western Escarpment of the Main Ethiopian Rift at about 130 Km North West of the regional town Awassa and 340km from Addis Ababa through the asphalt road from Addis Ababa to the Arbaminch town that passes via towns of Shashemane, Alaba Kulito, Wolayta Sodo of SNNPR. It can be also accessible through 230Km asphalt road from Addis Ababa to Hossana in Northern part. The Bilate River Basin is situated in southern Nation Nationalities and Peoples Region in Rift Valley Lake Basin and located approximately 6°38'18"North - 8°6'57"North latitudes and 37°47'6"East - 38°20'14" East of longitude. Bilate River drains to northern part of Lake Abaya-Chamo Drainage sub-basin and one of the three main perennial rivers such as Bilate, Gidado and Gelana that flow into Lake Abaya.

The Bilate River originates from the Gurage Mountain in the north towards the south into Lake Abaya. The main source of the water in the sub-basin is rainfall which comes from Gurage highland through Silte, Hadiya, and Kambata. Bilate River sub-basin is one of the major river watersheds in the RVLB having more land suitable for agriculture and it has to supply those most densely populated community. The altitude of the catchment ranges from 1116m at Lake Abaya to 3333m at mountain Ambaricho and at Alichu Woriro Woreda above sea level. This indicates that the topography of the area ranges from lowland plain areas to highly mountainous elevated terrains. Bilate sub-watershed covers a total area of 5324.3 Km² which is delineated by using 30m by 30m DEM in Arc GIS software.

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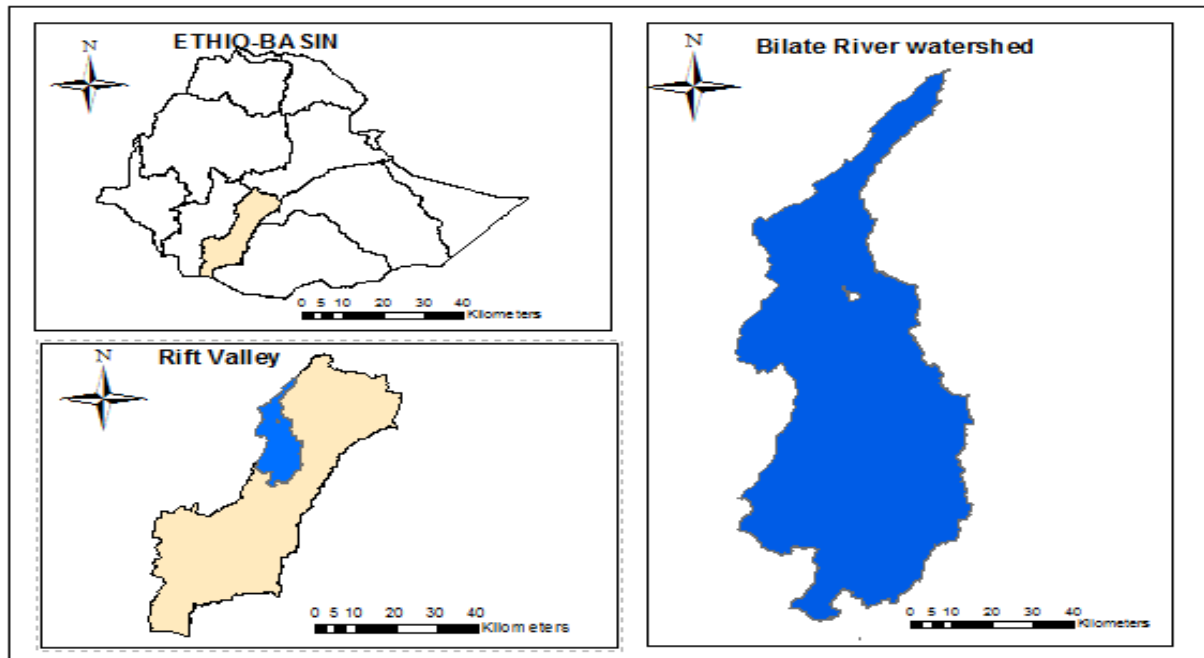


Figure 4:1 Location Map of Bilate River Watershed

4.2. General Description of the Wera District

4.2.1. Location

Halaba Zone is one of the Southern Nations' Nationalities and People Regional State Zone of Ethiopia located in 310 kms distance from Capital city of the Ethiopia and 85 km from regional city of Hawassa. It is named after the Halaba people, and covers part of their homeland. Located in the Great Rift Valley, Halaba zone is bordered on the south by an exclave of Hadiya Zone, on the southwest by the Kembata Tembaro Zone, on the west and north by Hadiya Zone, on the north east by Lake Shala, and on the east by Oromia Region.

Wera Woreda (Distinct) is one of the three woredas in Halaba Zone of the Southern Nations Nationalities and Peoples Regional states (SNNPR) and located in 310km from Addis Ababa through Shashemane, and 245 km through worabe and 83km distance from the Awassa town. In Halaba Zone, Wera woreda is bordered to the south by Siraro Woreda, to the west by Misirak Badawacho, to the north by Shashogo Woreda, to the east by AtoteUlo Woreda and to the West by Damboya Woreda. and it includes thirty-two (32) kebeles with in it. The geographic location of the woreda is between $7^{\circ} 17' N$ latitude and $38^{\circ} 10' E$ longitude. It covers an area of 318.5 Km².

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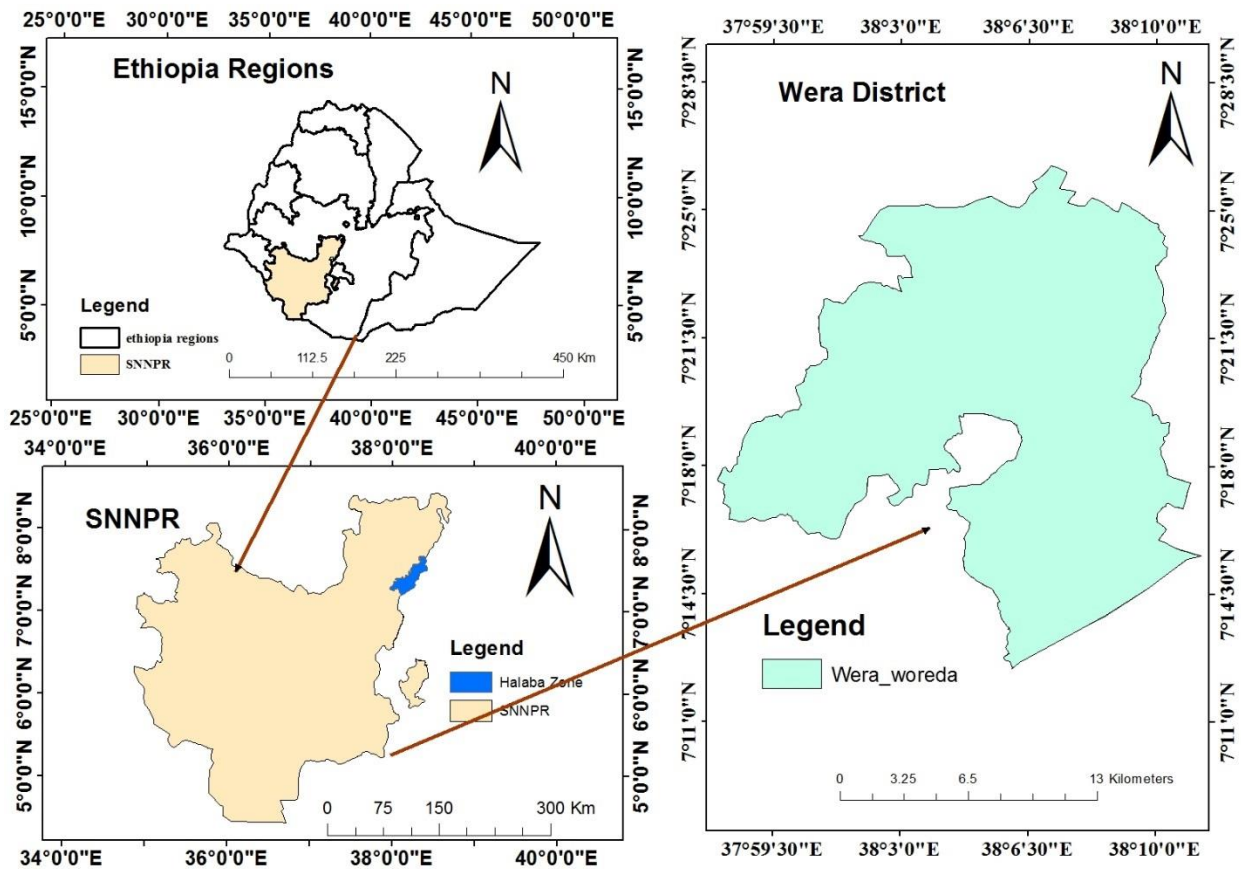


Figure 4:2 Study area Location maps

4.2.2. Topography of Study Area

Topography of Study Area was defined by Digital Elevation Model (DEM) of spatial resolution of 30 m x 30 m taken from the Rift valley DEM basin which is collected from Ministry of the Water and Energy (MoWE) of Ethiopia

The topography of the study area has very flat land, which is adjacent to the Bilate River flood plain because of the River passes through this woreda. Attitudinally, the Wera Woreda ranges from 1657-2210 m above seas level. The elevation difference between the maximum and minimum values indicates that high runoff which suspects the study area for flood disaster effect. The Woreda consists mainly of flat land (70%), while the mountainous slopes 3% and valley bottoms account for 27%.

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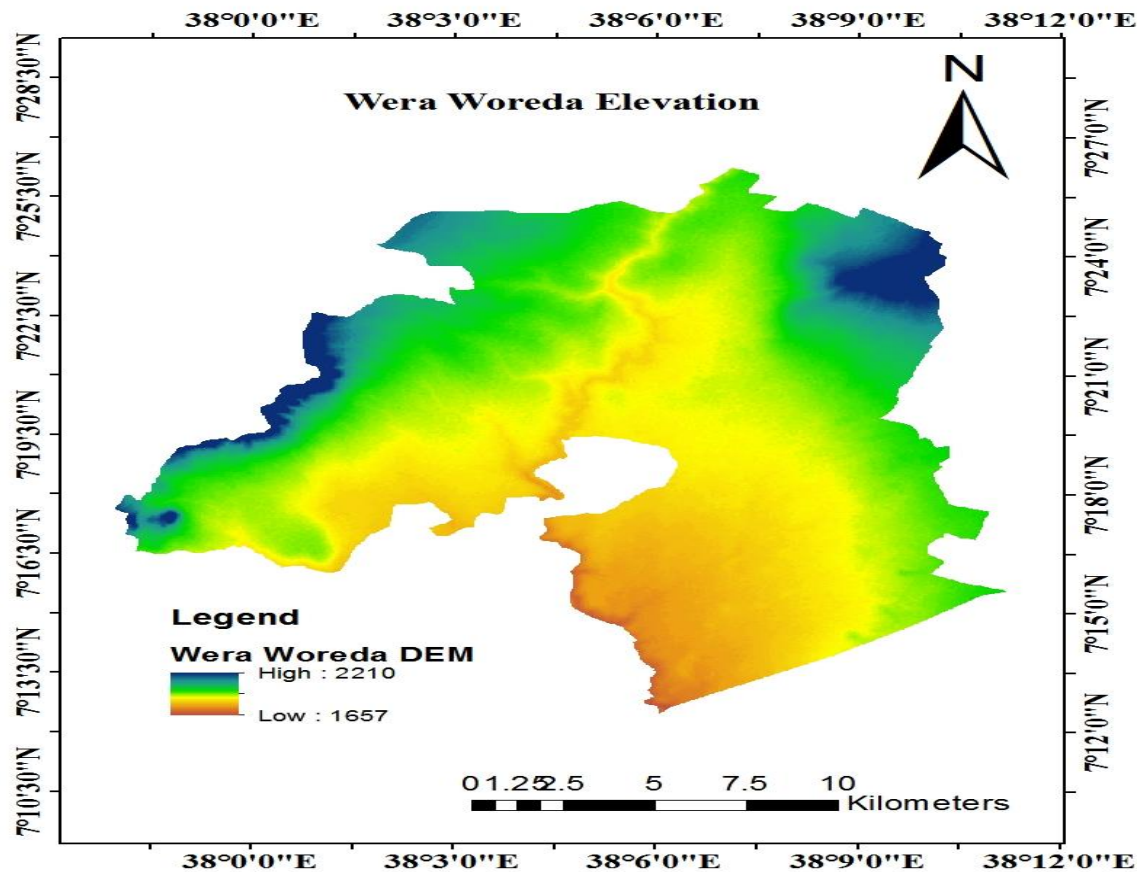


Figure 4:3 Elevation Map of the Wera District

4.2.3. Climate and Hydrology

The traditional way of classification of Ethiopia's climate is based on the characteristics of altitudes and temperatures. Based on such classification, there are five climate zones: Wurch with cold climate greater than 3000 m altitudes, Dega having temperate like climate-highland with 2500-3000 m altitude, Woyina Dega has also warm climate with 1500-2500 m altitude, Kola having hot and arid type with less than 1500 m altitude and Bereha have hot and hyper-arid type climate. According to this classification, the elevation values of the study area classified in Woyina Dega zone. The mean annual temperature is about 25 - 27 °C and the annual rainfall varies from 875 to 1110 mm. The area receives a bimodal rainfall (two rainfall increment seasons) where the small

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rain seasons are between March and April while the area receives highest rainfall during summer seasons (from July to September).

4.2.4. Land Use /Land Cover

Understanding about Land use/Land cover information of the specific area is used to identify for what purpose the land surface of the catchment is used or indicates direct interaction between land covers and action of people located in that communities. Land cover is what is physically appearing on the ground surface as a natural or manmade entity. Land use/Land cover in the country is changing due to population growth and urbanization. Most of the land surfaces are covered by infrastructure or construction works. This increases the level of imperviousness of the land surface contributing to flooding problems. The common land use/Land cover types in the District are Crop lands, Forest lands, Grass lands, Settlement and Wet lands.

According to Halaba zone Agricultural Department office unpublished report, the main crops grown in the Wera woreda are maize, pepper, bean, Wheat, Teff, Sorghum, potato and others. More than 90% of community householder's administrated by Agricultural production and the remaining 10% by Governmental or Non- Governmental works.

4.2.5. Soil texture

Soil type of the study area has a significant influence on the level of rainfall water infiltrated in to the ground surface and water holding capacity of the catchment and most of the time it may consider a key factor to identify flood prone areas. Not only this, but also it used as main important parameters to generate curve number grid of the area. The parameters of curve number generated from the soil and land use of study area was also used to estimate losses (initial losses) that we used in Soil Conservation Service (SCS) curve number (CN) method. Two main dominant soil types in Wera woreda are Sandy Loam and Loams,

4.2.6. Drainage System

Wera Woreda mainly consists of a flat, open plain across which the Bilate River flows into Lake Abaya. It passes through some kebeles of the woreda (Upper and lower Badane, Gedeba, Wanja, Shakate, Alemtena, 1st and 2nd Choroko, Asore, Muda Mayefa, and Chambula) of the wera woreda. The Bilate River forms the roadway on the study area and it passes through Alichu Woriro, Gumer,

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Hulbareg, Analemmo, Wera, Siraro Badawacho and others woredas from starting point to Lake Abaya. Bilate River originates on the high catchments to the south east plateau, and reaches the plains the gradient decreases and it forms meanders. During and after the rainy season, as the Bilate River approaches the level of flow, water overflows its banks and floods the surrounding area.

4.3. Flood problem in the study area

Halaba zone is one of the severely affected zones in both flash and river flood impacts. In this zone there are three woredas and a city administrator (Kulito town). According to Halaba zone unpublished Flood Report 2016, 51 Kebeles are affected by flood effect out of which 34 kebeles are highly damaged and the remaining 17 kebeles are moderately damaged.



Figure 4:4 Flood events in Halaba Zone (source from Halaba Zone 2015/16 flood report)

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Wera Woreda is a woreda in Halaba Zone that most of the time affected by flood events in several years both flash and River floods resulting from the over flow of the Bilate River the reason of river passes through this woreda. Flooding has been a problem in some parts of Wera Woreda in Bilate -sub catchment having the natural topography, which varies from the mountainous area to the flat lands. Topographically, Halaba Zone around Wera Woreda location was flat lands and hence it is severely affected by flooding every year. During rainy seasons, especially from June to September the level of River water rises. As a result, it inundates low lying area of Wera Woreda because of the River crosses the District. Batena and Guder Rivers are tributaries of Bilate Sub -catchment and the major source of flood waters in the human settlements in the flood plains of the Wera Woreda. The flood has frequently devastated agricultural crops. A total of 8296 ha of land, which were covered by different types of agricultural crops were drowned by the flood in the year 2016/7(Table1). The reduction in agricultural products due to flooding problem results in price increase of agricultural products in the next year, which in turn leads to poverty and related socio-economic problems.

As a result of heavy rainfall start from April 11/ 4/ 2016/17, 51 Kebeles out which 34 kebeles are highly Damaged and the remaining 17 kebeles was happen moderate damage.

Table 4:1 Crops damaged by the flood in the year 2016/17 (Source: Halaba Zone Agriculture Department, 2016/17)

<i>No</i>	Type of crop that were damaged by the flood	<i>Damaged Crops (Ha)</i>
<i>1</i>	Maize	3389
<i>2</i>	Pepper	1484
<i>3</i>	Bean and Potato	3423
<i>Total</i>		8296

Even though, the absence of satisfactory local record at Wera Woreda, the past record effects of flood were well explained by the local people during field visiting. The volume of the flood waters

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entering the river through Guder and Batena River contributes the capacity of the runoff entering in to river to become huge and the river become overflow in flood plain areas.

Table 4:2 Number of Kebeles in Wera Woreda damaged by flood in the year 2016/7 (Source: Halaba Zone Agriculture Department, 2016/7)

No	Level of the Damage in kebeles	
	Highly Damaged	Moderately Damaged
1	Gadeba	Aymale
2	Wanja	1 st and 2 nd Choroko
3	Laygnawo Bedane	Lower Lenda
4	Laygnawo Lenda	Alemtena
5	Galato	Merab Gortancho
6	Tachegnawo Bedane	Hamata

4.3. Material and Methodology

Software used in this Study

- Arc GIS Version 10.3 used to prepare river geometry, to map flood hazardous zones, to delineate study area and to processing Hec-RAS model.
- HEC-RAS 5.0 for Steady Flow Simulation and Water Surface Profile Generation
- HEC-Geo-HMS for Thiessen polygon Development, Curve Number Generation, HEC-HMS Project Development, Metrology Development and Basin Development etc.
- HEC-HMS 4 For Hydrologic and Metrologic data Processing and to Calibrate and validate simulated and Observed Flow Data

4.4. Research Methodologies and Procedures

In this section the Methods and procedures that will be applied in the research are explains as follows:

- ✚ Terrain preprocessing using DEM, ARC-GIS and Arc-Hydro tool for preparation of spatial hydrographic features to be used as an input for HEC-GeoHMS.

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- ✚ Curve Number (CN) Grid generation using land use and soil data of the study area
- ✚ HEC-GeoHMS data processing for Watershed delineation and for generation of Basin Model file and importing it in to HEC-HMS.
- ✚ Generating peak flow, time to peak, volume of discharge and the runoff hydrographs on the study area using HEC-HMS Hydrological Model by employing storm precipitation depth of the Study area
- ✚ The Elevation and other important components of flood hazard mapping of the area have been selected and analyzed using ArcGIS and HEC-GeoRAS. For wera woreda selected flood conditioning factors are: drainage density, elevation, land use/land cover, soil type, rainfall, and slope of the woreda. These criteria were combined and reclassified in raster format and weighted overlay by using ArcGIS spatial analysis tools with weight values of each factors.
- ✚ Finally, generate or develop flood hazard map of the study area and display the level of hazards based on our final output map.
- ✚ Recommend some important flood controlling mechanisms or mitigation measures for hazardous areas in the woreda.

