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SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

FLOOD DAMAGE ANALYSIS, FOR TEJI AREA /ILLU WOREDA/

Hydraulic Engineering Stream

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science.

The undersigned have examined the thesis entitled '**Flood Damage Analysis, For Teji Area/Illu Woreda/**' presented by **Bedilu Dejene**, a candidate for the degree of **Master of Science**, and hereby certify that it is worthy of acceptance.

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I confirm that research work titled "**Flood Damage Analysis, For Teji Area /Illu Woreda/"**" is my work. The work has not been presented elsewhere. Where material has been used from other sources it has been properly acknowledged.

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CERTIFICATION

The undersigned certifies that he has read the thesis entitled "Flood **Damage Analysis, For Teji Area/Illu Woreda**/ and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Flooding is one of the most common, wide-reaching, and destructive natural perils, affecting, on average, approximately 250 million people around the world each year. It is also common in Ethiopia during the rainy season between June and September. Most of the flood disasters in Oromia are associated with rivers that overflow and burst their banks succeeding heavy rains and inundated lowlands. Flooding of the upper basin and tributaries of Awash River affected 14 peasant’s associations (Pas) in Illu, Sebeta Awas, and Ejere woredas of southwest Shewa zone. The flood was reported to have affected a total of 14,790 people out of which 2,052 people were displaced and inundate along the river banks in lowland plains. The objective of the study is to quantify and estimate the damage of flooding on the economy in the Illu Woreda Teji Area using the HEC-FDA model. Adopting HEC-GeoHMS Arc-GIS extension physical characteristics of a catchment is obtained from the study area digital elevation model. Using the study area rainfall/meteorological data/ HEC-HMS model computes peak flow for different return periods near the outlet of the river catchment. Flood plain mapping near the Teji River was generated depend on the peak flow of the river for different return periods by the HEC-RAS model, Arc-GIS to the special data processing as well as HEC-GeoRAS to link Arc-GIS with HEC-RAS. Depending on the HEC-RAS result hydraulic model, applying the HEC-FDA model, numerically flood damages are estimated. The flood plain area across Teji River generated for 2, 5, 10, 25, 50, 100, 200 as well as 500 return periods were 308, 422, 459, 507, 535, 574, 598 as well as 622 ha consecutively. In the end, flood damage costs were estimated by the HEC-FDA model. From the study, the main output is expected annual damage (EAD). That is EAD is estimated to be 2,962,832.59$(Two Million Nine Hundred Sixty-Two Thousand Eight Hundred Thirty-Two Point Five Nine Dollar). Additionally using HEC-FDA model by assigning a levee the economic damage is reduced to 403.43$, and levee is proposed for flood plain management.

Keywords: Flood Damage, Teji River, HEC-HMS HEC-RAS, HEC-GEORAS, HEC-FDA and EAD

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ABBREVIATION

AMSL: Above mean sea level

DEM: Digital elevation model

DPPA: Disaster prevention and preparedness agency

DTM: Digital terrain model

EAD: Expected annual damage

E.C: Ethiopian Calendar

GIS: Geographical information system

GPS: Global Positioning System

HEC-FDA: Hydraulic Engineering Center for Flood Damage Analysis

HEC-GeoHMS: Geographic Hydrologic Modelling Extension

HEC-HMS: Hydrologic model

HEC-RAS: Hydraulic Engineering center for river analysis system

HEC-SAM: Spatial Analysis Methodology

LPIII: Log Pearson Type III

MOWIE: Ministry of Water Irrigation and Electricity

M-W: Mann-witney

NMA: National Meteorological Agency

NSE: Nash-Sutcliffe coefficient of Efficient

OECD: Organization for economic co-operation and development

USACE: Us army crops Engineer

USGS: United States Geological Survey

TIN: Triangular Irregular Network

RR: Rainfall Region

Chapter 1 INTRODUCTION

1.1 Background

Inundating is one of the greatest common, wide-reaching, and damaging natural hazards, disturbing, averagely, nearly 250 million people around the world each year (OECD, 2016). Practical considerations such as access to water supplies, fertile soil, waterborne transport, and the attractiveness of living near rivers and coasts have historically led to significant development in areas prone to inundating hazards. In many countries, substantial portions of the population now live in areas prone to inundation: for example, 49% of the people of Japan are located in Former River and coastal floodplains, and two-thirds of the people of the Netherlands live in flood-prone areas. Several mega-cities in Asia, including Ho Chi Minh City, Jakarta, and manila have been repeatedly affected by flooding in recent years. In the United States, floods accounted for almost two-thirds of all Presidential disaster declarations during the period 1953-2010 and have been responsible for the largest number of lives lost and the greatest damage over the last century when compared with former natural disasters. In Canada, floods have accounted for 40% of all recorded natural disaster events since1900 (OECD, 2016).

West, along with Central Africa, has practiced significant flooding during the rainy season of 2017, affecting massive, substantial, and human victims. A grouping of swollen streams, as well as great effect events, has led near the damage of structure and agricultural resources, people dislocation, and problems for admission and relief help. Rainfall predictions concluded December show nearby to above the seasonal average in extreme eastern congo and west of democratic republic of congo, to very likely above-average in the great eastern south-east of Central African Republic. (Report from UN Office, 2017).

Ethiopia has a large amount of rugged and mountainous topography with altitudes that range 4650m above the sea level to 420m below the sea level. The wide variation in elevation means that various climatic conditions exist in Ethiopia. The rainfall as well differs from place to place it reaches an average of 2400mm/year in the southwest and not greater than 150mm/year in the northern part. Although other portions of a country have suffered from limited rainfall, other parts of the country have suffered from heavy floods as long as the high rain in high land parts of a country. Flooding is common in Ethiopia during the rainy period among June as well as September and the main types of flooding which Ethiopia is experiencing are flash flood and river floods (floods and health in Gambella region, 2008).

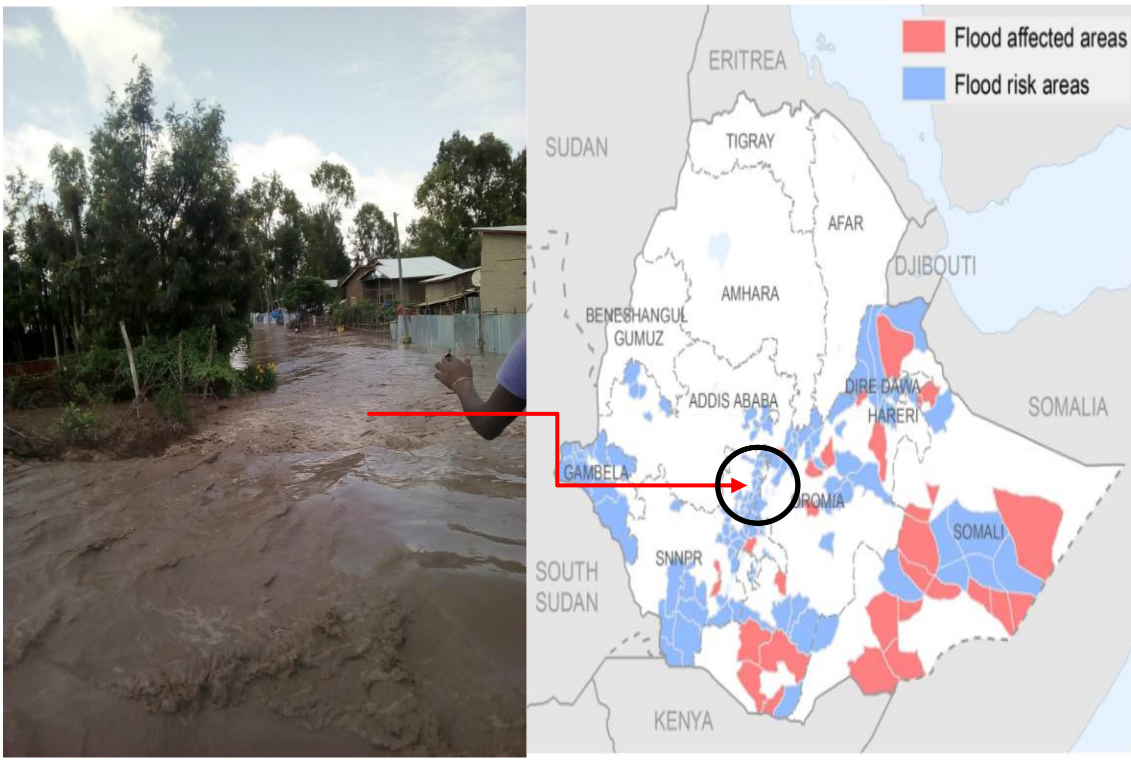
Flash floods remain those produced on or after additional rainfall occurring upstream of watersheds as well as gushing downstream with massive concentration, intensity, and power. They're always unexpected, and they seem unnoticed. (Loss & damage of Gambella region, 2013). Consequently, such floods frequently consequence in a significant toll; and the damage develops especially marked and devastating when they pass through or alongside human settlements and infrastructure meditation. The current event that the Dire Dawa City practiced is a typical expression of a flash flood. Instead, abundant of flood disasters in Ethiopia are attributed to rivers that overflow or burst their banks and inundate downstream plain lands. The flood that has recently assaulted the southern Omo zone and upper Awash Sub-basin (mainly Illu, Sebeta Awas, and Ejere woreda) is a typical manifestation of river floods. River floods pose a thoughtful hazard to millions of people alive in river basins worldwide. At the countrywide level, great floods may bring rear growth by nearly years and threaten national food security at the household level; a flood may leave people without housing, limit possibilities to get involved in economic activities, and may increase the burden of diseases. (Loss & damage of Gambella region, 2013). So, due to its topographic and altitudinal features, flooding, as a natural occurrence, is not novel to Ethiopia. They have been happening at dissimilar places and times with fluctuating levels (Loss & damage of Gambella region, 2013).

1.2 Statement of the Problem

Flood is one of the main natural disasters that have struck a variety of countries or states in the world year after year. Additionally, it is single of the basic natural perils in Ethiopia which affect major damages to lives and livelihoods in parts of the country. Flooding in Ethiopia is mostly linked with dense rainfall and the geography of the highland mountains and lowland plains with natural drainage schemes formed by the principal river basins. (Revised flood alert, 2018).

In Oromia regional states, flood frequently consequences from heavy rains bring about overflow on the surface. Abundant of the flood disasters in Oromia are linked to rivers that overflow and rush their banks succeeding heavy rains and inundated lowlands. Taking into consideration the forecast for the 2018 kiremt season, it is estimated that 707,556 people will expect to be affected (Joint Government–Humanitarian Partners National Flood Contingency plan, 2018 kiremt).

Flooding of the upper basin of Awash River and tributaries affected 14 peasant's associations (Pas) in Illu, Sebeta Awas, and Ejere woredas of southwest Shewa zone. The flood was reported to have affected a total of 14,790 people out of which 2052 people were displaced and inundated beside the river banks in lowland plains (Joint Government and humanitarian partners, 2006). In most cases, floods occur in Illu woreda as a consequence of prolonged heavy rainfall causing rivers to overflow and inundate areas along the river banks in lowland plains.



a) Part of Teji area of the 2011 E.C flood event   b) Inundation of impacted areas in Ethiopia

Figure 1.1: Flood incidents in the Teji area and affected areas and likely to be affected by the floods in Ethiopia

1.3 Research Questions

What is the magnitude of flood frequency for different return periods?

What is the expected annual damage in monetary value?

What are flood Plain areas?

1.4 Objective

1.4.1 General Objective

The main objective of the research is to analyze flood damage and to map flood plain areas to adopt proper flood management in the Illu woreda, particularly the Teji area.

1.4.2 Specific Objective

- To predict Peak flow in a river /flood discharges/ for different return periods.
- To identify flood plain areas.
- To estimate economic damage by flood.
- To adopt proper flood management

1.4 Significance of the Study

The study will assist the decision and policymakers, administrators, planners, and water resources professionals, who are responsible for the management of water resources, in planning and design of water resource projects and flood plain management, depending on the frequency and magnitude of peak discharges.

Chapter 2 LITERATURE REVIEW

2.1 Flood

A flood remains a remarkably great stage in a stream, typically the level at which the river runoffs its banks as well as floods the adjacent area. The damages caused by floods in terms of loss of life, goods and economic loss as a result of interruption of economic activity are all too well recognized. Thousands of crores of rupees are consumed every year in flood control and flood estimating. The hydrograph of great floods and stages equivalent to flood peaks provide valuable data for purposes of the hydrologic project. Additional, of the various features of the flood hydrograph, probably the greatest key and commonly used parameter is the flood peak. On a given location in a watercourse, flood peaks vary from year to year and their magnitude constitutes a hydrologic series that enables one to assign a frequency to a given flood-peak value. In the design of basically all hydraulic structures, the peak flow that can be likely with an assigned occurrence (about 1 in 100 years) is of main importance to sufficiently fraction the structure to provide accommodations its influence. The project of bridges, culvert waterways, and spillways for dams and estimation of scour at a hydraulic construction are some examples wherein flood-peak values are required (K. Subramanya, 2008).

2.2 Flood Prone Areas in Ethiopia

In Ethiopia, overflowing typically taking place at the ultimate of the kiremt raining period (July and August) in supreme flood-prone areas (DPPA, 2018). In Gambella overflowing frequently happens during August and September. In the Somali region, heavy rains in the adjoining highland areas of Oromia typically cause flooding throughout the kiremt season. Unseasonal furthermore to overhead-standard rainfall from October to January could also cause flooding in parts alongside the wabeShabelle and Genale Rivers in the Somali region and Omo River in SNNPR. In the same way, heavy rain in the adjoining highlands of Amhara, Tigray, and Oromia frequently effects in the overflow of the Awash River and its tributaries in Afar. Flooding nearby Lake Tana (Fogera and Dambia plains) is brought by the backflow of Lake Tana as well as the overflow of its major tributaries at times of heavy rainfall. It is furthermore likely that heavy belg/ganna periodic rain (Between March and June) induce flooding in belg profiting areas.

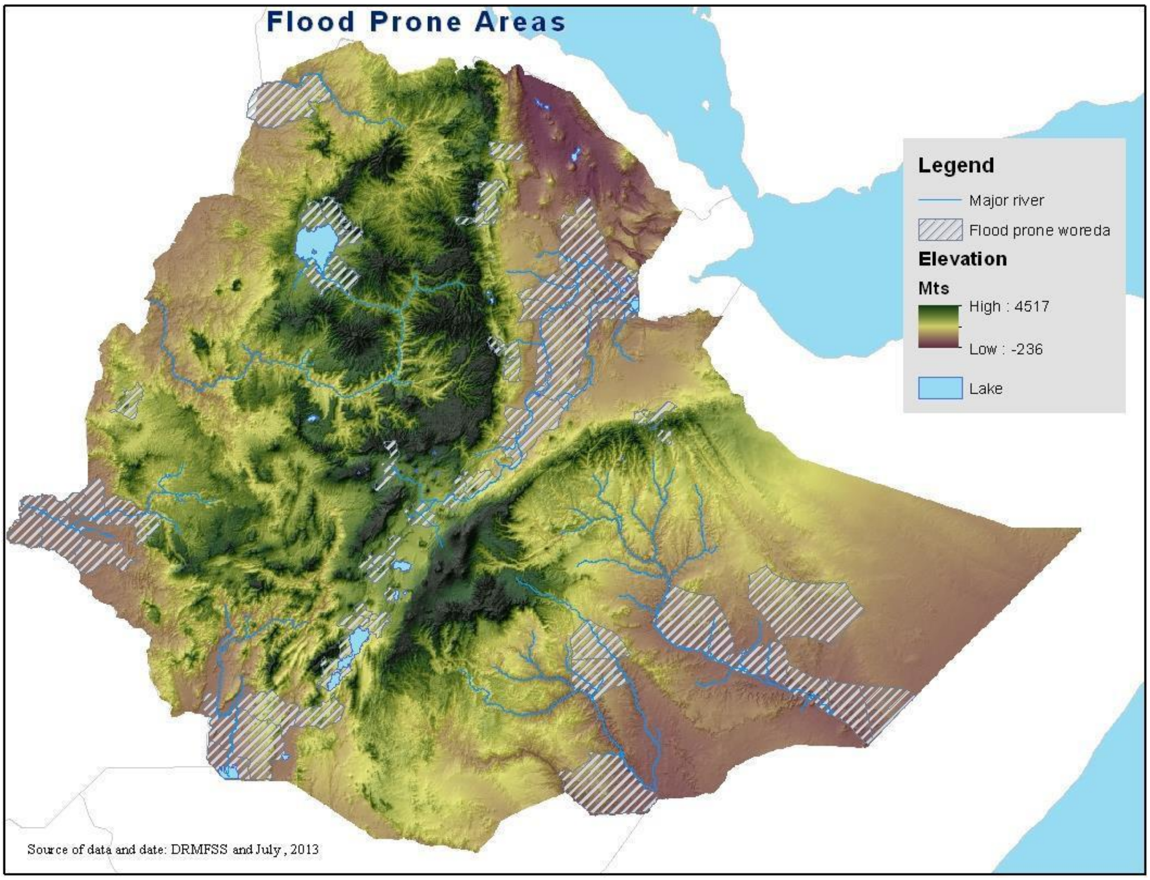


Figure 2.1: Flood-prone area map in Ethiopia

2.3 Flood Damage Assessment

Flood damage valuation is an identical essential area that is reflected in water engineering science. Flood destruction valuation has a widespread domain and depending on several factors can expect different results. At the macro managing level, the primary step in describing the water engineering plans is an economic investigation of plans. As a consequence, we can consider and evaluate the feasibility phase of flood damages, and this can be the basis for planning for the study area. Though in several engineering plans it is sufficed to flood area with particular return periods however by undertaking these types of training, the cost-profit ratio of the different project is studied well and this causes the application of the plans which flood mechanism will be its outcome (S.A. Mohammadi et al, 2014).

The numerical valuation of flood destruction is accomplished in different methods. One of these methods is a software demonstration of flood destruction analysis HEC-FDA. This model was established by the U.S. Army corps Engineers and is adequate for global resources. Depend on the hydraulic and hydrologic data of the study zone; we can calculate the estimated annual losses EAD in this way. A fact that would be well-known is that this model can approximate the economic quantity of flood damage and the flood damage valuation key is flood deepness (S.A. Mohammadi et al, 2014).

2.4 Flood Frequency Analysis

The first phase in flood risk management is the assessment of the flood danger for the region, which can be achieved on the basis of an analysis of the triggering factors causing the flood and/or a survey of the spatial scale of the historical events for the region, the flood frequency and the magnitude relationship assessment (Geo-hazards, 2009). The probabilistic approach method is commonly used to evaluate and quantify flood frequency and flow variance within a given region (Robson, 1999). The goal of Gumbel’s extreme value distribution is to create a relationship between the probabilities of the occurrence of a given event, its return time, and its magnitude (El-Naqa and Zeid, 1993). Robson (1999) provides different approaches to flood frequency statistical analysis for extreme events. The first method is focused on the calculation of peak flow and event flow, and the second methodology was focused on simulation techniques using parameter modeling in data in weak regions (Correia, 2009). The statistics of Pearson can be described as a significant tool for the analysis of the data fitness and various observations for the same combination of data explanatory variables of a given occurrence, its return time, and its magnitude (El-Naqa and Zeid, 1993). The best-suited probability function allocation can be analyzed using statistical replication for use in peak flow (Smyth, 2003).

2.5 The Selected Software

2.5.1 HEC – GeoHMS (Geographic Hydrologic Modelling Extension)

In Hydrologic Engineering Center’s (HEC) current improvement in Geographic Information System (GIS) tools for hydrologic as well as hydraulic modeling consequence from several years of attention in geospatial data usage. The initial work was initiated in the mid-1970s when HEC developed software depend on the ideas established in the Harvard University’s School of Landscape Architecture, Honey Hill project. That initial work concluded with the improvement of a Spatial Analysis Methodology (HEC-SAM) which contained a grid-cell data bank and analysis software intended for hydrologic and flood damage estimation. That initial work had the same ideas as those of today, but the limits in the computer hardware, GIS software, and data availability made well-known engineering applications challenging (USACE, 2000).

The recent improvement builds on those initial practices and takes the technology to numerous applied engineering products containing HEC-GeoHMS. HEC revived its previous efforts by revising recent GIS experiences in a link through Professor David Maidment from the University of Texas. HEC and Maidment(Dr) expressed Watershed data arrangements that would connect GIS as well as hydrologic models. Since that period, the description and content of the GIS and hydrologic data arrangements developed into a hydrologic GIS processor, pre-pro, taking advantages of the wealth of terrain and geographic data readily available over the internet and from government agencies, pre-pro delineates streams and watersheds and builds the hydrologic model arrangement on behalf of HEC–HMS. Pre pro was a successor to HEC-GeoHMS.

The improvement of pre-pro by the University of Texas was partly supported by HEC via the Crops' Civil Works R&D program. The struggle also received considerable provision from other national and international agencies. Pre pro improvement at the midpoint for Research in Water Resources at the University of Texas has been directed by Dr. Francisco Olivera. GeoHMS has been established by HEC and ESRI as an element of a cooperative research and Development Contract between those organizations. Dr. Maidment, Dr.olivera, and others at the center of Research in water resources have delivered Valuable assistance for the improvement of GeoHMS(USACE,2000). Other GIS products that have been released or are under development by HEC include HEC-GeoRAS, a GIS utility for use with the HEC-RAS river hydraulics program, and the HEC-GeoFDA flood damage analysis package.

For several years, HEC has developed several GIS modules for specific tasks, such as processing terrain for drainage path, generating grid-based rainfall, etc. Those modules required users knowledgeable of UNIX, ArcInfo, hydrology, and several miscellaneous sub-programs. HEC-GeoHMS combines the functionality of those ArcInfo programs into a package that is easy to use with a specialized interface. With this Arc View competence as well as a graphical user line, the user admissions customized menus, tools, and buttons as a replacement for the command-line interface in ArcInfo. With GeoHMS, users who are new to GIS have access to powerful GIS operations.

HEC-GeoHMS uses freely accessible digital geospatial information on the way to make hydrologic models further conveniently than using physical approaches. Furthermore, improvements in elementary watershed information determination aid the engineers in approximating hydrologic parameters. After gaining acceptable experience with using GIS-general parameters, users can take steps to streamline the technique of hydrologic parameter approximation.

HEC-GeoHMS ought to establish through the geospatial hydrology tool kit used for engineers and hydrologists through partial GIS understanding. The program permits users to envision spatial information, file watershed features, accomplish spatial investigation, as well as delineate sub-basins as well as streams, functioning through HEC-GeoHMS complete its interfaces, menus, tools, buttons, and context-sensitive online support, in a windows environment, permits the user to conveniently create hydrologic inputs that can be used directly with the Hydrologic Modeling System, HEC-HMS (USACE, 2013).

2.5.2 HEC – HMS Model (Hydrologic Modelling System)

The hydrologic model system (HEC – HMS) remains a result of a US Army corps of Engineers' Research and development program and is produced by a Hydrologic Engineers' (HEC). The program simulates precipitation–runoff and routing processes, both natural and controlled. A program is a successor to and replacement for the Flood Hydrograph package HEC-1 (USACE, 1998) and various specialized versions of HEC-1(USACE). The program advances upon the capabilities of HEC-1 in addition to delivers additional capabilities for distributed modeling in addition to continuous simulation (USACE, 2000).