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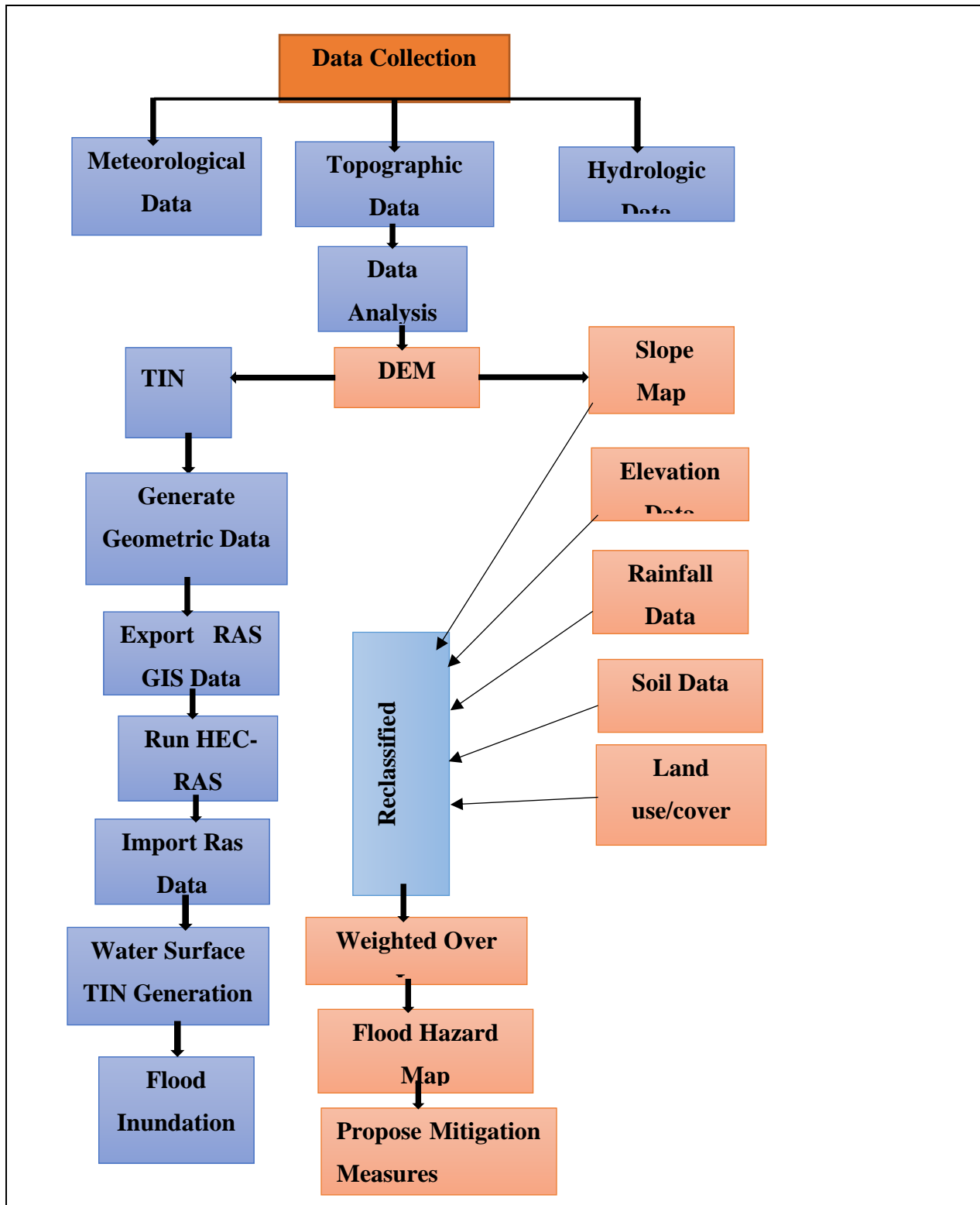
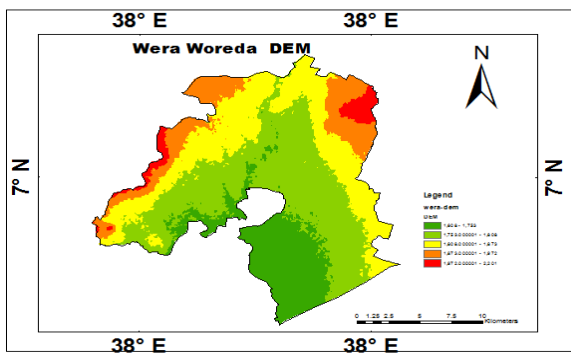


Figure 4:5 Conceptual Research methodology Frame Work

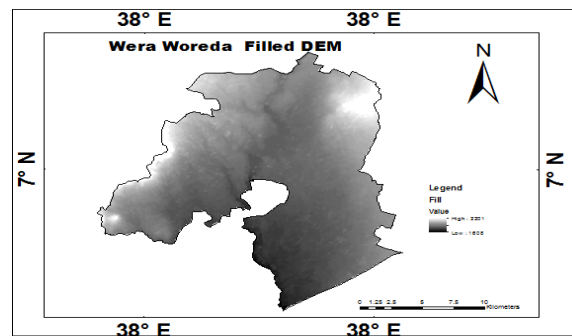
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4.4.1. Terrain Preprocessing

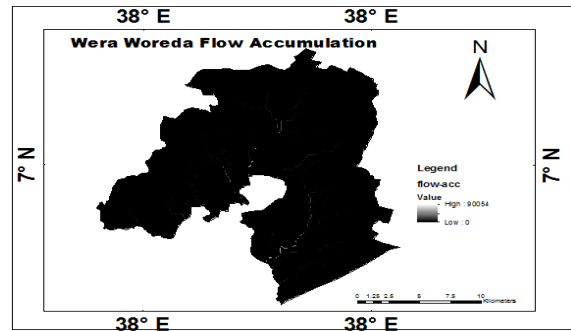
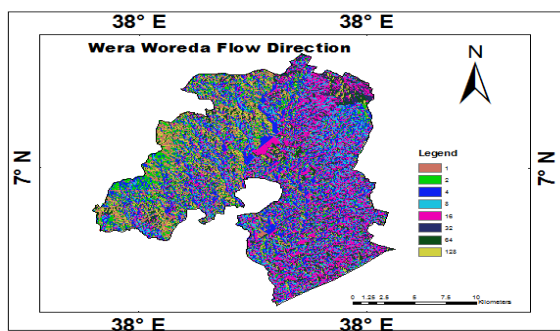
The first step in processing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, stream network density, etc. Nowadays, with the availability of digital elevation models (DEM) and Arc-GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain preprocessing. There are several tools available online for terrain pre-processing. In this research, Arc Hydro tools (version that works with Arc-GIS 10.3) was used to process a 30*30m DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. The results will then finally used to create input files for HMS hydrologic models. Terrain Preprocessing uses DEM to identify the surface drainage pattern. Once preprocessed, the DEM and its derivatives can be used for efficient watershed delineation and stream network generation. The whole procedure that was done in terrain processing is listed as follow for study area.



A)



B)



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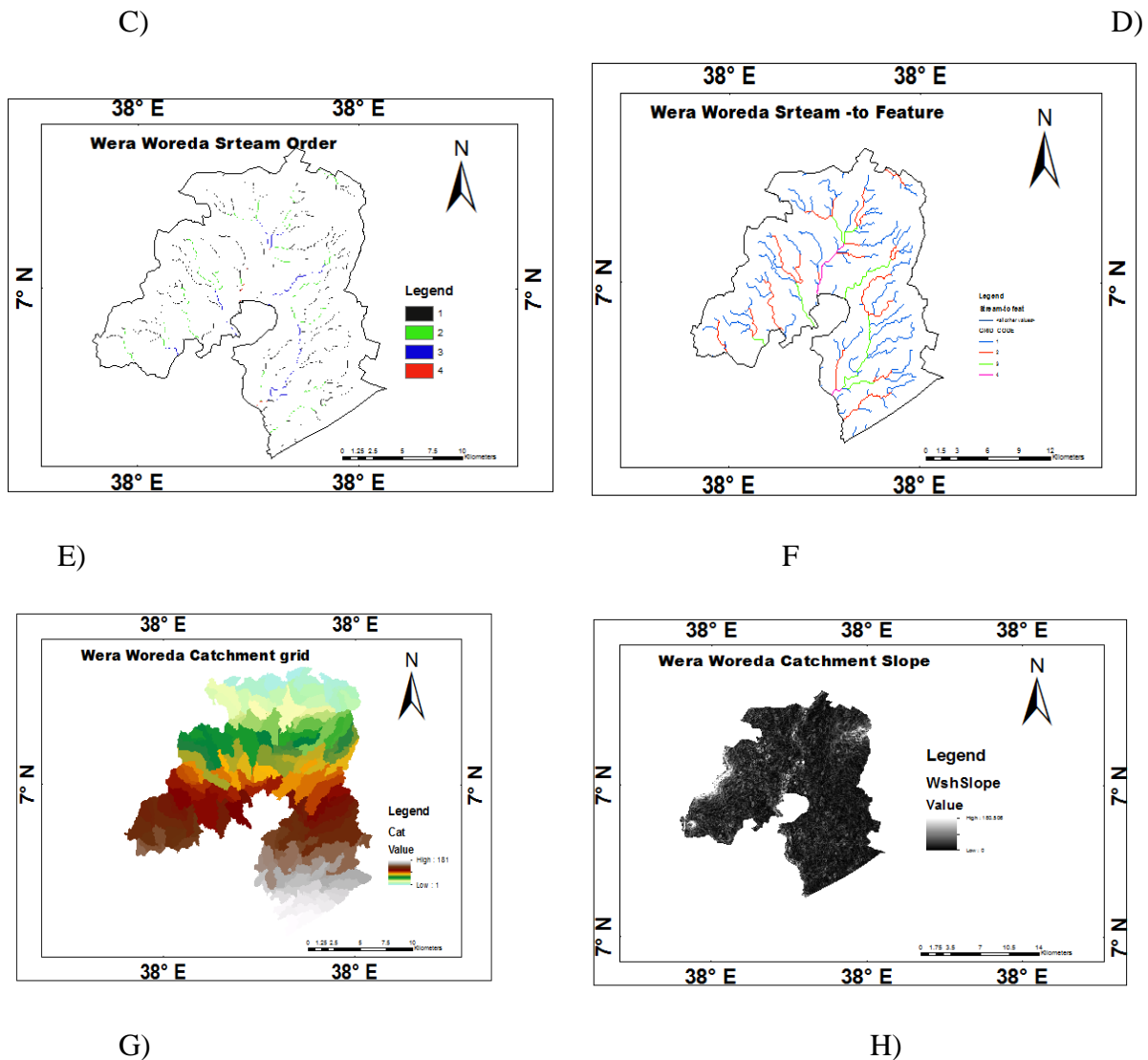


Figure 4:6 Terrain preprocessing for Wera woreda

4.4.2. Generation of SCS Curve Number Grid

The SCS curve number loss method should only be used for event simulation. Originally, the methodology was intended to calculate total infiltration during a storm. The program computes incremental precipitation during a storm by recalculating the infiltration volume at the end of each time interval. SCS curve number of the catchment is used to represent the different characteristics of the watershed area, soil type, land use, and the previous moisture condition. Soil type that must be contains Hydrologic Soil groups and land use shape file of the study area are merged in arc

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tool analysis that merged data also used as input to create a curve number grid using HEC-GeoHMS extension (ArcGIS 10.3 version). To generate Curve number Grid for study area, DEM for (30 x 30m resolution), Soil type shape file which consists of the Hydrological Soil Group of Ethiopia and land use/land cover shape file of study area are essential Parameters

4.4.2.1. Preparing land use data for CN Grid generation

A runoff curve numbers can be generated using available land use data, hydrologic soil type data, and a look-up table that relates curve number to land use and hydrologic soil group data.

To prepare land use data for CN grid generation: Clipped Land use data for the catchment and Union Land Use feature are created by using the analyst tools(overlay-union) in Arc GIS 10.3 Creating CN Grid are essential data

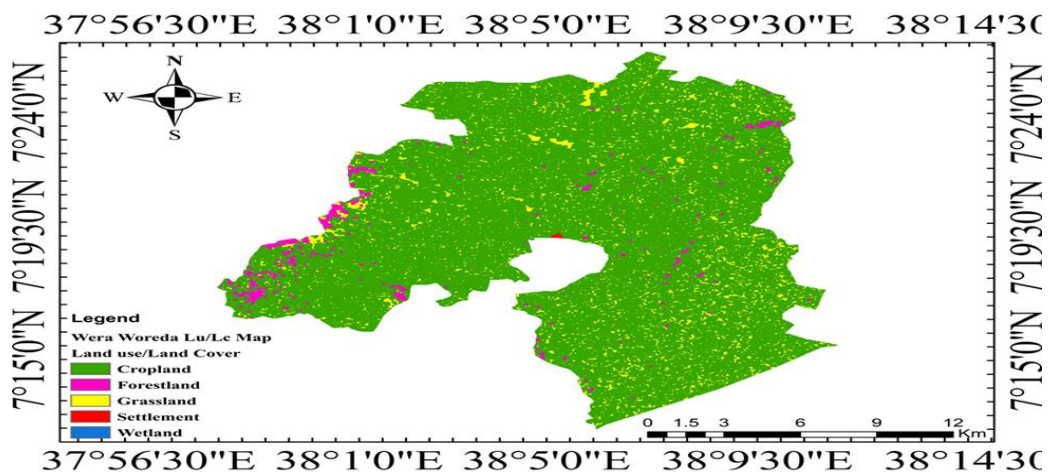


Figure 4:7 Wera Land use preparation for Curve number generation

4.4.2.2 Preparing soil data of the study area for curve number generation

The Soil shape file of the study area (Wera woreda) is second most important parameter to create Curve number grid.

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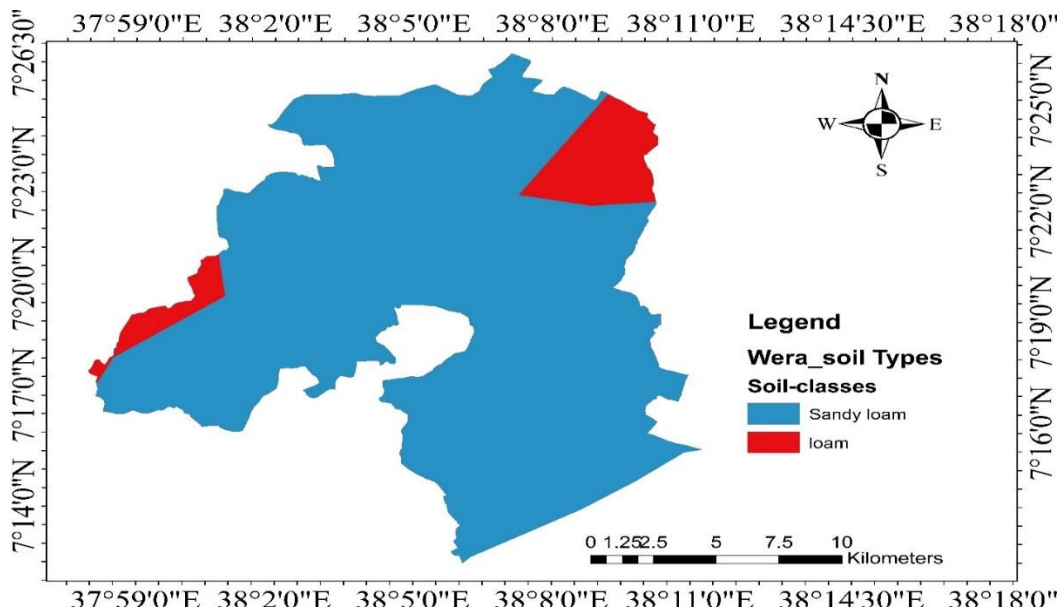


Figure 4:8 Soil Types of Wera woreda

4.4.2.3. Merging of Soil and Land Use Data of the Study Area

The soil types and land use/land cover data of the Wera Woreda that was prepared above by including all the required attribute was combined or merged for the purpose of CN-Look up development to generate the curve number grid for the study area. The merged data should include some necessary attribute from both land use and soil of the study area. Finally, the ArcGIS Arc tool box proximity was used for merging both data.

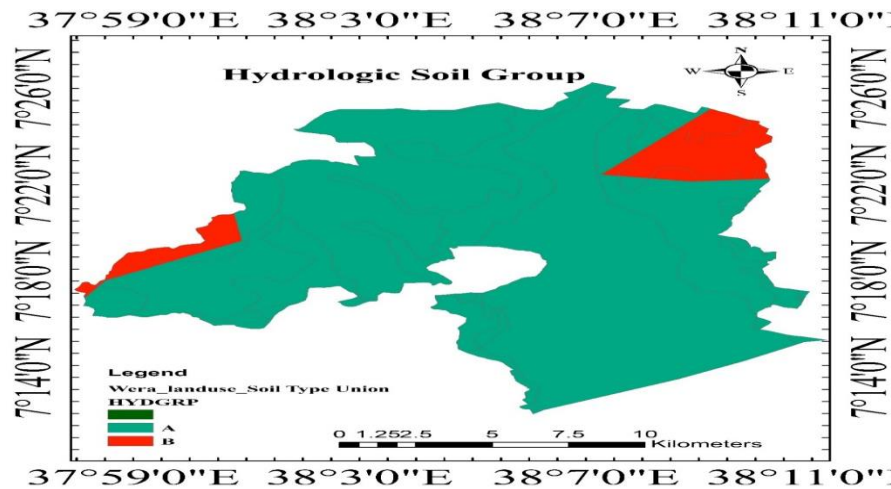


Figure 4:9 Merged soil and Land use for curve number generation

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After developing composite map (Union of Soil and land use /land cover map) for the Study area then create lookup table that will have curve number for different combination of soil and land use groups. Creating CN Look-up table in ArcMap we must consider "CNLook-Up" that was created in ArcMap and adding data within its open attribute features for Land use value.

4.4.2.4. Creating CN Grid

HEC-GeoHMS was used to create the curve number grid. HEC-GeoHMS uses the DEM of study area, merged feature class, and the lookup table (CNLookUp) as input to generate the curve number grid.

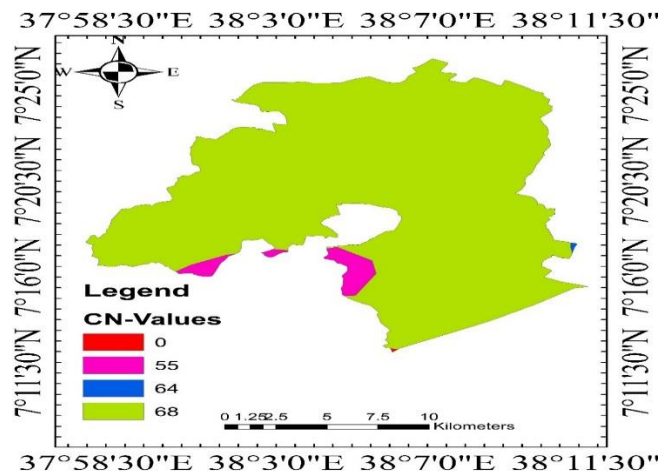


Figure 4:10 Curve Number grid of the Wera Woreda

4.5. Hydrologic Analysis: HEC-HMS

The HEC-HMS-4.0 was used for the implementation of the mathematical methods designed to describe the natural processes of the watershed to convert precipitation into streamflow at the outlet. Applying the model properly used for the approximately accurate estimation of the basin hydrologic flow and specific discharge characteristics at the defined point of interest such as the outlets of the selected bridge site. The methods used to carry out the rainfall-runoff modeling with HEC-HMS can be categorized into three; creating a basin model, preparing hydrologic model parameters, and hydrologic model completion.

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4.5.1. Basin Model development Using HEC-Geo-HMS

The Arc-Hydro and HEC-GeoHMS tools, extensions of ArcGIS-10.3 were then used to create the basin model from 30-meter DEM. The terrain data was projected into a compatible projection that is the World Geodetic System, WGS84, UTM Zone-37N projection. During basin and stream network delineation, several datasets such as fill sink, flow direction and accumulation, stream definition and segmentation, catchment polygon and drainage line processing, and watershed processing were derived. These datasets help to create and define the stream elements of the hydrological model. HEC-GeoHMS contains tools for merging and splitting sub-basins and reaches to develop a stream and sub-basin network.

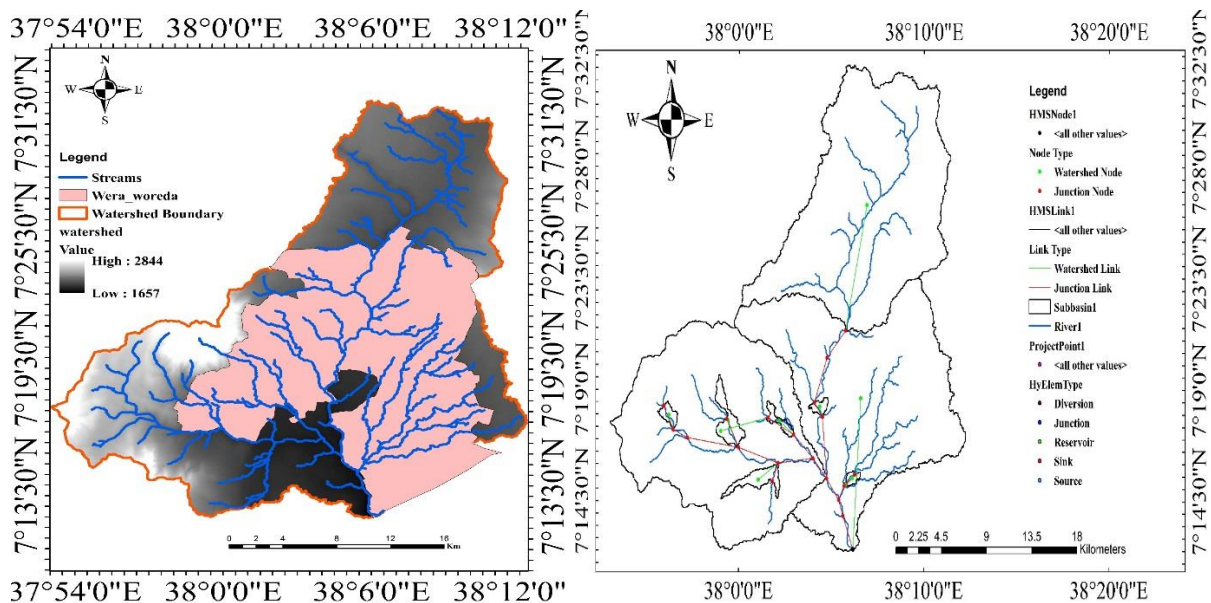


Figure 4:11 Watershed Delineation and Basin model representation of the catchment in HEC-GeoHMS

To process the above-shown sub-basins and the drainage networks, various parameters were computed including; for river include; river length and river slope, and for basin include; basin slope, longest flow path, basin centroid, centroid elevation, and centroid longest flow path.

4.5.2. HEC-HMS model Parameters Development

Input data for HEC-HMS in the form of a background-map file with sub-basins and stream networks and the meteorological model were generated using HEC-GeoHMS. The output from HEC-GeoHMS produces a stream network schematic representative of the primary hydrologic flow and various input nodes and junctions (Figure 4.11). The stream networks provide an easy way to input the model into HEC-HMS.

Following characterization of the watershed and stream characteristics in the study area

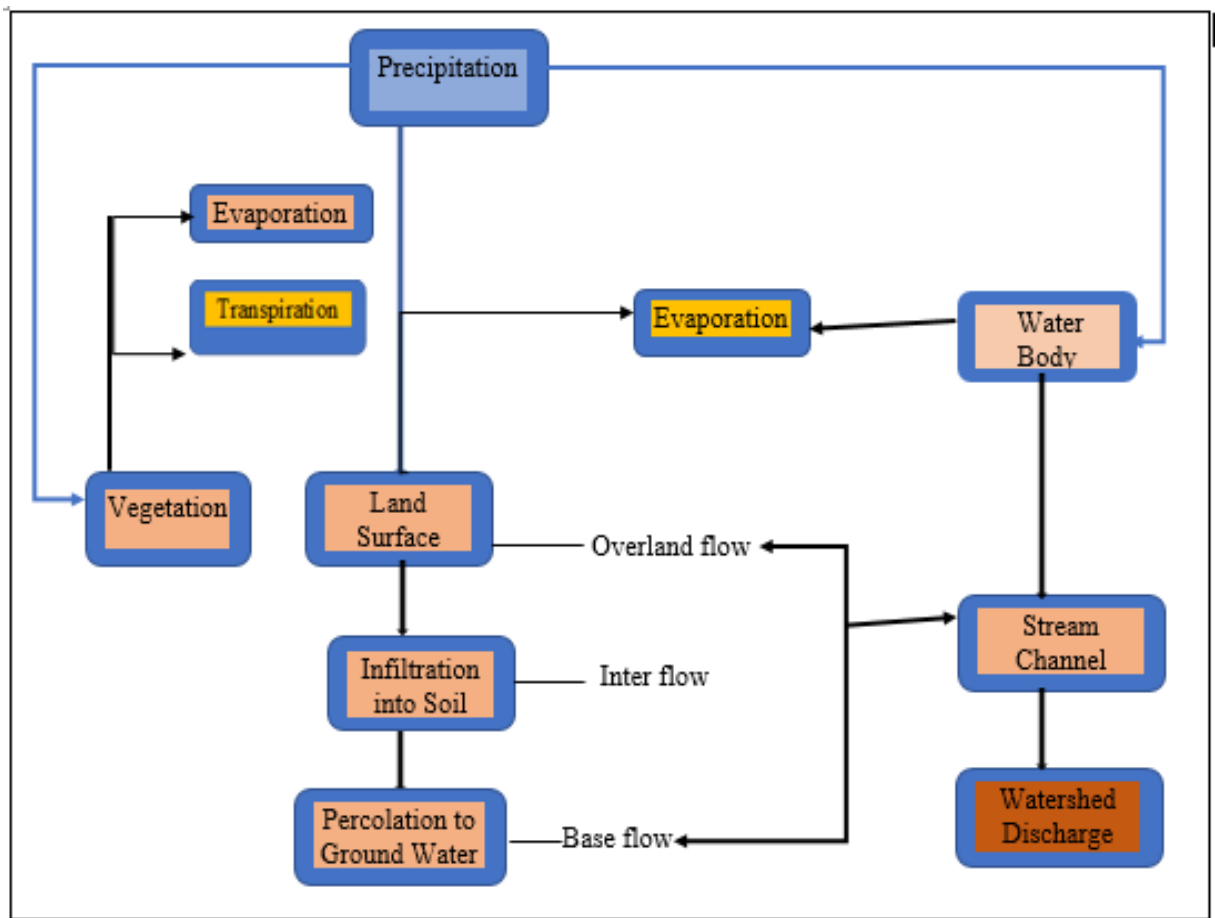


Figure 4:12 HEC-HMS Representation of Watershed runoff

4.5.3. HMS Model Components

Three main components to run HEC- HMS model are: basin model, metrological model and control specifications. The model files were imported from HEC-GeoHMS as; the basin files with

extension „. basin“, and the meteorological files with extensions „. Met“ and „. gage“. Basin model describes the catchment’s physical properties; while the meteorological model includes precipitation data. The time span of a simulation is controlled by control specifications including a starting and ending date and time, and computational time-step

4.6. Basin Model

Basin model in HEC-HMS represents the physical description of the watershed. Basin Model describes the different elements of the hydrologic system i.e. sub-basins, reaches, junctions, discharge diversions, source and sink elements with relevant information of physical attributes of the model. Some important generated information was processed in HEC-GeoHMS and imported to HEC-HMS program and displayed as basin model map of the study area. Sub-basin element in Basin model used to processes Rainfall-Runoff (Rainfall to Runoff). The Basin model in HEC-HMS includes four major models: Loss model, Direct Runoff model, Base flow model and Routing model to calculate different elements in the runoff processes.

4.6.1. Loss method

Loss model estimates amount of precipitation, which is interacted by vegetable or other things before reaching the ground surface, infiltration in to the soil, becomes surface runoff, and subsurface processes together at the sub basin. The loss method allows choosing the process, which calculates the rainfall losses absorbed by the ground. In this study, the Soil Conservation Service Curve Number loss method was selected to calculate direct runoff from a specific or design rainfall.

4.6.1.1. Basic concept of SCS Curve Number method

The Soil Conservation Service (SCS) curve number (CN) method is one of the most commonly used method in loss model for computing the amount of runoff from a rainfall storm. SCS CN method used to calculate the runoff volume by calculating the volume of water that is intercepted before reach the ground, infiltrated through the soils, stored on the ground surface, evaporated/transpired and subtracting all those losses from the precipitation. It is popular method because of its simplicity, easy to understand and apply, and stable. SCS CN method also accounts for most of the runoff generating watershed characteristics, such as soil type, land use, hydrologic

condition, and antecedent moisture condition. The SCS-CN method was originally developed for its use on small agricultural watersheds and has since been extended and applied to rural, forest and urban watersheds. This method is used widely and is accepted in different hydrologic studies and has several advantages compare to other loss methods in that: It is a simple conceptual method for the estimation of the direct runoff amount from a storm rainfall event, and is well supported by empirical data; it depends only on the curve number, which is a function of the soil type and land use/cover that are the major runoff-producing watershed characteristics.

4.6.2. Transformation Method

After the losses are computed and subtracted it from rainfall to estimate runoff volume, the time distribution and magnitude of runoff is computed with a rainfall to runoff transform. The transform prediction models in HEC-HMS simulate the process of the direct runoff of excess precipitation on the watershed, and converts excess precipitation computed by the loss model to direct surface runoff. In this study, SCS unit hydrograph method was used for this research work.

4.6.2.1. Basic concept of SCS unit hydrograph method

The SCS unit hydrograph method was used for this study because of the required parameter can simply extracted from catchment characteristics using HEC-GEO-HMS for initial estimations. Not only that, it was well applicable model on different catchment of the other country like USA. Therefore, this model was generating good result as compared with other method for my study area. The SCS unit hydrograph method requires only one parameter for each sub-basin: lag time between rainfall and runoff in the sub-basin. The unit hydrograph peak (U_p) and its estimated time to peak (T_p) are defined by the following relationship.

$$U_p = 2.08 \frac{A}{T_p} \quad \text{And} \quad T_p = \frac{\Delta t}{2} + tlag \dots \dots \dots \text{Equation 4.1}$$

Where: U_p is peak unit hydrograph, A is watershed area, T_p is time of peak/time of rise, Δt is the excess precipitation duration and $tlag$ the basin lag, defined as the time difference between the center of mass of rainfall excess and the peak of the UH.

SCS UH method in the HEC-HMS requires only one parameter, which is the lag time, $tlag$ (minute). This helps in simplifying the modeling process. The initial value of the lag time was

determined in HEC-GeoHMS using the Lag method mainly depends on the curve number of the watershed and it was exported into the HEC-HMS model. The equation is given by;

$$t_{lag} = \frac{L^{0.8}(S+1)^{0.7}(S+1)}{1900SW^{0.5}} \dots\dots\dots \text{Equation 4.2}$$

Where, t_{lag} , L , Sw , S are the lag time, longest flow path of the watershed, watershed slope, and maximum retention in the watershed ($S = \frac{25400}{CN} - 254$), CN is the SCS curve number for the watershed. The CN -grid was generated by superimposing the land use and soil maps of the study area in HEC-GeoHMS.

4.6.3. Base Flow model/ Base Flow Estimation

Base flow is a flow of water that returns to the stream or land surface from groundwater aquifers. While a sub basin element conceptually represents infiltration, surface runoff, and subsurface processes integrating together, the actual subsurface calculations are performed by a base flow method contained within the sub basin.

4.6.3.1. Monthly Constant Method

The constant monthly base flow method allows the specification of a constant base flow for each month of the year. Best estimated, empirically with measurement of channel flow when storm runoff is not occurring. In absence of such records observed data may use to establish the mean flow. The constant monthly method is a simple approach that uses a constant base flow at all simulation time steps falling within a particular month. Monthly constant method was selected for this study because of availability of observed flow for estimation of minimum flow during fair weather conditions and storm runoff is not occurring from historical data.

4.7. Routing model

Once excess precipitation has been transformed into overland runoff and routed to the outlet of a sub watershed, it enters the stream at that point and is added to stream flow routed from upstream. There are several methods available in HMS model for stream flow routing including Kinematic Wave, Lag, Modified Puls, Muskingum, Muskingum-Cunge, and Straddle Stagger. As mentioned

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above, Muskingum method was selected for this process. This method requires two parameters K, and X. Muskingum X is the weighting between inflow and outflow influence; it ranges from 0.0 up to 0.5. Muskingum K the travel time through the reach and it was determined through calibration depends on catchment characteristics. The values of the X parameter affect attenuation travel time through reaches of streamflow volume.

4.8. Model calibration

Model Calibration techniques is used to adjust model parameters to increase the predictive accuracy of a model. Model parameters are changed in a systematic way and the model is run repeatedly until the simulated values match measured values within a range that is considered acceptable. Model calibration is the method of defining the optimal standards of model factors that will contribute the smallest variance among the measured and the simulated values.

According to the Canadian Foundation for Climatic and Atmospheric sciences (CFCA), a single event hydrologic modeling should be used for simulating storm and frontal rainfall induced floods. Continuous modeling approach should be then employed for snow melt and mixed rainfall snowmelt flooding, as well as for simulating the prolonged periods of summers of low flows. The value of each parameter found in HEC-HMS must be specified to use the model for estimating runoff volume and routing hydrographs. How then can the appropriate values for the parameters be selected? If rainfall and stream flow observations are available, calibration is the answer. Calibration uses observed hydro- meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. To compare a computed hydrograph to an observed hydrograph, the program computes an index of the goodness-of-fit.

A total of 25 years historical data from 1990 to 2014 was used, and out of this (1990- 2010) was used for calibration at the study watersheds. Manual and automatic calibration was used for optimization of observed and simulated flow data using initial parameter from watershed characteristics. Calibration was done by taking initial parameters generated from HEC-GeoHMS and Arc Hydro for the catchment. With the initial parameters, the calibration was then processed until the simulated value resembles the observed data.

4.9. Model validation

The model validation is the process of testing model ability to simulate observed data without using other data used in calibration with acceptable accuracy. During validation process the calibration model parameters are not subjected to change, their values kept used. The quantitative measure of the match is again the degree of variation between computed and observed hydrography. The data selected for validation was (2011-2014) for the selected watersheds of the Wera Woreda.

4.10. Evaluation Model performance

A forecast efficiency criterion is therefore necessary to judge the performance of both hydrologic and hydraulic models. Evaluating model performance depends on subjective and/or objective estimates of the approximate values of the simulated and observed data. Performance of the HEC-HMS model was evaluated in a subjective way by following the basic approach of assessing model efficiency by visual inspection. In model calibration, the model parameters have to be adjusted until the observed natural system output and the simulated model output show an acceptable level of agreement. The goodness of fit is always evaluated through an objective function which is selected based on several criteria. These criteria should be selected properly to evaluate different aspects of the hydrograph. The criteria that was considered in selecting the objective function are as follows:

Nash-Sutcliffe efficiency: The Nash-Sutcliffe efficiency (NSE) is used to evaluate the overall agreement of the shape of the simulated and observed hydrograph. NSE measures the efficiency of the model by relating the goodness of fit of the simulated data to the variance of the measured data. NSE indicates a correlation of computed values and agreement of the means.

NSE can be defined according to the following equation:

$$NSE = 1 - \frac{\sum_{i=1}^n ((Q_{obs} - Q_{sim})^2)}{\sum_{i=1}^n ((Q_{obs} - Q_{obsavg})^2)} \dots\dots\dots \text{Equation 4.5}$$

Where: NSE = the Nash-Sutcliffe coefficient,

Q_{obs} = observed discharge,

Qsim = simulated discharge and

Qobsavg: is the mean observed value.

Coefficient of determination (R²): it expresses the measure how well trends in the measured data are reproduced by the simulated results over a specified time period and for a specified time step. It indicates the proportion of the variances between the observed data and the simulated results. The values of R² is varies between 1 and 0. If R² equal to zero, the model cannot reproduce observations and R² equal to one (1) the model reproduce observations without error.

Coefficient of determination can be defined according to the following equation:

$$r^2 = \frac{[\sum_{i=1}^n (qsim - qsimavg)(qobsi - qobsavg)]^2}{\sum_{i=1}^n (qsim - qsimavg)^2 (qobsi - qobsavg)^2} \dots \dots \dots \text{Equation 4.6}$$

- Where: qsim is the simulated value
- qobsi is the observed values
- qsimavg is the average simulated value
- qobsavg is the average observed value

4.11. Hydraulic Modelling: HEC-GeoRAS

According to the (USACE,, 2010), HEC-GeoRAS is a set of ArcGIS tools specifically design to process geospatial data for use with HEC-RAS. HEC-GeoRAS extension allows users with GIS experience to create HEC-RAS import file containing geometric attribute data from an existing terrain (TIN or DEM data sets. The interface allows the preparation of geometric data for import into HEC-RAS and processes simulation results exported from HEC-RAS. The user creates a series of line groups pertinent to developing geometric data for HEC- RAS. The types of line these created are the Stream Centerline used to establish the river reach network system for the model, Flow Path lines used to determine the downstream reach lengths between cross-sections in the

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main channel and over bank areas, Main Channel Banks used to separate the main channel from the overbank floodplain areas., and Cross Section Cut Lines used as a key inputs parameter for HEC-RAS.. Additional RAS Themes may be used to extract additional geometric data for imports in HEC-RAS these themes include Land Use, Levee Alignment, Ineffective Flow Areas, and Storage Areas. Water surface profile data and velocity data exported from HEC-RAS simulations may be processed by HEC-GeoRAS for GIS analysis for floodplain mapping, flood damage computations, ecosystem restoration, and flood warning response and preparedness.

4.11.1. HEC-GeoRAS Tools

The Benefits of Using HEC-GeoRAS are connect input data, hydraulic modeling, and final floodplain mapping, Better utilize detailed topographic information, Improve modeling efficiency and display/Visualize results to improve model accuracy, HEC-GeoRAS toolbar has four menus such as RAS Geometry that contains functions for pre-processing of GIS data for input to HECRAS, RAS Mapping that contains functions for post-processing of HEC-RAS results to produce Water surface TIN and floodplain mapping using raster, ApUtilities menu contains functions mainly for data management, and Help menu is self-explanatory and seven tools (Assign River name, Reach name, Assign from Station to Station, Assign Line Type, Construct XS Cutline, Plot Cross Section, and Assign Levee Elevation).

4.11.2. Geometric Data Pre-Processing

Geometric data was generated in pre-processing stage of the Hec-georas by using Ras geometry menu and imported into GIS. The imported geometry data or file for HEC-RAS contains information on cross-sections of the river, hydraulic structures, river banks and other physical attributes of river channels. The preprocessing using HEC-GeoRAS involves creating these attributes in GIS, and then exporting them to the HEC-RAS the geometry file. In HEC-GeoRAS, each attribute is stored in a separate feature class called as RAS Layer.

The HEC-GeoRAS creates a geodatabase in the same folder where the map document is saved, gives the name of the map document to the geodatabase (flood mapping.mdb), and stores all the feature classes or RAS layers in this geodatabase. After creating RAS layers, these are added to

the map document with a pre-assigned symbol. Since these layers are empty, the task is to populate these layers depending on the project needs, and then create a HEC-RAS geometry file.

4.12. HEC-RAS

HEC-RAS is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. Hydrologic Engineering Center's River Analysis System (HEC-RAS) is the software predominately used in the field of hydraulic analysis for floodplain delineation. The HEC-RAS program, like the other software, it can be downloaded free of charge from the Hydrologic Engineering Center's. The model is used for determination of water surface profiles for different flow scenarios, is intended for steady flow water surface profile computations and unsteady flow simulation; perform sediment transport simulation and perform water quality simulation. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendrite system, or a single river reach.

For each HEC-RAS project, there are three required components:

- Geometry data-consists of a description of the size, shape, and connectivity of stream cross-sections.
- Flow data - contains discharge rates and
- Plan data - contains information pertinent to the run specifications of the model, including a description of the flow regime

Geometrical profile

The Geometric data has been imported from GIS to the HEC-RAS but the geometric data processed may not appropriate with the actual data, so that it is necessary to edit them in HEC-RAS software. Therefore before any proceed, it is good to perform a quality check on the data to make sure no erroneous information is imported from GIS. Therefore cross-section data editor should be displayed with the downstream reach lengths (left over bank, right over bank and the channel), the Manning's n value for the channel, main channel bank station (left and right bank) and the contraction and expansion coefficient of the channel should be edit and entered new data.

4.13. Manning’s roughness coefficient

Manning’s roughness coefficient is one of the most important parameter for developing accurate water surface profile. In general, if the profile information is well known, the value of “n” must be adjusted more precisely. According to Cowan's techniques the following equation that shows the effect of all these factors on the roughness value of flood plain:

$$n = m(nb + n1 + n2 + n3 + n4) \dots\dots\dots, \text{Equation 4.7}$$

Where n_b is the value of the natural material contained in the proper channels, n_1 is the value used for taking surface irregularities, n_2 is the value used for the shape of the channel cross-section, n_3 is the value used for the obstacles in the channels, n_4 is the value used for the vegetation in the channels, and m is the correction factor to take into account the meandering of the channel. The method involves the selection of a base value of n and then correcting the base value based on the following five factors:

1. The degree of regularity of the surfaces of the channel cross section.
2. The character of variations in the size and shape of cross sections.
3. The characteristics of obstructions in the channel.
4. The effect of vegetation on flow conditions.

General procedure for estimating n involves first, the selection of a basic value of n for a channel and floodplain materials involved, then, through critical consideration of the factors listed above, the selection of a modifying value associated with each factor. The modifying values are added to the basic value to obtain n for the channel under consideration

1: Selection of basic value (n_b).

The selection of a basic n value of the study area is assumed that for the character of a bottom and sides of the channel and floodplain are of different materials involved.

2: Correction for channel irregularity (n_1).

The modify value n of the study area is assumed that the degree of roughness or irregularity of the channel surfaces of sides and bottom is good dredged channels; slightly eroded or scoured side slopes of canals or drainage channels.

3: Correction for cross-section variation (n_2).

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The modifying value n of the study area is assumed that the character of variations of size and shape of cross sections is large and small sections alternating frequently or shape changes causing frequent shifting of main flow from side to side these changes causing the greatest turbulence.

4: Correction for obstructions (n_3)

The selection of modifying value n for obstructions is based on the presence and characteristics of obstructions such as debris deposits, stumps, exposed roots, boulders, fallen and lodged logs. But in these step care should be taken that conditions considered in other steps are not re-evaluated or double-counted for both of channel and floodplain the obstruction is negligible.

5: Correction for vegetation (n_4)

The retard effect of vegetation is probably due primarily to the turbulence induced as the water flows around and between the limbs, stems and foliage, and secondarily to reduction in cross section. As depth and velocity increase, the force of the flowing water tends to bend the vegetation. Furthermore, the amount and character of foliage; that is, the growing season condition versus dormant season condition is important. Therefore, modify value n of the study area is assumed that the effect of vegetation for channel is low and floodplain is high. Finally, Compute values of n for the reach.

Table 3 Summary computation sheet for manning's roughness coefficient

Variables	Description	Recommended	Actual Value of the channel	Actual Value Of Flood Plain
Base value, n_1	Earth	0.02	$n_1=0.022$	$n_1=0.02$
	Rock	0.025		
	Fine Gravel	0.024		
	Course Gravel	0.028		
Irregularity n_2	Smooth	0.000	$n_2=0.005$	$n_2=0.005$
	Minor	0.005		
	Moderate	0.010		
	Severe	0.020		

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Variation in channel cross section n3	Gradual Occasional Alternating	0.000 0.005 0.010-0.015	n3=0.012	n3=0.005
Obstruction n4	Negligible Minor Appreciable Severe	0.000 0.01-0.015 0.02-0.03 0.04-0.06	n4=0.00	n4=0.00
Vegetation n5	Low Medium High Very High	0.005-0.01 0.01-0.02 0.025-0.05 0.05-0.1	n5=0.005	n5=0.0085
Total Reach, n			0.044	0.0385

Therefore, the total reach “n” values were obtained for main channel of Bilate River and floodplain. Finally, were performed the computation sheet calculation of a manning roughness coefficient value of 0.044 for the main channel and 0.0385 for the left and right bank of the floodplain

Expansion and Contraction coefficient

Contraction and expansion coefficients are used to evaluate the amount of energy loss that occurs because of a flow contraction or expansion. The coefficients are multiplied by the change in velocity head from the current cross section to the next downstream cross section. In other words, the values entered at a particular cross section are used to compute losses that occur between that cross section and the next downstream cross section.

4.13.1 Entering and editing flow data

Flows are typically defined at the most upstream location of river. After analysis of the flow data recorded for the site found in the Ministry of Water and Energy, those should be used as an input for the software. Each flow that needs to be simulated is called a profile in HEC-RAS. For carrying out the analysis here, the peak flood having 2, 5, 10, 25, 50 and 100 year return period of flow was used.

4.13.2 Boundary condition

Boundary conditions are necessary to establish the starting water surface at the ends of the river system upstream and downstream. A starting water surface is necessary in order for the program to begin the calculation. In a subcritical flow regime, Boundary conditions are only necessary at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, Boundary conditions are only necessary at the upstream ends of the river system. If the mixed flow regime calculation is going to be made, then Boundary condition must be entering at all ends of the river system. According to the model, there are four types of boundary conditions namely:

- ✚ Known water surface elevation
- ✚ Normal depth
- ✚ Critical depth and
- ✚ Rating curve .So that for this thesis normal depth had been selected. A normal depth should be calculating for upstream and downstream end profile of the study area the slope of the channel bottom was calculated and inserted. Finally, run the model for steady flow simulation.