HEC-HMS remains a numerical model (computer program) that contains a great set of approaches to simulate watershed, channel, and water-control structure behavior, thus estimating flow, stage, as well as timing. The HEC-HMS simulation methods are:-

- **Watershed precipitation, evaporation**. It defines the spatial in addition to a temporal scattering of rainfall on in addition to evaporation from a watershed.
- **Runoff volume**. It locates questions around the volume of precipitation that falls on the watershed: How much infiltrates on former surfaces? How much run off of the impervious surfaces? When does it run off?
- **Direct runoff**, containing overland flow in addition to interflow. These techniques describe what occurs as water that has not infiltrated or been stored on the watershed travels over or just underneath the water surface.
- **Baseflow**. It simulates the slow subsurface drainage of water from a hydrologic system into the watershed's channels.

- **Channel flow**. These so-called routing methods simulate one-dimensional open channel flow, thus predicting time series of downstream flow, stage, or velocity, given upstream hydrographs.

2.5.3 HEC RAS (River Analysis System)

River Analysis System (HEC – RAS) is software which agrees you accomplish one – dimensional steady as well as unsteady streamflow hydraulics approximation, sediment transport – mobile bed modeling, and water temperature analysis. The HEC – RAS software replaces the HEC-2 river hydraulics package, which remained a one – dimensional, steady flow water surface profiles program (USACE, 2010). The HEC-RAS software is a significant advancement over Hec-2 in terms of both hydraulic engineering and computer science. This software is a product of the corps' civil works system Wide Water Resources Research program (SWWRP).

The primary version of HEC–RAS (version 1.0) was released in July of 1995. Since that time there have been several major releases of this software package, including versions: 1.1, 1.2; 2.0; 2.1; 2.2; 3.0, 3.1; 4.0; and in January 2010, 4.1 and know 5.0.7.

HEC-RAS software was established by the Hydrologic Engineers' (HEC), which is a separation of the Institute designed for Water Resources, the Army of Corps Engineers. The software was intended by Mr. Gray W. Brunner, lead of the HEC–RAS improvement team (USACE, 2010). The user interface and graphics were encoding by Mr. Steven S.piper. The sediment transport computations module was encoded by Mr. Stanford Gibson. Mr. Tony Thomas (Author of HEC-and HEC-6T) improve the sediment transport routines used in HEC-RAS. The water quality computational modules were designed as well as established by Dr. Cindy Lowney and Mr. Mark R. Jensen. The interface for channel plan/adjustments was programmed by Dr. Robert L. Barkau (Author of UNET and HEC-UNET). A stable channel plan functions were automated by Mr. Chirs R. Goodell. The routines for modeling snow cover and wide-ranging river ice jams were established by Mr. Steven F. Daly of the Cold Regions Research and Engineering Laboratory (CRREL) (USACE, 2010).

Khattak et al, (2016) studied the application of the HEC-RAS model, in combination with Arc-GIS, to simulate water surface profiles and to establish flood plain maps or inundation areas under different return periods for the Kabul River in Pakistan. Maximum instantaneous discharge available at the Warsak Dam and Nowshera Bridge was used to estimate peak discharges for different return times using frequency analysis to estimate the water surface profiles and the magnitude of the flood area. Water surface data were collected from HEC-RAS via HEC-GeoRAS and then integrated into the floodplain map via GIS, using the water surface data and the DEM produced for the basin, the flooded areas under 10, 50, 100, 200, 500, and 1000 years are 252, 266.28, 270.09, 271.86, 275.26 and 279.02 km^2 respectively.

2.5.4 Flood Mapping and Damage Assessment in Ethiopia

Negese Roba, (2017) Studied Flood Hazard Mapping and Damage Analysis for Meki River Using, HEC-RAS, and HEC-FDA models, the study establishes flood hazard maps and damage analysis along the Meki River. The automated elevation model of the catchment using the HEC-GeoHMS hydrological model was used to produce flow hydrographs for 2, 5, 10, 25, 50, and 100 years at the outlet of the catchment area using rainfall design. Flood inundation and hazard maps along the Meki River have been established on the basis of flow hydrographs for 2, 5, 10, 25, 50, and 100 year return periods using the HEC-RAS model, simulating water surface profiles and defining flood plain or flood plain areas under 2, 5, 10, 25, 50 and 100 year return periods for the Meki River in Meki town to Lake Ziway. Water surface data were collected from HEC-RAS via HEC-Georas and then integrated into the floodplain map via GIS, using the water surface data and the DEM generated for the basin, the flooded areas under 2, 5, 10, 25, 50, and 100 years are returned at 11.52, 12.50, 12.95, 13.57, 14.02, 14.99 and 15.52 km^2 respectively. Finally, the cost of flood damage was measured using HEC-FDA, and mitigation measures were suggested to mitigate the damage caused by flooding in the study area. The total amount of the estimated annual damage was 707,193,871birr; after the study, it was suggested to increase the width of the river canal or construct of levee to mitigate the economic damage caused by flooding in the lower Miki river.

Zelalem Abera, (2011), Flood Mapping and Modeling on Fogera Flood Plain: A case study of Ribb River. The analysis explains the frequency and depth of floods in the area for the 2, 10, 50, and 100 Years flow conditions derived from historical data on the Ribb River. The hydrological model is calibrated using HEC-HMS for hourly time series data for return periods of 2, 10, 50, and 100 years. The value obtained from the hourly data of the HEC-HMS is contrasted with the different methods of frequency analysis. One dimensional hydraulic model HEC-RAS with HEC-Georas interface in conjunction with Arc-GIS was used for research. The Triangulate Irregular Network (TIN) was prepared from the form file created from the floodplain spot elevations via field survey data and the DEM of the Arc-GIS study area. Required data sets such as stream centerline, banks, flow paths, and cross-sections have therefore been prepared in HEC-Georas, creating an import file and imported into HEC-RAS. The boundary condition for downstream was specified in HEC-RAS. In the same way, flood discharges for various return times have also been entered and steady flow analyzes have been carried out for the effects. The HEC-HMS hydrological model result indicates a flow value of 91.8, 202.4, 273.1, and 308.4m3 / s for the 2, 10, 50, and 100 return cycles, respectively. The result was compared to the frequency analysis using the Ribb River event flow values. According to the food map, the 2, 10, 50, and 100 years flooded area is 12.63km2, 18.63km2, 21.31km2, and 22.5km2 respectively. The flood depth classification showed that most of the flood area had a depth of less than 1.5 m. On the other hand, 88 percent of agricultural land, 11.6 percent of agro-pastoral land, and 1.36 percent of the river are flooded.

Webeshet Hailu, (2019), Flood Damage Analysis Using HEC-FDA Software (In case of Upper Awash Sebata - Awas Woreda). The report outlines the technical approach to flood risk research, with the goal of a thorough study of the environmentally feasible flood control strategy and the management of flood damage. Frequency of the floods for various return times, by choosing the required probability distribution established on the fitness test. Statistical analysis, i.e. outlier, isolated, stationary, and filling missing data for the flow observed at the Awash Belo Gauge Station. Contour of 1 m interval (Digital Elevation Model) DEM12.5m prepared for the determination of depth damage feature. Flood inundation mapping in ArcMap and field survey conducted to estimate property losses. Triangulate Irregular Network (TIN) prepared from the contour of ArcMap with Georas extension to set the layout for both the canal and the shore. However, the cross-section has been entered from field info. Manning number and boundary conditions estimated in the field. Water surface elevation calculated using the HEC-RAS model. The data being observed are independent and have no outlier. Flood frequency measured by Gumbel (Extreme I) system 42.36, 49.01, 53.41, 58.97, 63.10, 67.20, 72.59 and 76.66 m^3 / s for 2, 5, 10, 25, 50, 100, 250 and 500 years respectively. These floods are used for calculating the water surface profile. Planned and equal, the annual amount of damage reduced for various overrun probabilities calculated. Total economic loss $69423.77 estimated annual damage without a project. By having a channel, the loss will reduce to $5572.80 per year and reduce the ton of sediment. Canal losses are very low per household. Inland flood control and dyke integrated into the Canal nullifies ($0) the predicted damage per year. Equivalent annual damage report indicates no scheme, canal, and incorporation of dyke and inland flood control canals were $69423.77, $5572.80, and $0 respectively over a project life of 50 years. By providing a canal we can reduce loss to 5572.80 $ s per annum and reduce a ton of sediment. Canal loss which very low per household. Inland flood protection and dyke integrated to Canal nullifies (0 $) expected damage per annum. Equivalent annual damage report shows without a project, Canal and Integration of Canal with dyke and Inland flood protection are 69423.77 $, 5572.80 $, and 0 $ respectively through project life 50 years. Planned annual damage and corresponding annual damage to the HEC-FDA model statics indicate that a flood management plan is needed.

Wondwosen Dejenne, (2011), Flood Modelling Using 2D Hydrodynamic Model in the Fogera Flood Plain, The research was conducted to perform a floodplain analysis and risk assessment of Fogera and surrounding areas. This research involves the application of the 2D Hydrodynamic Modeling Method with Geographic Information Systems (GIS) to establish a regional floodplain identification and representation model. The analysis explains the degree of the velocity, the inundation depth in the region for the various flow conditions derived from the historical flow data of the Gumera River. Flood frequency analysis is used to estimate peak flow for regular time series data and Gumbel and Log Pearson type III are used and Gumbel Distribution is used with (R^2 = 0.994) and peak flow of the River for return periods of 2, 5, 10, 25, 50 and 100 years. The boundary condition for upstream and downstream has been established. Similarly, flood discharges for 2, 5, 10, 25, 50, and 100 return times were also entered as inlet boundary and steady flow analyzes were carried out for the data. Gumbel Distribution results indicate a flow value of 233,281, 312, 352, 382, and 411 m^3/s for return periods of 2, 5, 10, 25, 50, and 100 years respectively. Detailed topographic maps obtained from various utility organizations and 2-dimensional computational hydrodynamic models were used for simulations. Model outcomes were tested for six different scenarios ranging from 2, 5, 10, 25, 50 and 100 years of return. In the end, a flood map was made.

2.5.5 HEC–GeoRAS

Geometric Data will import to HEC-RAS from HEC-GeoRAS. HEC-GeoRAS is ArcGIS extension tools specially designed to progression spatial data for use through the HEC-RAS. The user creates stream centerline, flow path centerline, main channel banks, and cross-sectional cut lines referred to as the RAS team. RAS team also imports land use, levee Alignment, unsuccessful flow areas, and storage areas (USACE, 2010).

2.5.6 HEC–FDA (Flood Damage Analysis)

The design and development of the Hydrologic Engineering Center Flood Damage Reduction Analysis (HE-FDA) computer program has been a team effort over several years. Several past and present members of the Water Resource Systems Division played significant roles. Harry Dotson primarily designed and tested the hydrologic engineering portions of the program (USACE, 2008). Penni Baker was responsible for much the technical coordination of debugging the code, testing the program, instrumental in the overall design, and oversaw the creation of this user’s manual. David Goldman. Hydrology & Hydraulics Technology Division, developed the complex algorithms and code for the Monte Carlo Simulation, the primary computations required for risk-based analysis.

Numerous people outside of HEC contributed to the program improvement. David Moser, from the crops’ Institute for Water Resources, contributed considerably to the economics portion of HEC-FDA (USACE, 2008). Wayne Haythorn, a private consultant, intended and coded the database features of HEC FDA as well as provided general consultations on the overall program design. Richard Rachiele and John DeGeorge of Resources Management Associates established the graphical user interface as well as supported with debugging as well as the overall design. Michael Deering, chief, Water Resources Systems Division, provided general direction in the program director in the program improvement (past Division chiefs, have been Michael Burnham & Christopher Dunn), HEC software is under the guidance of Christopher N. Dunn, Director, Hydrologic Engineering Center (USACE, 2008).

HEC-FDA is Hydrologic Engineers’ Center Flood Damage Analysis; the program provides state of the art analysis for expressing as well as estimating flood destruction reduction strategies using peril-based analysis approaches. It remains one of HEC’s “Next Generation” (NexGen) in hydrologic engineering as well as water resources development software. The NexGen project encompasses rainfall-runoff analysis (HEC-HM), river hydraulics (HEC-RAS), reservoir system analysis (HEC – ResSim), flood damage analysis (HEC – FDA), and real-time river forecasting for reservoir operations. The NexGen software has a windows style user interface and operates on Windows XP and Windows NT. The HEC – FDA program replaces HEC's previous pc versions Flood Destruction Analysis package comprising packages FDA2PO, SIDED, SID as well as Expected Annual damage EAD (April 1994). The new HEC – FDA program comprises improved versions of altogether their features in addition to peril-based analysis techniques for expressing as well as estimating flood destruction reduction measures (USACE, 2008).

S.A. Mohammadi, M, Nazariha, N, Mehrdadi, (2013), Flood Damage Estimate (Quantity), Using HEC-FDA Model, case study the Neka river. In the model, the assessment of flood damage in the metropolitan area of the Neka River, existing structures in the direction of flow is considered. The target area was divided into six intervals, and for each interval was consider residential, commercial, manufacturing, public, parkland, and agricultural use. The hydraulic and hydrological flow data shall be entered for the return periods of 2, 5, 10, 20, 25, 50, 100, 200 years. Thus, the HEC-RAS model output is stored in the FDA format and the HEC-FDA model is used as input. In other words, flood depth values are considered for different sections. This shall be done with all the considered intervals. The thirty years of historical data for various intervals were used. Finally, a quantitative valuation of the damage to the Neka river in the urban area of Neka is made on the basis of the given interval. Taking into account the data set described above by running the flood risk analysis model with HEC-FDA, the expected annual damage (EAD) over the entire study period is estimated at 3,076,105,000 rails, which is the expected annual damage over six periods.

2.6 Previous Studies on Illu Woreda

Still, Illu Woreda is described as high flooded area, and there are few studies. This days flood problem and few studies in the area shows the importance of the study in depth. Research Analysis conducted by Dawit Sisay Dec (2015) with the title of, **Flood Risk Analysis in Illu Flood Plain, Upper Awash River Basin Ethiopia**, The flood risk analysis for Illu Woreda is focused on the flood frequency analysis as well as the Awash River flow forecast. The purpose of the study was to quantify and estimate the risk of flooding to crop production in the study region. The basic assumptions in the statistical flood frequency analysis are the independence and stationary existence of the data series besides that the data derived from the same distribution. Homogeneity and stationarity tests at different levels of significance were performed using Wald-Wolfowitz and Mann-Whitney tests for homogeneity and stationarity tests at different levels of significance. Using the system of moments of parameter estimation methodology, the time series of flow data was calibrated to the extreme value of form one (EV I). The flood threat mapping was done by HEC-GeoRAS and HEC-RAS tools. Finally, by comparing the amount of crop yield previously produced from a hectare of land and the predicted crop yield from the flooded area, flood damage could be calculated. This implies that the improved Awash Bello streamflow gauge station calculates flow data correctly for the entire duration, i.e. it properly records flow data without any disruptions from 1960 to 2010. The flow data for the Awash Bello station were found to be independent, homogeneous, stationary, and not an outlier at a 5 % significance stage. Quantile approximations of the 2, 5, 50, 100and 500 year return duration for the site was also found to be 39.30, 50.38, 73.86, 80.69, and 96.46 m^3/s, respectively. These floods have flooded croplands of 1,959.50, 2,107.38, 2,299.16, 2,318.84, 2,354.06 hectares, respectively. These corresponded to losses of 44,088.66, 47,415.96, 51,731.03, 52,173.84, 52,966.25 crop quintals, respectively. This study found that the uppermost portion of the cultivated region is more inundated than the middle and lower portions. The areas affected by the floods are situated nearer to the Awash River. The affected areas must therefore be free from any agricultural activity, infrastructure growth, investment, and people's residence to avoid the risk of flooding in the area especially close to the Awash River.

But Illu woreda is flooded by two rivers, the Awash River and for my Study Teji River.

Chapter 3 MATERIAL AND METHODOLOGY

3.1 Description of Study Area

3.2 Location of Study area

Illu is among the Ethiopia Woredas in Oromia Region, and part of South Westshoa Zone /Debub Mirab Shewa Zone/. Illu is bounded on the North by Sebeta Hawas Woreda, on the East by Dawo as well as Becho Woreda, on the West by Ejeree Woreda as well as on South by Tolee Woreda. The woreda has 15 Rural Keble and 2 (Teji and Asgori) Town. A town of the woreda which is called Teji is found 55km South West of the Capital Addis Ababa. The Woreda total area is **37,294ha** and the Geographical location is found between Latitude $8^0$42’0” N – $8^0$52’30” N and Longitude $38^0$13’30” E – $38^0$24’0” E.

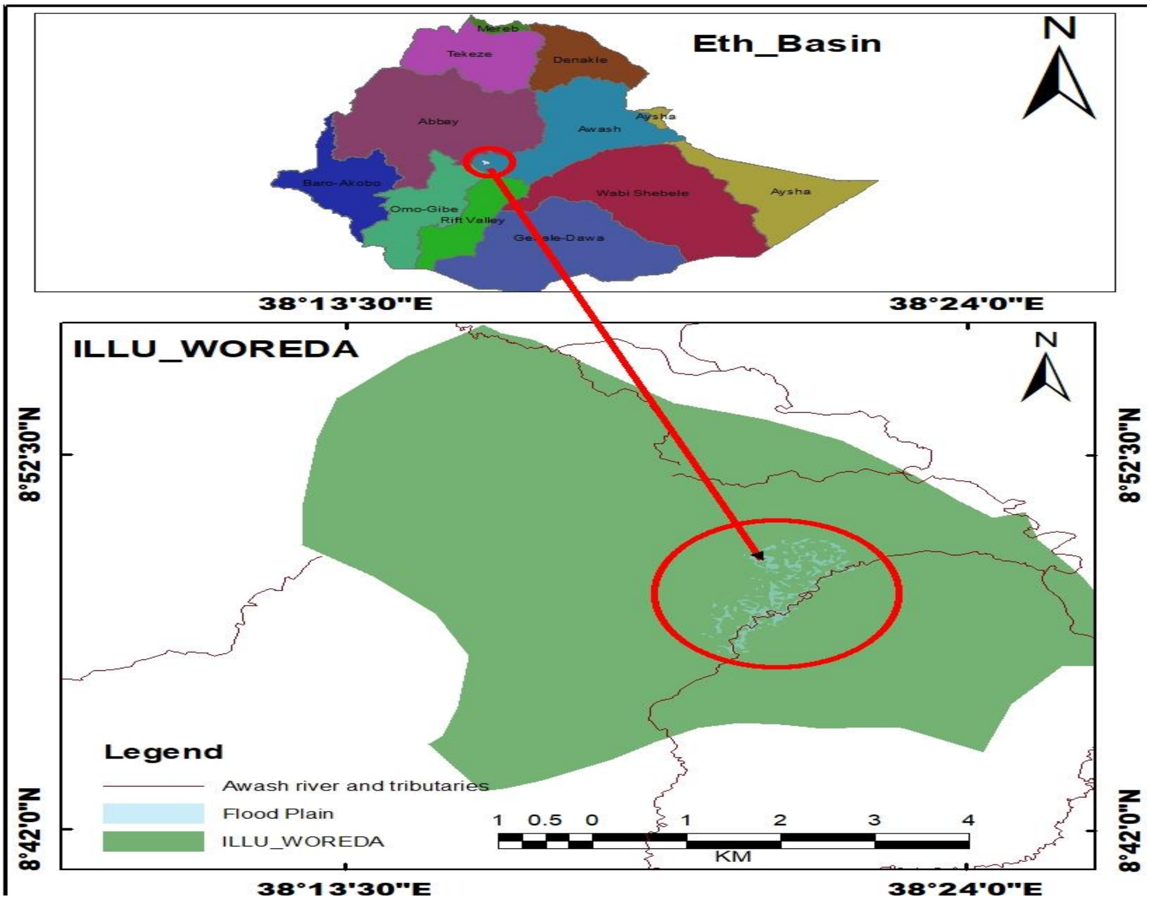


Figure 3.1: Study area map

3.2.1 Topography, Climate type, and Rainfall Distribution in the Woreda

The rainfall distribution in Illu Woreda is differed by place and time but the average annual rainfall is estimated to be from 700 – 1400 mm, the rainy season in the woreda is from

June to September, and there is high rainfall in the rainy season. The altitude ranges between 2060 – 2100m above sea level and the Temperature Varies from 15 – 25^{0}c. The climate Zone in the woreda is 100% **Woina Dega /Subtropical zone/.**

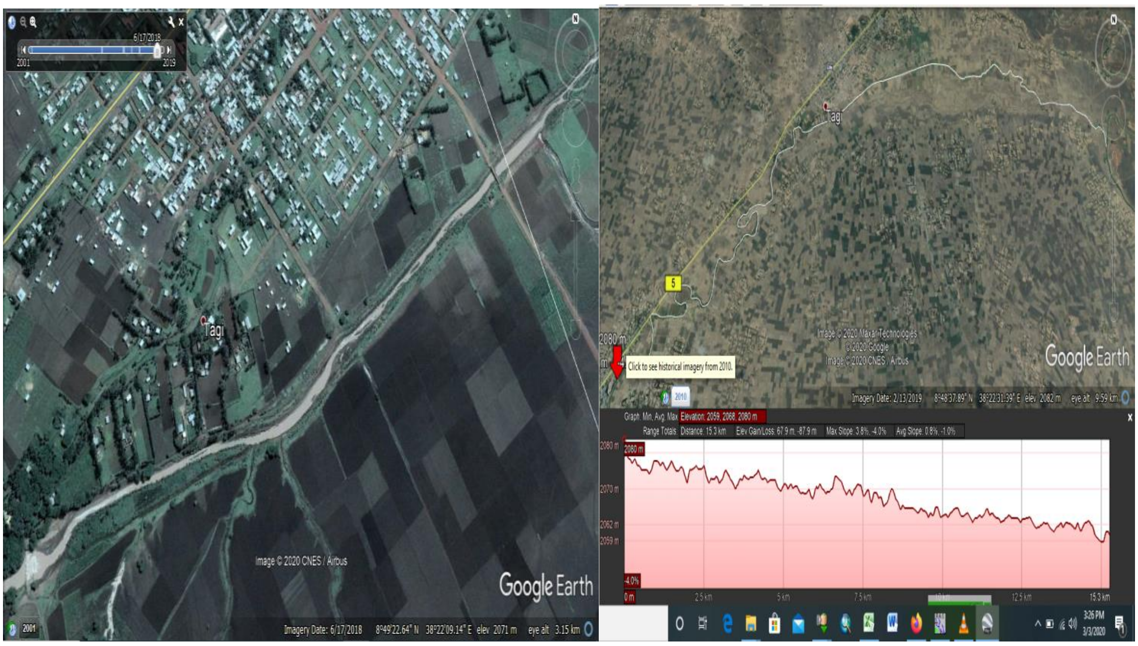


Figure 3.2: Study area map and river profile from google earth

3.2.2 Land and Terrain Type in the Woreda

The woreda land feature is only flat terrain Geographic and the Weather condition varies, according to the woreda agricultural development office, the total area is **37,294ha**.

3.2.3 Land Use in the Woreda

Land use significantly affects the parameter of a runoff event. Land use and human activity within most watersheds vary with time. E.g. a rural watershed can be developed into a commercial area in a short period. Factors subject to change with general variations in land use include the following:

- Permeable and impermeable areas;
- Vegetation
- Minor topographic features; and
- Drainage systems.

All of the factors usually affect the rate and volume of runoff that may be expected from a watershed. Therefore, it is essential to consider current land use as well as a future potential land-use change in the development of the parameters of any runoff hydrograph.