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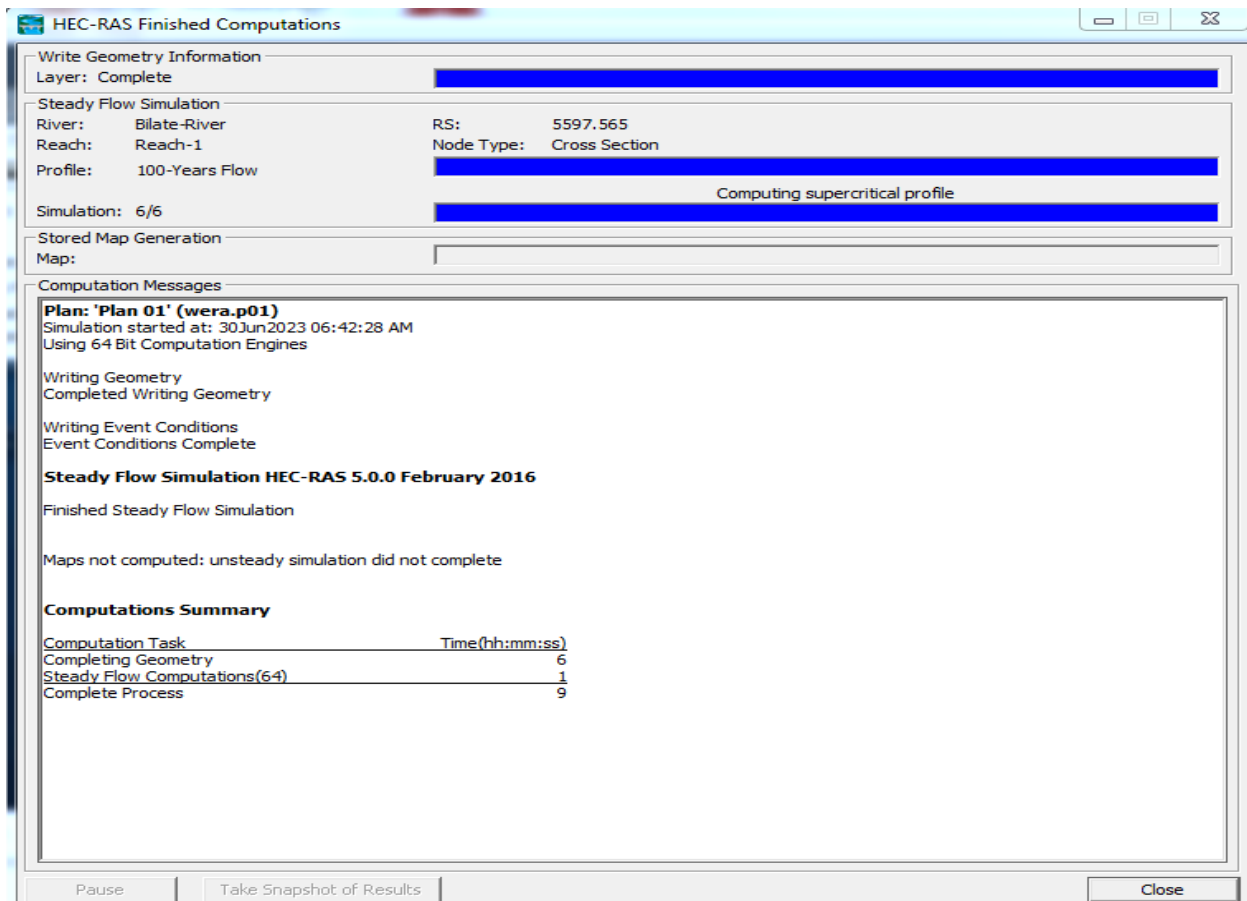


Figure 13 Steady flow simulation in Hec-Ras model

4.13.3. HEC-RAS Calibration and Validation by observed and simulated water Surface Elevation

The calibration of HEC-RAS model was carried out to obtain optimal values for manning roughness numbers by comparing observed and simulated flood water depth at particular cross sections or points. Channel roughness is a sensitive parameter in development of hydraulic model for flood forecasting and flood inundation mapping. In my case, try to use trial and error by changing the values of manning coefficient for calibration until observed and simulated water surface Elevation become approximately similar. The Selected gauge discharge was calibrated by the adjusting the manning n values. The least difference between simulated and observed flood level were used as calibration criterion for selected discharge. Then the calibrated parameters were validated for five different peak events of the discharge to compare water surface elevations.

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Based on trial and errors, model runs a manning roughness coefficient of 0.044 and 0.0385 produced the best fit against the observed data for the river main channel and flood plain respectively. The flood depth from the optimal manning's in relative agreement with all simulated ones. The validation result was also good with difference water surface elevation being small. The overall validation process R2 and Nash Sutcliffe model efficiency coefficient was 0.999 and 0.82 respectively. Therefore, the model performs reasonable well and could use to asses change in flood.

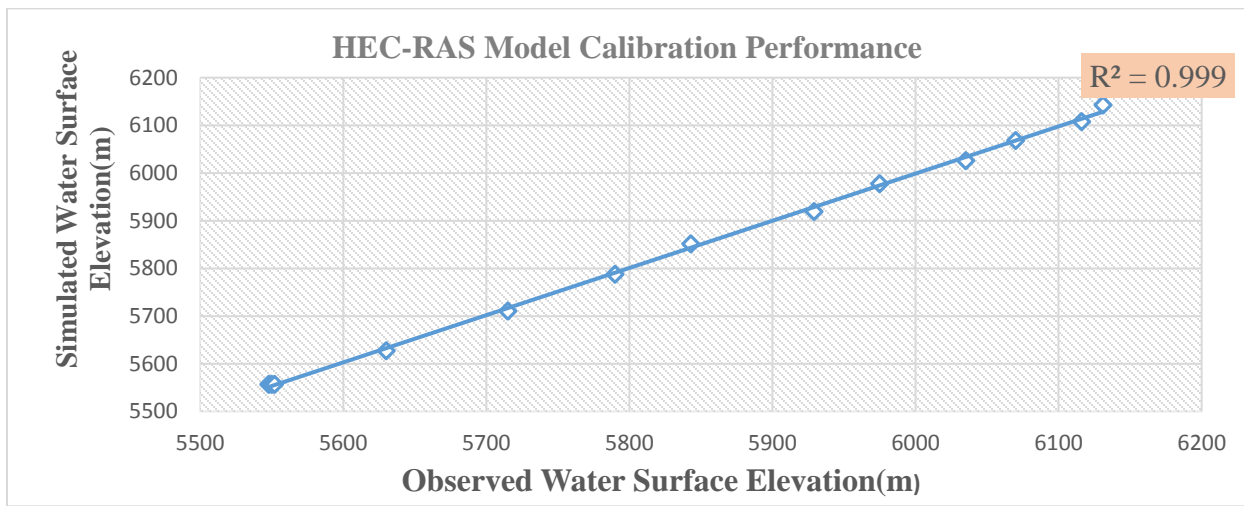


Figure 14 Model Performance Evaluation

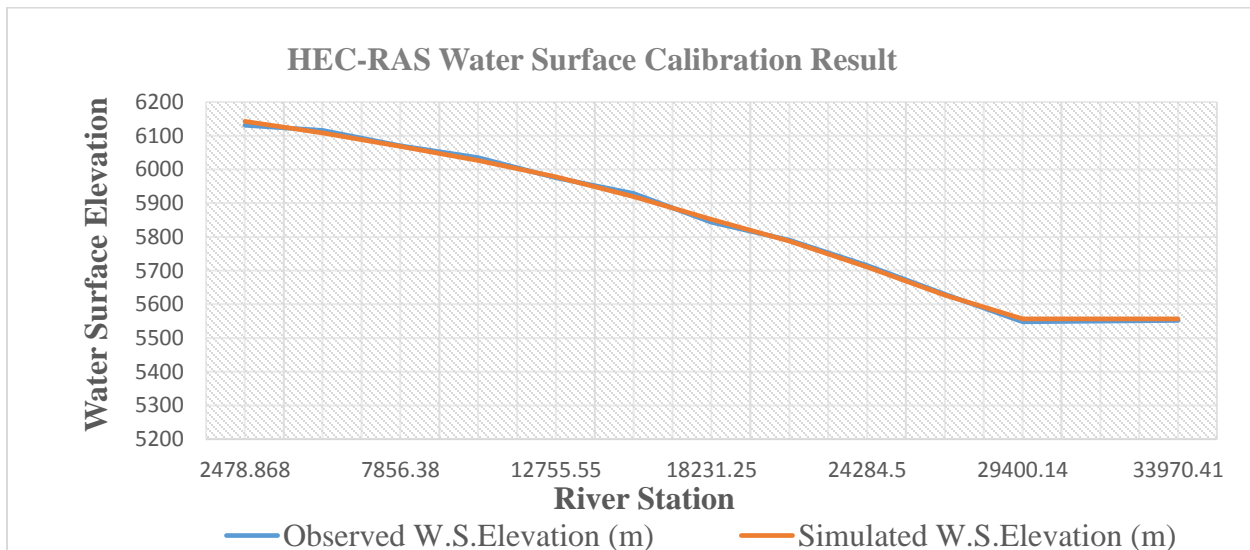


Figure 15 Observed and Simulated Water Surface Profile

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4.13.4 Post-RAS processing of geometric data

After successful simulation of HEC-RAS, the exported HEC-RAS results to ArcGIS to post-processing of them, as a result flood inundation mapping should be produced for the different return period to propose mitigation measure.

Bounding polygon

These define the study area based on cross section extension across the river. It identifies where flood inundation should be analyzed

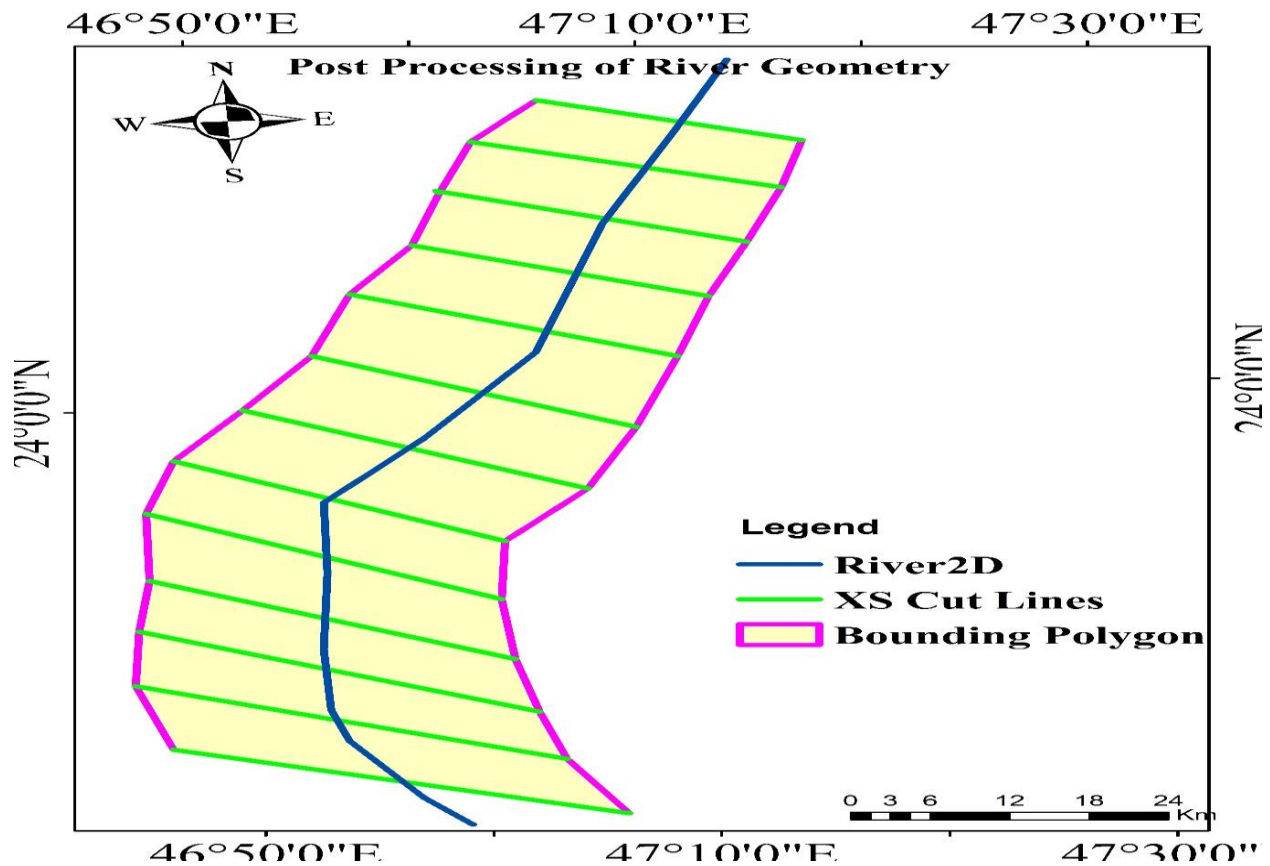


Figure 16 Bounding Polygon in Hec-Georas imported from the Hec-Ras

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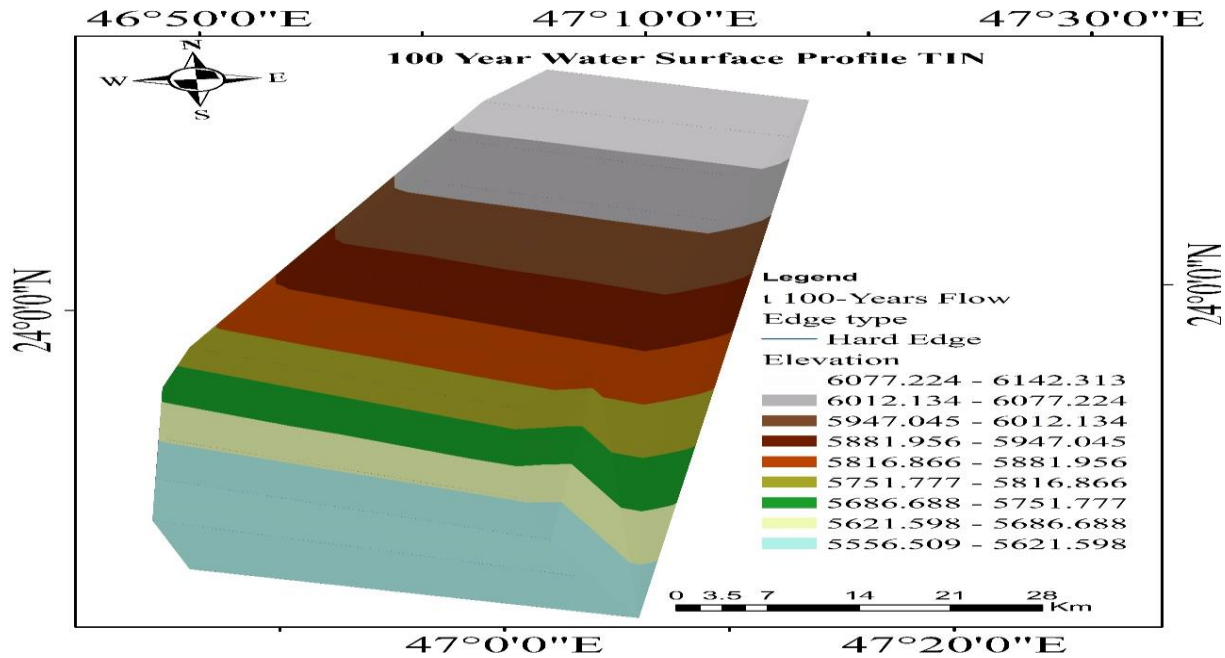
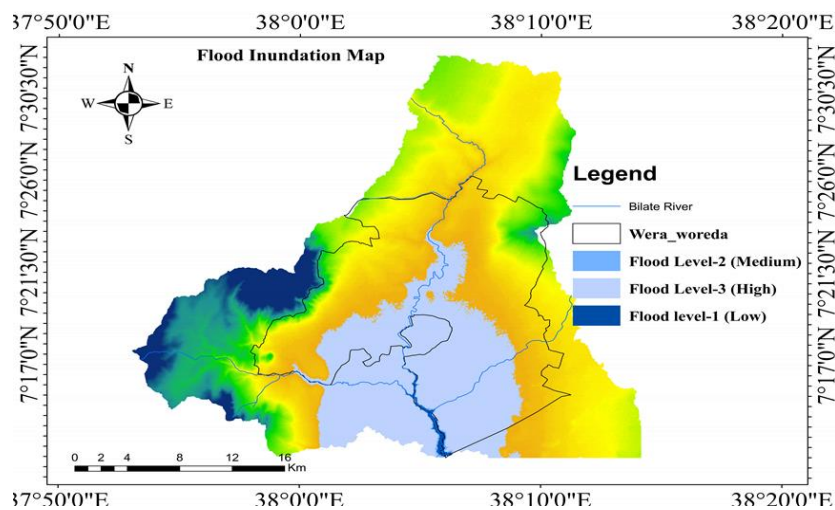


Figure 17 Water Surface TIN generated using cross-sectional cut line

4.13.5 Flood inundation area mapping

To generate an area that was inundated by flood for specific area was mainly depends on the DEM of the area. In this part the floodplain map shows the area extent that can be delineated as buffer zone. Hec-georas, Hec-Ras and Arc Gis are used one after another. Areas inundated by flooding occur wherever the elevation of the floodwater exceeds that of the land. Surface.

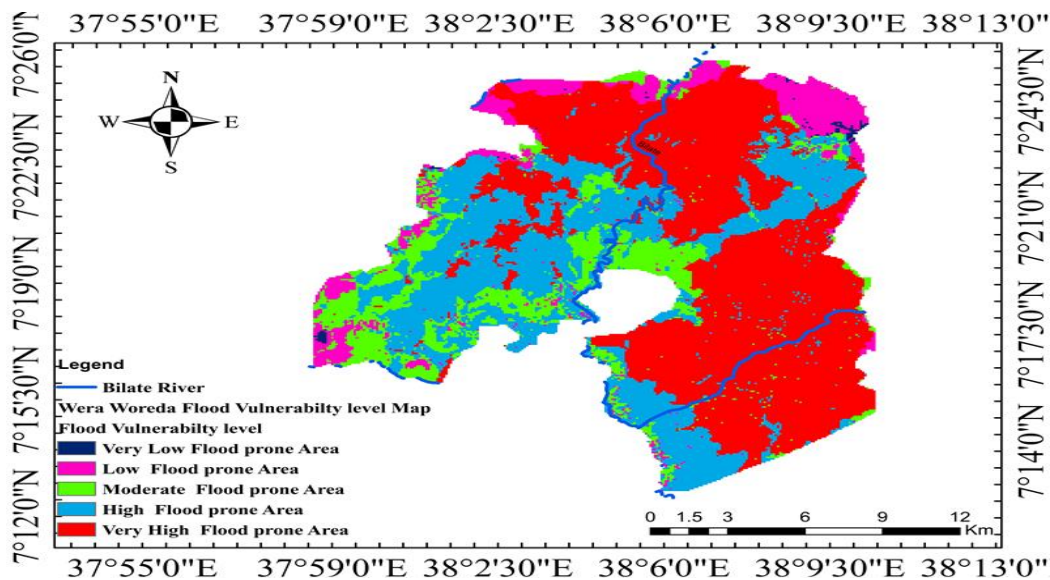


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Figure 18 Flood Inundation Map

4.14. Flood Prone Area Maps

Flood prone area maps show areas likely to be affected by flood at several times due to over flow of the river, stream, bay, ocean, or other watercourse as determined from readily available information. Flood prone area maps of the specific or the study area used to identify affected areas in the watershed, this information was also important for planners and decision makers will prepare themselves to minimize flood impacts by using Either structural or non-structural measures as soon as possible. For example, starting from land use planning to mitigation measures to be taken to control the people live in flood plain areas and their property from flood hazards. To develop flood prone area, first consider flood generating factors of the area during field visiting and reading written documents or literatures. Particularly, selected flood generating factors for Wera Woreda are slope, elevation, drainage density, soil type, and land use/land cover. The last steps in mapping of flood prone area of the study area is merging identified flood causative factors with their respective weight value in ArcGIS Spatial Analyst extension tool Weighted overlay function. Finally, composite map of the study area was developed and representing areas with their respective flood prone area classes that produced and reclassified as per the requirement.



4.15. Flood Hazard governing Factors in the study area

The major challenge in Flood hazard mapping is understanding how to combine information from multiple criteria to generate a single map of the study area. To identify flood generating factors, data collected during field visiting, information gathered from experts and literature were used. As a result, slope, drainage density, elevation, land use/land cover, soil texture and rainfall were prioritized in terms of flood hazard relevance's were combined and classified in raster format and then weighted overlay using ArcGIS package.

4.15.1. Slope Factor

Slope map of the study area was derived from the DEM using the ArcGIS Spatial Analyst extension of surface module, which enabled to divide the area according to the steepness and the gentleness of the terrain. Slope of the catchment is significant factor in identifying flood-prone/hazardous areas in a given catchment. Slope difference with in the catchment affects the speed and frequency occurrences of runoff, as well as the rate of infiltration capacity, in an area. Based on the slope map of the study area simply identify the level of flood hazard that happen within our target area. Lower value of the slope shows that the area should be flat and the higher slope value indicates steep area. So, for a given rainfall to become runoff (Rainfall-Runoff processes), slope of the watershed is one of the essential factors. The slope become steeper; the runoff generation will be higher since the soil will not get a time to infiltrate the water through its pore spaces. The relationship between slope and flood impacts of the catchment is inverse in such a way that steeper slope indicates that amount of runoff generation is high and the rate of flood hazard in that specific area is low. Whereas, in flat plains the runoff generation rate is low because the soil will have get a time to infiltrate flood water stored on the ground surface and that shows that high flood hazard level of the catchment.

For Wera Woreda, the slope is calculated using DEM data in ArcGIS spatial analyst extension tool. The slope calculated and reclassified in to five groups and the result shows that 48% of the watershed area has a gentle slope in class of 0- 2.39 lower slope values indicates flatter topography and categorized in very high flood hazard rating of the area and 0.8% area has a very steep slope and low flood hazardous area as shown in Table 4.3. The slope in the Wera Woreda ranges from

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0 to 43.52 degree. Finally, Lower slope values represented flatter topography that was especially vulnerable to flooding, whereas higher slope values represented steeper topography that was less vulnerable to flood hazard.