Accordingly from a total area of 37,294ha in the woreda

- Agricultural Land ……………………………………………....24081ha /64.57%/
- Forest and Shrubs Land ....400ha /1.07%/
- Grass Land ……………………………………..........................1000ha /2.68%/
- Land cover by construction and community recreation….……..…3134ha/8.4%/
- Land Covered by Bureau and uncultivated ………………………3659ha/9.81%/

3.2.4 Land Cover and Cultivation in the woreda

Major cultivated Crop types in the Woreda

- Teff
- Chickpea
- Wheat
- Grass pea
- Lentil

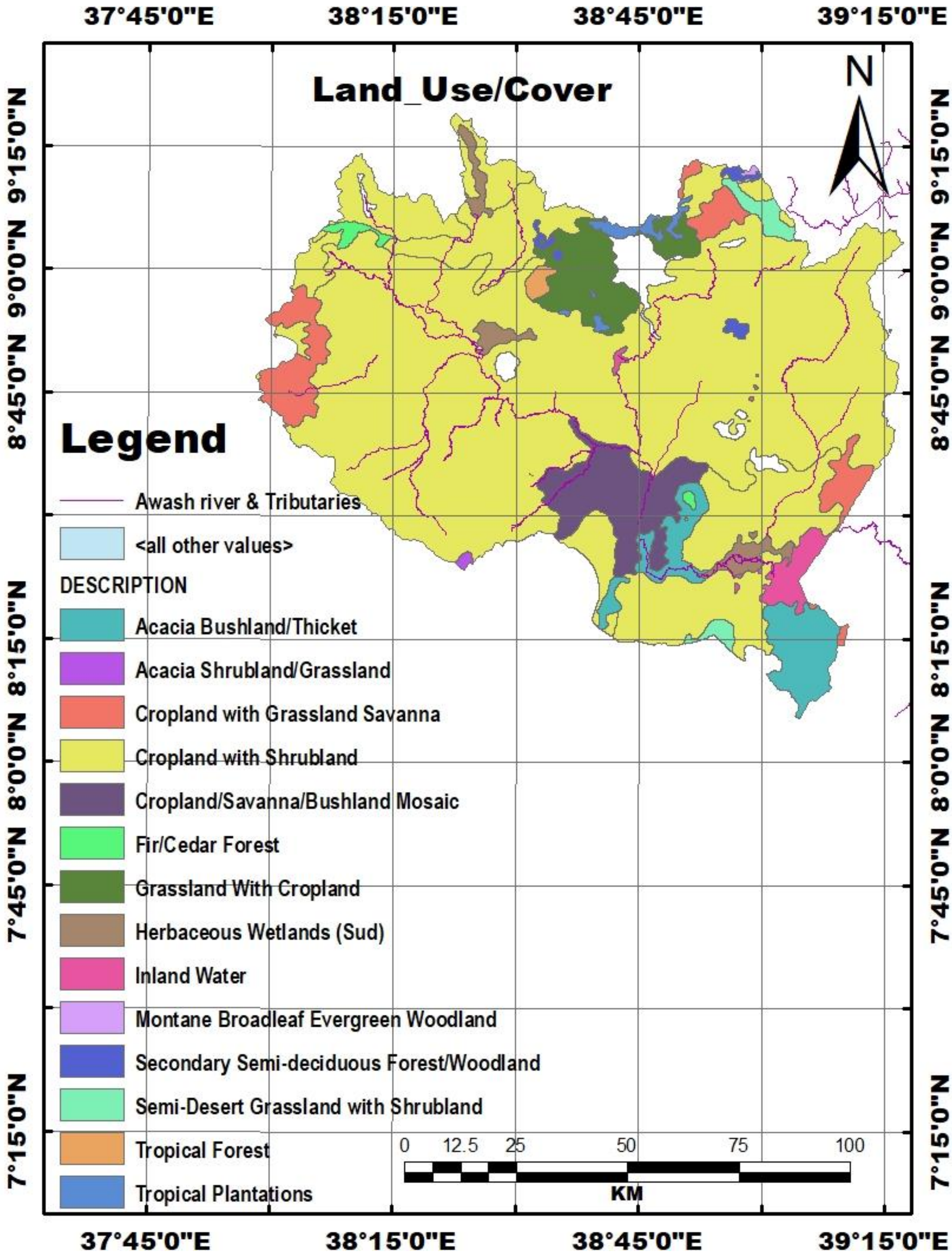


Figure 3.3: Land use/land cover in the study area river catchment

3.2.5 Soil Type in the Woreda

Soil type can have considerable influence on the discharge rates of a runoff hydrograph; the soil type directly affects the permeability of the soil and thus the rate of rainfall infiltration. The Natural Resources Conservation (NRCS) is a good repository for information about soils.

In the study area, the major soil groups are groups B, C, and D.

- **Group B**: loam, or silt loam. Soils having a moderately low runoff potential due to moderate infiltration rates. E.g. Orthic Solonchaks, Vertic Cambisols, Calcic Xerosols, Chromic Cambisols, Eutric Fluvisols, Eurtic nitisols, Orthic Luvosols
- **Group C**: Sandy clay loam. Soils having a moderately high runoff potential due to slow infiltration rates. E.g. Luvic Phaeozems
- **Group D**: silty clay, sandy clay silty loam, clay loam, or clay. Soils having a high runoff potential due to very slow infiltration rates. E.g. Leptosols, Chromic Vertisols, Pellic Vertisols.

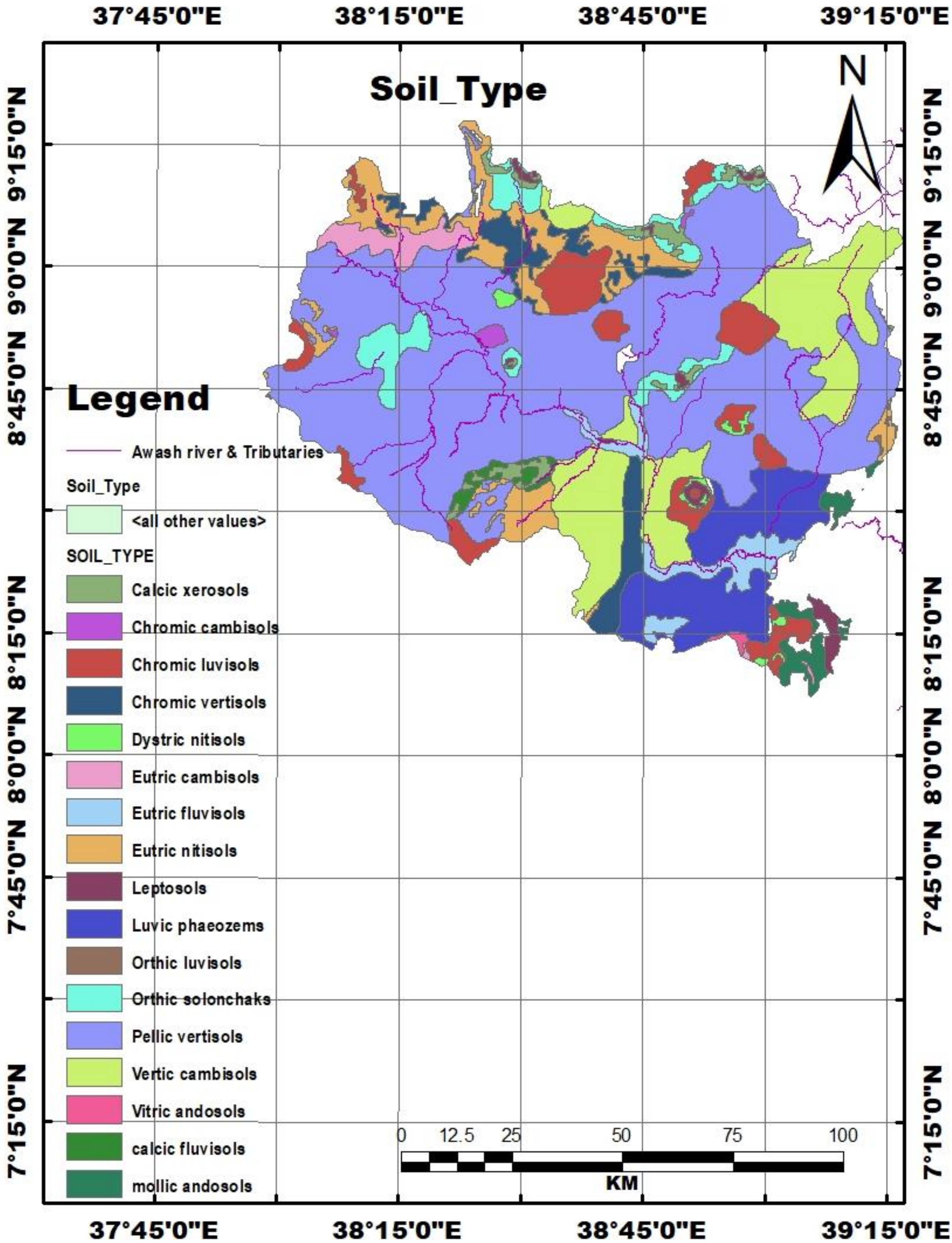


Figure 3.4: Soil type in the study area river catchment

3.2.6 Demographic Characteristics of the Study Area

Illu woreda has 15 rural Keble and 2 towns the towns are Asgori and Teji. On the location map, the woreda of the study area is seen. The population of the woreda was also similar to the geographical coverage. The urban and rural populations were listed below.

Table 3.1: Total number of people in Woreda

No.	Rural population			Urban Population		
	M	F	Total	M	F	Total
1	28,282	28,304	56,586	8,357	12,330	20,687
	Total Population in the woreda					
	M		F		Total	
2	36,639		40,634		**77,273**	

Source: Illu Woreda Flood Risk Management and Preparedness Office 2011 E.C Report.

3.2.7 Socio-Economic Characteristics in the Study Area

According to the 2011E.C Illu Woreda Agricultural and Rural Development Office Report, from the total population in the woreda above 84.5% live in a rural area. Accordingly more than half of the socio-Economic in the woreda depend on Mixed Farming, Crop Cultivation, and Animal production. According to this the benefits that are gain from farming become the sources of food, income, and raw material for industries.

3.2.8 Element at Risk in Illu Woreda

The issue of any flood vulnerability analysis is the collection of components that are at risk of being damaged by flood events. Element at-risk indicators specify the quantity of economic, social, or ecological systems which are at risk of being affected regarding all kinds of perils in a particular zone, e.g. household, persons, firms, economic production, private as well as public infrastructures, public buildings, cultural assets, ecological species and landscapes located in a risky area.

In Illu Woreda several Population and Agricultural land are under flood risk tabulated in the table below.

Table 3.2: Population and agricultural land under flood risk in Illu Woreda.

Woreda	Keble	River which Cause Flood	The Number of Population/household/ that are under Flood Risk in Illu Woreda						Total	Agricultural land /ha/
			Household			House Hold Family				
			M	F	Sum	M	F	Sum		
Illu	Asgori	Teji	2739	2213	4952	13695	11065	24760	29712	-
	Teji		2310	2120	4430	11550	10600	22150	26580	-
Total			5049	4333	9382	25245	21665	46910	56292	
Illu	Jigduu Midaa	Teji & Awash	184	40	224	770	200	970	1194	275
	Tulluu Manguraa		96	22	118	480	110	590	708	250
	Duwa Bisee	Awash	83	24	107	440	124	564	671	151
	Amdoo Quncoo		237	85	322	1185	425	1610	1932	254
	Bilii	Teji	112	68	180	560	340	900	1080	102
	Alangoo Tulluu	Teji & Awash	118	36	154	590	180	770	924	96
	Wasarbi Basii	Teji	87	42	129	435	210	645	774	126
	Buti Talgoo		520	193	713	2600	965	3565	4278	348
	Muloo Sattay	Awash	451	73	524	2255	365	2620	3144	603
	Wareerso Qalinaa		513	92	605	2565	460	3025	3630	789
Total			2401	675	3076	11880	3379	15259	18335	2994

Source: Illu Woreda Flood Risk Management and Preparedness Office 2011 E.C Report.

3.3 Materials Used

The materials used for the study are:- Hydrological data that is streamflow data which is was gain from MOWIE and used for calibration and validation of the model and also for the estimation frequency analysis, Meteorological data specifically rainfall data that were gain from National Meteorological Agency and used for HEC-HMS rainfall-runoff modeling, Physical data namely land use/ land cover gain from MOWIE used for HEC-HMS configuration and also to know the characteristics of the study area, River networks that are river shape file gain from MOWIE used for river simulation and configuration of the model, Crop data which are average yield/ha and percentage of crop cultivated in the woreda gain from woreda agricultural rural development office used to estimate economic damage in HEC-HMS model, Scio-economic data that is flood damage depth gain from woreda flood risk management and preparedness office with field observation for damage cost estimation. Optical level and tape to measure river cross-section and tape is used also to measure flood depth and also GPS to determine the average elevation of the landscape above mean sea level.

3.4 Software Used

The software used for this study are:- Arc-GIS 10.4 to prepare all secondary data needed in the study, HEC-GeoHMS it is Arc-GIS extension used for basin simulation, HEC-GeoRAS is also Arc-GIS extension used to prepare Ras-layer and flood plain generation, HEC-HMS used for rainfall-runoff modeling, HEC-RAS used for river analysis computation, HEC-FDA used for flood damage analysis, Easy-curve fit for selection of goodness fit /best/ fit for frequency analysis, Google earth to site the exact study area and also Microsoft-Excel to prepare data and to analyze HEC-HMS output.

All HEC-Groups are downloaded free from the HEC website (www.hec.Usace.army.mill). Arc-GIS buy the license from the market and Easy-curve fit free download from (Easy-curvefit.en.softonic.com) and Computer embedded in Microsoft office 2013.

3.5 Methodology Procedures

3.5.1 Watershed Delineation

Watershed delineation is the creation of a boundary that represents a contributing region for a particular control point or outlet. Used to establish borders/boundaries / of the study area and/or to divide the study area into sub-areas / sub-basins/. Delineated watersheds are required for HEC-HMS modeling and sub-watershed characterization reports. For this analysis, the delineation approach used was DEM based / automatic delineation / that is, the boundary is generated automatically by the device or Arc-GIS. Arc-GIS was used to define the boundary of the study river, river networking, catchment configuration, and location of the gauge and meteorological station.

3.5.2 Data Collection

Daily Meteorological data /Rainfall data/ from (1996–2012) for five rain gauging stations namely Teji, Tulubolo, Dilela, Bantu liben, and Bu’i located within and around Becho Sub-catchment, was collected from the National Meteorological Agency (NMA). For the successful completion of this objective, everyday streamflow data of Teji near Asgori river gauging station was collected from the Ethiopian Ministry of Water, Irrigation and Energy (MOWIE) with additional flow data from two river gauging stations that were a nearby outlet. Spatial data like Digital Elevation Model (DEM), Land use land cover, and soil data were collected from different sources. For instance, high-resolution DEM (i.e. 12.5 m X

12.5 m) was downloaded from the ALASKA Satellite Facility website (https://vertex.dac.asf.alska.edu) and DEM (30m X 30m) was downloaded from the United States Geological Survey (USGS) http://earthexplorer.usgs.gov/ and additionally, DEM (30m X 30m) was collected from (MOWIE) and analyzed in Arc-GIS for the extraction of watershed hydrological elements and physical parameters. This digital model shows elevation ranges from low elevation to high elevation, (e.g. 1849–3381 m above mean sea level). Land use land covers as well as soil data were collected from the Ethiopian Ministry of Water, Irrigation, and Energy (MOWIE).

The socio-economic data such as flood damage data is collected from the woreda flood risk management and Preparedness office, field observation, and interview/ Questionaries'/ also done. And crop data such as Average yield per hectare and percent of the crop to be cultivated were collected from the woreda Agricultural and rural development office tabulated in appendix A. And also the river cross-section is surveyed.

3.5.3 Filling of Missing Data

Before the utilization of Hydro–Metrological data analysis, it is advisable to undertake data preparation and Assessment of missing data values. These days many methods are available for missing data value estimation. From identified methods, Multiple Regression methods were used to estimate missing rainfall data filling. Whereas the linear regression method was used for estimating streamflow data fill. Data consistency was computed using a double mass curve and data outliers are tested using Log–Pearson type III test method.

3.5.4 Estimating of Missing Flow Data

Streamflow data is used to calculate the peak flow of a year through the river, so before using we should check the data. The missing data is filled using Linear Regression Method.

3.5.5 Regression Method

For many rivers, downstream or upstream data are missing. In this case, the flow data from the nearby rivers can be used to estimate the missing flows. The regression analysis is the method frequently used to solve this problem. The dependent variables are the flows of the nearby stations having drainage basins with similar hydrological characteristics.

3.5.6 Linear Regression Analysis

If X, as well as Y, is two related variables, then linear regression analysis helps us to calculate Y value for a known X value or vice versa, expressed through

$$Y = \beta x + \alpha \qquad (3.5.1)$$

Where β and α are the slope and y-intercept respectively

In my case, Awash at Belo gauging station is used as a dependent variable to estimate the miss of the Teji river near Asgori gauging station.

3.5.7 Estimating Missing Rainfall Data

Often, due to the absence of some observer or instrumental malfunction, the rainfall sum for a certain day(s) at a certain gauging station may be missing. In such situations, the missing amount of rainfall would need to be approximated by approximating the value from nearby gauge station information (Santos Kumar Garg, Aug 2005).

Multiple regressions were used in this study. This helps to estimate the Y values for given values of X1, X2, X3,…………Xk worth.

Established values Xk. Expressed hereunder

$Y = \beta 1X1 + \beta 2X2 + \beta 3X3$ ……………. $\beta kXk + \alpha$ ………………………………3.5.2

Where: β1, β2, β3, and β k are parameters to determine and α is y-intercept.

Meteorological Rainfall stations used for the study are:-

3.5.8 Data Quality Checking

3.5.9 Outlier Test

Data points that depart significantly from the trend of the remaining data are called outliers (A.R.Rao and K.H.Hamed, 2000). Hydrologic data are often assumed to have come from a lognormal or Log - Pearson III scattering. For this study Log–Pearson III is used.

$YH = YM + KNSy$ ………..……………………………………….....……….3.5.3

$YL = YM - KNSY$ ……………………………………………….................3.5.4

Where: YH and YL- are the log of higher and lower outlier limits respectively.

YM- is the mean of the log of the sample flows,

SY- is the standard deviation of the logs of the sample flows, and

KN- is the critical deviate taken from the table

3.5.10 Consistency Test

Sometimes a significant change may occur in and around a particular gauging station. Such change occurring in a particular year will start affecting the gauging data, being reported from that particular station. After several years, it may be felt that the data of that station is not giving consistent rainfall values. To detect any such inconsistency, and to correct and adjust the reported rainfall values, a technique, called the double mass curve method, is generally adopted (Santos Kumar Garg, Aug 2005).

3.5.11 Statistical Tests of Hydrological Data

The statistical test is a technique leading to a judgment about a specific hypothesis. The basic assumptions in statistical flood frequency analysis are the independence and stationarity of the data series along with that the data arise from the same distribution homogeneity and outlier, it is better to check the flow data at different significance levels to reach an accurate estimate.

3.5.12 Test of Independence and Stationarity

The basic assumption in the statistical analysis of flood frequency is independent besides stationarity of that data series. Forgiven size N, the Wald-Wolfowitz method used to test for independence of the data set and test for the existence of a trend in it. Forgiven data set X_1, X_2, X_3 … X_N then determinant factor R estimated below

R = $\sum_{i=1}^{N-1} XiX1 + 1 + X1XN$ ……………………………………….……3.5.5

When the elements of the sample are independent, R follows a normal distribution with mean and variance given below equation.

R= $\frac{S1^2 - S2}{N-1}$……………………………….........................…………3.5.5.1

Var(R) = $\frac{S1^2 - S2}{N-1}$ - $\overline{R^2}$ + $\frac{S1^4 - 4s1s2 + 4s1s3 + S2^2 - 2s4}{(N-1)(N-2)}$……………………3.5.5.2

Where: Sr is n^{th} moment about the origin.

$R^{-}$is the mean determinant R

Var (R) is the variance of determinant R.

The statics t = $\frac{R-\bar{R}}{Var(R)^{\frac{1}{2}}}$ is approximately normally distributed with mean zero and variance unity and is used to test the hypothesis of independence at significant level α, by comparing the statics t with the standard normal variate $t\alpha/_2$corresponding to the probability of exceedance.$\alpha/_2$

3.5.13 Areal Rainfall Determination

Several methods are commonly used for estimating average rainfall over a watershed. The choice of the method requires judgment in consideration of the quality and nature of the data, and the importance, use, and required precision of the result ((Yilema Seleshi (Dr.), April 2005).

3.5.14 Changing Point Rainfall to Areal Rainfall

When the area of a basin exceeds about 25 Km^2, rainfall observations at a single station even if it is at the center of the catchment, will usually be inadequate for the design of drainage works. Rainfall records within the catchment and its immediate surroundings thus must be analyzed to take proper account of the spatial and temporal variation of rainfall over the basin (Yilema Seleshi (Dr.), April 2005). Thiessen polygon areal rainfall determination method was selected due to its sound theoretical basis and availability of computational tools. The assumption in the method is that at any point in the watershed, the rainfall is the same as that at the nearest gage so depth recorded at a given gage is applied out to a distance halfway to the next station in any direction. The relative weights of each gage are determined from the corresponding application areas within a Thiessen polygon network, the boundaries of the polygons being created by the perpendicular bisectors of the line connecting adjacent gages.

$$\bar{P}= \sum_{i=1}^{n} \frac{PiAi}{AT} \quad \text{……………………………………………………………………}3.5.6$$

Where $\bar{P}$ is the average precipitation over the catchment

$P_1, P_2 \ldots\ldots P_n$ are the rainfall Magnitude recorded by the stations of 1, 2….n

$A_1, A_2 \ldots\ldots A_n$ Thiessen polygons areas

N is the number of stations

3.5.15 Peak Flow Estimation

For this study peak flow is estimated by two methods that are HEC-HMS and flood frequency analysis. After calibration and validation using frequency storm peak flow was estimated by HEC-HMS. And also we can estimate using flood frequency analysis using the distribution method.

3.5.16 Flood Frequency Analysis

Strong steps also influence hydrological processes (Chow, 1951), Such as heavy hurricanes, droughts, and floods. The degree of an extreme occasion is inversely proportionate to its incidence frequency, with extremely serious occurrences occurring less often than more mild occurrences. The goal of the hydrological data frequency study is to equate the degree of extreme events with their frequency Rate of occurrence by using distributions of chance. The hydrological data analyzed are believed to be independent and distributed identically, and the hydrological mechanism that generates them (e.g. a mechanism of storm rainfall) is called stochastic, space-independent, and time-independent. This is also accomplished in practice by choosing the annual limit of the variable to be evaluated (e.g., the annual maximum discharge, which is the largest instance).with the expectation that successive observations of this variable from year to year will be independent. The results of flood flow frequency analysis can be used for many engineering purposes: for the design of bridges, culverts, dams, and flood control structures; to determine the economic value of flood control projects; and to delineate flood plains and determine the effect of encroachments on the flood plain.

The frequency of flood that can be predicted to occur is the equivalent likelihood or chance of the flood being equaled or surpassed in a known year. If a flood has a 20 percent accidental of being equal or surpassed annually, the flood would be equal to or surpassed on an average once every five years for a long period. A five-year flood is not one which is necessarily equal to or exceeded every five years. There is a 20 percent probability that every year the flood would be equivalent or exceeded; thus, in many consecutive years, the 5-year flood could likely occur. The same holds for flooding and other return times (ERA, 2013). The 2, 5, 10, 25, 50, 100-year flood frequency is also used to define the likelihood of flood occurrence. For example, a 100-year flood is sometimes referred to as a 1% flood. Some of the frequency distribution functions widely used for the estimation of extreme flood values are:

- **Gumbel Method: -** The general characteristics of the Gumbel extreme–value distribution is; the mean flow occurs at the return time of T=2.33 years and it has a positive skew (i.e. it is biased towards the large flows or extreme values).

$X_T = \bar{X} + K_{Tr}S_{n-1}$ …………………………………………………………… 3.5.7

Where: X_T is Maximum flood peak discharge

$\bar{X}$ The Average values of discharge.

S_{n-1} Standard deviation of sample size

$K_{Tr} = -\frac{\sqrt{6}}{\pi}\{0.5772 + \ln[\ln(\frac{Tr}{Tr-1})]\}$ wherever: - Tr is return Period

For each damaged area, the stage-frequency curve function at the corresponding index point was developed and incorporated into the HEC-FDA as input based on flood events with AEPs of 10, 4, 2, 1, 0.5, and 0.2 percent (10-, 25-, 50-, 100-, 250-, and 500-year return period) (USACE, 2008).

- **Log-Pearson III Distribution: -** If the vector log (x) assumed distribution of Pearson III, then the distribution of variable x is the distribution of Log-Pearson. This distribution is widely used by the USA for the US government-sponsored project. If x is a variation of random hydrologic series, the Z variation series is defined below.

$Y = \mathrm{Log}(x)$ …………………………………………………………………3.5.8

$K_{Tr} = Z + (Z^2-1)K + \frac{1}{3}(Z^3-6Z)k^2-(Z^2-1)K^3 + ZK^4 + \frac{1}{3}K^5$………………………..3.5.8.1

$K = \frac{Cs}{6}$ ……………………………………………………………………………3.5.8.2

$Z = W - \frac{2.51557+0.802853W+0.01032W^2}{1+1.432788W+0.189269W^2+0.001308W^3}$ ……………………………………..3.5.8.3

$W = [\ln(\frac{1}{p^2})]^{1/2}$………………………………………………………………3.5.8.4

$Z = \overline{Y} + \sigma_{sy}K_{Tr}$ …………………………………………………………………...3.5.8.5

X_T = antiLog(Z)……………………………………………………………3.5.8.6

Where; X_T Maximum Flood Discharge

P is $\frac{1}{T}$ (reciprocal of return period)

Sc is Skewness

K_{Tr} is the frequency factor

Z and w: - are constant; they are a function of the return period

- **Lognormal Distribution: -** If the accidental variable Y = log X is normally scattered, then X is assumed to be log-normally scattered.

3.5.17 Selection of Parent Distribution

The choice of distributions to be used in the study of flood frequency determines the precision of the expected peak flow. The goodness of fit test, Kolmogorov-Smirnov test, and L-moment ratio diagram is the most common parent selection methods (A. R. Rao and K. H.Hamed, 2000).

3.5.18 The goodness of Fit Test

Fitness test goodness is a very effective method for choosing the best-suited distribution. Among the most common fit testing goodnesses are Chi-Square, Anderson Darling, and Kolmogorov-Smirnov Test. All three kinds of goodness fit test determined by the easy fit program and ready for a selection of the parent distribution. The goodness match parent selection test method involves comparing the theoretical and actual events (A. R. Rao and K. H.Hamed, 2000). In this study, chi-square is chosen and the values are shown below.

$X^2_v = \sum_{j=1}^{k} \frac{Oj-Ej}{Ej}$ ………………………………………………………3.5.9

Where: O_j is observed events in the class interval j,

E_j is the number of events that are expected from the theoretical distribution.

X^2 = distribution with v degrees of freedom

3.5.19 Water Surface Profile and Flood Plain Generation

Using HEC-RAS and HEC-GeoRAS water surface and flood plain should be done.

3.5.20 Flood Damage Analysis

Importing water surface profile from HEC-RAS and using economic data HEC-FDA can estimate flood damage.

3.6 Data Processing

3.6.1 Flow Data

Teji River Daily Discharge data is collected from the Ministry of Water Irrigation and Energy. The daily discharge data has full data composition for the considered stations to represent the study area. The discharge gauge is located near Asgori where the downstream end is considered a Flood-prone area. For this Research Seventeen (17) years of daily discharge is used. The Flow data is used to calculate the magnitude of the flood and in the undulation area map for the flood. Generally, it is required to estimate the flood for the different return periods. Teji River is located in the upper awash sub-basin and tributaries of Awash River. The River originates from urago higher mountains of Becho Catchment.

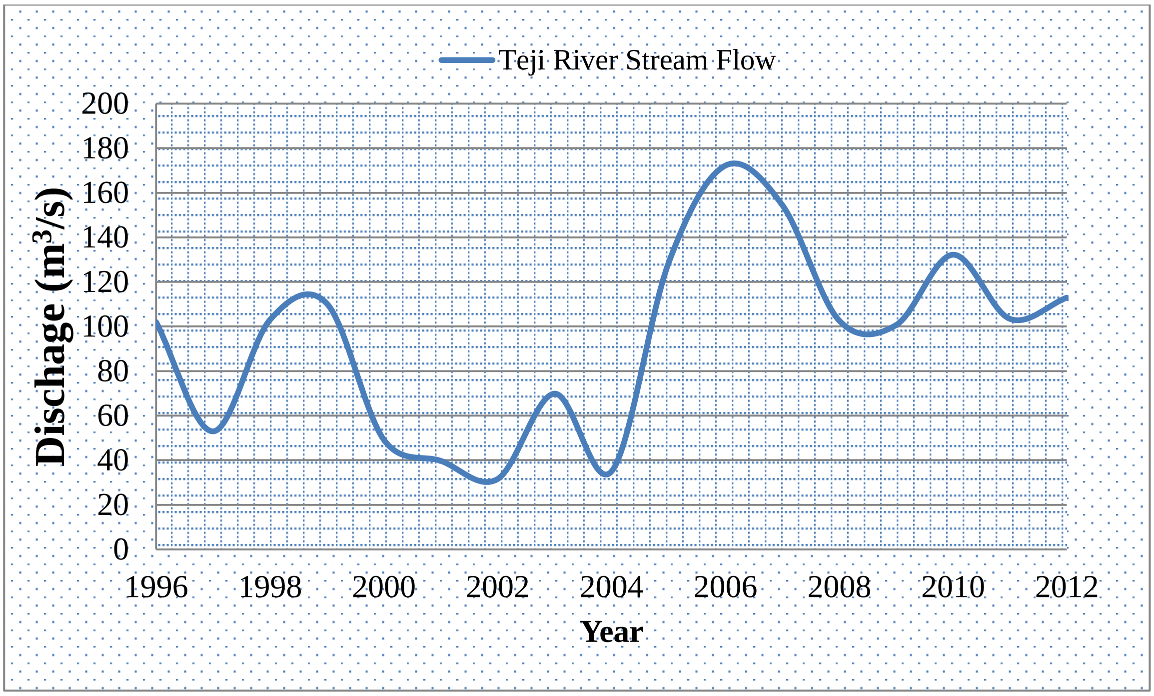


Figure 3.5: Time series of annual maximum discharge

3.6.2 Testing of Outliers

As mention in the previous section outlier test were done using the log-Pearson type III test using equation 3.5.3 and 3.5.4

Table 3.3: Outlier test deviates (K_N) at a 10% significance level

Outlier Test Deviates (K_N) at 10% Significance Level

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

Source: U.S Water Resources Council, 1981

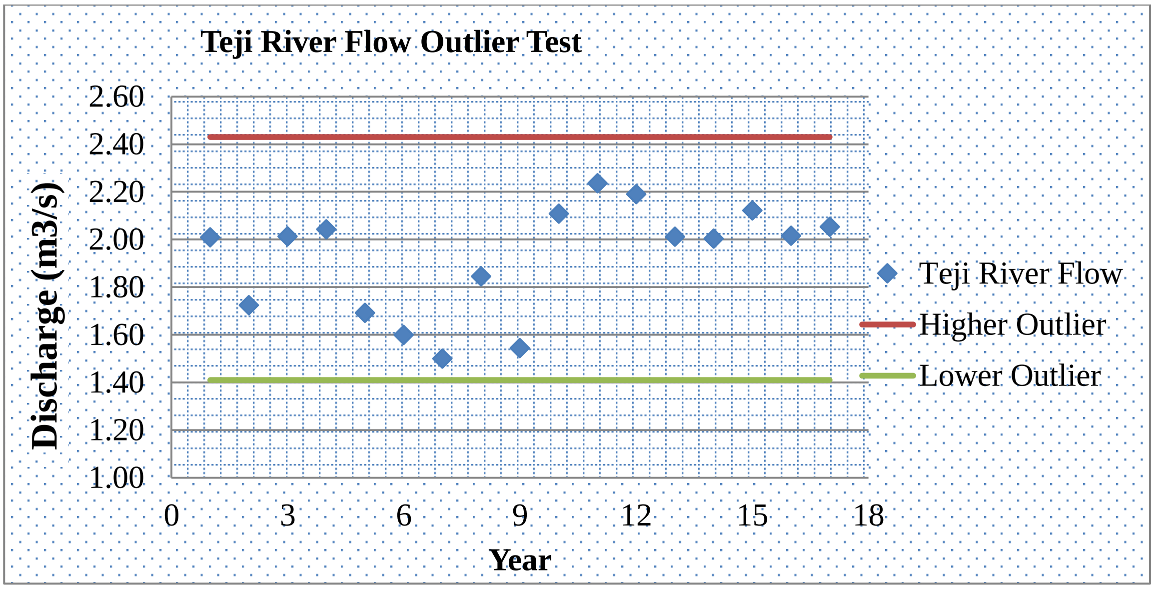


Figure 3.6: Outlier tests of Teji river flow data.

It shows that there are no data points that are outlier.

3.6.3 Test of Independence and Stationarity

By using the equation from 3.5.5 to 3.5.5.2, the test value t = 0.77 is smaller than the critical value at the 5 percent significance level, t0.025 = 1.96. We can therefore accept the assumption of independence and stability of the Teji River flow data at a 5 % significance level.

3.6.4 The goodness of Fit Test

In this study, using an easy fit-curve model, chi-square is chosen and the values are shown below. By using equation 3.5.9 the result become,

$X^2_{6,\,0.95} = 12.6 > 6.047$ this shows that the distribution is accepted. Shown in Appendix F.

3.6.5 Peak Flow Estimation

Using the easy fit curve method the system or the mode selects the Extreme value Type I (Gumbel) method using the Gumbel equation the parameter of distribution was estimated with annual maximum flow data to different return periods and tabulated in Appendix F.

3.6.6 Flow Duration Curve

Duration curve (FDC) is a plot of flow against the percentages of time a particular flow could be anticipated or exceeded. Flow duration curve merely reorders flows in order of magnitude instead of the true time ordering of flows inflow versus time plot. Flow duration curve, plotted using the average monthly values of the flow. The total period /rank-ordered method is used for this study. The total period method /rank-ordered method: considers a total time series of flows that represent equal increments of time for each measurement value of monthly flows and ranks the flows according to magnitude.

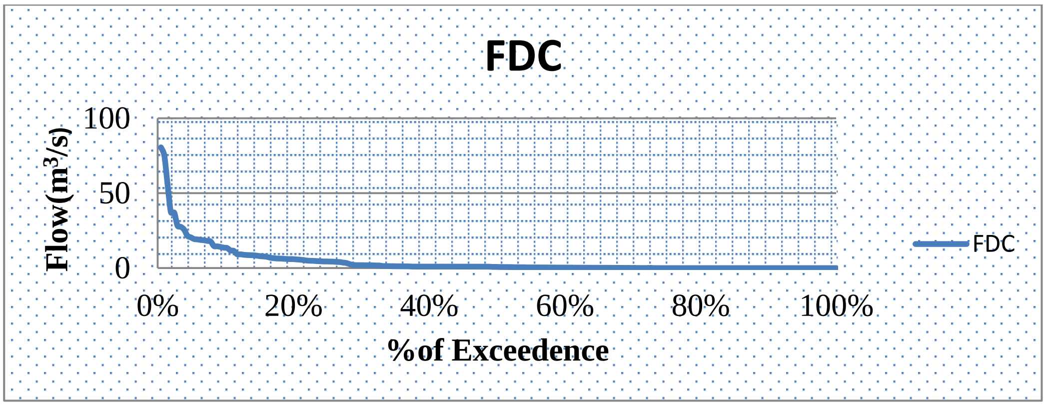


Figure 3.7: Flow duration curve of Teji river streamflow

3.6.7 Meteorological Rainfall Station

This study uses rainfall data from five meteorological stations regularly for the time scale 1996-2012 obtained from the National Metrological Agency of Ethiopia (NMA). The precise locations and the rainfall cycle data record of the weather stations are listed below.

Table 3.4: Spatial overview of meteorological stations and rainfall data recording period

Station Name	Longitude	Latitude	Period of Recorded Used
Teji	38.367	8.8	1996 - 2012
Tulubolo	38.217	8.583	
Dilela	38.05	8.617	
Bantu Liben	38.267	8.617	
Bu’i	38.55	8.35	

The mean monthly rainfall of each station is shown in the figure below. The selection of stations was made on the basis of quality, long-range data.

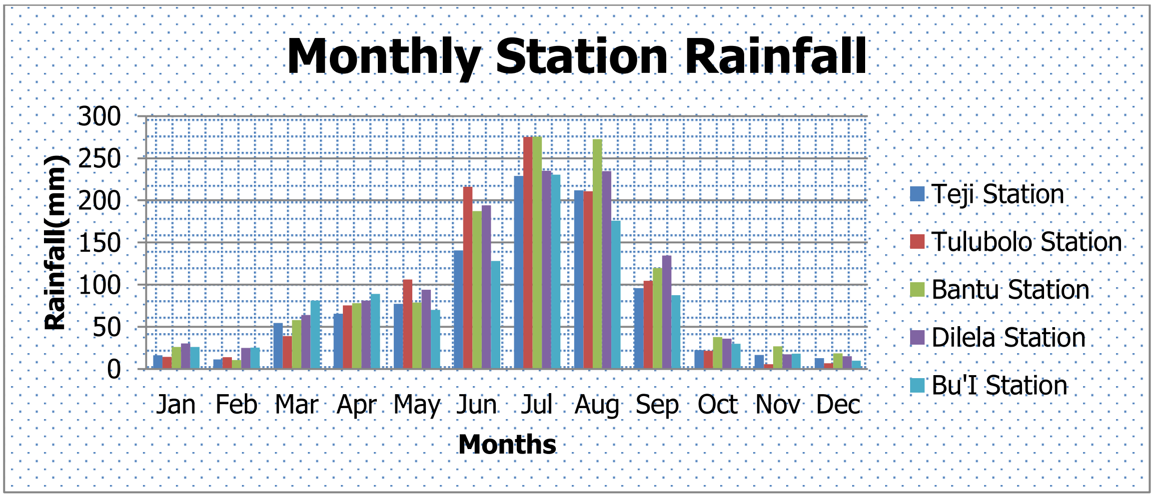


Figure 3.8: Mean monthly rainfall for selected stations averaged over the period 1996-2012.

There remain three (3) seasons of four (4) months each, categorized according to the meteorological means of rainfall and temperature in Ethiopia. The seasons are recognized locally as Kiremt (September, August, July, and June), Belg (May April, March, and February), and Bega (January, December, November, and October).

3.6.8 Testing Outliers for rainfall Data

As stated earlier outlier testing was done using log-Pearson type III with the formula of 3.5.3 to 3.5.4 and the result is shown in the figure below.

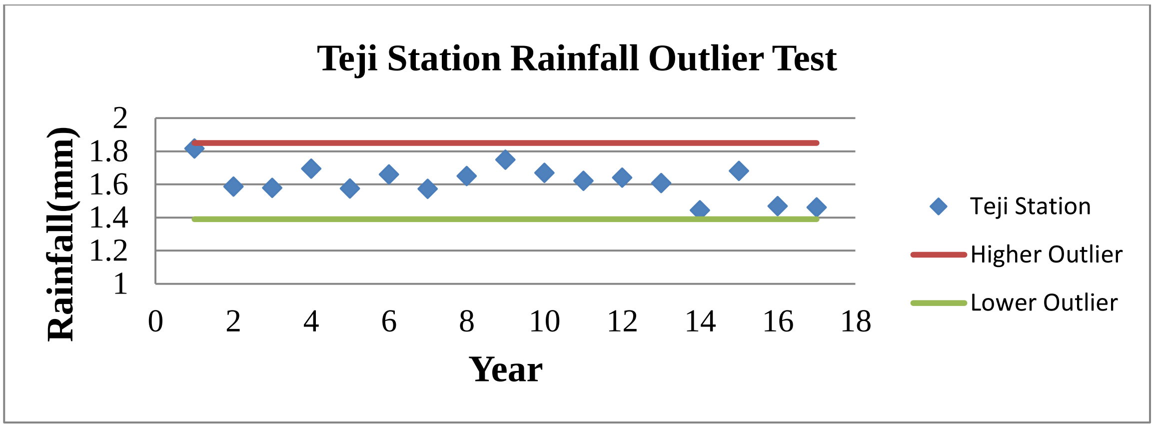


Figure 3.9: Teji station rainfall data outlier test

Figure 3.9 implies that there is no data point that is an outlier for Teji station. And the other stations are shown in Appendix E.

3.6.9 Checking the Consistency of the Selected Rainfall Stations

A Double Mass Curve measures the proportionality with which cumulative rainfall/ hydrological data are plotted against all neighboring stations' mean values. For this study, all selected stations are based on a double-mass-curve analysis consistence. A double mass curve consistency test for the selected stations is indicated below.

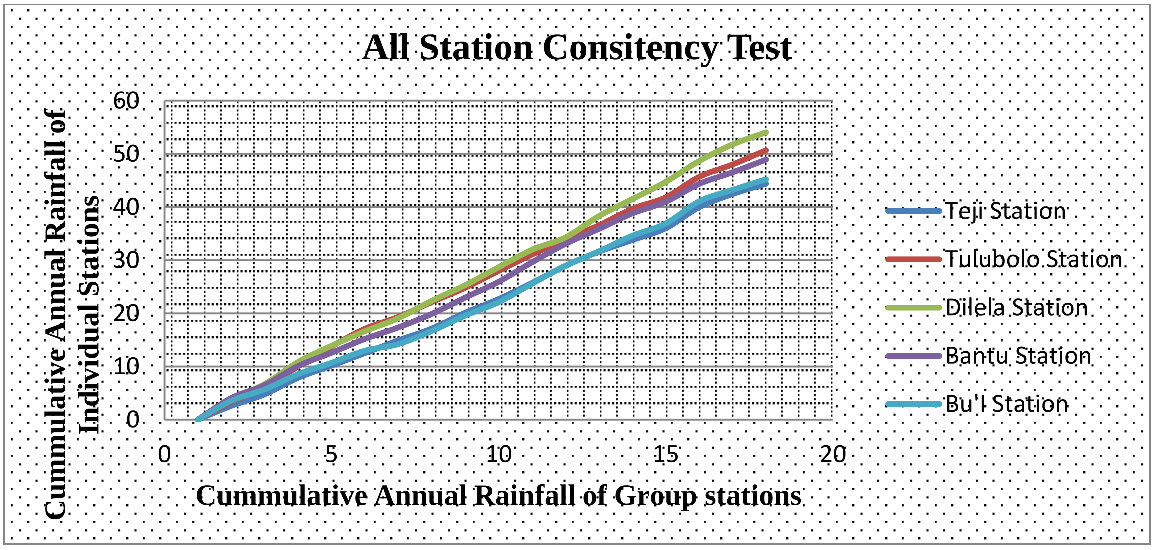


Figure 3.10: Double mass curve test for rainfall stations

3.6.10 Areal Rainfall Determination

Arc-GIS and HEC–GeoHMS software is used to Create Thiessen polygon area for the determination of weighted areal rainfall. The polygon is created as well as the aerial rainfall ratio is calculated for each. When the calculation is computed for Awash

Melkakunture station become insignificant and also almost zero for that reason the station is ignored. But for the rest, other stations were calculated manually and entered for the HEC-HMS model.

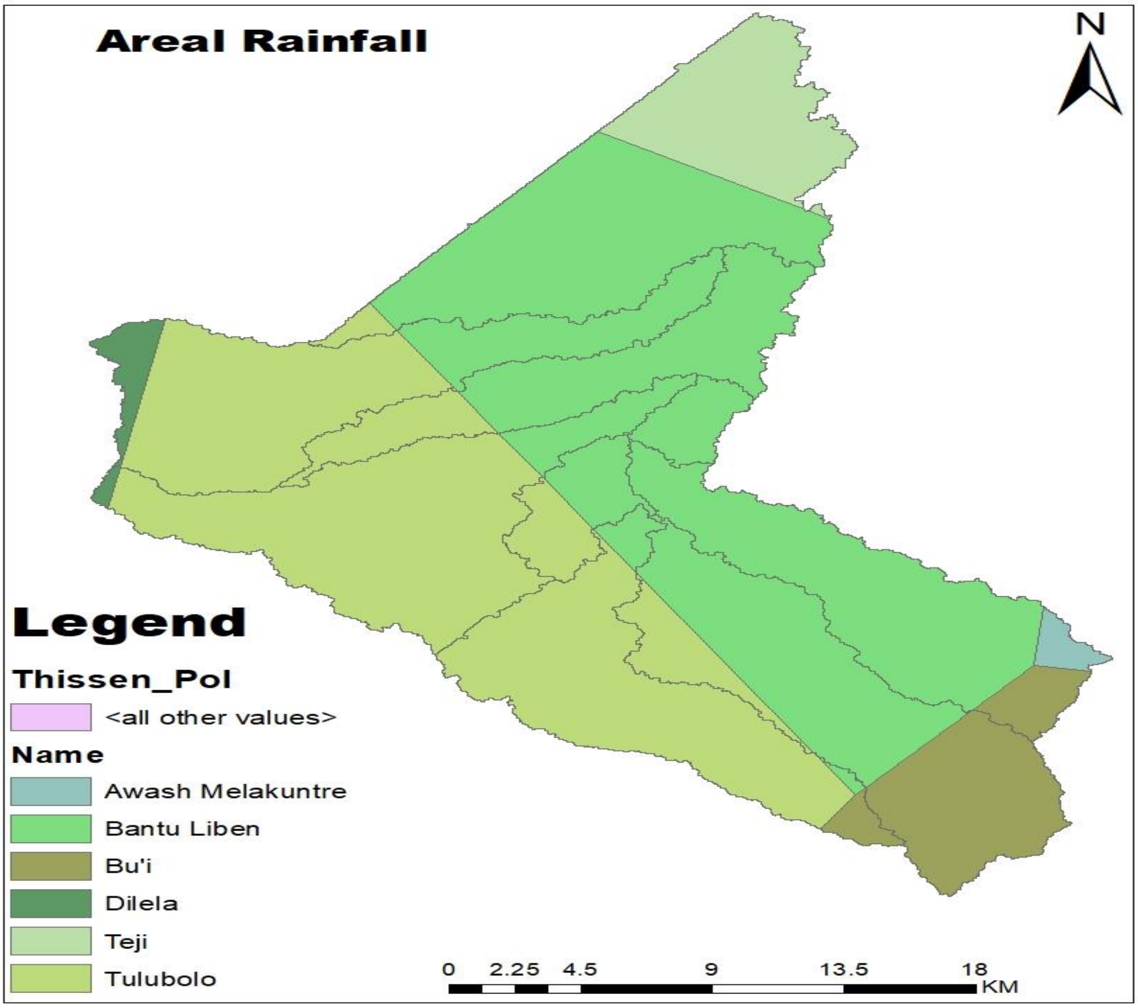


Figure 3.11: Thiessen polygon created using Arc-GIS software.