Table 4:4 Slope classes in Wera Woreda identified with their respective flood Hazard Rating

Slope class (Degree)	Level of Flood Hazard	Area cover-age in(km ²)	Percentage (%)
0-2.39	Very High	153	48
2.39-4.94	High	122	38.3
4.95-9.72	Moderate	33.5	10.5
9.73-18.09	Low	7.5	2.4
18.10-43.52	Very Low	2.5	0.8
Total		318.5	100

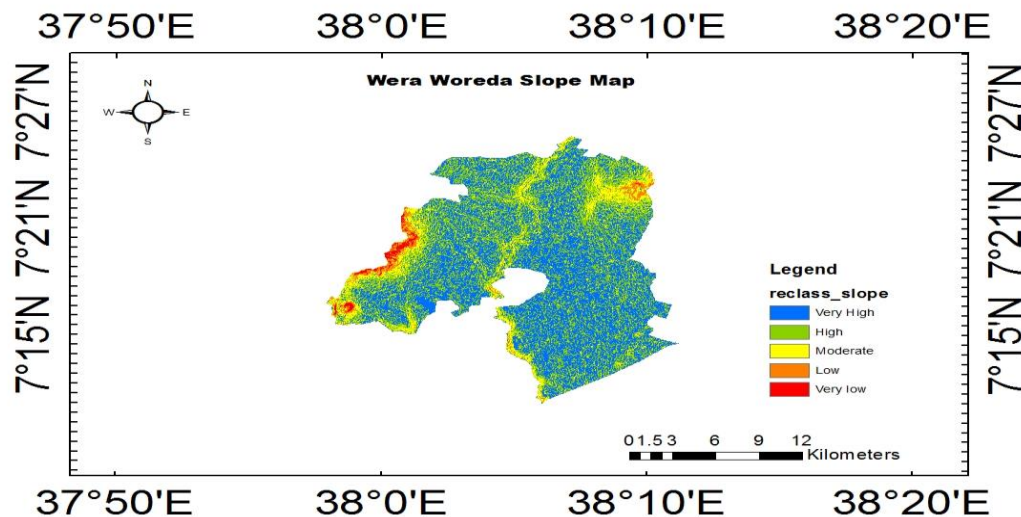


Figure 4:20 Reclassified Slope map of Wera Woreda

4.15.2. Drainage density

Drainage Density of the catchment can be explained as the summation of the all stream lengths of the watershed divided into area coverage of catchment. Drainage density of the watershed indicates

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that the degree of runoff formation at that specific area. High drainage density of the catchment indicates low infiltration capacity and steep slope in that particular area. Then the drainage density of the study area was generated from the stream shape file of the watershed which used as the input polyline features using ArcGIS spatial Analyst tools of density (line density) module. Line density calculates a magnitude per unit area from polyline features that fall within a radius around each cell and density was calculated in units of length per unit area. The drainage density was reclassified in to five classes of drainage density using equal interval classification scheme (Fig 15 Highest scale is given for the denser class and the scale decreases as density decreases. The ranks given to individual slope classes are shown in Table 4.4

Table 4:5 Reclassification of the Drainage Density of the study area

Drainage Density (km/km ²)	Flood Hazard Level	Area(km ²)	Percentage
0-0.56	Very High	121	38%
0.57-1.53	High	79	25%
1.54-2.69	Moderate	68	21%
2.70-4.22	Low	38	12%
4.23-7.53	Very Low	12	4%
Total		318.5	100

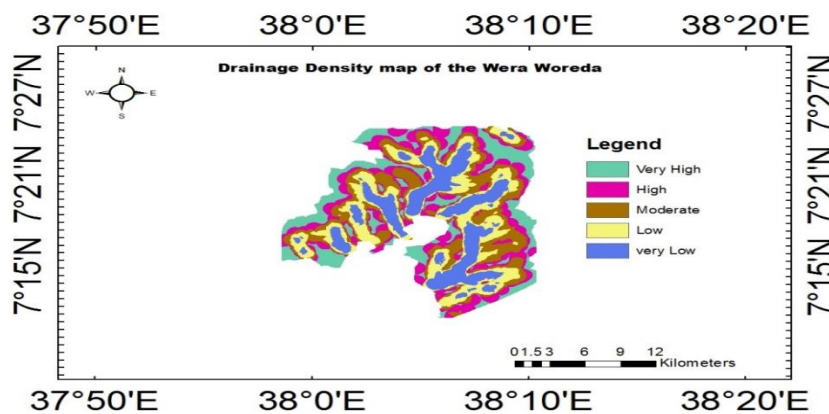


Figure 4:21 Reclassified Drainage Density map of Wera Woreda

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4.15.3. Elevation Factor

Topography is defined by a DEM that describes the elevation of any point in a given area at a specific spatial resolution. SRTM 30 × 30 DEM of watershed was extracted from DEM of the Rift Valley that was collected from Ministry of Water and Energy (GIS Department), to derive slope maps and other related spatial data that may use to delineate study area. Elevation is one of the essential input data to develop flood hazard mapping and it was reclassified into five groups using equal interval scheme. In nature water discharges from higher elevation to lower one. This indicates that in highland catchments (higher elevation) the occurrence of the flood effect is small but in lower elevation or low land areas the chance of the flood occurrence is high. Finally, the lower elevation value indicates the higher the flood hazard level was and the higher elevation value shows the lower flood hazard level.

Table 4:6 The rank and the level of hazard of the elevation classes are given in Table

Elevation(m)	Level of Flood Hazard	Area(km ²)	Percentage
1657-1772	Very High	55	17
1772-1826	High	128	40
1826-1890	Moderate	85.5	27
1890-1989	Low	39	12
1989-2210	Very Low	11	4
Total		318.5	100

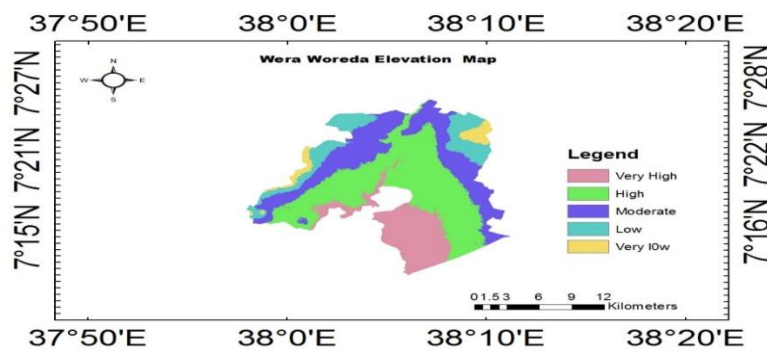


Figure 4:22 Reclassified Elevation Map of the Wera Woreda

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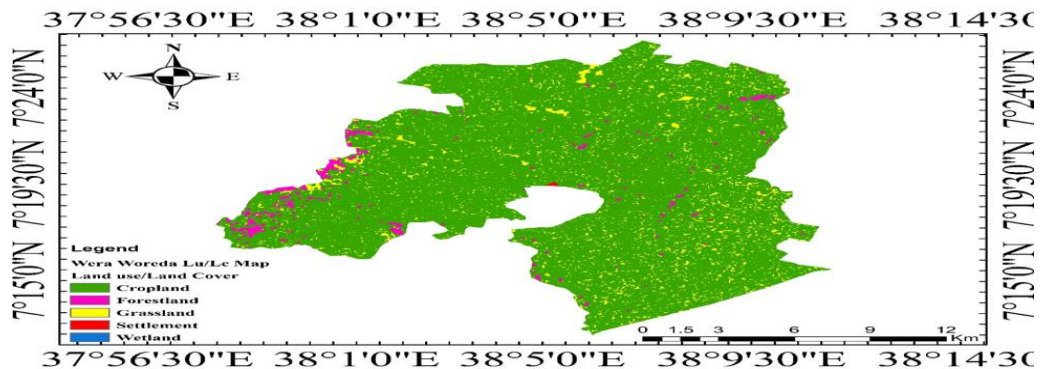
4.15.4. Land use/Land cover

Land use/Land cover (LULC) map of the study area is used to show for what purpose the land surface is used. LULC refers to the type of soil deposits and the distribution of Settlement areas, grasslands, forestlands, Wet lands and Crop /agricultural lands within a study area.

We know that some areas of the land surface are covered by construction works that may increase probability of occurrence of the flood in that area. According to Wera District land use/land cover map, most of the area (105.556km²) or 33% was covered by agricultural lands in research zone, this increases the level of imperviousness of the surface contributing to flooding impacts, whereas Barren lands, Built-up areas, Shrubs/ grass lands, , and forestland areas account for 11, 13, 31 and 11%, respectively. Land use/land cover map of the study area is one of the common floods generating factor in the catchment and its reclassification is used as input parameter for the generation of hazard produced by flood by using weighted overlay analysis in ArcGIS spatial analysis tools.

Table 4:7 Reclassification of the Land use/Land cover of the study area

Land use/Land cover	Level of Flood Hazard	Area in (km ²)	Percentage
Crop Lands	High	105.556	33%
Wet Lands	Moderate	35.529	11%
Settlement Areas	Very High	40.925	13%
Grass Lands	Low	99.853	31%
Forest Lands	Very Low	36.558	11%
Grand Total		318.5	100%



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Figure 4:23 Reclassified Land use/Land cover Map of the Wera Woreda

4.15.5. Soil Factor

Soil type of the catchment is an essential parameter in flood study since it affects the infiltration capacity directly and the runoff indirectly. In a particular Catchment, the infiltration capacity of the soil is high the vulnerability to flood damage will be low compare to soils have low infiltration capacity. Types of Soil with in a given watershed has significant impact on both infiltration rate and the water holding capacity of the area. For this reason, types of soil may be considered as one of the key factors in defining flood hazardous zones.

Table 4:8 Reclassification of the Soil types of the study area

Soil Types	Level of Flood Hazard	Area (km2(Percent (%)
Sandy loam	Low	293	92
Loam	Moderate	25.5	8
Total		318.5	100

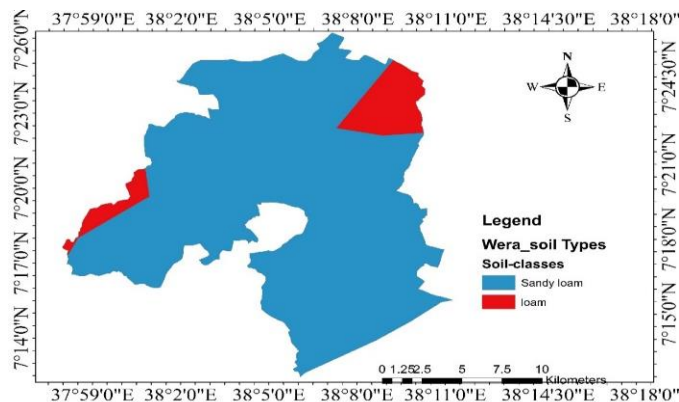


Figure 4:24 Soil Types Map of Wera Woreda

4.15.6. Rainfall Factor

Flood hazard mapping for flood plains depends on areal rainfall intensity data. However, Data collected from NMA are only point rainfall data for selected Meteorological Stations those are located with in and around the catchment. The long year rainfall data has been collected from the

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different Meteorological stations within the study area and outside the study area. The annual average of the rainfall data from each Meteorological station was calculated and interpolates rainfall surface from the point data using an Inverse Distance Weighted (IDW) technique. For this research work 25 years daily rainfall data was collected from three (3) selected meteorological stations which are found inside and outside the study area boundary. Meteorological stations were selected based on the availability of long period data and similarity in their hydro meteorological characteristics. Using the data, 25 years mean annual rainfall is estimated for each station. All collected rainfall data are point data and don't displayed on software desk top/ its lack of representativeness. For this reason, the point rainfall data should be converted to mean areal rainfall value within the watershed in ArcGIS extension using Inverse square distance technique. The reclassified rainfall was given a value 1 to 5 with the higher value indicates very high flood hazard level, while the lower value shows that low flood hazard level of the study area. Therefore, an area with very high rainfall was ranked as Very High-Level flood hazard zone and an area with low rainfall was ranked as Low-Level flood hazard zone. Accordingly, the raster and the reclassified rainfall data are shown below fig 19

Table 4:9 Mean annual rainfall class identified with its respective flood Hazard level

Rainfall Class (mm)	Level of Flood Hazard	Area (km ²)	Percentage
875 – 913	Very Low	104	33%
913 – 948	Low	111	35%
948 – 987	Moderate	68	21%
987 – 1036	High	26	8%
1036 – 1109	Very High	9.5	3%
Total		318.5	100%

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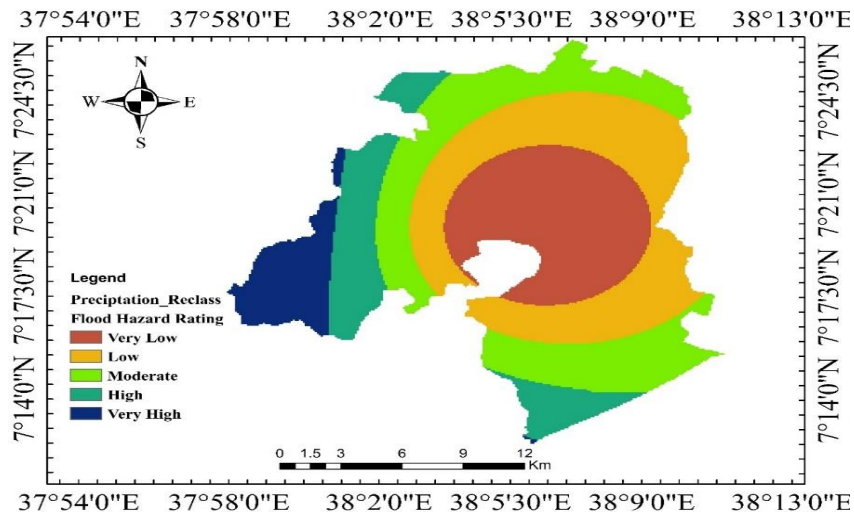


Figure 4:25 Rainfall distribution map of Wera Woreda

4.16. Flood Hazard Analysis

Flood hazard map for study area was generated by Weighted Sum Overlay of selected flood conditioning factors. In this research work particularly selected flood generating factors are shown above. The weights for each selected factor were given based on information gathered during field visiting time discussion with concerned bodies (experts), observing natural settlement of the watershed and reviewing previous researches (literature). The importance of Relative weights of parameters are used to generate flood hazard map equation for study area. After computing Relative weights for each factors, our comparisons are must be checked consistent or not. To check whether the comparison, correct/consistent or not, the consistency check can be performed using equation given below. The consistency Index (CI) can be calculated using the following equation

$$CI = \frac{\lambda_{max} - N}{N - 1} \dots \dots \dots \text{Equation 4.8}$$

Where: CI is consistency index is number of factors being compared in the matrix and λ_{max} is the highest/maximum eigenvalue of pair-wise comparison matrix.

The Analytical Hierarchy Process used to compute maximum eigenvalue (λ_{max}) of the comparison matrix considered on the following steps:

- ✚ Each value in column in matrix table multiplying by Relative Weight

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- ✚ Computing the weighted sum value of factors by adding the values in the rows.
- ✚ Calculating the ratio of the weighted sum value to criterion weight
- ✚ Averaging the ratio of weighted sum value to criterion weight

Finally, the consistency ratio (CR) can be computed from the following equation to verify the consistency of the comparison.

$$CR = \frac{CI}{RI} \dots\dots\dots \text{Equation 4.9}$$

Where *CR* is consistency ratio, *CI* is the consistency Index, and *RI* is random Index which is varies according to number of factors used in pair -wise comparison matrix. If *CR* is below 0.10, the pair-wise comparison matrix has an acceptable consistency. Otherwise, if *CR* is greater than or equal to 0.10, pair-wise comparison matrix has an inadequate consistency, and the comparison process must be repeated until the value of *CR* is achieved below 0.

Consistency Ratio is varying with number of factors and its value can be read from the table of random Index based on the number of the elements (N). In this case six (6) elements were selected for Wera District flood hazard mapping and CR is equal to 1.25. All necessary calculation and filled table for computing relative weight for selected parameters that was used to explain flood hazard map equation for our target (Appendix F-H)

$$CI = \frac{\lambda_{\max} - N}{N - 1} \dots\dots\dots \text{Equation 4.10}$$

$\lambda_{\max}=6$, $N=6$ then, *CI* is equal to zero there for *CR* is below 0.10, the pair-wise comparison matrix has an acceptable consistency.

Table 4:10 Weight value calculated and rank given to each criterion used in flood hazard mapping

Sn	Factors	Weight Value %	Rank
1	Elevation	29.1%	1
2	Slope	26.0 %	2
3	Rainfall	16.20%	3
4	Drainage Density	12.5%	4

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5	Land use/Land cover	10.3%	5
6	Soil Type	5.9 %	6

Flood Hazard Map was expressed by the following equation

$$FHM = 0.291 * Elevation + 0.260 * Slope + 0.162 * Rainfall + 0.125 * DD + 0.103 * LuorLc + 0.059 * Soil\ tecture \dots\dots\dots, \text{Equation 4.11}$$

In weighted overlay function of ArcGIS software, all the criterions set were inserted with their respective relative weight values and the composite map of the study area showing flood hazard zones were produced and reclassified in to five classes to separate flood hazard rates as Shown in Figure 20.

4.17. Flood Hazard Mapping

The impacts resulting from occurrence of flood effect in specific area can be social impacts (people’s displacement/ relocation, died transportation problem), Economical impact like decrease crop production, increase number of un-employees, increase food aid peoples and Environmental impacts such as deforestation, soil erosion, climate change /weather variation. Flood Hazard is a potentially damaging physical event, phenomenon that may cause the loss of life, property damage, and environmental degradation, social and economic disruption.

Flood hazard mapping is a process by which areas are identified as being at risk for flooding. Utilizing various data sources, hydrologic models, and Geographic Information System technologies, flood hazard mapping can be used to generate maps with the purpose of providing a better understanding of the nature and extent of a potential flood hazard. This can then be used to inform decision-making in land use, water resources management, and disaster preparedness. Flood hazard mapping is a powerful tool for understanding, mitigating and preparing for the dangers posed by flooding. Utilizing multiple data sources and technologies, flood hazard maps offer a comprehensive view of potential areas of risk. Additionally, GIS technology can be used to analyze these maps and assess the potential damage that could be caused by a flood event. Through an understanding of the data and models used to create these maps, decision-makers can be better informed of potential risks and prepare accordingly

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Flood Hazard Mapping means simply displaying or showing the flood hazard events of the catchment on the map that is the intensity of flood situations and their associated exceedance probability a specific flood affected area. The study area is one of the most commonly affected by the flood effects, so developing flood hazard map for the District is important for the future researchers, government officials, NGOs and other organizations simply identify or visualize areas that have affected by flood impacts/ flood hazardous areas. Not only these but also used as flood hazard zones identifying tools in planning, designing and developing any water-related projects along the watershed. In this Research work, the flood hazard map of the study area was developed by considering the six reclassified factors (Slope, Precipitation, Soil type, Elevation, Land use, and Drainage Density) of the study area. Finally, these reclassified data are combined in the weighted overlay analysis tool and flood hazard map of the study area was developed (Fig 20).

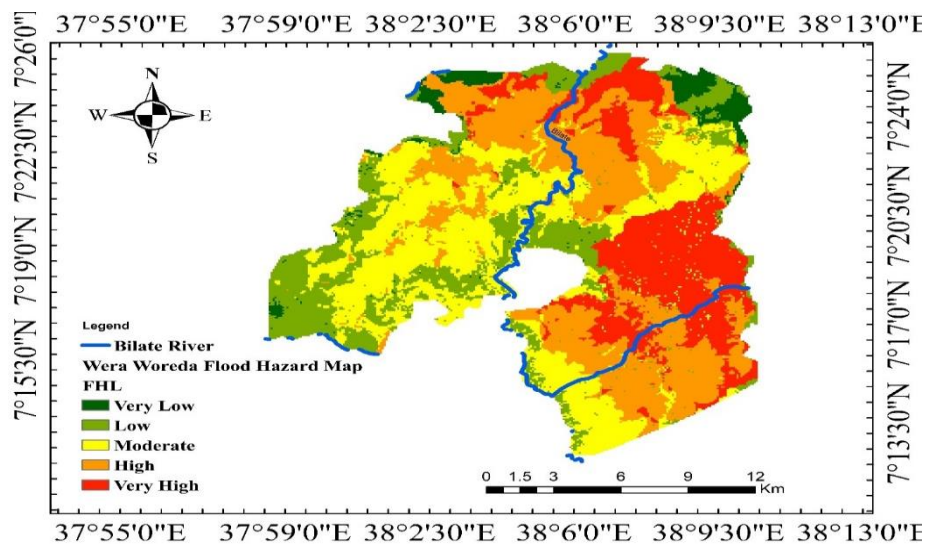


Figure 4:26 Flood Hazard Map of Wera Woreda

From the above map, the Levels, Areas and Percentage of flood hazard in the study area was calculated and given in Table 11.

Table 4:11 Flood Hazard level of the Wera Woreda

Sn	Flood Hazard level	Area (km ²)	Percentage
1	Very Low	12.5	4%

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2	Low	58	18%
3	Moderate	93	19%
4	High	91	29%
5	Very High	60	30%
	Total	314.5	100%

4.18. Flood Mitigation measures

Only developing flood hazard map for specific area was not solution to minimize impacts caused by flood at that specific area, but also propose or recommend some appropriate mitigation mechanisms based on finally displayed map of the area are also essential to eliminate possible adverse effects as soon as possible. The potential disaster posed by floods is so very wide that it has been responsible for thousands of lost lives and millions in damage to property all over the world. Hazard due to flooding can be mitigated either structural or Non-structural measures. These flood mitigating measures are used to managing flood effects by controlling flood water and minimizing flood damages with in the flood prone areas.

These mitigation mechanisms could be implemented to prevent flood impacts by reducing the amount of the run-off by increasing height of the existing structure/levees, water level of the flood prone area that can be taken in order to reduce the chances of disastrous flooding and the destruction it causes. These techniques can prevent the damage attributable to flooding, or they can be applied to reduce the probability of flooding occurring, thereby minimizing the amount of property or lives lost during floods. One of the most common popular flood hazard mitigation measures taken against floods is levee/embankment construction along the channel.

Constructing levees by using soil, sand, or concrete along a waterway can create a barrier between the shoreline and rising waters. Although this method of mitigation is expensive, its effectiveness is well compared to non-structural method. In addition, a levee can be used to channel the water in a specific direction, thus limiting the risk of extensive flooding.

Another potential flood hazard mitigation strategy is to create special zones dedicated to floodwater storage and shoreline protection. This requires building ponds coupled with structures such as berms that offer protection from rising waters. When a flood does occur, these zones can

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absorb excess water and protect the shoreline from further destruction. Furthermore, deepening and widening of existing drainage channels and waterways may help decrease flooding severity and duration in an area.

Land use planning/management is also a vital flood hazard mitigation measure, as it helps limit urbanization and unnecessary development in risk zones near watercourses. Land use planning method used to protect flood effects by applying the less vulnerable land-use activities in floodplains. Moreover, the implementation of strict regulations concerning construction near water bodies can help protect people and property in those locations from the destructive force of flooding.

Finally, another mitigation measure to consider is the implementation of early warning systems. These systems alert residents to the potential of a flood before it actually occurs so that people can quickly move to safe ground and prepare for the coming flood effect. Additionally, the system can be used to warn local authorities of the impending danger, which can help save lives and reduce the amount of damage caused by the flood. While no single mitigation measure can offer foolproof protection against flooding, a combination of these methods can be effective in minimizing the risk of flooding and protecting lives and property in flood prone areas. Timely implementation of responsible and effective flood hazard mitigation strategies is one of the best ways of preventing the destruction caused by floods.

A good mitigation strategy is able to withstand disaster and reduce the damage, loss of affected community. For minimizing the losses due to floods, various flood control measures are adopted. The flood control measures which should more correctly be termed as 'flood management' can be planned either through structural engineering measures or non-structural measure. Wise application of engineering science has afforded ways of mitigating the ravages/destroy due to floods and providing reasonable measure of protection to life and property. Such measure comprises multipurpose reservoirs and retarding structures which stores flood waters, Channel improvements which increase flood carrying capacity of the river, embankments and levees which keep the water away from flood prone areas, detention basin which retard and absorb some flood water, floodways which divert flood flows from one channels to another channel and aver all improvement in the drainage system. Finally. Flood preventing mechanisms are involved to alter the natural of flood

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threat, decrease flood vulnerability community and to reduce the exposure to the threat of possible disaster.