3.7 Model Setup

3.7.1 Hydrological Modelling

3.7.2 HEC-GeoHMS and HEC-HMS

HEC-HMS input data is preprocessed using HEC-GeoHMS which is the extension in the Arc–GIS framework. In this study, HEC-GeoHMS is used to drive the catchment's river network, delineate sub-basins, and extract the physical characteristics of the catchment's sub-basins and sub-basins area, and river length and other catchment characteristics from the digital elevation model.

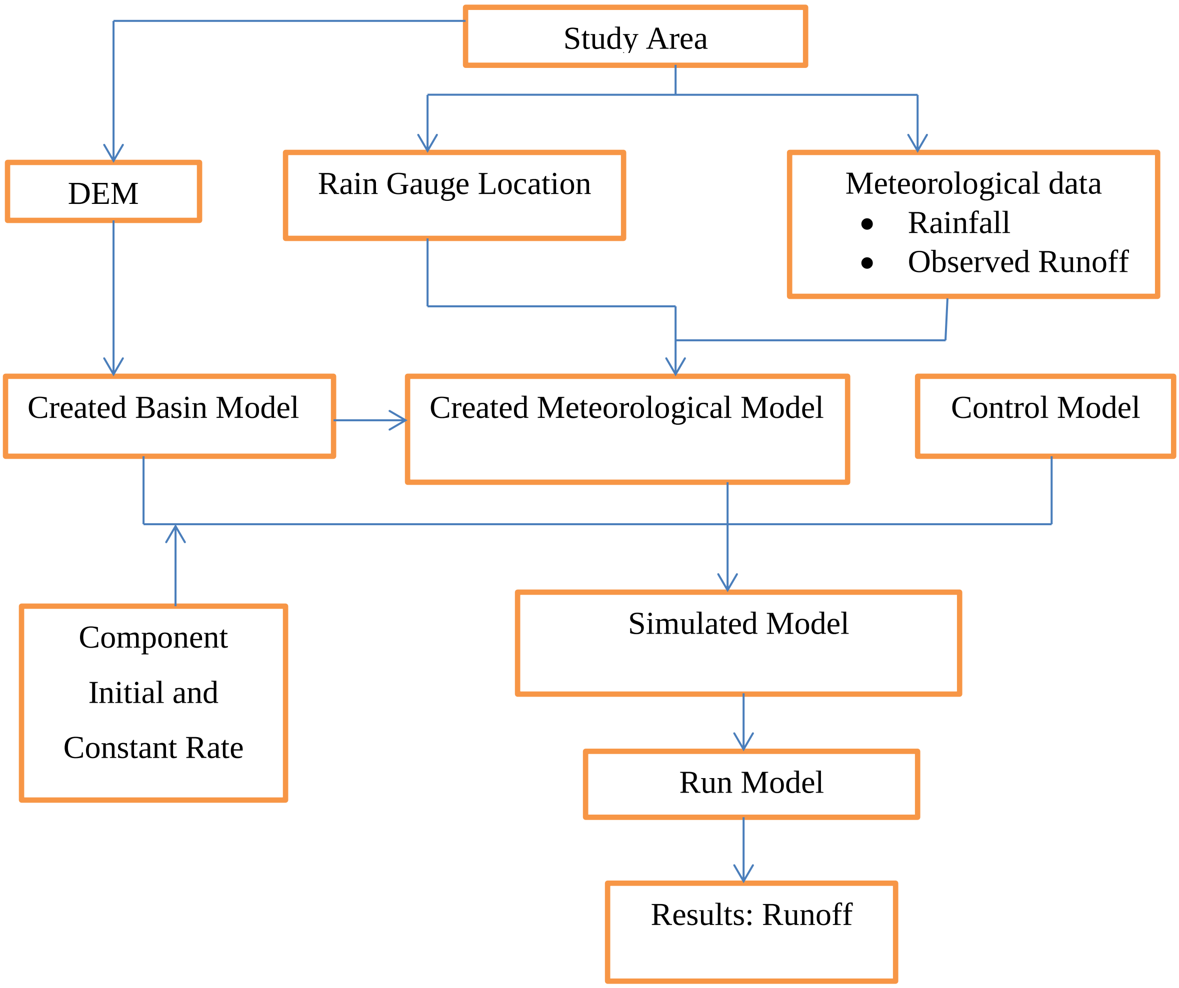


Figure 3.12: Flow chart of the HEC-HMS model

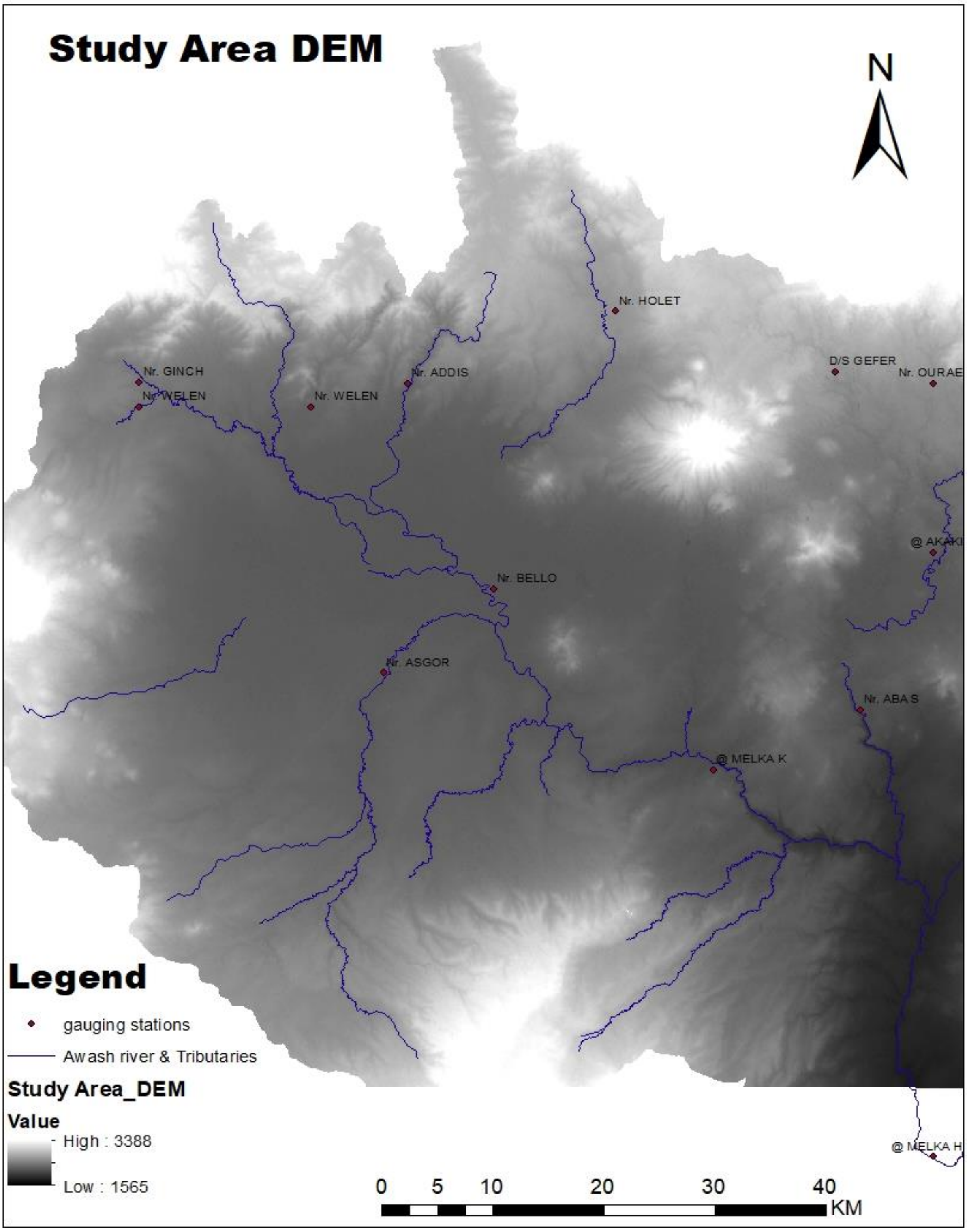


Figure 3.13: Study area DEM, river network, and gauging stations

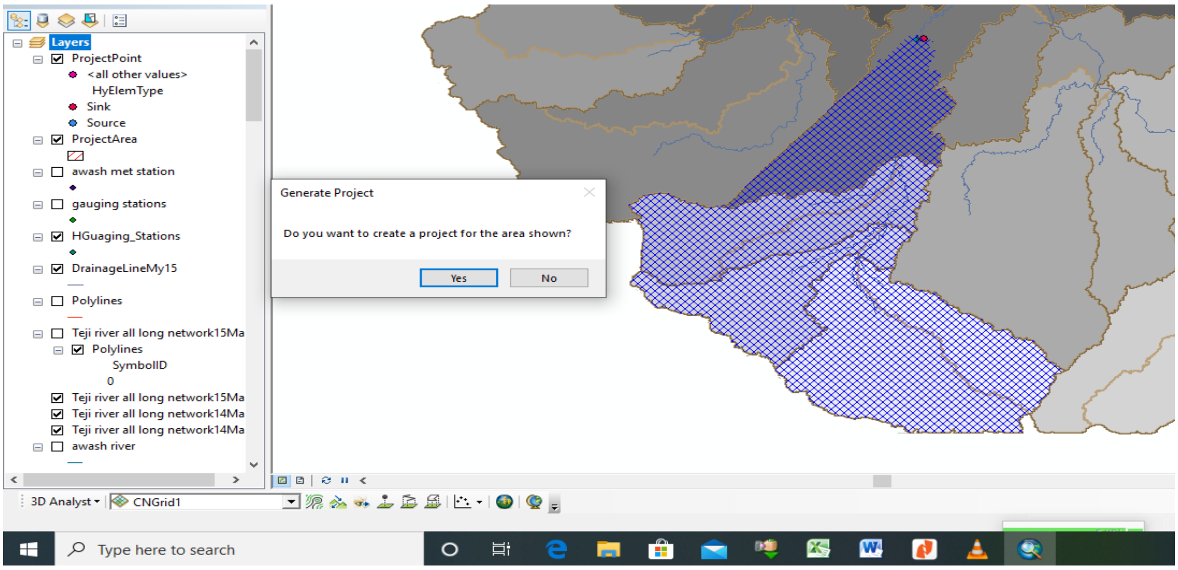


Figure 3.14: Study river catchment project setup

HEC–GeoHMS is to visualize the spatial information of the catchment, document catchment characteristics, perform spatial analysis, delineate sub-basins and streams and also construct inputs file to hydrological models by integrating with Arc–GIS. It creates background map files, a lumped basin model, and a meteorological model, which is used by HEC–HMS to simulate the rainfall-runoff process of the catchment.

The major procedures to start a project in GeoHMS to develop a hydrological model using DEM. are;

- Terrain preprocessing includes fill the sink, flow direction determination, flow accumulation, stream definition, Stream segmentations, catchment delineation, development of catchment polygon, and drainage line processing and catchment aggregation stepwise.

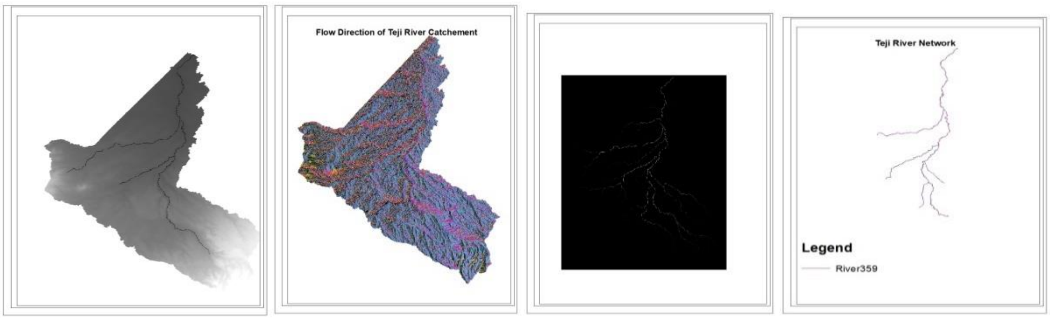


Figure 3.15: Terrain processing of Teji river catchment

- Project setup
- Catchment characteristics
- Hydrological parameter estimation and HEC-HMS preparation file to export.

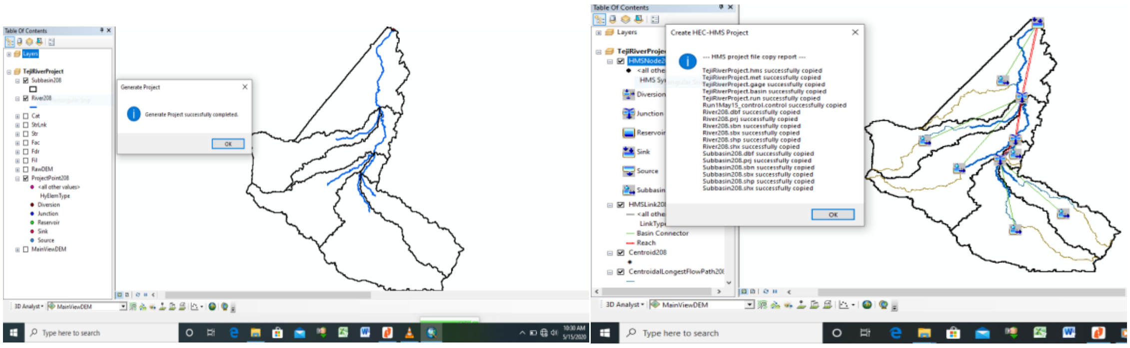


Figure 3.16: Flood area river network and preparing file to HEC-HMS export

Table 3.5: Teji river catchment sub-basin parameter obtained from HEC-GeoHMS

Sub-basin Name	Sub-basin Area in Km^2	Area-HMS
W100	124.808229	124.808229
W110	91.081408	91.081408
W120	53.170434	53.170434
W130	97.031383	97.031383
W140	10.573655	10.573655
W150	19.747593	19.747593
W160	78.723042	78.723042
W170	80.239481	80.239481
W180	103.763582	103.763582

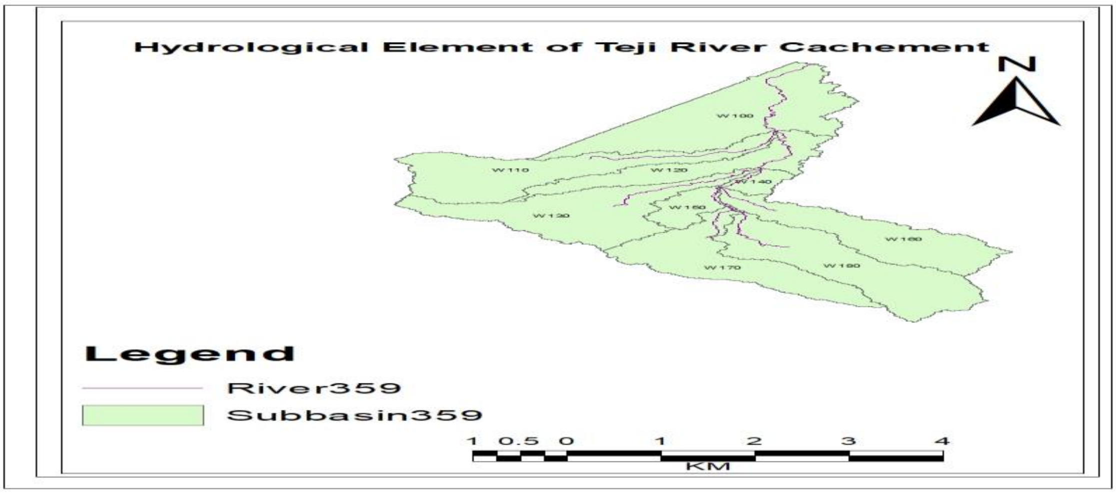


Figure 3.17: Hydrological element of Teji river catchment

3.7.3 Rainfall-Runoff Modelling

The Hydro-meteorological data analyzed and the generated curve number remained used in the US Army of crops Engineers Hydrological Engineering Centers hydrologic Modelling System (HEC–HMS) to extract rainfall-runoff modeling. A hydro-meteorological data of 17 years (1996 - 2012) was used both for model Calibration as well as Validation. HEC–HMS consists of different methods for precipitation loss modeling, direct runoff modeling, and flood routing. For this study, Soil Conservation Services – Curve Number method, Soil Services- Unit Hydrograph method, Muskingum method was preferred for precipitation loss modeling, direct runoff modeling, and flood routing respectively.

3.7.4 Precipitation Loss

Precipitation loss occurs due to different factors such as evaporation, interception, infiltration, etc. The Soil Conservation Service Curve Number was used to estimate excess precipitation. Calculated below.

$S = 254(\frac{100}{CN} - 1)$ in mm ………………………………………………………………3.6

Where S = Potential maximum retention and CN – Curve number

$Ia = 0.2*S$ ……………………………………………………………………………….3.6.1

Ia = Initial abstraction and it represents precipitation loss before the commencement of surface runoff.

3.7.5 Direct Runoff

SCS–unit hydrograph was used to convert precipitation to direct runoff. The SCS–Unit hydrograph requires basin lag time in minutes, Curve number in mm, and was exported from HEC–GeoHMS for every sub-basin watershed.

3.7.6 Flood Routing

HEC–HMS models have different methods of flood routing that require various parameters. From the methods provided in the HEC–HMS for flood routing, the Muskingum method was selected. The calibrated and validated flood wave travel time (K = 0 -150) and the Weighted discharge coefficient (X = 0 – 0.5) were used.

3.7.7 Watershed Physical Parameters

While different physical parameters of the watershed affect the amount of surface runoff, this study focused on curve number, initial abstraction, and basin lag time, as HEC-HMS mainly uses these parameters. The curve number reflects the effect on the watershed response to hydrological parameters of land use, land cover variation, and soil type. The curve number for this study was created in collaboration with Arc-GIS and HEC-GeoHMS using land use/land cover and soil data. The Curve Number value ranged from 30 to 100.

3.8 Calibration and Validation of the Model Parameters

Calibration: - is a systematic method of adjusting the parameter values of the model until the effects of the simulated model match the data observed acceptably. The quantitative measure of fitness between the model's simulated result and observed flow is called the objective function. It tests a degree of difference between the hydrograph being simulated and the observed. The goal of this analysis is to change the delicate parameters. Among the various parameters used in HEC–HMS for this analysis, the most sensitive parameters were found to flood wave travel time (Muskingum–K) and weighted discharge coefficient (Muskingum–X).

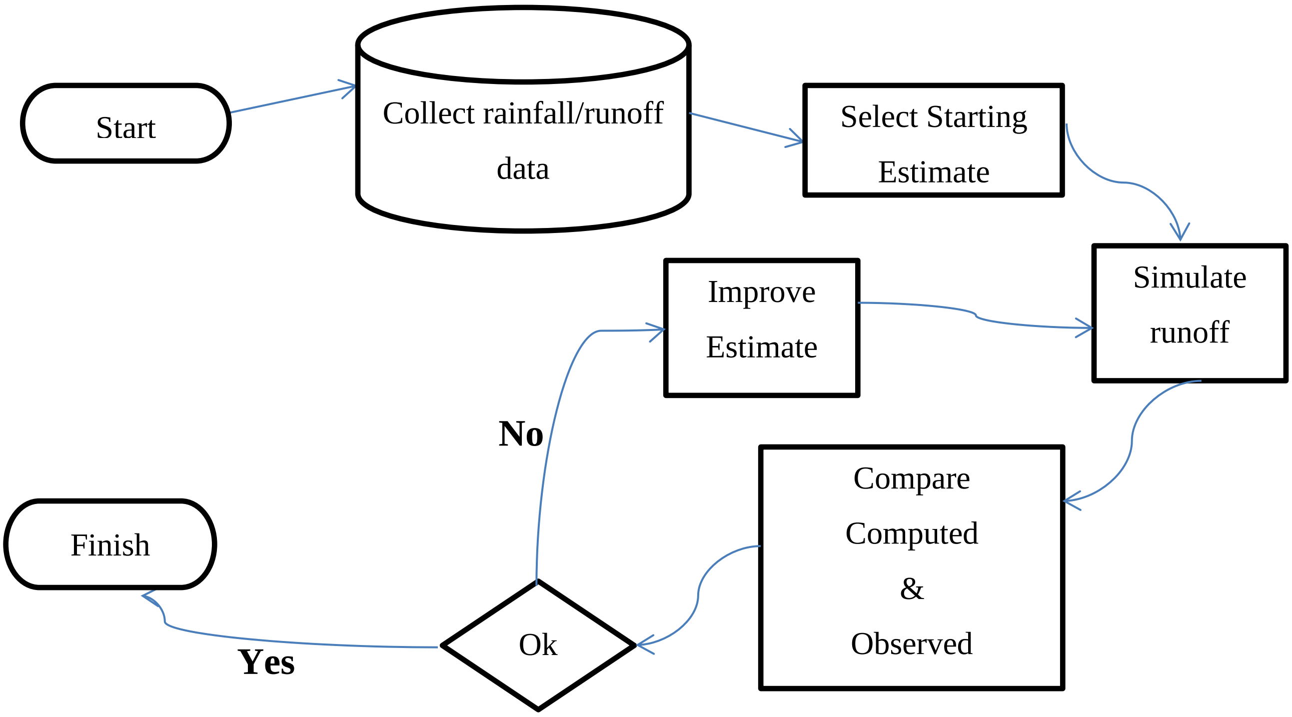


Figure 3.18: Schematic of the calibration procedure

Validation is a comparison of the model outputs with an independent data set without making further adjustments. The process continues until the model errors between observed and simulated become minimized (USACE, 2016).

3.8.1 Model Performance Evaluation Criteria

The important sides of the calibration as well as the validation of hydrological as well as water quality models are a prerequisite for model performance assessment. Performance measurement allows for visual comparison of data from simulated and measured output responses, helps to identify model bias, identify variations in peak timing and magnitude (e.g. peak flows) and recession curve shape, etc. (Moriasi, 2015).

The performance assessment criteria recommended for the model were chosen based on the following factors:

- Robustness in terms of applicability to different materials, models, and weather conditions.
- Widely used, approved, and recommended in literature published as well as
- Found strengths in model assessment

The performance of the HEC–HMS model here in the analysis was evaluated on two very significant performance assessment parameters. These were Nash Sutcliff Efficiency (NSE), determination coefficient (R^2), and correlation coefficient(r) for Pearson.

Pearson's correlation coefficient (r) and **Coefficient of Determination (R^2)**: Pearson's correlation coefficient (r) and coefficient of determination (R^2) describe the degree of collinearity between simulated and measured data. **The correlation coefficient (r)**, which ranges from -1 to 1, is an index of the degree of the linear relationship between observed and simulated data. If r=0, no linear relationship exists. If r = 1 or -1, a perfect positive or negative linear relationship exists. **Similarly, R^2** describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al, 2001, Van Liew et al, 2003). Although r and R^2 have been widely used for model evaluation, these statistics are oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999).

The **R^2** is expressed by equation (3.7).

$$R^2 = \frac{\sum_{i=1}^{n}[(Oi - \overline{Oi})\,(Si - \overline{S})]}{\sum_{i=1}^{n}(Oi - \overline{O})^2 (Si - \overline{S})^2} \quad \ldots 3.7$$

Where Oi is observed flow at i^{th} period,

Si is simulated flow at the i^{th} period and

O¯is the mean of the observed flow

$\bar{S}$ mean of simulated flow at the time i

Nash-Sutcliffe Efficiency (NSE): Nash-Sutcliffe Efficiency (NSE) is a standardized statistic that specifies the relative magnitude of the residual variance related to the data variance measured (Nash and Sutcliffe, 1970). NSE shows how well the plot observed versus simulated data suits in line 1:1. NSE is observed versus simulated data that fits the 1:1 line. NSE is computed as shown in equation 3.8.