Comparing various flood mitigation measures is an important part of creating an effective plan to prevent or reduce damages caused by flooding. Actually, consequence of flood is not completely avoided, but it may eliminate by using several alternative mitigation measures and propose appropriate one for the flood vulnerable area.

When comparing flood mitigation measures, the first step is to assess the risk factors associated with that particular area and considering the needs and goals of that particular community.. Essential issue to be considered when we examine different alternative flood mitigation measures is evaluate the impact of different flood mitigation measures on the physical environment, the social, economic, and ecological aspects of the community. Local stakeholders should be consulted during this process to ensure that the chosen measures are compatible with local concerns, values, and resources. The cost-effectiveness of the different options should be also another factor to be considered while comparing various flood mitigation measures. The costs associated with property loss, restoration, and reconstruction should be considered, as well as any short term or long term economic impacts. In addition, environmental and social implications should be taken into account.

Another important aspect of comparing flood mitigation measures is to ensure that they are both effective and sustainable in the long-term. Prevailing conditions should also be taken into account, as well as the potential for extreme flooding events in the future. Different flood mitigation measures should be analyzed alongside disaster management plans and other safety measures to maximize the effectiveness and efficiency.

Finally, any legislative constraints and regulatory policies concerning flood mitigation should be taken into account when comparing mitigation measures. This helps to ensure that the chosen measures are compliant with local, state, and federal regulations, and that the plans do not involve any environmental or legal violations.

5 RESULT AND DISCUSSION

HEC-HMS Model Calibration, Validation and Result

The main purpose of using HEC-HMS Model was to estimate the different frequency discharge using frequency storm. The HEC-HMS program was selected for the current study due to its versatility, capability for flow generation, automatic parameter optimization and its connection with GIS through HEC- Geo-HMS. The systematic search for optimum parameter is carried out using automatic HEC- HMS Model parameter optimization from model compute tool bar with reference to observed flow at Halaba Kulito station. Model parameters were calibrated manually followed by HEC-HMS automatic optimization until satisfactory agreement between simulated and observed flow was obtained. The model goodness of fit and the model performance were evaluated after adjusting the parameters. During calibration and validation periods, the simulated data matched well with the observed data. . Flow calibration was made by using 21 years (1990-2010) hydro-meteorological data with an equal length of time. The first performance evaluation Nash and Sutcliffe Model Efficiency (NSE) for daily stream flow calibration is 0.894. The second performance evaluation result that is Pearson’s Coefficient of Determination (R²) gives 0.805, for daily data calibration.

Table 12 Objective function result during calibration

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	23369.55	23932.15	-562.60	-2.35
Peak Flow (M3/S)	264.9	223.6	41.3	18.5
Time of Peak	25Oct1997, 08:00	25Oct1997, 01:00		
Time of Center of Mass	17Jul2001, 19:36	28Jun2000, 13:29		

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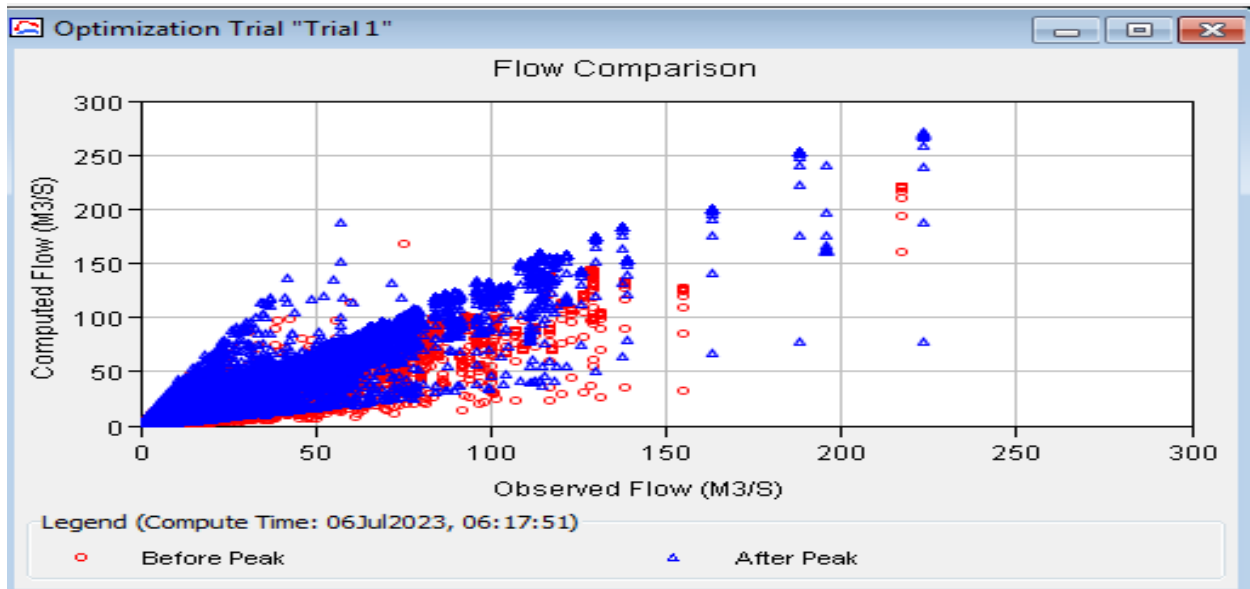


Figure 27 Flow comparison before and after peak

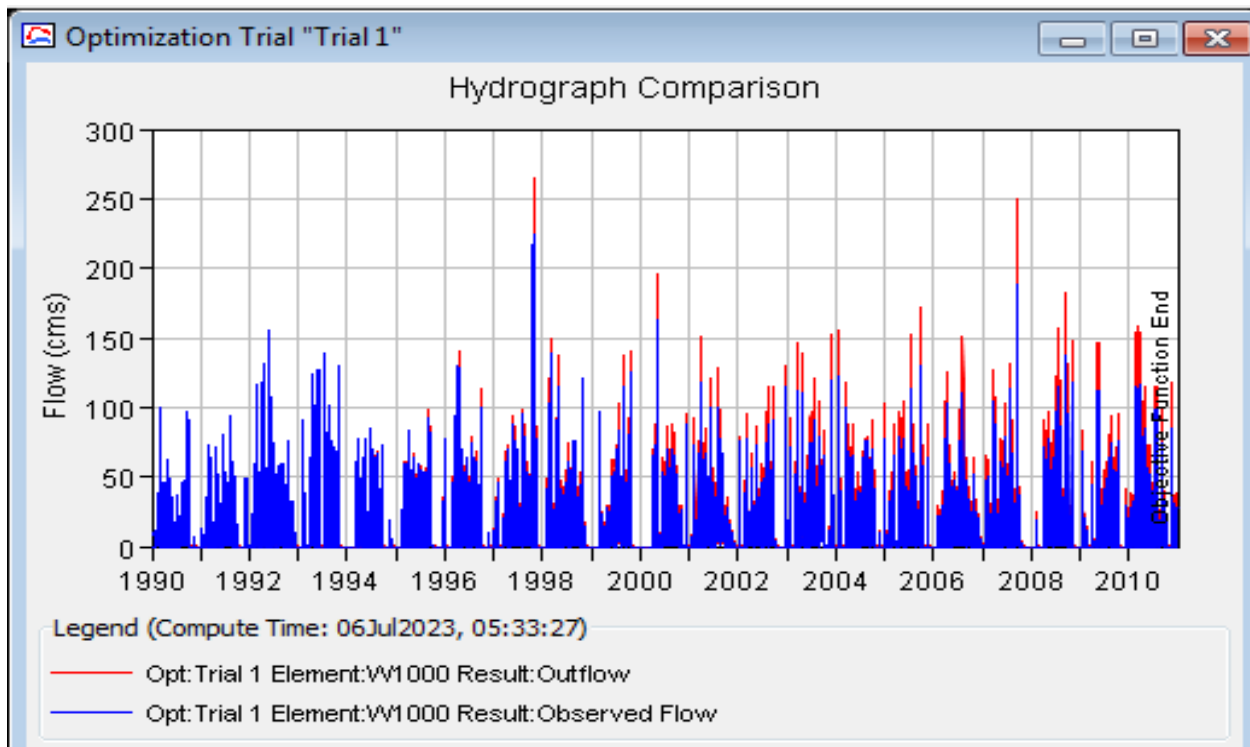


Figure 5:28 Calibrated Model Output daily Time series

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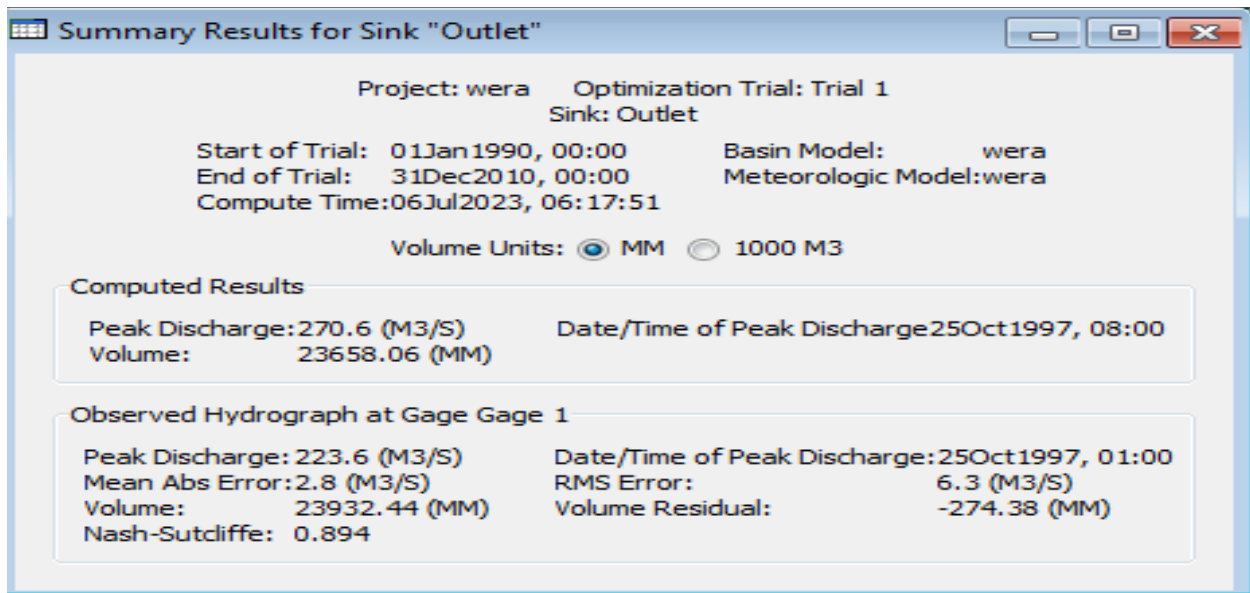


Figure 5:29 Summary outputs of the outlet

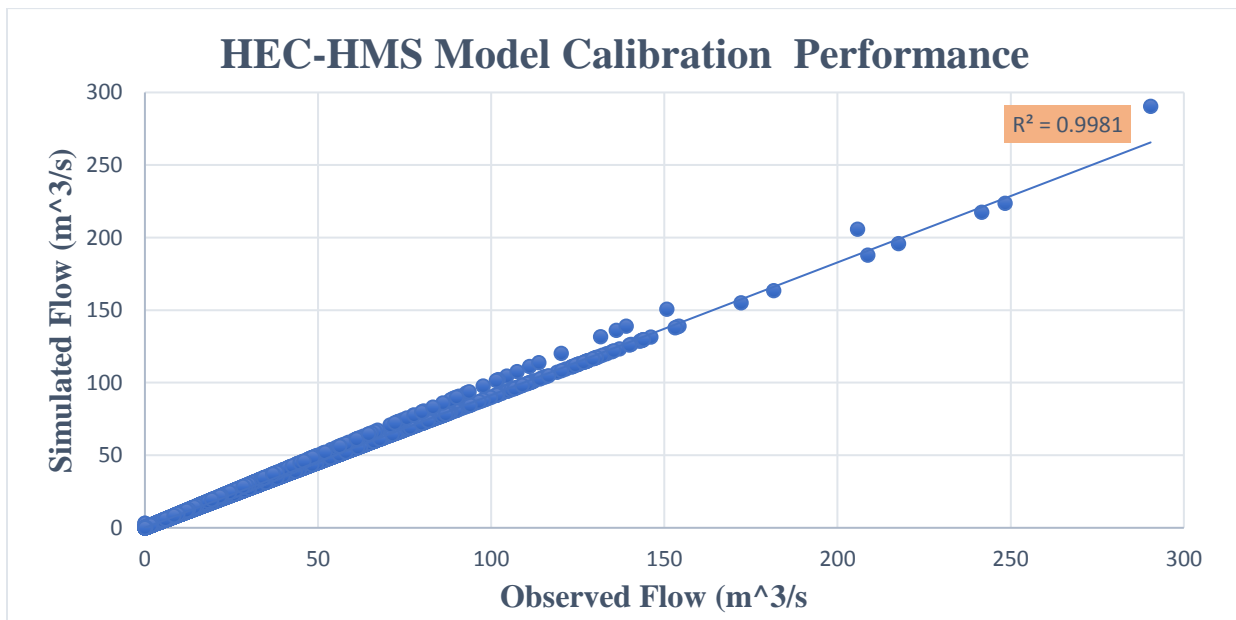


Figure 30 Calibration Performance for Observed and Simulated flow

Flow Validation at Halaba Kulito Station

The model performance is validated accordingly. For the HEC-HMS model there are a total of 25 years taken for both calibration and validation. The validation time was selected as the last four

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years of the total (2011-2014). Accordingly, good match between measured and simulated flow was obtained in validation period ($R^2 = 0.85$ and $NSE = 0.99$). The model captures the peak flow and simulated flow follows the pattern of observed flow

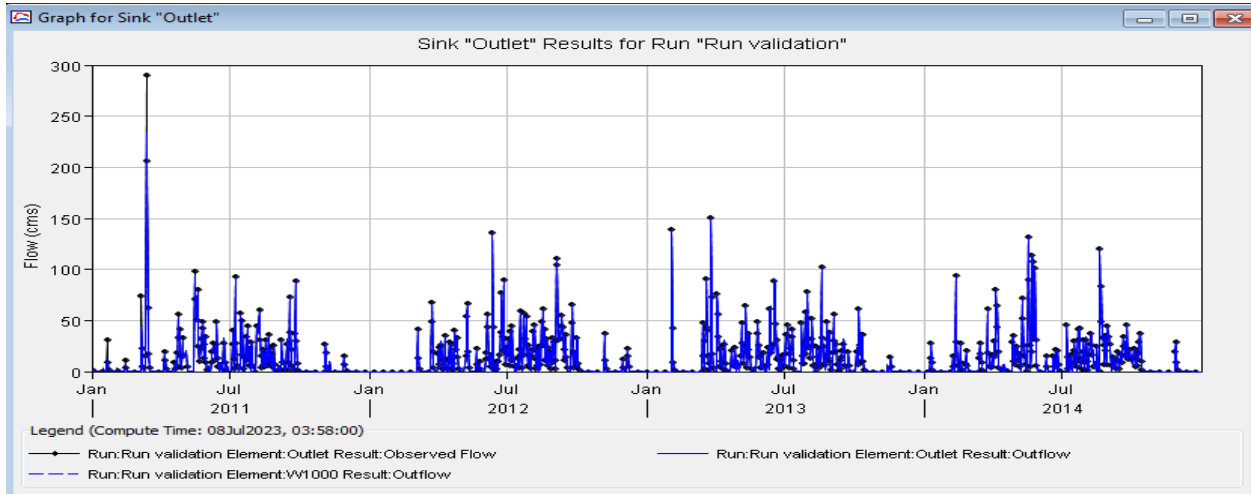


Figure 5:31 Validated Model Output daily Time series



Figure 32 Flow Validation Summary Result on daily basis

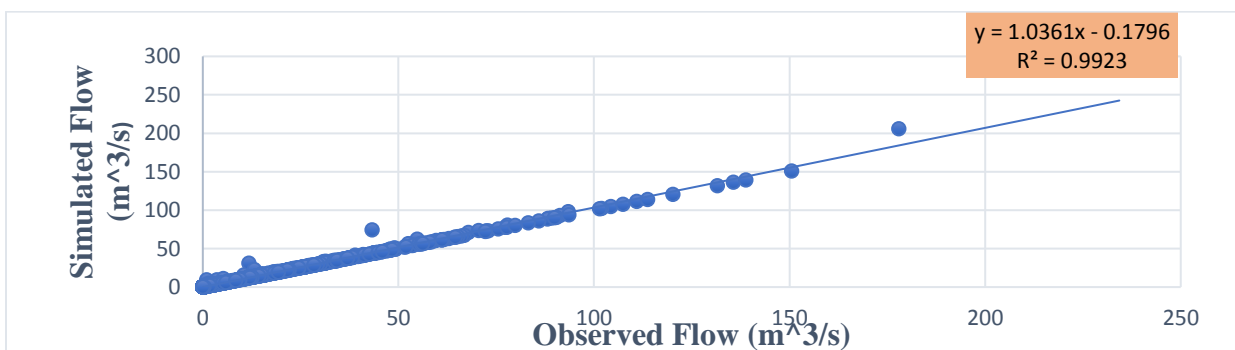


Figure 33 Simulated Versus Observed Flow for Validation

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Flood hazard map of the Wera Woreda that was developed by using ARC GIS software and AHP techniques will be useful information for future flood management, flood disaster preparedness and mitigation planning. The weights for very low, low, moderate, high, and very high hazard zone were formulated based on different possible realizations as well as from the information of previous studies. Flood hazard map of the District shows that 60 Km² area (30 %), 91 Km² area (29 %), 93 Km² area (19%), 58 Km² area (18 %), and 12.5 Km² area (4%) are affected very high, high, moderate, low and very low respectively.

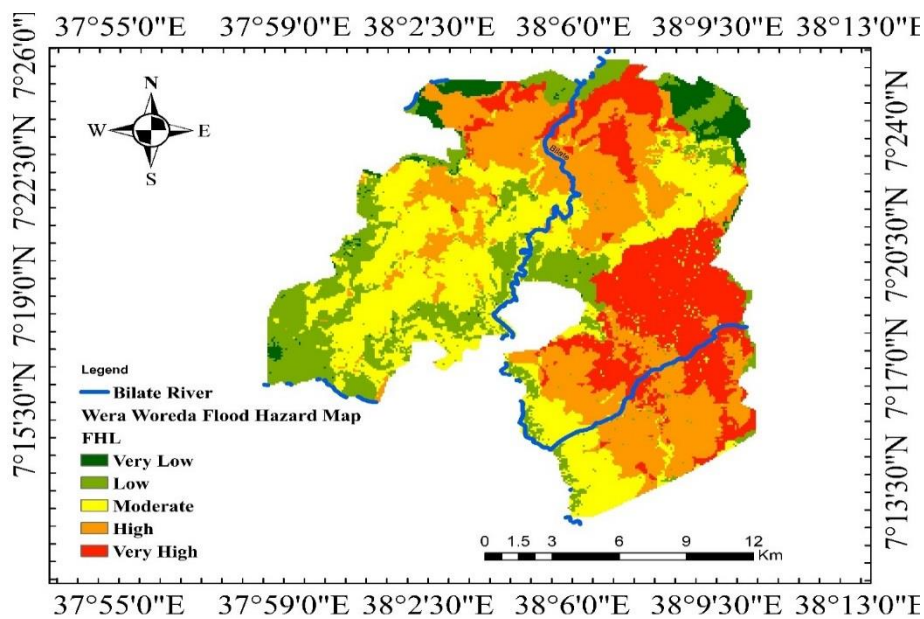


Figure 34 Flood Hazard Map of Wera Woreda Developed by using Arc Gis and AHP

5.1. Hydraulic model Analysis/ River Geometry Analyzes

HEC-RAS was developed to perform 1D analysis of steady flow water surface profile, unsteady flow routing, movable boundary sediment transport computation, and water quality analysis. For the purpose of flood modeling relevant information about the river geometries like stream center lines, bank lines, flow lines and Cross-section cut lines are required.

5.1.1. Stream Centerline

The river and reach network are represented by the stream centerline layer. The network is created on a reach basis, starting from the upstream end and working downstream following the Bilate River channel. Each reach is comprised of a river name and reach name. The Stream Centerline

layer is used for assigning river station to cross section and to display as a schematic in the HEC-RAS geometric editor.

5.1.2. Bank Lines

Bank lines are used to separate the main stream channel from overbank flood plain areas. Bank station will be assigned to each cross section based on the intersection of the bank lines with the cut lines. It is often more efficient to skip this layer and complete the data in HEC-RAS using the graphical cross section editor tools.

In general, the bank lines will used to: Assign bank stations, calculate overbank flow paths, and Serve as the distinction between channel and floodplain roughness.