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Oi-Si)^2}{\sum_{i=1}^{n}(Oi-\overline{O})^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3.8$$

Where Oi is observed flow at ith period,

Si is simulated flow at the ith period and

O¯is the mean of the observed flow

S¯mean of simulated flow at the time i

NSE ranges between -∞ and 1.0 (1 inclusive), with NSE =1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values < 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance.

3.9 Frequency Storm Method

The Frequency Storm method is constructed from statistical precipitation data to generate a synthetic storm. HEC-HMS measures the frequency storm with a predicted depth of precipitation for a storm with a particular duration and likelihood with exceeding. The source of 2, 5, 10, 25, 50, 100, 200, and 500-year return cycle Precipitation depth (rainfall intensity) is from the Ethiopian Roads Authority Drainage Manual (ERA, 2013).

Table 3.6: 24hr Rainfall depth versus frequency

24hr Rainfall Depth (mm) Vs Frequency (years)								
Return Period Years	2	5	10	25	50	100	200	500
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.0
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B3	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	69.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146	163.44

Source: Ethiopian Roads Authority Drainage Manual, 2013

For drainage areas in Ethiopia, the rainfall intensity can be determined at any appropriate time using the 24-hour rainfall depth, known as the rainfall intensity duration – frequency (IDF) ratio.

$$R_{Rt} = \frac{t}{24}\frac{(b+24)^n}{(b+t)^n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

Where: R_{Rt} = Rainfall depth ratio Rt: R24

Rt = Rainfall depth in a given duration’t’

R24 = 24hr rainfall depth

b as well as n = coefficients b=0.3 as well as n=10.78-1.09

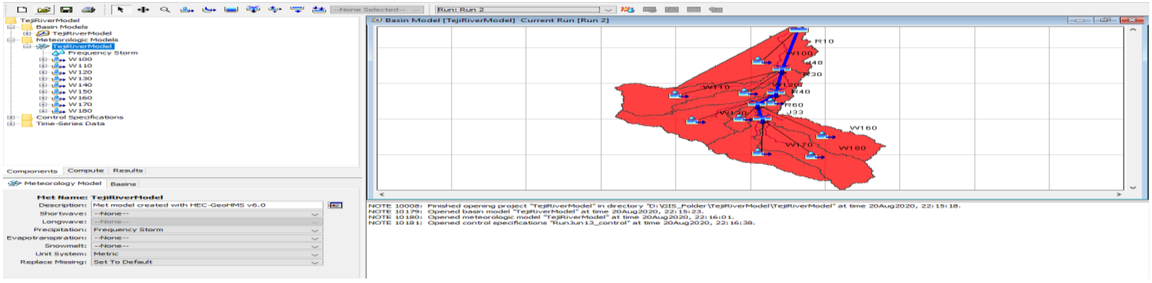


Figure 3.19: HEC-HMS Schematic view

3.10 River Flow Profile Computation

For the HEC-FDA model execute the instruction (run) river flow profile is required. River flow is usually computed by the HEC-RAS model. Once the river profile imported exceedance probability, function with uncertainty and stage-discharge function with uncertainty derived from the river flow profile by the HEC-FDA model.

3.10.1 Flood Plain Area Map

For this study, the floodplain mapping was done using Arc-GIS, HEC-GeoRAS, and HEC-RAS. The preprocessing stage consisted mainly of the preparation of model input data and was done in Arc-GIS using the HEC-GeoRAS extension with the editing of filed data. The processing stage was performed entirely inside HEC-RAS using the geometry of the river prepared in the previous stage. The final stage is an interpretation of the findings from the HEC-RAS model within ArcMap. HEC-GeoRAS assists in generating the data required for the HEC-RAS.

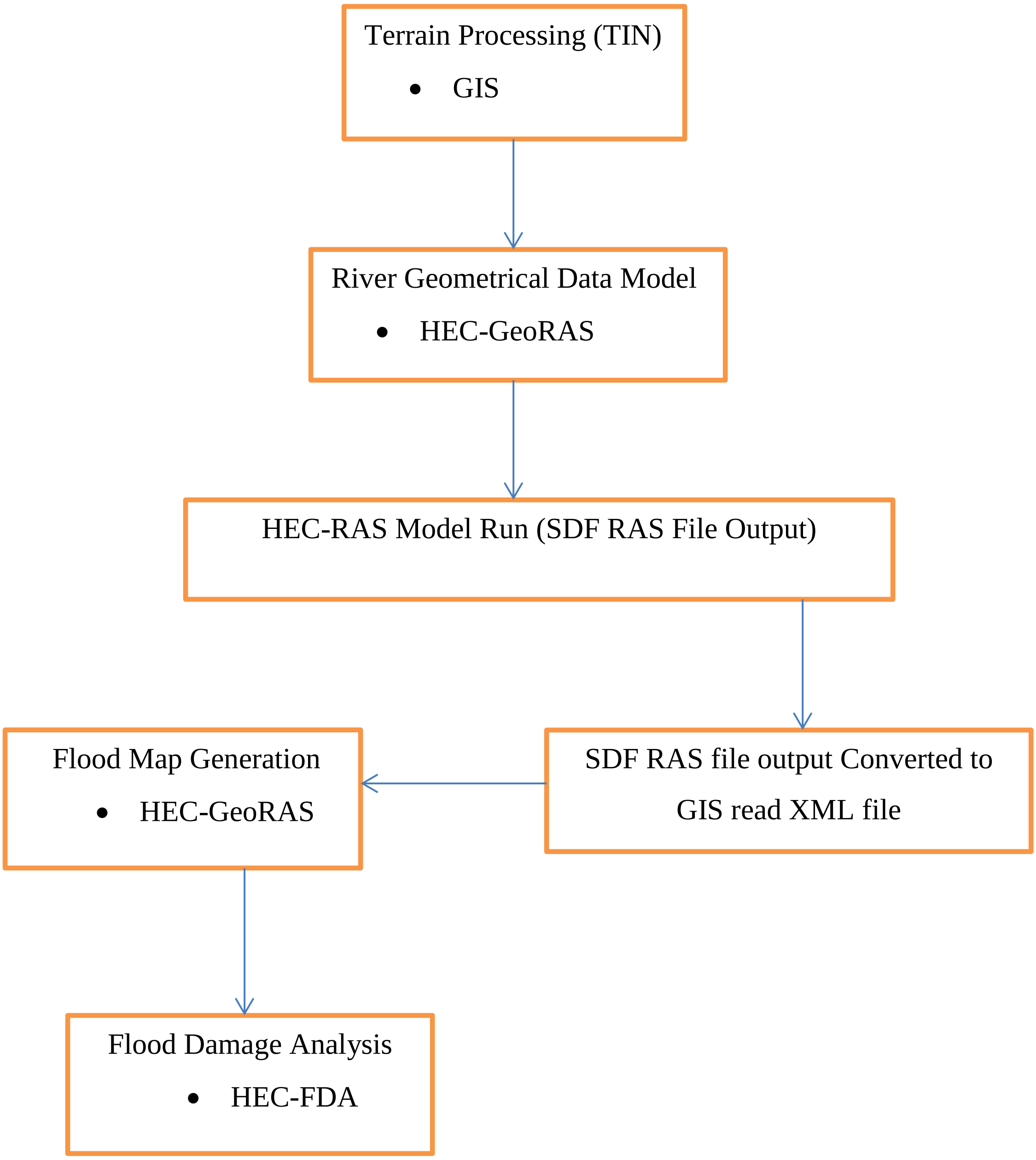


Figure 3.20: Flood plain map generation and flood damage analysis flow chart

3.10.2 Hydraulic Flow Simulation

First in GIS software, using the digital elevation model (DEM) 12.5m, we get the TIN model of the study area. In this study, a 12.5m interval DEM is used to represent area terrain. Compared to HEC-RAS, a DEM offers lower accuracy when describing in-stream channel geometry. Therefore, an integrated digital terrain model in the form of a TIN, containing both HEC-RAS in-stream data and DEM over bank data, was developed. Then considering the flow of the river, cross-sections, the axis of the river, the river band, and the edge of the river and flow path will be drawn.

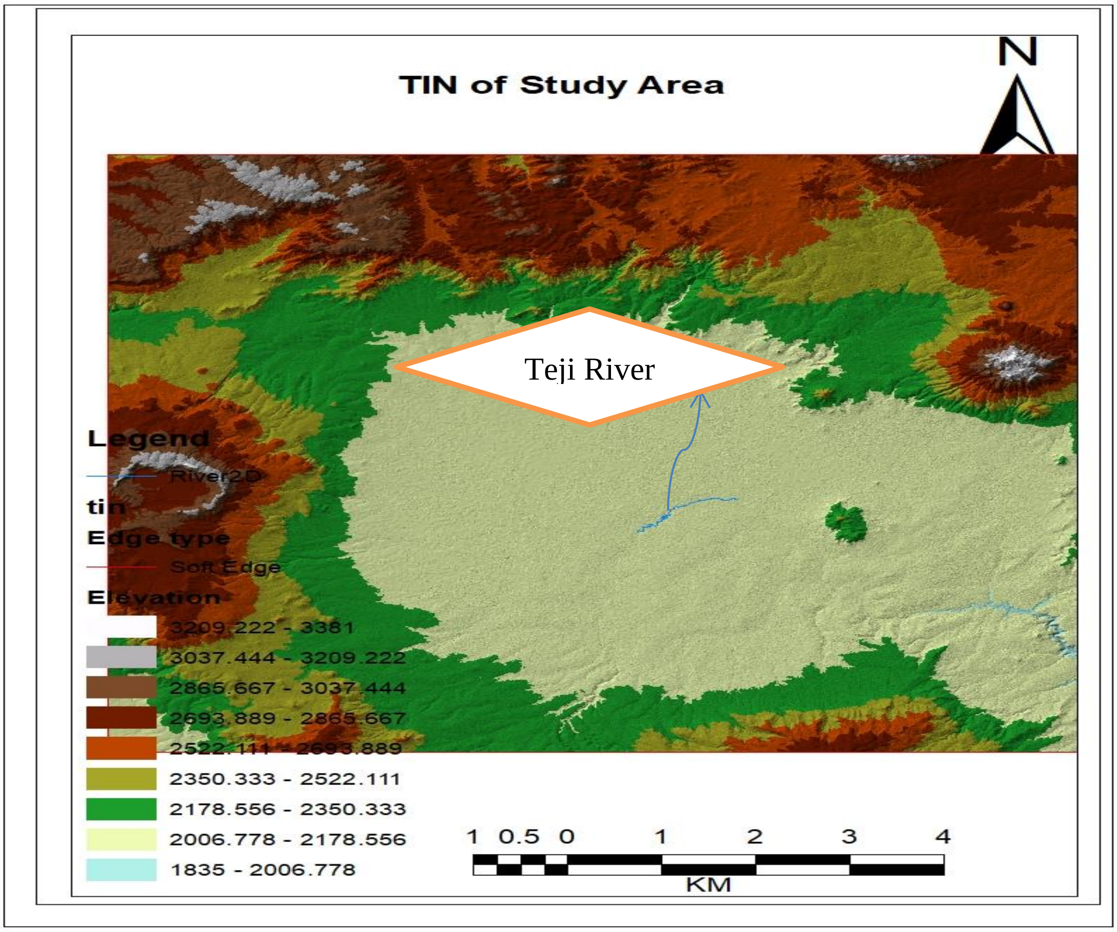


Figure 3.21: Overview of the TIN of study area

3.10.3 HEC-RAS (River Analysis System) Model Description

HEC-RAS is an integrated hydraulic analysis program, in which the user interacts with the device using a graphical user interface (GUI). The device can perform steady flow water surface profile calculations, one and two-dimensional unsteady flow calculations, sediment transport /movable boundary/ calculations, water quality analysis, and many hydraulic design computations (USACE, 2016).

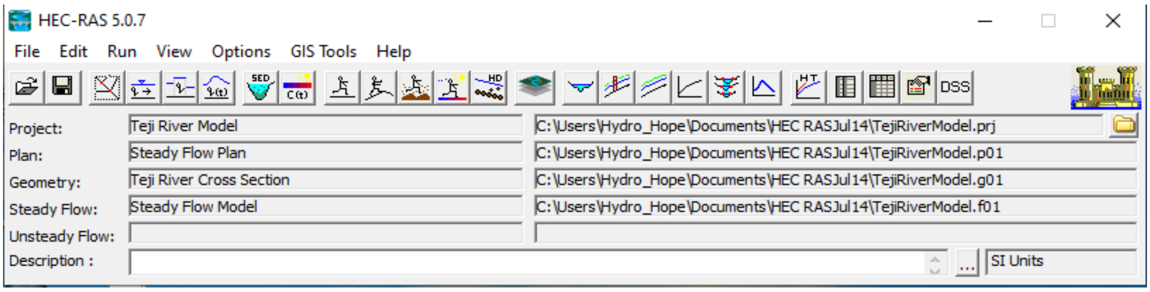


Figure 3.22: HEC-RAS Main window of Teji river model

The system is capable of modeling subcritical, supercritical, critical, and mixed flow regimes for streams consisting of a full network of channels, a dendrite system, or single river reach. For HEC-RAS data required are - Geometric data, Flow data, and Plan data. The geometric data consists of a description of size, shape, and connectivity stream cross-sections (G.J.E.D.T, 2012). Similarly, flow data contains discharges rates, and plan data contains information relevant to run specification of the model, such as a description of flow regimes. HEC-RAS's primary method for calculating water surface profiles takes on a smooth, increasingly varied flow scenario. The basic computational method is based on an iterative energy equation solution (3.9) demonstrated (Butler & Davies, 2011).

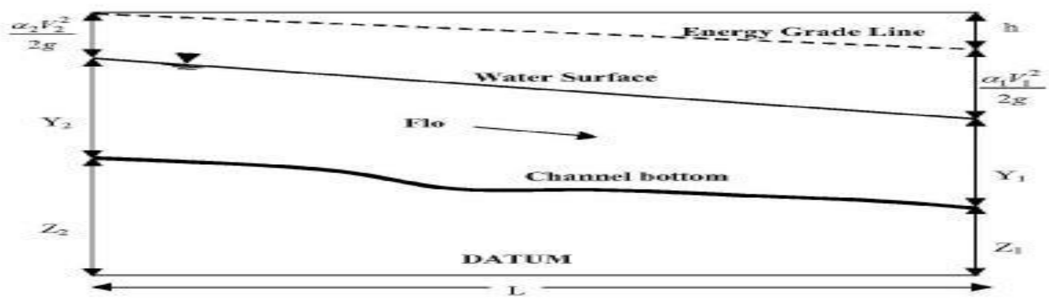


Figure 3.23: Energy equation parameter for gradually varied flow

Based on these parameters, the water surface elevation is the sum of y and Z.

$H = Z + \frac{p}{\rho g} + \frac{V^2}{2g}$ ……………………………………………………3.10

Where H = Total Energy Head (m)

Z = Potential head (m)

$\frac{P}{\rho g}$ = Pressure head (m)

P = Pressure (N/m^2)

ρg = Unit weight (N/m^3)

V = Velocity of flow (m/s)

g = Acceleration due to gravity (m/s^2)

HEC-RAS uses multiple input parameters to hydraulically analyze the structure of the stream channel and the flow of water. Set a sequence of cross-sections along the stream. The cross-section is divided into segments of the left flood path, main channel, and right flood path as shown in the below figure.

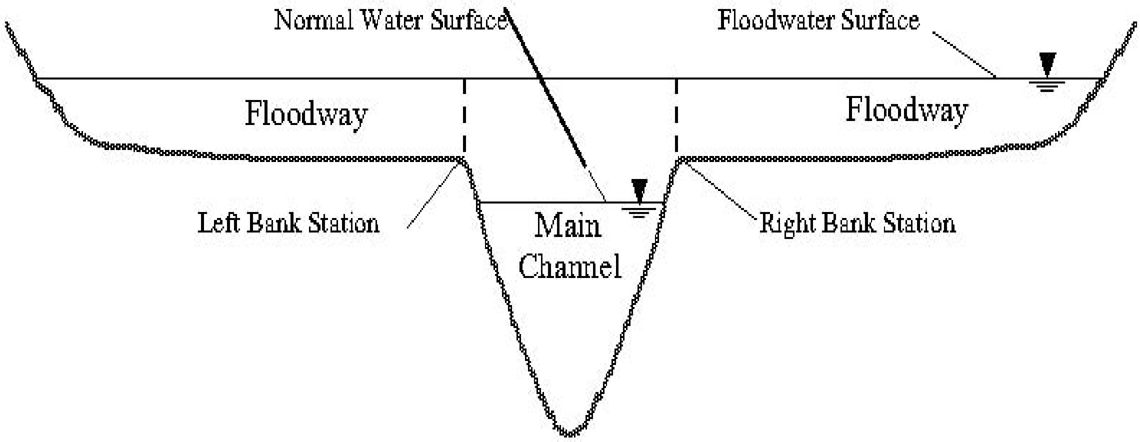


Figure 3.24: HEC-RAS stream cross-section

HEC-RAS undertakes that energy is constant at each cross-section axis, as well as that the vector of velocity is perpendicular.

3.10.4 Importing GIS Data and Editing Geometric Data

3.10.5 Geometric Data

The geometric data consists of a description of size, shape, and connectivity stream cross-sections. In this study geometric data were analyzed from DEM and google Earth in Arc-GIS software. Finally, Geometric data imported from the HEC-GeoRAS Arc-GIS extension to HEC-RAS. Accordingly, the geometric data processed may not be proper with the actual data, due to this it is required to improve the geometric data with HEC-RAS software.

In the geometric editor, Tools, Graphical Cross-section Edit. Bank elevations were adjusted accordingly by comparing with field survey cross-sectional elevations. The entire bank stations were adjusted by multiplying them with suitable factors to decrease the width of the cross-section (from survey data) with the width imported from Arc-GIS.

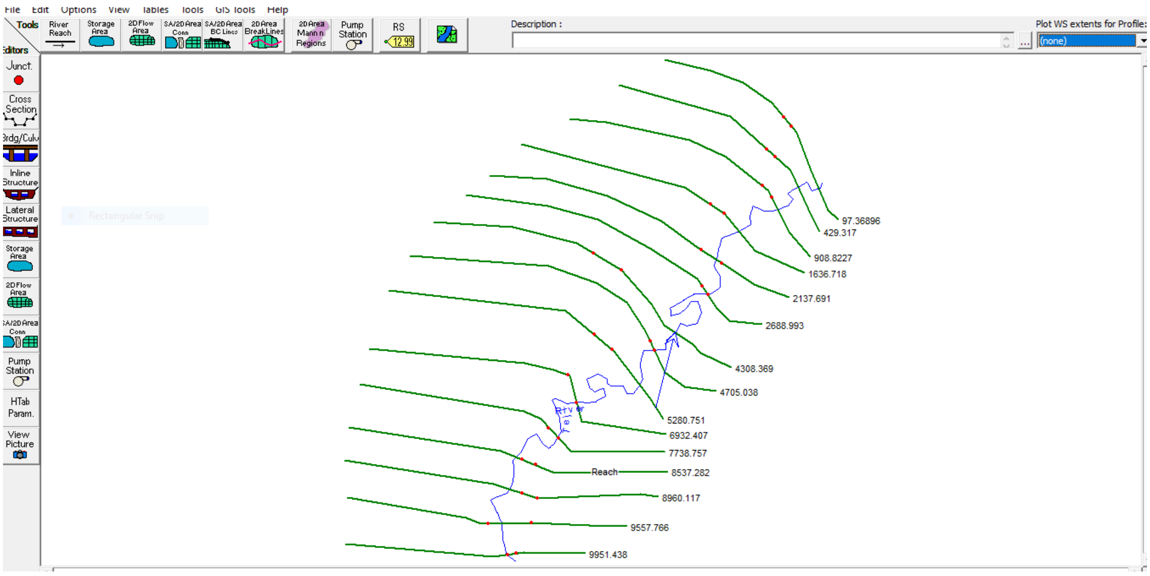


Figure 3.25: Geometric data model setup

3.10.6 Manning's Coefficient

Manning coefficient n is a coefficient that signifies the roughness or friction applied to the flow in the waterway (IJERT, 2015). The roughness of a surface affects the characteristics of runoff, whether the water is on the surface of the watershed or in the channel. For overland flow, increased roughness delays the runoff and increases the potential for infiltration. Reduced velocities associated with increased roughness should also decrease the quantity of erosion. The manning roughness for manmade channel or canal was reviewed from literature (USACE, 2016). The general effects on flow in a channel are similar to those overland flows. There are various methods available for the estimation of manning's number in channel and flood plain (G.W. Brunner, 2008). These are:-

- Field Observation
- Photo of calibrated stream
- Published documents
- Formulas
- Calibrated to observed profile

Calibrated to observe water surface profile is the best method if there is a known water surface profile (rating curve). For this study field observation or commonly known Cowan method is used to estimate the manning roughness coefficient (G.W. Brunner, 2008). Cowan establishes a technique accounting for two factors that influence the determination of manning's n coefficient:

- The size and type of the bank and channel bed materials and
- The shape of the channel

The approach contains breaking the roughness estimate into six categories, which could be determined by visual observation and does not require a specific measurement. As stated by Cowan manning's n coefficient is determined by applying Equation (3.10.1). The manning's coefficient table and filed survey of Teji River are shown in appendix B. Equivalent manning's roughness as a function of channel and flood plain condition.

$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m$ ………………………………………………….3.11

Where: n is the Equivalent manning number

n_b is manning roughness number bare soil

n_1 is channel as well as flood plain irregularities correction

n_2 is channel as well as flood plain cross-section correction

n_3 is channel as well as flood plain irregularities correction

n_4 is Vegetation cover correction

m is Meandering effect correction

Table 3.7: Manning roughness estimation for the river (channel)

Manning roughness (n)	Channel Condition	Recommended "n"	Estimated (n) for Channel
Manning of natural bare soil (n_b)	Natural bare soil	0.025	0.025
Degree of Irregularity (n_1)	Moderate	0.006-0.010	0.008
Variation in Channel Cross Section(n_2)	Alternative Frequently	0.01-0.015	0.0125
Effect of Obstruction(n_3)	Negligible	0.000-0.004	0.002
Amount of vegetation (n_4)	Small	0.002-0.01	0.012
	Medium	0.010-0.025	0.035
	Large	0.025-0.050	0.0375
	Average = 0.028		
Degree of Meandering (m)	Sever	1.30	1.3
Equivalent (n)			= **0.098**

Table 3.8: Manning roughness for flood plain source

Manning roughness (n)	Flood Plain Condition	Recommended "n"	Estimated (n) for Flood Plain
Manning of natural bare soil (n_b)	Natural bare soil	0.025	0.025
Degree of Irregularity(n_1)	Sever	0.011-0.02	0.016
Variation of Floodplain Cross Section (n_2)	Not Applicable	0.000	0.00
Effective of Obstruction (n_3)	Minor	0.005-0.019	0.024
Amount of Vegetation (n_4)	Small	0.001-0.010	0.006
	Medium	0.011-0.025	0.036
	Large	0.025-0.05	0.038
	Very large	0.05-0.10	0.075
	Extreme	0.1-0.2	0.15
			Average = 0.305
Degree of Meander (m)		1.0	1
Equivalent (n)			**= 0.37**

3.10.7 Boundary Condition in HEC-RAS

A boundary condition specifies the starting water level at the end of the river which is required to begin the calculation of the program. HEC-RAS lets the boundary condition be defined in one of the following options:

Established Water Surface: This is the established profile water surface. This alternative refers to cases where a given discharge was measured at the water level. Critical depth: this method measures the section's critical depth and uses it as a limit condition. This option applies to cases where there is a control structure which controls weir, gate, or drops

- **Known Water Surface**: This is the established profile water surface. This alternative refers to cases where a given discharge was measured at the water level.
- **Critical Depth**: this method measures the section's critical depth and uses it as a limit condition. This option applies to cases where there is a control structure that controls the weir, gate, or drops.
- **Rating Curve**: In this choice, the water level from the defined rating curve is interpolated. Usually, this case refers to a control station where constant measurement of water levels and discharge is made.
- **Normal Depth**: In this option, the program uses the energy slope to calculate the normal depth with manning's equation. And for this study normal depth was used.

Natural depth (Normal depth) is the most widely used boundary state. Although the normal depth is uncertain, it is generally approximated either by using the slope of the channel or the slope of the surface of the water near the limit station. Standard depth is utilized for this analysis.

The average normal depth for the study river ascending and downstream end profile. The channel bottom slope as shown in the figure below was 0.008 and 0.006.

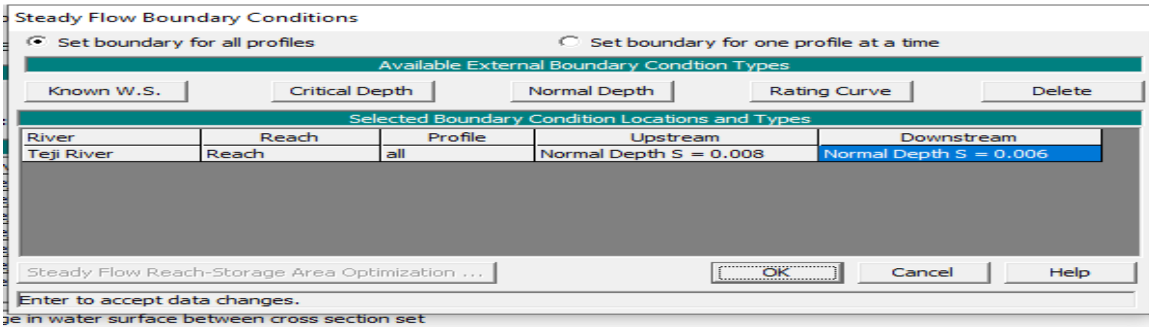


Figure 3.26: Boundary condition of the steady flow

3.10.8 Steady Flow Computation

Computing the model, with the type of flow and flow regime to be calculated should be identified. For this study, a steady flow type and mixed flow regime is selected. A mixed flow regime is selected because profile computation begins (starts) and proceeds from upstream for subcritical to downstream for supercritical flow.

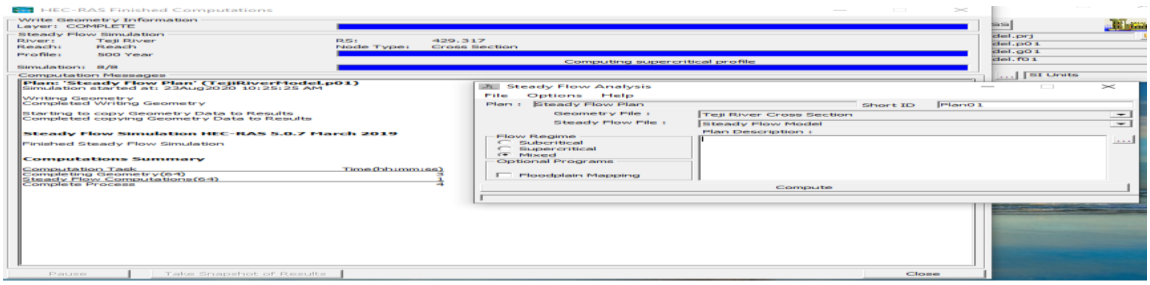


Figure 3.27: Steady flow computation

3.10.9 Post-RAS Processing of Geometric Data

Following the successful computation, of HCA-RAS the results export to Arc-GIS to generate a flood plain map. In the end, flood damage should be estimated.

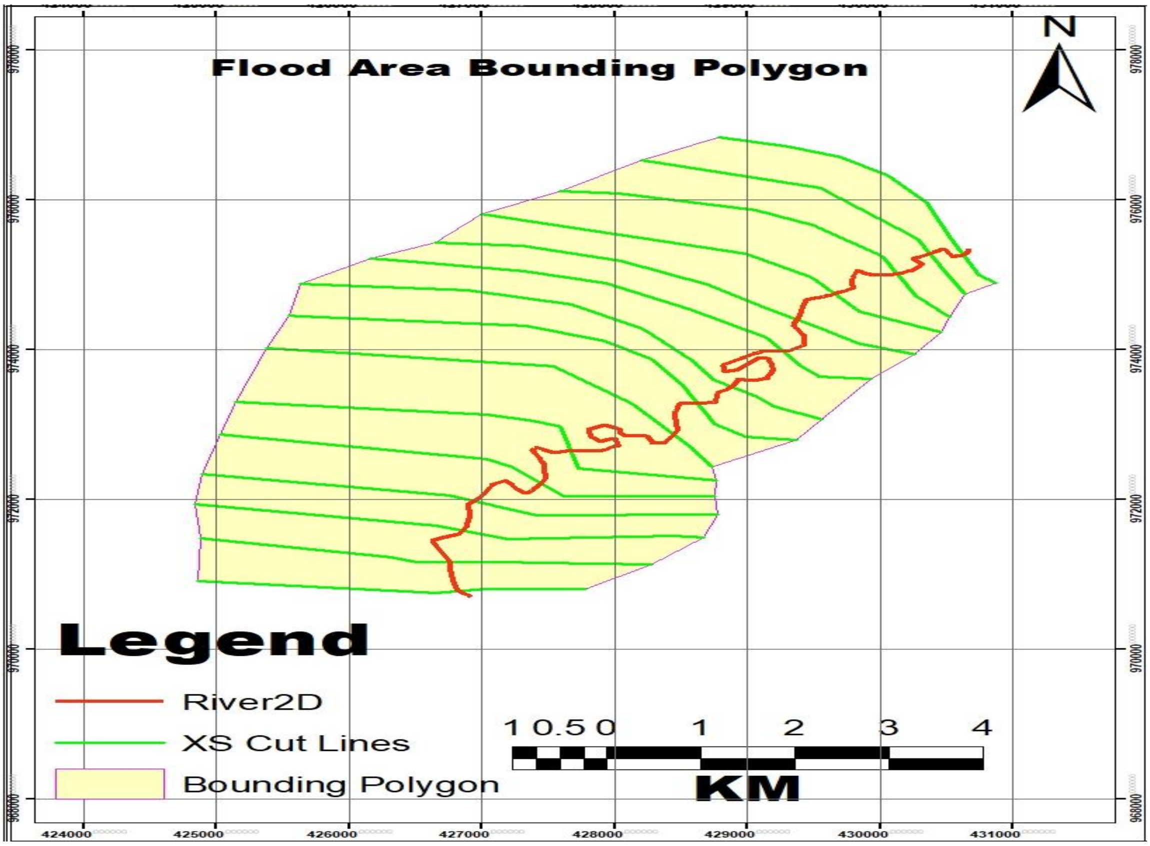


Figure 3.28: Flood Plain Area bounding map

3.11 HEC-FDA (Flood Damage Analysis)

The flood damage analysis results, namely Expected Annual Damage. Equivalent Annual Damage and Project Performance are computed by the HEC-FDA Program. The program computes three functions from the imported water surface profile and manually arranged depth damage estimation (USACE, 2016). The functions are discharge exceedance function, depth exceedance function, and aggregate depth damage function.

3.12 HEC- FDA Model Input

HEC-FDA needs a large amount of external data, and the criteria for input data vary depending on the size of a sample (USACE, 2008). A brief overview of the individual data sets needed by HEC-FDA is given below.

3.12.1 Study Configuration Data

Research Configuration Data is the basic data identified for a study area; the positions of physical streams (streams, damage reaches), and the specific plans (years of review, plans).

3.12.2 Streams

Streams include various water bodies such as rivers, streams, ditches, canals, bayous, lakes, ponds, etc. streams are defined for the study area and common for all plans and analysis year (USACE, 2016). One or more streams may be included in the analysis. In this analysis, only one stream is identified as the Teji River.

3.12.3 Damage Reaches

Damage reaches are specific flood susceptible geographical areas within a flood plain (USACE, 2016). They are used to define consistent data for plan evaluations and to aggregate structure and other potential flood inundation damage information by stage of flooding. In the study from flood map and HEC-RAS 3D perspective view, the damage reaches stretch from 97.36896 river station to 9951.438 river stations.

3.12.4 Plans

A plan may represent with or without project conditions (USACE, 2016). For this study without the project, the condition is considered. For this study with and without a project is considered.

3.12.5 Analysis Years

Analysis Years define damage and project performance information for specific periods during the project life, such as the base year and most likely future year (USACE, 2016) for this study analysis year is (2020-2050) or 30 years is considered.

3.12.6 Flood Damage Economics

Flood damage economics is where we perform data entry and computations to produce stage-damage functions with uncertainty for flood damage reduction (USACE, 2016).

3.12.7 Damage Categories

The damage categories are used to consolidate large numbers of structures into specific categories with similar characteristics for analysis and reports (USACE, 2016). Typically damage categories include; residential, commercial, industrial, and public facilities. In this study, according to woreda flood risk management and preparedness office report and field observation, the damage types are categorized as residential and agricultural tabulated in appendix A.

3.12.8 Structural Occupancy Type

The structural occupancy type describes a class of structures. Data entered for a structure occupancy type is applied to all the structures assigned to that structure occupancy type. In this study four Keble is considered, the structure ground level is approximated from the google earth, field survey with GPS, and finally, counter generated from DEM. The structural occupancy depth damage is estimated from a field survey, measuring the flood depth damage with tape and diving by the total structural current market value cost.

3.12.9 Structural Inventory

Structural inventories are performed to develop a record of the attributes of unique or groups of structures relevant to flood damage analysis. The information is used to compute an aggregated stage-damage function by damage category at the damage reach index location station.

3.12.10 Structural Damage Cost

Several houses in the study area are built from wood, grasses, and mud walls, which are easily damaged by floods. Accordingly, the cost of structural damage is the maintenance cost of poorly damaged mud walls, and mud disposal deposited in the home due to flood is estimated by randomly sampling homes in the USA dollar.

Figure 3.29: Building damage during a flood event

3.12.11 Content Cost Damage

Content cost includes the cost of damaged household food, animal meals, and home substance lost due to flood. And it is randomly estimated from random sampling during field surveys using interviews and questionnaires and shown in Appendix C.

Figure 3.30: Content damage in houses during a flood event

3.12.12 Other Cost

The other factor is the risk of damage to the agricultural area. The most recorded damage per year is farm damage. The land is inundated from the water surface profile in hectares by Arc-GIS.

Figure 3.31: Agricultural damage caused by floods overflowing

The land inundated from the water surface profile in hectares by ArcGIS. C_T (\$) = Z*W (%cultivated)*A_T ………………..……………………………3.12

Where: C_T (\$) is the damage cost of cultivated land at a given elevation

A_T is land inundated due to the rise of water in the river (ha)

Z is yield in kuntal or 100kg/ha

W is $(\frac{cost(\$)}{Kuntal})$ cost of one kuntal (100 cultivated land yield) in dollars or birr

% cultivated is the percent of different crops sown.

3.12.13 Expected and Equivalent Annual Damage Analysis

Expected and equivalent annual damage is the model output. The model uses Monte Carlo simulation to derive the expected annual damage (EAD) corresponding to a particular plan or analysis year for a damage reach. EAD is the mean damage obtained by integrating the damage exceedance probability curve for the damage reach. The inclusion of uncertainty for these variables requires a numerical integration approach to be applied (USACE, 2016).

EAD = $\int_0^\infty Df(D)dD \sim \sum_{i\ 1}^{i=N} D_i \Delta_p$…………………………………….…………..3.13

Where: EAD is Expected Annual Damage

Δp is the probability of damage

Df is damage exceedance probability

D is annual damage

N is the number of intervals

Equivalent annual damage is flood damages associated with a plan that is calculated in average annual equivalent terms. The procedures discount the expected annual damage stream to the beginning of the period of analysis or the base year.

3.12.13 Project Performance

Plan and damage reach project performance analysis are based on target standards defined for without-project conditions for the study. There are three different cases to determine the target (USACE, 2016).

- For reaches without levees, the target is based on an approximation of the stage at which significant damage begins for the without condition,
- For reaches with a levee that has no geotechnical failure, the target is the top of levee stage, and

- For reaches with a levee that has a geotechnical failure, the target is based on both the annual exceedance probability of failure.

Experience at HEC has shown that a 5 percent residual damage associated with the 0.01 exceedance probability event is normally a good target stage and was adopted as the FDA default target stage.

3.13 Flood Plain Management

3.13.1 Methods of Flood Control

The flood is an infrequent high stage of a river breaching its banks and flooding marginal lands. Design The magnitude of the floods is needed for the design of spillways, reservoirs, bridge openings, drainage of cities and airports, and the construction of floodwalls and levees.

Damage due to devastating floods may be minimized by the following flood control measures, either alone or in combination.

- By restricting the flow between high banks, by creating levees, dykes, or floodwalls.
- By improving the channel, by cutting, straightening, or deepening, and by following river training.
- By diversion of a portion of the flood bypasses or floods. It is a low section of the levee that, once over the top, will be out quickly and will develop full discharge capacity into the floodway.
- By providing temporary storage for peak floods, by building upstream reservoirs and retarding basins (detention basins).
- By adopting measures to protect the soil (land management in the catchment area).
- By temporary and permanent relocation of the flood plain and flood plains by enacting legislation.
- By floodproofing unique properties by creating a ring levee or flood barrier around the property.
- By setting up flood forecasting – short-term, long-term, rhythm signals, and radar and warehousing centers in vulnerable areas.

But it is proposed to construct a levee for this study.

3.13.2 Flood Control by Levee

3.13.3 Levee Design General

Levee is described as a bank that runs parallel to the river's path and is intended to protect the zone behind it from flooding. Building levees along the river as an obstruction to high water levels was one of the ancient forms of flood control. For this study, levee is recommended in zones where the elevation of the flood is above the banks of the river. The following features of the levees are determined for the secure building of the levees. Levee or floodwalls have been built for peak floods of 50 to 100 years (K Subramanya, 2008). HEC-FDA specifies that the levee size and failure characteristics are defined and the inner versus outer levee-associated relationship be defined (USACE, 2016). There is currently no slight structure built in the study zone. Therefore, no features of failure or likelihood of failure have been determined. Levee size, inner and outer stages were determined on the basis of the computed water surface profile and average ground level.

3.13.4 Levee Height

Height of a levee is established on the plan flood level with the necessary freeboard added to it. In this case, the flood water level should be determined and the longitudinal gradient of the provisional configuration of the flood level should be considered. The plan of a water level was established on the plan of the discharge for a return period of 100 years. Established on the HEC-RAS study of a water surface profile for a 100-year return cycle, the flood water level above the banks has been calculated. Adding a freeboard to the depth of a flood above a bank, a height of the levees was estimated (Manual on Flood Control Planning, March 2013).

Levee Height = Design Flood Level + Freeboard …………………………………...3.14

3.13.5 Levee Freeboard

The key goal of the Free Board is to provide enhanced protection against extraordinary flood events. It should be adequate to allow for settlement and contain wind-driven waves.

Table 3.9: Minimum freeboard needed for levee

Design Flood Discharges (Cumecs)	Freeboard (m)
< 200	0.6
200 - 500	0.8
500 - 2000	1.0
2000 - 5000	1.2
5000 – 10,000	1.5
>10,000	2.0

Source: Manual on Flood Control Planning, March 2003

3.13.6 Levee Slope

The slope of the levee has a gentle gradient of 2:1 (Horizontal to Vertical) or less. The slope is decided on the basis of the body of the levee. In general, a gradient greater than 2:1 is not preferable given the stability of the slope face (Manual on Flood Control Planning, March 2003).

3.13.7 Levee Crest Width

The overall width of the levee shall comply with the design of the flood discharge and will not be less than the value shown in the table below.

Table 3.10: Recommended crest width for levee

Design Flood Discharges (Cumecs)	Crest Width (m)
< 500	3
500 - 2000	4
2000 - 5000	5
5000 – 10,000	6
>10,000	7

Source: Manual on Flood Control Planning, March 2003

Chapter 4 RESULTS AND DISCUSSION

4.1 Calibration and Validation

Calibration: - Flow calibration was done from (1996–2007) for twelve (12) years of hydro-meteorological data with an equal length of time (12 years). By reducing parameter sensitivity for all reaches and sub-basins, the model output produced nearly the same value as observed flow, as shown in fig below.

Optimized Parameter Results for Trial "Trial 2"

Project:TejiRiverModel Optimization Trial:Trial 2

Start of Trial: 01Jan1996, 00:00 Basin Model: TejiRiverModel
End of Trial: 31Dec2007, 00:00 Meteorologic Model:TejiRiverModel
Compute Time:01Jul2020, 19:33:53

Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
W130	SCS Curve Number - Initial Abstraction	MM	46.060	69.090	-0.00
W130	SCS Curve Number - Curve Number		42.197	37.977	0.00
W130	SCS Unit Hydrograph - Lag Time	MIN	15.000	15.000	0.00
W140	SCS Curve Number - Curve Number		40	36.000	0.00
W140	SCS Unit Hydrograph - Lag Time	MIN	14.000	14.000	0.00
W140	SCS Curve Number - Initial Abstraction	MM	47.040	70.560	-0.00
W150	SCS Curve Number - Initial Abstraction	MM	38.220	57.330	-0.00
W150	SCS Curve Number - Curve Number		40.190	36.171	0.00
W150	SCS Unit Hydrograph - Lag Time	MIN	15.000	15.000	0.00
W160	SCS Curve Number - Initial Abstraction	MM	38.220	57.330	-0.00
W160	SCS Curve Number - Curve Number		40.181	36.163	0.00
W160	SCS Unit Hydrograph - Lag Time	MIN	15.000	15.000	0.00
W170	SCS Curve Number - Initial Abstraction	MM	48.020	72.030	-0.00
W170	SCS Curve Number - Curve Number		52.500	35.000	0.00
W170	SCS Unit Hydrograph - Lag Time	MIN	13.000	13.000	0.00
W180	SCS Curve Number - Initial Abstraction	MM	40.196	60.294	-0.00
W180	SCS Curve Number - Curve Number		35.000	35.000	0.01
W180	SCS Unit Hydrograph - Lag Time	MIN	15.000	15.000	0.00

Optimized Parameter Results for Trial "Trial 2"

Project:TejiRiverModel Optimization Trial:Trial 2

Start of Trial: 01Jan1996, 00:00 Basin Model: TejiRiverModel
End of Trial: 31Dec2007, 00:00 Meteorologic Model:TejiRiverModel
Compute Time:01Jul2020, 19:33:53

Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
R10	Muskingum - K	HR	150	150.00	-0.02
R10	Muskingum - x		0.12	0.11760	0.00
R30	Muskingum - K	HR	150	150.00	-0.02
R30	Muskingum - x		0.13	0.12740	0.00
R40	Muskingum - K	HR	150	150.00	-0.01
R40	Muskingum - x		0.14	0.13720	0.00
R60	Muskingum - K	HR	150	150.00	-0.01
R60	Muskingum - x		0.15	0.14700	0.00
W100	SCS Curve Number - Curve Number		39.784	35.805	0.01
W100	SCS Unit Hydrograph - Lag Time	MIN	18.000	18.000	0.00
W100	SCS Curve Number - Initial Abstraction	MM	79.380	119.07	-0.00
W110	SCS Curve Number - Initial Abstraction	MM	72.030	108.04	-0.00
W110	SCS Unit Hydrograph - Lag Time	MIN	17.000	17.000	0.00
W110	SCS Curve Number - Curve Number		42.499	38.249	0.00
W120	SCS Curve Number - Initial Abstraction	MM	45.080	67.620	-0.00
W120	SCS Unit Hydrograph - Lag Time	MIN	13.000	13.000	0.00
W120	SCS Curve Number - Curve Number		37.175	36.432	0.00
W130	SCS Curve Number - Initial Abstraction	MM	46.060	69.090	-0.00

Figure 4.1: Flow optimized and initial value during calibration

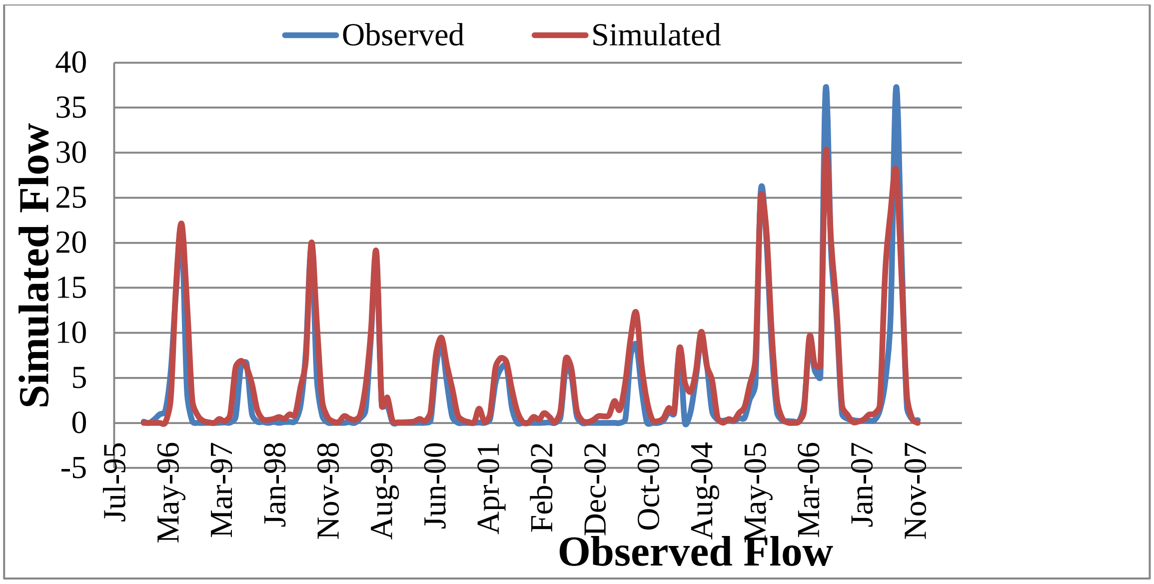


Figure 4.2: Average monthly simulated and observed flow comparison from HEC– HMS during parameter calibration.