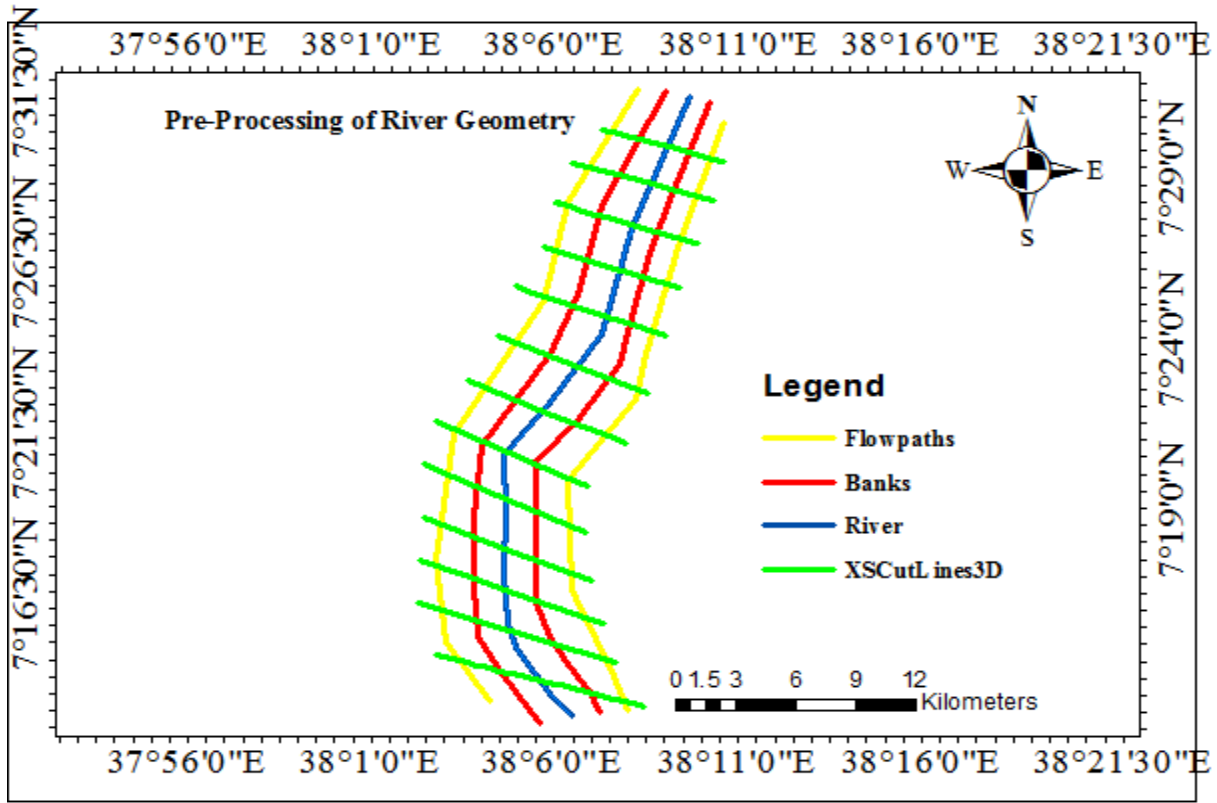
5.1.3. Flow Paths Center Lines

The flow path centerlines layer is used to identify the hydraulics flow path in the, left overbank, main channel and right over bank by identifying the center of mass of flow in each region. Flow path are created in the direction of flow from upstream to downstream. The flow path lines are used to determine the downstream reach lengths between cross sections in the main channel and over bank areas

5.1.4. Cross-Section Cut Lines

Cross-sections are one of the key inputs to HEC-RAS. Cross-section cut lines are used to extract the elevation data from the terrain to create a ground profile across channel flow. The intersection of cut lines with other RAS layers such as stream centerline and flow path lines are used to compute HEC-RAS attributes such as bank stations (locations that separate main channel from the floodplain), downstream reach lengths (distance between cross-sections) and Manning's coefficient, n .

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*Figure 5:35 Schematization of Stream line, Banks, Flow paths and Cross-section cut lines of
Bilate River*

5.2. HEC-RAS

HEC-RAS is the software predominately used in the field of hydraulic analysis for floodplain delineation. The HEC-RAS program, like the other software, it can be downloaded free of charge from the Hydrologic Engineering Center's.

The model is used for determination of water surface profiles for different flow scenarios, is intended for steady flow water surface profile computations and unsteady flow simulation; perform sediment transport simulation and perform water quality simulation. The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendrite system, or a single river reach. For each HEC-RAS project, there are three required components: Geometry data consists of a description of the size, shape, and connectivity of stream cross-sections., Flow data contains discharge rates. Finally, Plan data

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contains information pertinent to the run specifications of the model, including a description of the flow regime.

The Geometric data has been imported from GIS to the HEC-RAS but the geometric data processed may not appropriate with the actual data, so that it is necessary to edit them in HEC-RAS software. Therefore, before any proceed, it is good to perform a quality check on the data to make sure no erroneous information is imported from GIS. Therefore cross-section data editor should be displayed with the downstream reach lengths (left over bank, right over bank and the channel), the manning's n value for the channel, main channel bank station (left and right bank) and the contraction and expansion coefficient of the channel should be edit and entered new data.

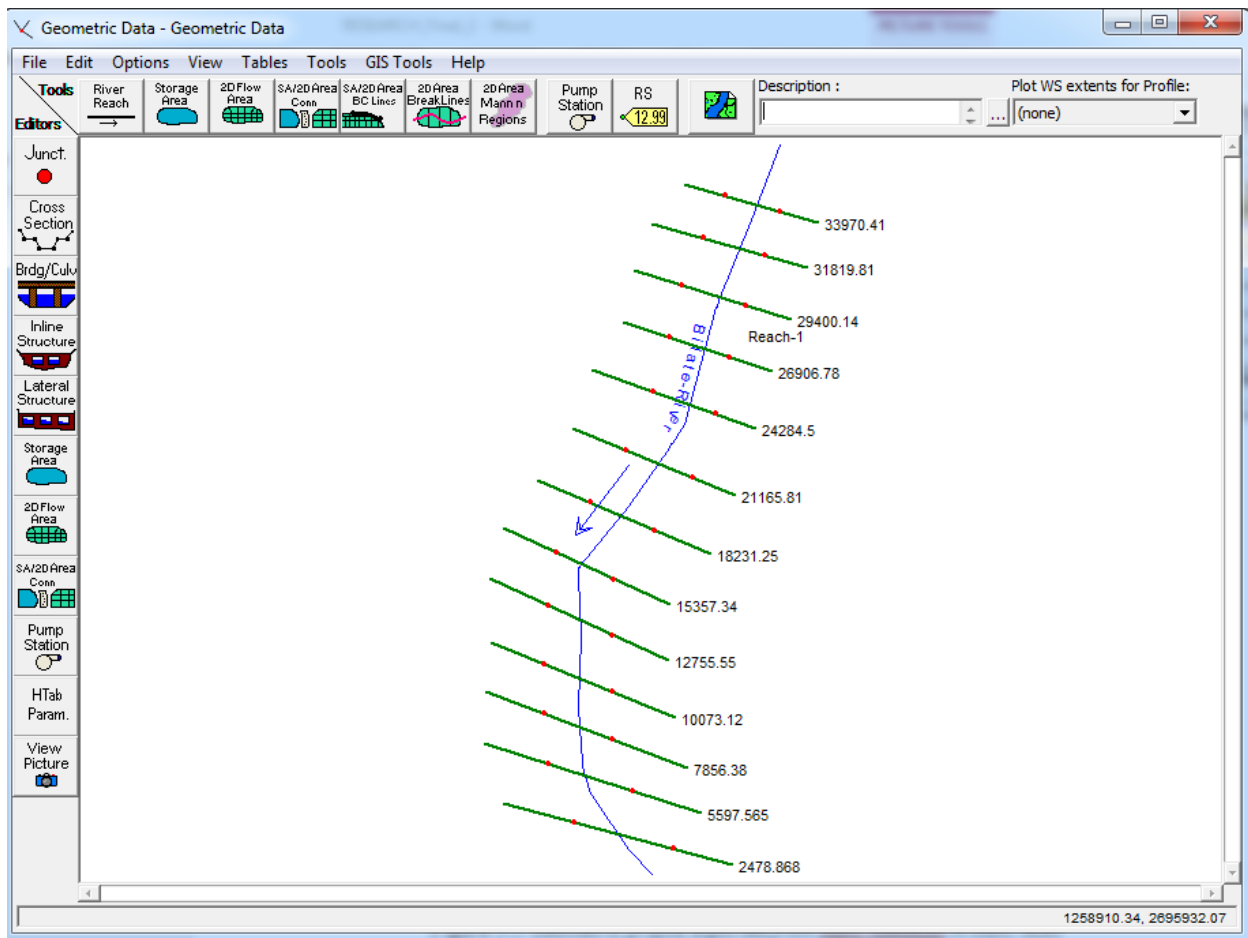


Figure 5:36 Geometric profile exported from HEC-GeoRAS in HEC-RAS

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5.3. HEC-RAS outputs

5.3.1. Cross-Sectional View

The sample cross-sections at the river stations 5597.565 are shown in Fig. 5.5

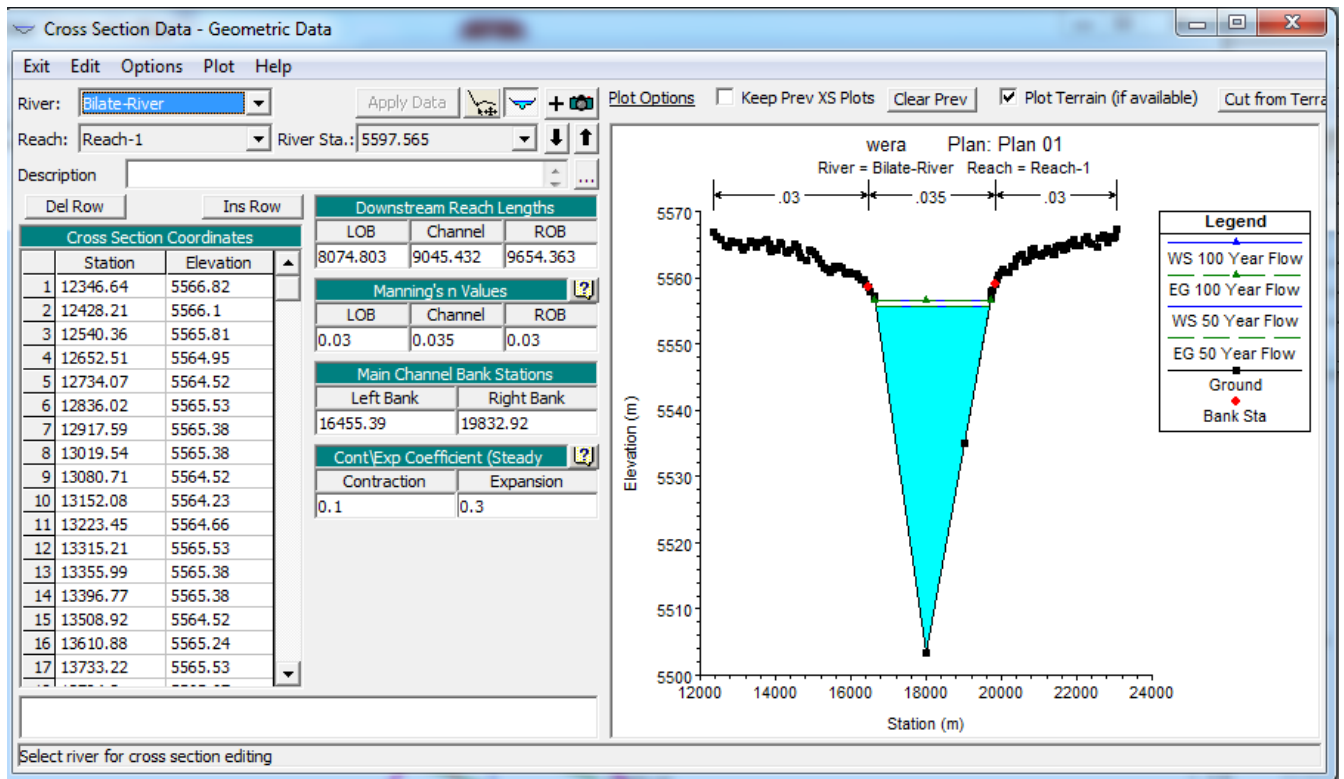


Figure 5:37 Cross-sections view at river station 5597.565 of Bilate River for 50 and 100-year floods

5.3.2. Water Surface Profile

The water surface profiles of the different return periods, i.e.2, 5, 10, 25, 50 and 100 years, are shown in Fig.5.7.

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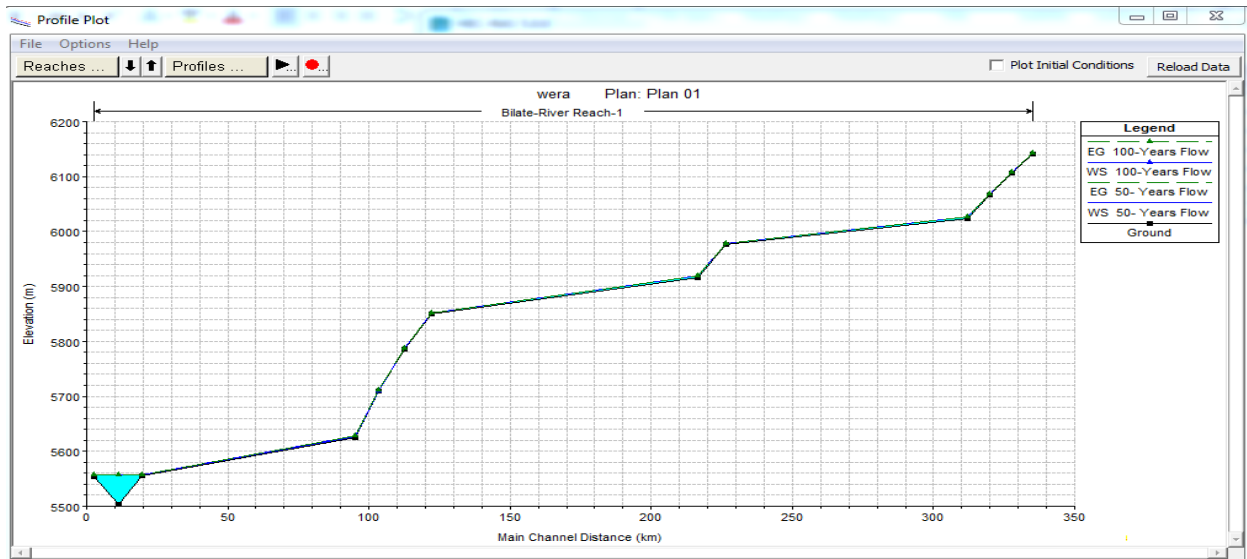


Figure 5:38 The water surface profiles of the different return periods, i.e. 50 and 100 years

5.4. Forms of flood mitigation measures

For flood prone areas, appropriate mitigation measures are recommended /proposed to prevent people who are located in flood prone areas and their properties from flood hazards. The main purpose of flood mitigation is to minimize the problems raised from flood disasters in the flood affected area. Commonly used flood mitigation approaches are classified into two categories: structural and non-structural

5.4.1. Structural mitigation Measures

Structural measures are any physical construction /engineering approach to minimize possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Structural mitigation measures are better when situations in which parts of the adjacent residential areas are located about the higher flood level, or when it is important to control land adjacent to the river from the flood inundations because of an existing flood damages. For frequently flood affected areas, flood hazards eliminated by implementing structural mitigation measures. These approaches are based on engineering technique such as building revetments, channels, levees, seawalls to control flood. Some Structural mechanisms for flood protection are:

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- ✚ Dams.
- ✚ Flow Diversions.
- ✚ Increase flood water holding capacity of the river by Deepening/Widening.
- ✚ Build Levees/Embankment along the streams

5.4.2. Non-structural mitigation measures

Any measures not involving physical construction to reduce possible impacts of hazards. Non-structural measures rather it focuses on policy and legal-related works. It includes activities like land-use planning laws and their enforcement, research and assessment, information resources and public awareness programs and early flood forecasting. Non-structural approaches can be performed by local government such as emergency and recovery politics, training and education, land use planning tool and insurance as flood programs.

Some Non-structural methods used to control and minimize flood hazards in flood prone areas are:

- Giving Perception, Policies, Guide Lines and Laws for the community how to protect properties and themselves from flood events.
- Controlled development in flood plains.
- Use Flood Forecasting and Warning mechanism.
- Permanent relocation of population from the flood plain.

For the case of Wera District, I try to compare two Different structural methods and which have been proposed as better flood mitigation measures. These alternatives are:

- ✚ Levee Construction along the river reach;
- ✚ Modifying existing channel.

Alternative 1: Levee Construction along the river Channel;

A levee can be defined as an artificial wall that used to control flood water from flood plain that may affect frequently by flood impacts. Levees may be used to increase available land for habitation or divert a body of water so the fertile soil of a river or seabed may be used for agriculture. Levee structures are designed to minimize flood hazards by blocking flood water; however, they do not eliminate the risk entirely. It is always possible that a flood will exceed the capacity of a levee, no matter how well the structure is built. Levees work by providing a physical

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wall or barrier through which water cannot permeate in the event of a flood, thereby protecting land, property, wildlife, and people.

According to long-time human experiences have shown that constructing levees along the channel are an effective means of flood mitigation measure if it used properly. On the other hand, flood hazards can be considerably amplified if levees are improperly installed. In general, levees should be built to protect locations where the flood hazards are high and should be used to reduce flood impact that may happened at that area. Finally, constructing levees along reach used to eliminate pressure produced by flood water by that would cause damage to homes or other structures in the protected regions. The main purpose of constructing levee for flood prone area is to increase the ground Elevation that block the flood water before inundate prone area, and reduces the risk that may happen in the area.

How to Defining Levees in HEC-RAS

HEC RAS allows how to define levees to constrain the flow to the main channel by defining a left and/or right levee station and corresponding elevation at a cross section. When levees are defined, water cannot go left of the left levee station or right of the right levee station until the corresponding levee elevation is exceeded. A simple way to do this is to set a levee station and elevation that is above the existing ground. If a levee elevation is placed above the existing geometry of the cross section, then a vertical wall is placed at that station up to the defined levee elevation. When we use the Cross Section Data dialog box to manually define the levees by selecting horizontal stations and elevations for each of the levees. We can select the horizontal stations from either the Map View or from the displayed cross section plot. Before start to design the flood mitigation measure first select recommended return period for our flood plain area.

Table 13 Recommended return periods for different flood plain characteristics for this particular study, a return period of 100 years

Flood- plain characteristic	Recommended flood return period (years)
Expensive agriculture (Partially farming	6-7
Intensive agriculture	15-20
Thinly or medium Populated areas	100-200
Densely populated living areas and industrial centers	200-1000

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Important urban center	>1000
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When we construct levees along the main Channel, a compound cross-section is obtained, the form of which depends on the distance of the levees from the stream bank.

It is obvious that the same discharge could be carried between higher levees construct near to the riverbank, and low levees placed away from the river. The distance from the riverbanks and thus the heights to the levees is generally based upon economics, safety, and hydraulics and freeboard consideration. The main purpose of the free board is to provide for additional safety against exceptional flood events. It should be sufficient to allow for settlement and to contain wind driven waves. This additional height is 0.30-0.4m (Kinor, B., 1984).

The design water levels were based on design discharge of return period of 100 years. From the

River Station	Levee Length (m)	River Elevation +Free Board (m)	Water Surface Elevation (m)	Levee Height (m)
33970.41 - 31819.81	2150.6	6142.89	6142.47	0.42
31819.81 - 29400.14	2419.67	6108.58	6108.28	0.3
29400.14 - 26906.78	2493.36	6069.21	6068.57	0.64
26906.78 - 24284.5	2622.28	6026.79	6026.45	0.34
24284.5 - 21165.81	3118.69	5978.42	5977.83	0.59
21165.81 - 18231.25	2934.56	5919.83	5919.5	0.33
18231.25 - 15357.34	2873.91	5851.88	5851.58	0.3
15357.34 - 12755.55	2601.79	5789.05	5787.81	1.24
12755.55 - 10073.12	2682.43	5711.65	5710.55	1.1
10073.12 - 7856.38	2216.74	5627.8	5627.49	0.31
7856.38 - 5597.565	2258.815	5557.21	5556.84	0.37
5597.565 - 2478.868	3118.697	5562.45	5561.85	0.6
2478.868 - end	1411.368	5557.23	5556.73	0.5

HEC-RAS result of water surface profile analysis for 100-year return period, the flood water level above the banks has been determined.

Table 14 Height and Lengths of the Levee

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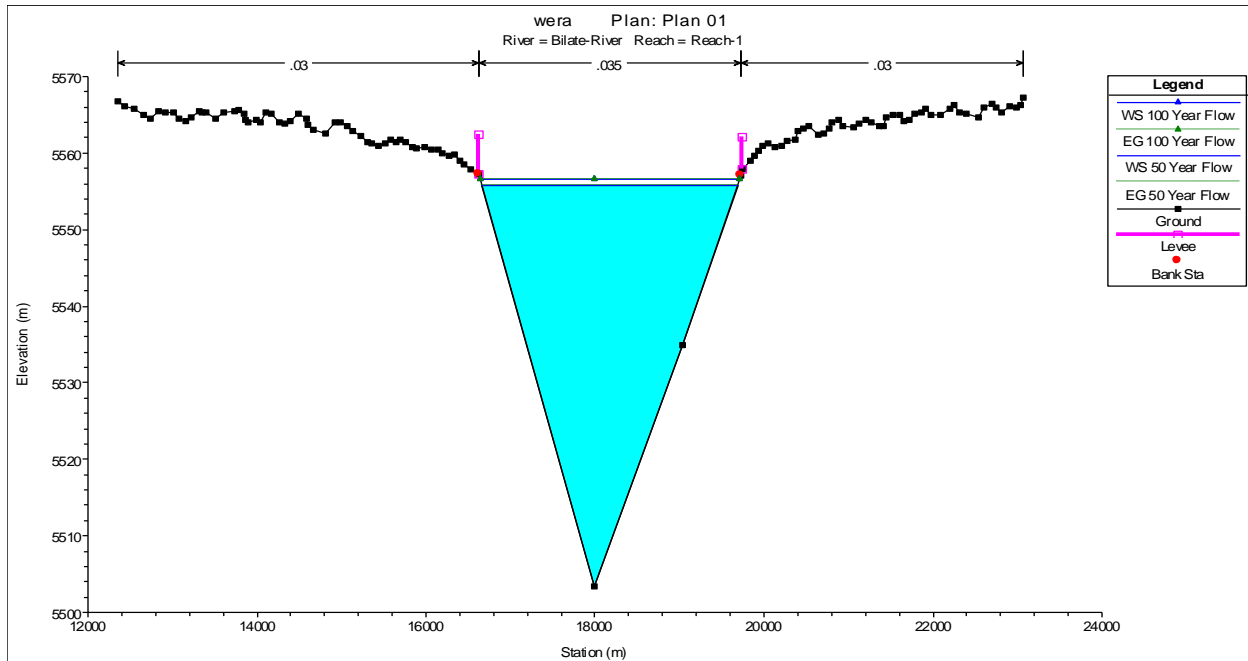


Figure 5.8 Left and right Levee Layout along the channel

Alternative 2: Channel modification

This method is also another alternative way to minimize the flood impacts of flood plains. Channel modification alternative was processed in hydraulic model (HEC-RAS). The main purpose is to increase water holding capacity of the existing channel geometry and it is important to design hydraulic flood protection channels. Channel modification method is conducted in two stages to construct a compound river channel. Channel modification is the process of altering the flow of a water way to achieve various goals. It can take many forms like from excavation and dredging to the construction of levees and dams. It is often necessary to manage natural disasters such as floods or to harness the power of water for human needs such as Agriculture, transportation, and energy production. These structures are designed to prevent floods by containing water within a designated channel. Excavation and dredging in channel modification can be used to deepen a channel, remove accumulated sediments from the channel, or create new paths for water to flow through. Channel modification alternative can be used to prevent flooding and providing a stable

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water supply for human needs (agriculture and energy production) and improve navigation and provides recreational opportunities for boating, fishing and other activities.

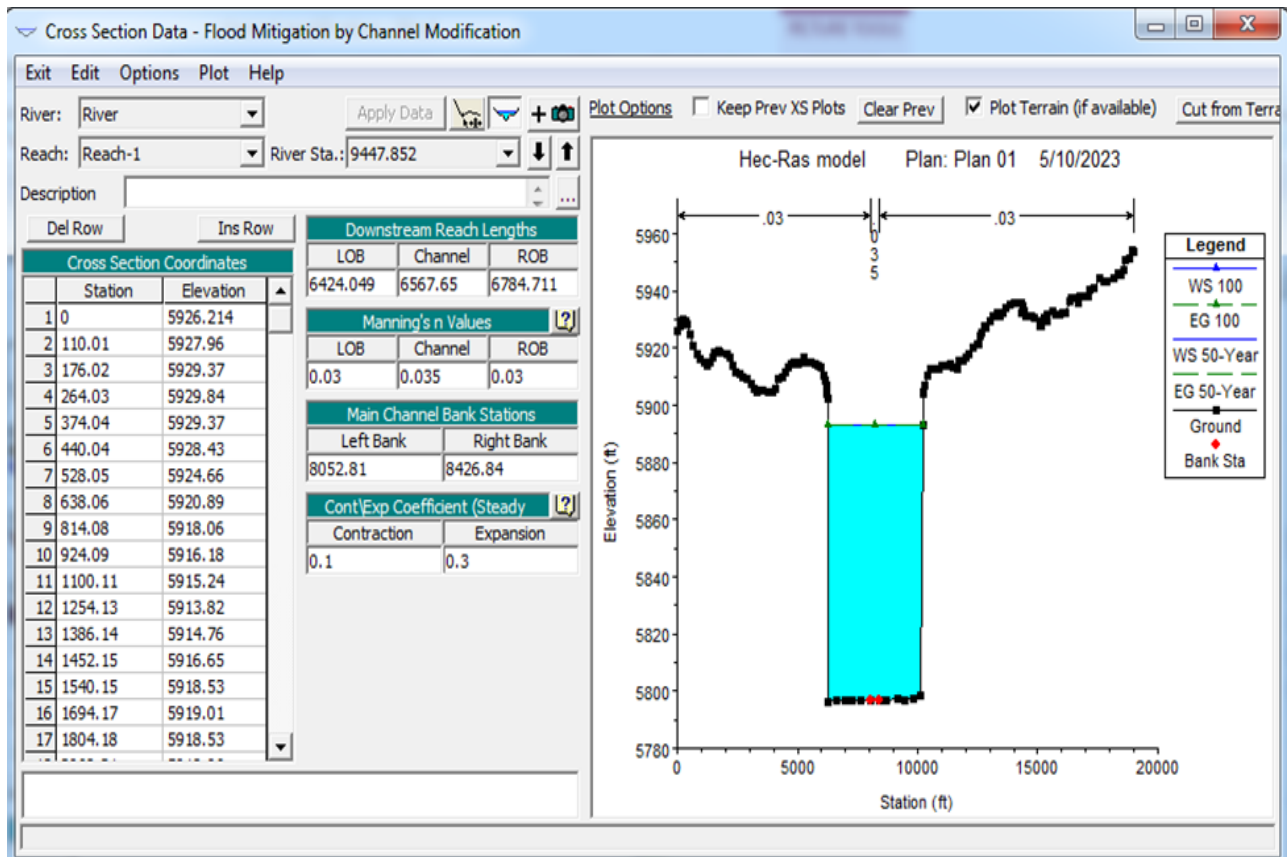


Figure 39 Cross Section Shape file for Rectangular Chanel Modification

6 CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The main aim of this study is to develop flood hazard map by using GIS software packages and hydraulic model (HEC-RAS) program to simulate the surface profiles formed in different recurrent flows of the Bilate River in Wera District, as well as that the flood boundaries in a public area can be easily obtained by using the HEC-RAS package program. The HEC-RAS package program of hydraulic model allowed to develop flood hazard map at the Bilate River sub-basin specifically Wera Woreda or District. Hec-Georas environment is also useful tool as preprocessing for the visualization of the hydraulic model.

Integrating flood generating factors and analysis relative weights for each factors are main things to generate flood hazard map of a given catchment. Selected flood generating factors of the study area were processed in ARC GIS environment to develop their flood hazard map in ARC GIS software package. The weights for each flood generating factors were computed by using Analytical Hierarchy Process /pair wise comparison method for final weighted overlay analysis to obtain main target flood hazard map equation of the study area.

Flood hazard map of the Wera Woreda that was develop by using ARC GIS and AHP techniques will be useful information for future flood management, flood disaster preparedness and mitigation planning. The weights for very low, low, moderate, high, and very high hazard zone were formulated based on different possible realization as well as from the information of previous studies. Flood hazard map of the Wera woreda shows that 60 Km² area (30 %), 91 Km² area (29 %), 93 Km² area (19%), 58 Km² area (18 %), and 12.5 Km² area (4%) are affected very high, high, moderate, low and very low respectively. Also flood inundated area was generated by using Hec-Ras and Arc Gis package and Classify the catchment in to level low, medium and High.

To minimize these and like impacts caused by flooding select appropriate mitigation measures strategies and techniques applied to reduce the severity of flooding. Mitigation measures employed to prevent damage, protect lives, and minimize the economic impact of floods. These techniques can be applied to reduce the probability of flooding occurrence, thereby minimizing the amount of property or lives lost during floods. To decide the best Comparing different flood mitigation measures is an important part of creating an effective plan to prevent damages caused by flooding.

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Various factors to be considered when we compare flood mitigation measures like: needs and goals of the particular community, cost-effectiveness, ensure that they are both effective and sustainable in the long-term and rules concerning flood mitigation. In my case, try to compare both constructing levee along the channel and modifying the existing river geometry.

Based on the above considerations, one of the most effective flood mitigation measures is the construction of flood walls or levees. Levees are built to prevent water from overflowing into communities and other areas that are at risk of flooding.

Flood mitigation by Levee construction is the most effective alternative method in flood hazardous area reduction as compared with the channel modification technique.

Another common Non-structural flood mitigation measure is the use of sandbags. Sandbags are utilized to control water flow and prevent it from entering buildings and homes in flood-prone areas. Sandbags are filled with sand and are piled up around buildings to create a barrier that prevents water from entering. Additionally, the use of drainage systems is an effective way to mitigate flood damage.

6.2. Recommendation

- ❖ Constructing Levee structures and modification of exiting channel can be taken as mitigation mechanism to protect the area from flood effects from different return period.
- ❖ Integrated watershed management activities like afforestation, land use management, soil and water conservation activities should be done to minimize the flood capacity in catchment.
- ❖ Decision making criteria should be considered to select the best alternative from the both alternatives proposed for study area.
- ❖ The water profile of the study area could be updated more frequently due to continuous changing of hydrologic, hydraulic conditions and land use in the basin.
- ❖ The social and environmental impact of the above mitigation measure proposed for the study area should carefully considered like bank erosion and sedimentation problem.
- ❖ Emergency action plan should be developed for the prone area residents and properties.
- ❖ Crop and plants that can resist flood should be grown there with modern agricultural technique.
- ❖ Flood related awareness should be given to the local residents. Detail study for flood prone are like Wea worda should be done for the study area on flood disaster.
- ❖ Giving perception how to prevent their community from flood damages by using simplest and cheapest methods like compact sand bags by available materials.

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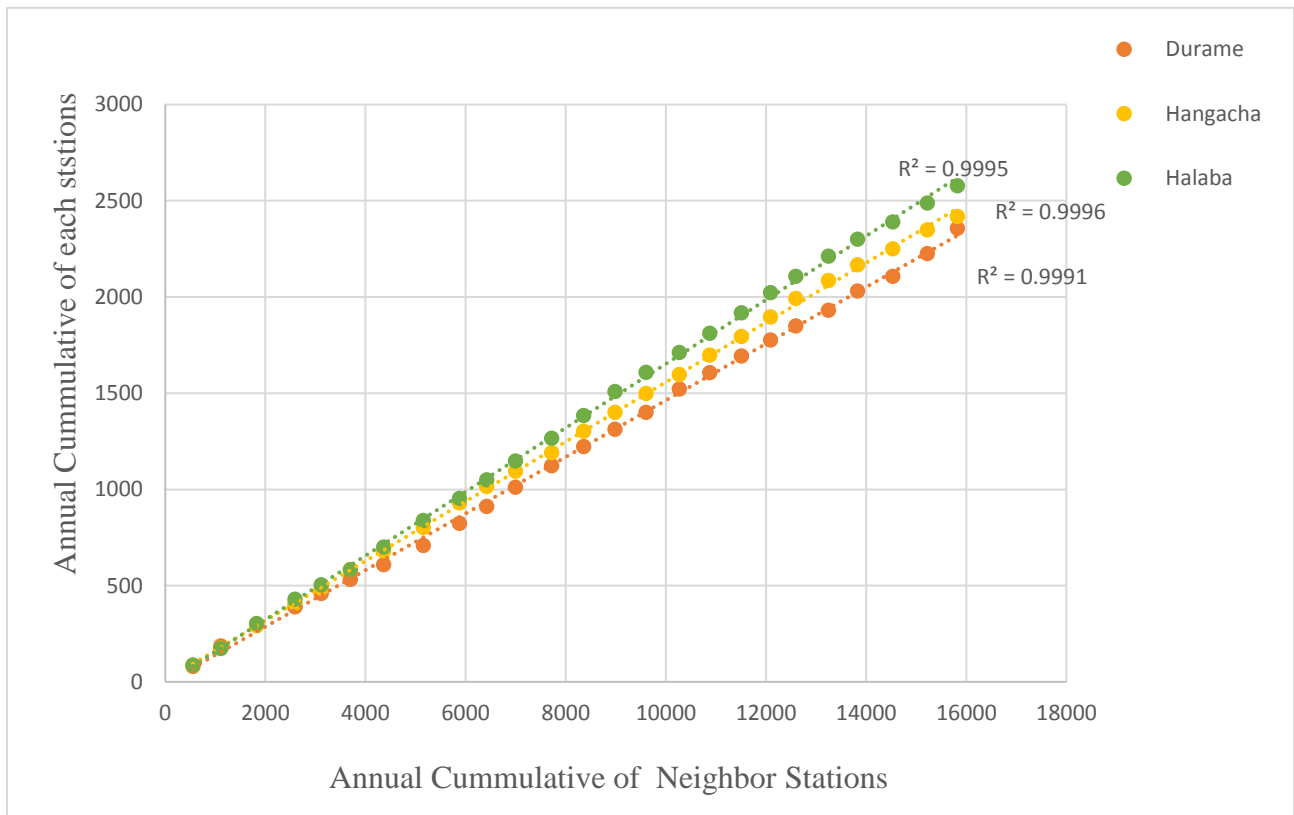
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ANNEXES

Appendix A: Double Mass Curves of the selected stations



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Appendix B: Table to read K values for Outlier test

OUTLIER TEST K VALUES

10 PERCENT SIGNIFICANCE LEVEL K VALUES

The table below contains one sided 10 percent significance level K_N values for a normal distribution (38). Tests conducted to select the outlier detection procedures used in this report indicate these K_N values are applicable to log-Pearson Type III distributions over the tested range of skew values.

Sample size	K_N value	Sample size	K_N value	Sample size	K_N value	Sample size	K_N value
10	2.036	45	2.727	80	2.940	115	3.064
11	2.088	46	2.736	81	2.945	116	3.067
12	2.134	47	2.744	82	2.949	117	3.070
13	2.175	48	2.753	83	2.953	118	3.073
14	2.213	49	2.760	84	2.957	119	3.075
15	2.247	50	2.768	85	2.961	120	3.078
16	2.279	51	2.775	86	2.966	121	3.081
17	2.309	52	2.783	87	2.970	122	3.083
18	2.335	53	2.790	88	2.973	123	3.086
19	2.361	54	2.798	89	2.977	124	3.089
20	2.385	55	2.804	90	2.981	125	3.092
21	2.408	56	2.811	91	2.984	126	3.095
22	2.429	57	2.818	92	2.989	127	3.097
23	2.448	58	2.824	93	2.993	128	3.100
24	2.467	59	2.831	94	2.996	129	3.102
25	2.486	60	2.837	95	3.000	130	3.104
26	2.502	61	2.842	96	3.003	131	3.107
27	2.519	62	2.849	97	3.006	132	3.109
28	2.534	63	2.854	98	3.011	133	3.112
29	2.549	64	2.860	99	3.014	134	3.114
30	2.563	65	2.866	100	3.017	135	3.116
31	2.577	66	2.871	101	3.021	136	3.119
32	2.591	67	2.877	102	3.024	137	3.122
33	2.604	68	2.883	103	3.027	138	3.124
34	2.616	69	2.888	104	3.030	139	3.126
35	2.628	70	2.893	105	3.033	140	3.129
36	2.639	71	2.897	106	3.037	141	3.131
37	2.650	72	2.903	107	3.040	142	3.133
38	2.661	73	2.908	108	3.043	143	3.135
39	2.671	74	2.912	109	3.046	144	3.138
40	2.682	75	2.917	110	3.049	145	3.140
41	2.692	76	2.922	111	3.052	146	3.142
42	2.700	77	2.927	112	3.055	147	3.144
43	2.710	78	2.931	113	3.058	148	3.146
44	2.719	79	2.935	114	3.061	149	3.148

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Appendix C: Reduced mean and Reduced Standard Deviation in EV1 Distribution

Table 7.3 Reduced mean \bar{y}_n in Gumbel's Extreme Value Distribution

N = sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.4952	0.4996	0.5035	0.5070	0.5100	0.5128	0.5157	0.5181	0.5202	0.5220
20	0.5236	0.5252	0.5268	0.5283	0.5296	0.5309	0.5320	0.5332	0.5343	0.5353
30	0.5362	0.5371	0.5380	0.5388	0.5396	0.5402	0.5410	0.5418	0.5424	0.5430
40	0.5436	0.5442	0.5448	0.5453	0.5458	0.5463	0.5468	0.5473	0.5477	0.5481
50	0.5485	0.5489	0.5493	0.5497	0.5501	0.5504	0.5508	0.5511	0.5515	0.5518
60	0.5521	0.5524	0.5527	0.5530	0.5533	0.5535	0.5538	0.5540	0.5543	0.5545
70	0.5548	0.5550	0.5552	0.5555	0.5557	0.5559	0.5561	0.5563	0.5565	0.5567
80	0.5569	0.5570	0.5572	0.5574	0.5576	0.5578	0.5580	0.5581	0.5583	0.5585
90	0.5586	0.5587	0.5589	0.5591	0.5592	0.5593	0.5595	0.5596	0.5598	0.5599
100	0.5600									

Table 7.4 Reduced Standard Deviation S_n in Gumbel's Extreme Value Distribution

N = sample size

N	0	1	2	3	4	5	6	7	8	9
10	0.9496	0.9676	0.9833	0.9971	1.0095	1.0206	1.0316	1.0411	1.0493	1.0565
20	1.0628	1.0696	1.0754	1.0811	1.0864	1.0915	1.0961	1.1004	1.1047	1.1086
30	1.1124	1.1159	1.1193	1.1226	1.1255	1.1285	1.1313	1.1339	1.1363	1.1388
40	1.1413	1.1436	1.1458	1.1480	1.1499	1.1519	1.1538	1.1557	1.1574	1.1590
50	1.1607	1.1623	1.1638	1.1658	1.1667	1.1681	1.1696	1.1708	1.1721	1.1734
60	1.1747	1.1759	1.1770	1.1782	1.1793	1.1803	1.1814	1.1824	1.1834	1.1844
70	1.1854	1.1863	1.1873	1.1881	1.1890	1.1898	1.1906	1.1915	1.1923	1.1930
80	1.1938	1.1945	1.1953	1.1959	1.1967	1.1973	1.1980	1.1987	1.1994	1.2001
90	1.2007	1.2013	1.2020	1.2026	1.2032	1.2038	1.2044	1.2049	1.2055	1.2060
100	1.2065									

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Appendix D: Table for Ks in Log-Pearson Type III Distribution

Table 7.6 $K_z = F(C_s, T)$ for Use in Log-Pearson Type III Distribution

Coefficient of skew, C_s	Recurrence interval T in years						
	2	10	25	50	100	200	1000
3.0	-0.396	1.180	2.278	3.152	4.051	4.970	7.250
2.5	-0.360	1.250	2.262	3.048	3.845	4.652	6.600
2.2	-0.330	1.284	2.240	2.970	3.705	4.444	6.200
2.0	-0.307	1.302	2.219	2.912	3.605	4.298	5.910
1.8	-0.282	1.318	2.193	2.848	3.499	4.147	5.660
1.6	-0.254	1.329	2.163	2.780	3.388	3.990	5.390
1.4	-0.225	1.337	2.128	2.706	3.271	3.828	5.110

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1.2	-0.195	1.340	2.087	2.626	3.149	3.661	4.820
1.0	-0.164	1.340	2.043	2.542	3.022	3.489	4.540
0.9	-0.148	1.339	2.018	2.498	2.957	3.401	4.395
0.8	-0.132	1.336	1.998	2.453	2.891	3.312	4.250
0.7	-0.116	1.333	1.967	2.407	2.824	3.223	4.105
0.6	-0.099	1.328	1.939	2.359	2.755	3.132	3.960
0.5	-0.083	1.323	1.910	2.311	2.686	3.041	3.815
0.4	-0.066	1.317	1.880	2.261	2.615	2.949	3.670
0.3	-0.050	1.309	1.849	2.211	2.544	2.856	3.525
0.2	-0.033	1.301	1.818	2.159	2.472	2.763	3.380
0.1	-0.017	1.292	1.785	2.107	2.400	2.670	3.235
0.0	0.000	1.282	1.751	2.054	2.326	2.576	3.090
-0.1	0.017	1.270	1.716	2.000	2.252	2.482	2.950
-0.2	0.033	1.258	1.680	1.945	2.178	2.388	2.810
-0.3	0.050	1.245	1.643	1.890	2.104	2.294	2.675
-0.4	0.066	1.231	1.606	1.834	2.029	2.201	2.540
-0.5	0.083	1.216	1.567	1.777	1.955	2.108	2.400
-0.6	0.099	1.200	1.528	1.720	1.880	2.016	2.275
-0.7	0.116	1.183	1.488	1.663	1.806	1.926	2.150
-0.8	0.132	1.166	1.448	1.606	1.733	1.837	2.035
-0.9	0.148	1.147	1.407	1.549	1.660	1.749	1.910
-1.0	0.164	1.128	1.366	1.492	1.588	1.664	1.880
-1.4	0.225	1.041	1.198	1.270	1.318	1.351	1.465
-1.8	0.282	0.945	1.035	1.069	1.087	1.097	1.130
-2.2	0.330	0.844	0.888	0.900	0.905	0.907	0.910
-3.0	0.396	0.660	0.666	0.666	0.667	0.667	0.668

[Note: $C_v = 0$ corresponds to log-normal distribution]

Appendix E: Theoretical Estimated manning roughness coefficient

Variables	Description	Recommended	Actual Value of the channel	Actual Value Of Flood Plain
Base value, n1	Earth	0.02	n1=0.022	n1=0.02
	Rock	0.025		
	Fine Gravel	0.024		
	Course Gravel	0.028		

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Irregularity n2	Smooth Minor Moderate Severe	0.000 0.005 0.010 0.020	n2=0.005	n2=0.005
Variation in channel cross section n3	Gradual Occasional Alternating	0.000 0.005 0.010-0.015	n3=0.012	n3=0.005
Obstruction n4	Negligible Minor Appreciable Severe	0.000 0.01-0.015 0.02-0.03 0.04-0.06	n4=0.00	n4=0.00
Vegetation n5	Low Medium High Very High	0.005-0.01 0.01-0.02 0.025-0.05 0.05-0.1	n5=0.005	n5=0.0085
Total Reach, n			0.044	0.0385

Appendix F: Pairwise comparison Matrix

Pairwise comparison of six (6) criterion Matrix						
Factors	Elevation	Slope	Rainfall	DD	Land use/cover	Soil type
Elevation	1	2	2	3	2	3
Slope	1/2	1	3	3	2	4
Rainfall	1/2	1/3	1	2	2	3
Drainage Density	1/3	1/3	1/2	1/2	2	3
Land use/cover	1/2	1/2	1/2	1/2	1	2
Soil type	1/3	1/4	1/3	1/3	1/2	1
Sum	3.17	4.42	7.33	9.83	9.50	16.00

Appendix G: Normalized pair-wise comparison matrix table

Normalized pair-wise comparison matrix table									
Factors	Elevation	Slope	Rainfall	D D	Lu/Lc	Soil type	Sum	R.Wight	Influence (%)
Elevation	0.316	0.453	0.273	0.305	0.211	0.188	1.744	0.291	29.1

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Slope	0.158	0.226	0.409	0.305	0.211	0.250	1.559	0.260	26.0
Rainfall	0.158	0.075	0.136	0.203	0.211	0.188	0.971	0.162	16.2
Drainage Density	0.105	0.075	0.068	0.102	0.211	0.188	0.749	0.125	12.5
Lu/Lc	0.158	0.113	0.068	0.051	0.105	0.125	0.620	0.103	10.3
Soil type	0.105	0.057	0.045	0.034	0.053	0.063	0.356	0.059	5.9
Total							6.000	1.000	100.0

Appendix H: The Analytical Hierarchy Process

RW	0.291	0.260	0.162	0.125	0.103	0.059			
Factors	Elevation	Slope	Rainfall	D./D	Lu/Lc	Soil Type	Weighted sum value	Rw	Ratio
Elevation	0.291	0.520	0.324	0.374	0.207	0.178	1.893	0.316	6.000
Slope	0.145	0.260	0.486	0.374	0.207	0.238	1.709	0.285	6.000
Rainfall	0.145	0.087	0.162	0.250	0.207	0.178	1.028	0.171	6.000
D/ D	0.097	0.087	0.081	0.125	0.207	0.178	0.774	0.129	6.000
Lu/Lc	0.145	0.130	0.081	0.062	0.103	0.119	0.641	0.107	6.000
Soil type	0.097	0.065	0.054	0.042	0.052	0.059	0.369	0.061	6.000
Average									6