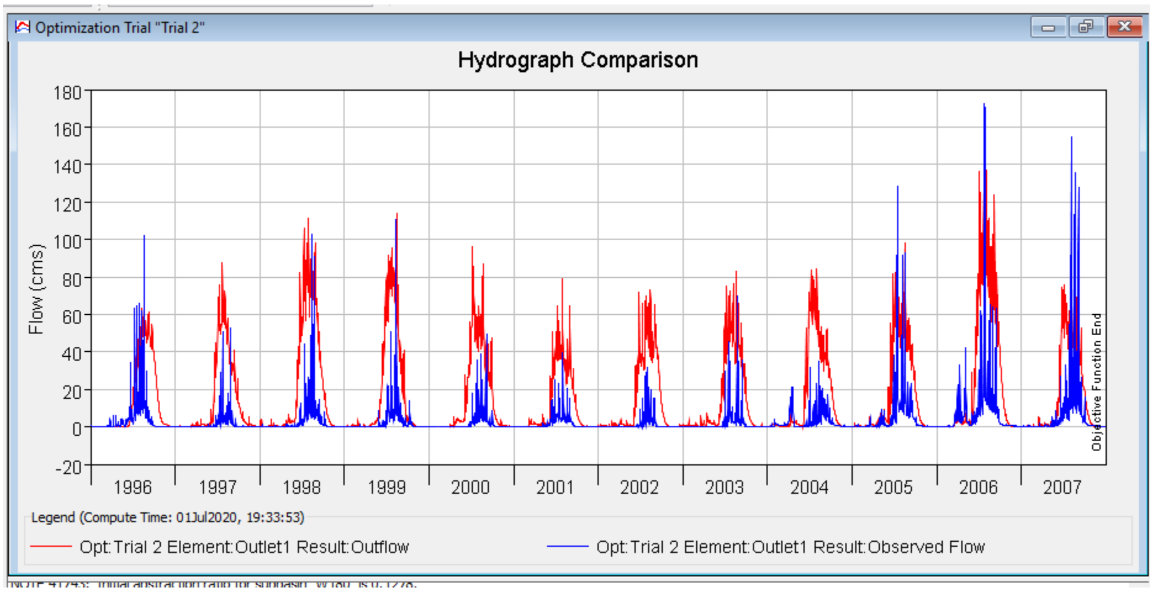


Figure 4.3: Daily flows hydrograph comparison

Nash Sutcliff Efficiency (NSE) and coefficient of determination (R^2) are the best criteria that are widely used to verify the HEC–HMS model performance (chea and oeurng, 2017, and Bitew et al, 2019). Both NSE and R^2 were applied to evaluate the model performance, and the HEC–HMS showed good performance with R^2 = 0.883 and NES = 0.863. The obtained value of these model performance evaluation criteria in this study are within the preferred range, the model was performed well. The computed and observed Peak flow is 147.9m3/s and 172.2m3/s respectively.

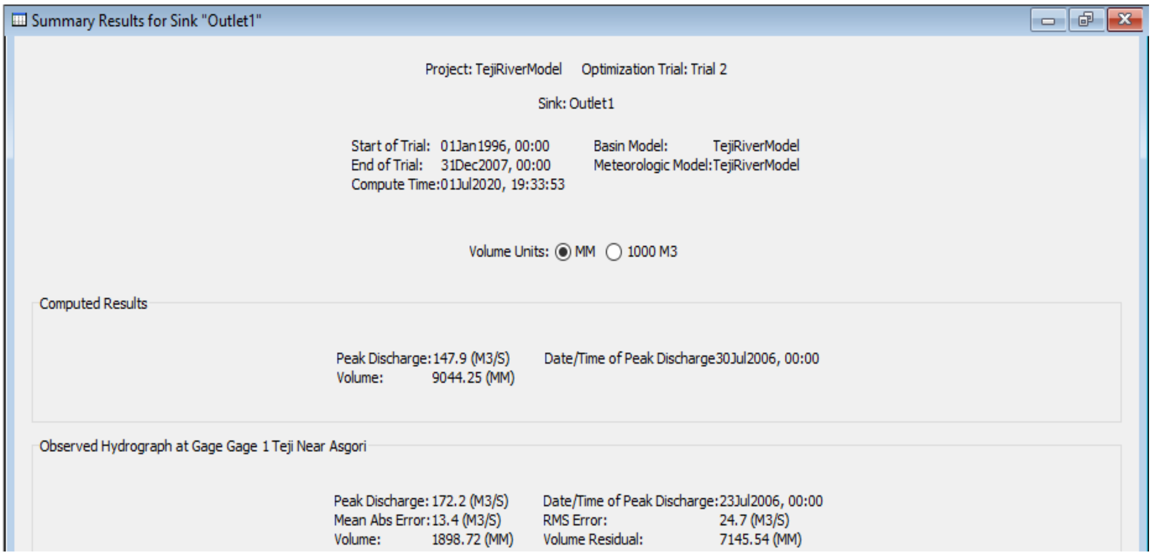


Figure 4.4: Description computed versus observed findings

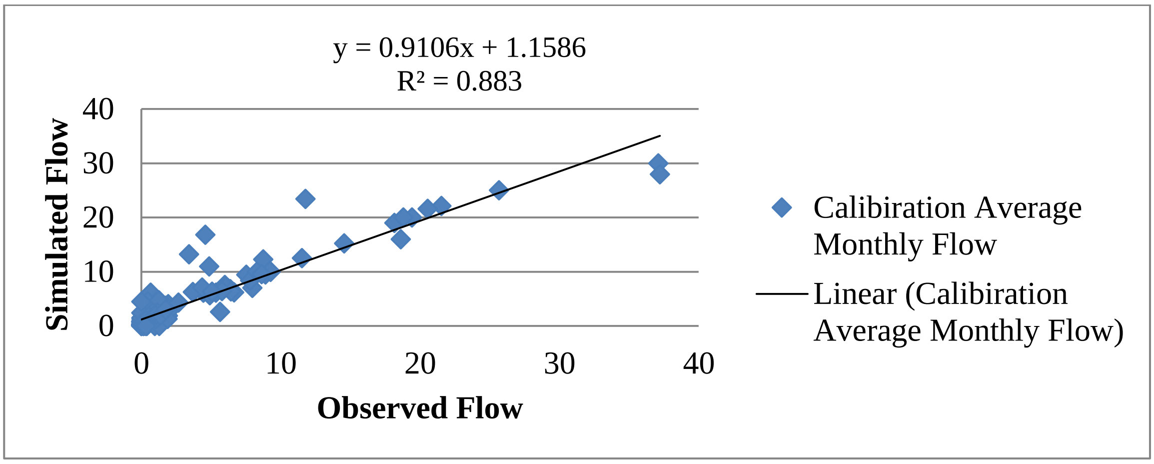


Figure 4.5: Comparison of observed and simulated flow with a scatter diagram.

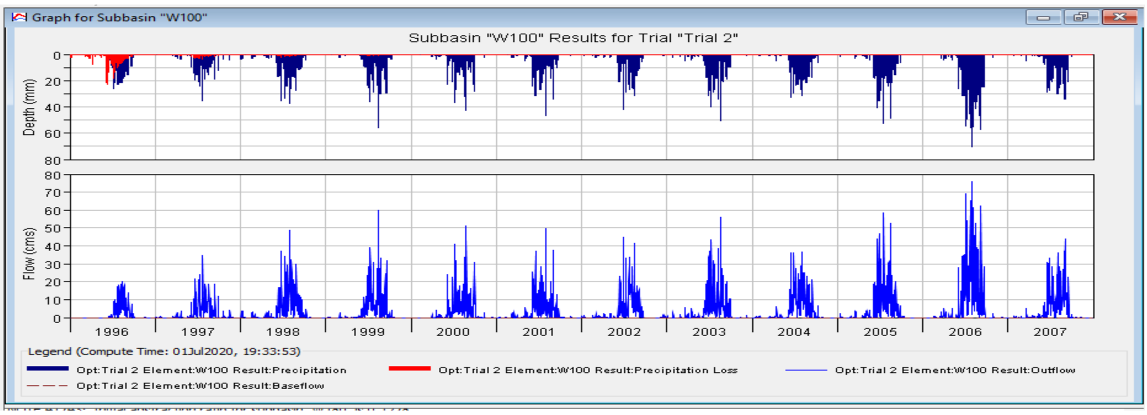


Figure 4.6: Flow Comparison at w100 Sub-basin during calibration

Validation is a comparison of the model outputs with an independent data set without making further adjustments. After adjusting all the sensitive parameters and completing the model setup, 5 years (2008 – 2012) of raw hydro-meteorological data was used to assess model validity with HEC HMS. The model result agrees with the observed flow (fig below), ensuring model validity with the new raw data. The model performance evaluation criterion indicated that the model performed well with raw data during model validation with R^2 = 0.852 and NSE = 0.837. The result of the model shows that HEC-HMS can apply to the Teji river sub-basin.

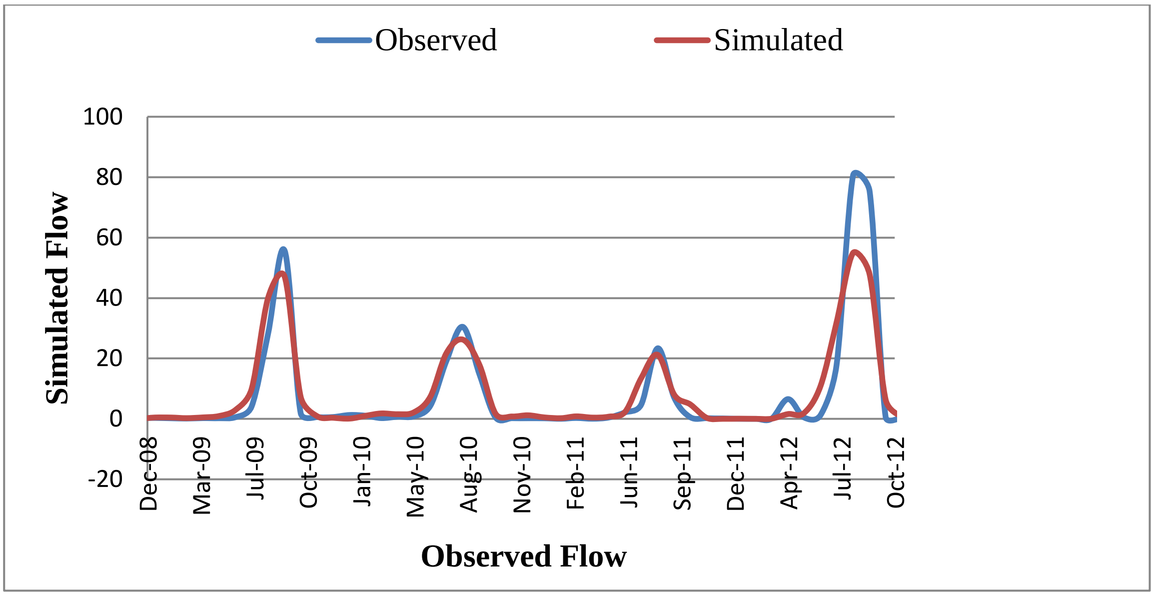


Figure 4.7: Average monthly observed and simulated comparison during validation

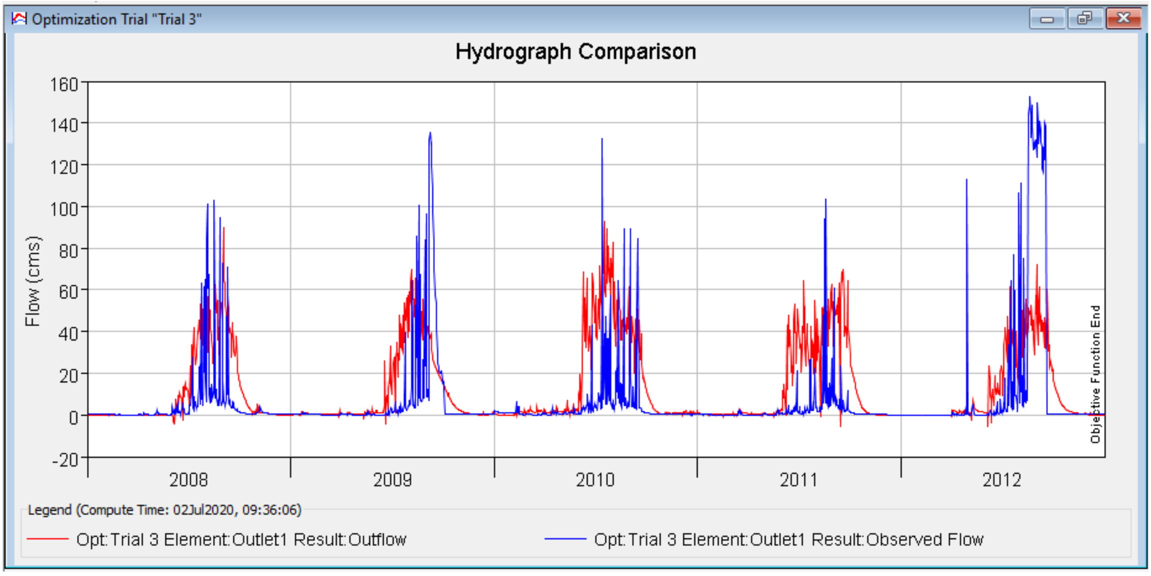


Figure 4.8: Daily flow hydrograph comparison during validation

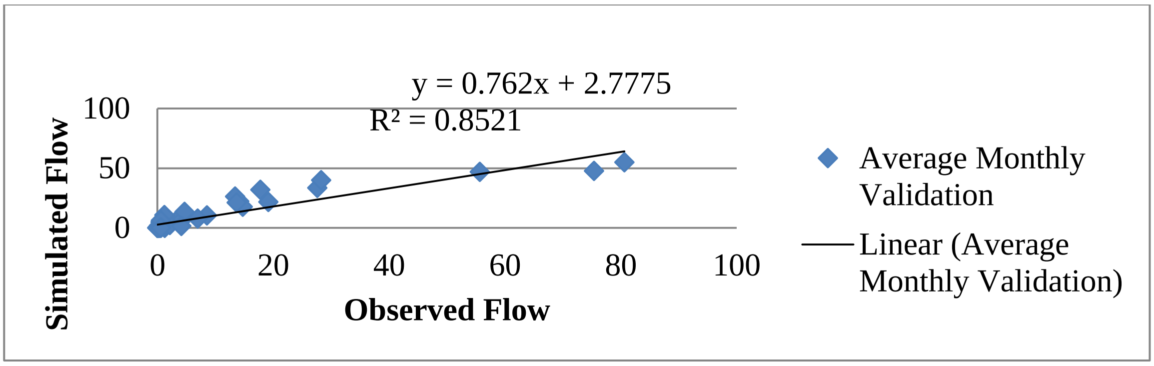


Figure 4.9: Comparison of observed and simulated flow by scatter diagram

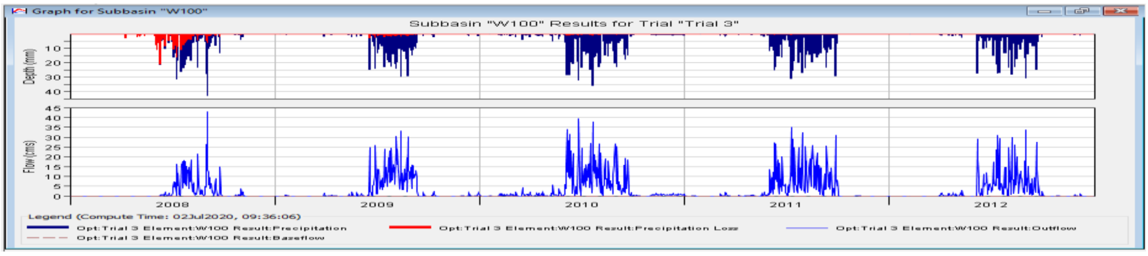


Figure 4.10: Flow comparison at sub-basin W100 during validation

4.2 Frequency Storm and Flood Frequency Analysis

For the case of this study, the main objective of rainfall-runoff modeling was to obtain peak flood at the outlet of the sub-basin that was later used in the computation of flood inundation mapping and it can be used in concerning the flood damage. HEC-HMS measures the frequency storm with a predicted depth of precipitation for a storm with a particular duration and likelihood with exceeding. Flood frequency analysis is to equate the degree of extreme events with their frequency rate of occurrence by using the distribution of chance.

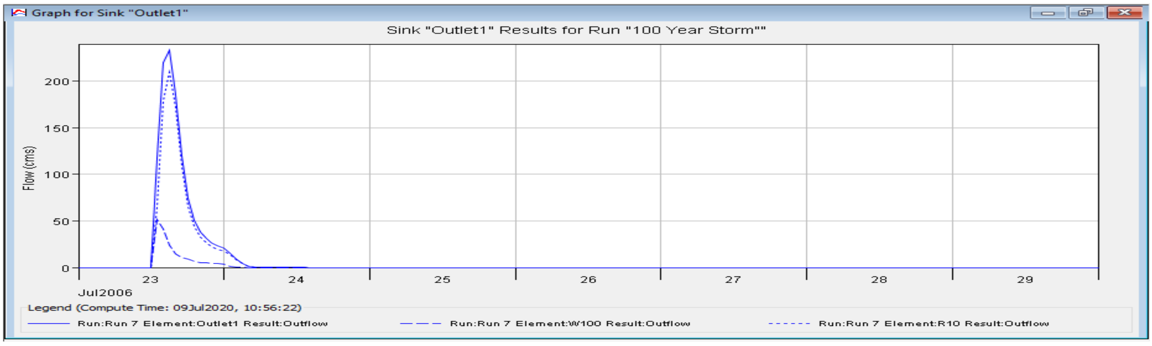


Figure 4.11: Frequency storm of 100 Years at the outlet.

Of course, the outcome of the HEC–HMS model is related to the results of the frequency analysis taking into account various techniques. The methods used in this paper are chosen based on their usefulness and simplicity. According to the Easy curve fit the Gumbel method is chosen and computed as well as compared with the HEC-HMS result.

Table 4.1: Comparison flow data of frequency analysis and HEC - HMS

Year		2	5	10	25	50	100	200	500
Method		Peak Discharge $Q_t(m^3/s)$							
Frequency Analysis	Gumbel Method	87	123	147	177	199	221	243	273
HEC-HMS		62	115	138	173	195	233	258	288

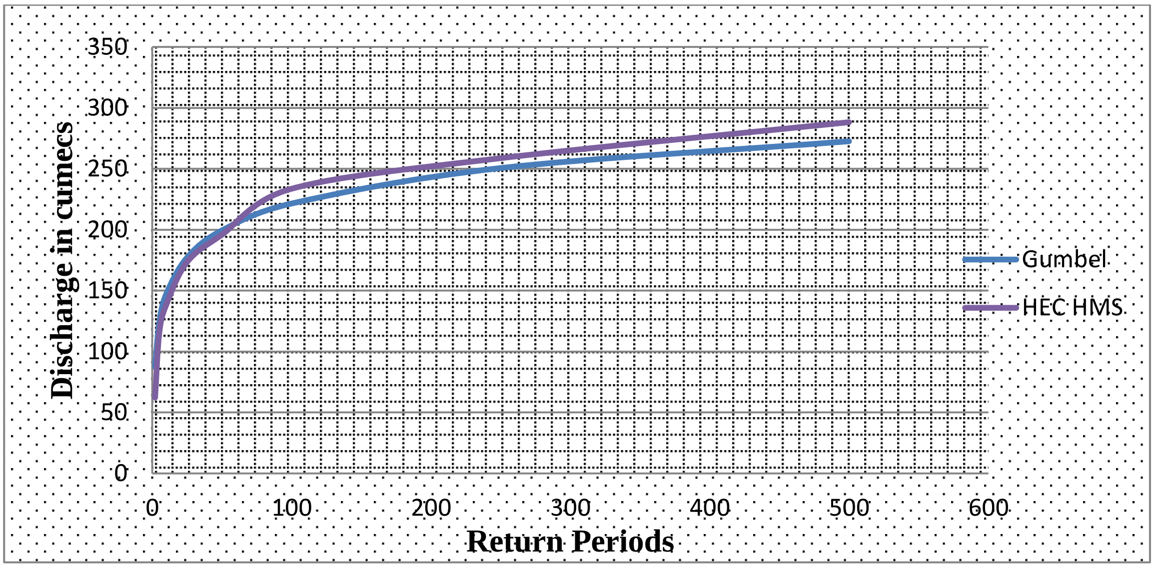


Figure 4.12: Scatter graph comparison of Teji river flow data

The above graph shows that the discharge value estimated by Gumbel's method is highly related to the discharge computed by HEC–HMS. The HEC-HMS estimation value is used as input to the HEC-RAS model to delineate flood plain area.

4.3 HEC-GeoRAS Output

4.3.1 Stream Centerline

In the HEC-GeoRAS river and reach network are represented by the stream centerline layer. The river and reach network is created on a reach basis, starting from the upstream end and working downstream following the Teji river channel. 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.

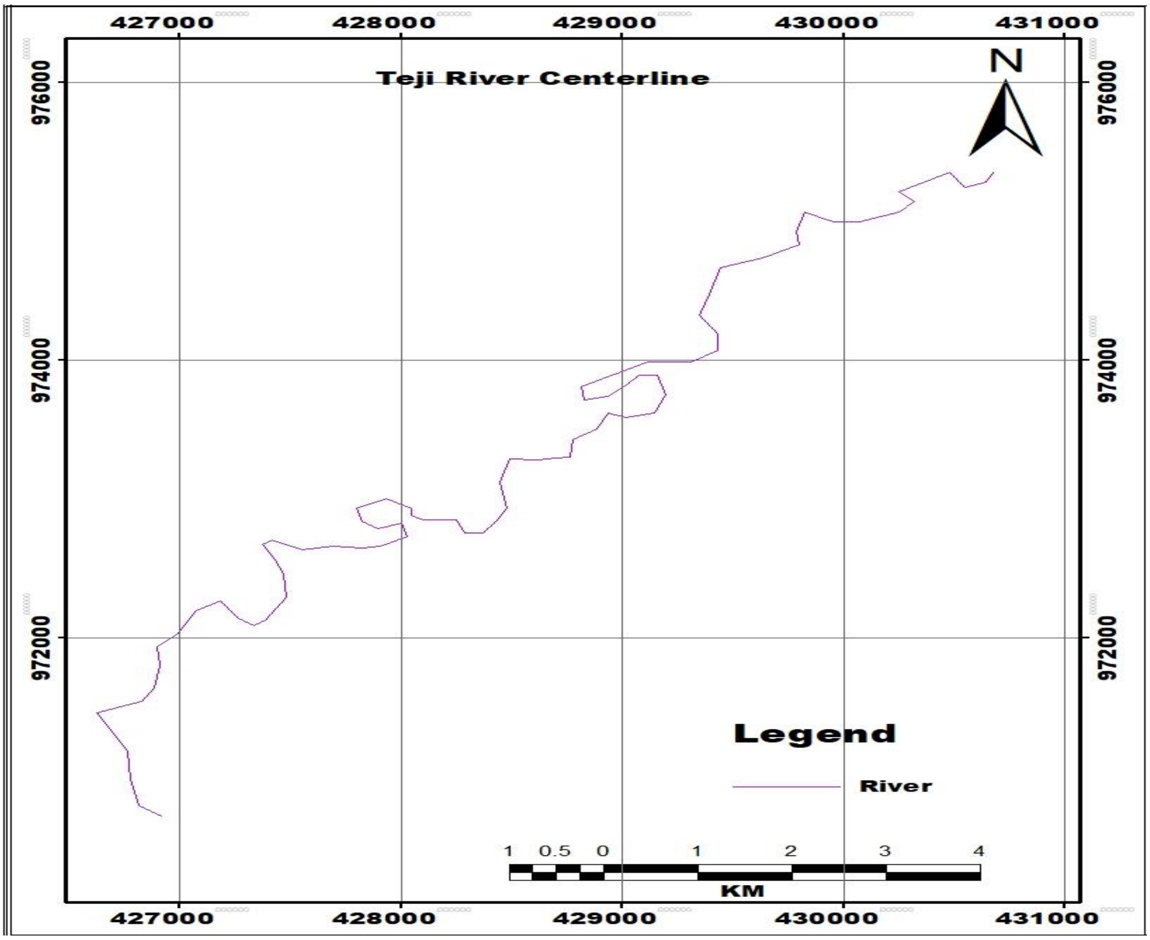


Figure 4.13: Teji river centerline

4.3.2 River Bank Lines

The bank lines layer shows the main channel flow from flow in the over banks. Bank station will be assigned to reach cross-section based on the intersection of the bank lines, with the cut lines. Blank lines are more operative to skip this layer and complete the data in HEC-RAS using graphical cross-section editor tools.

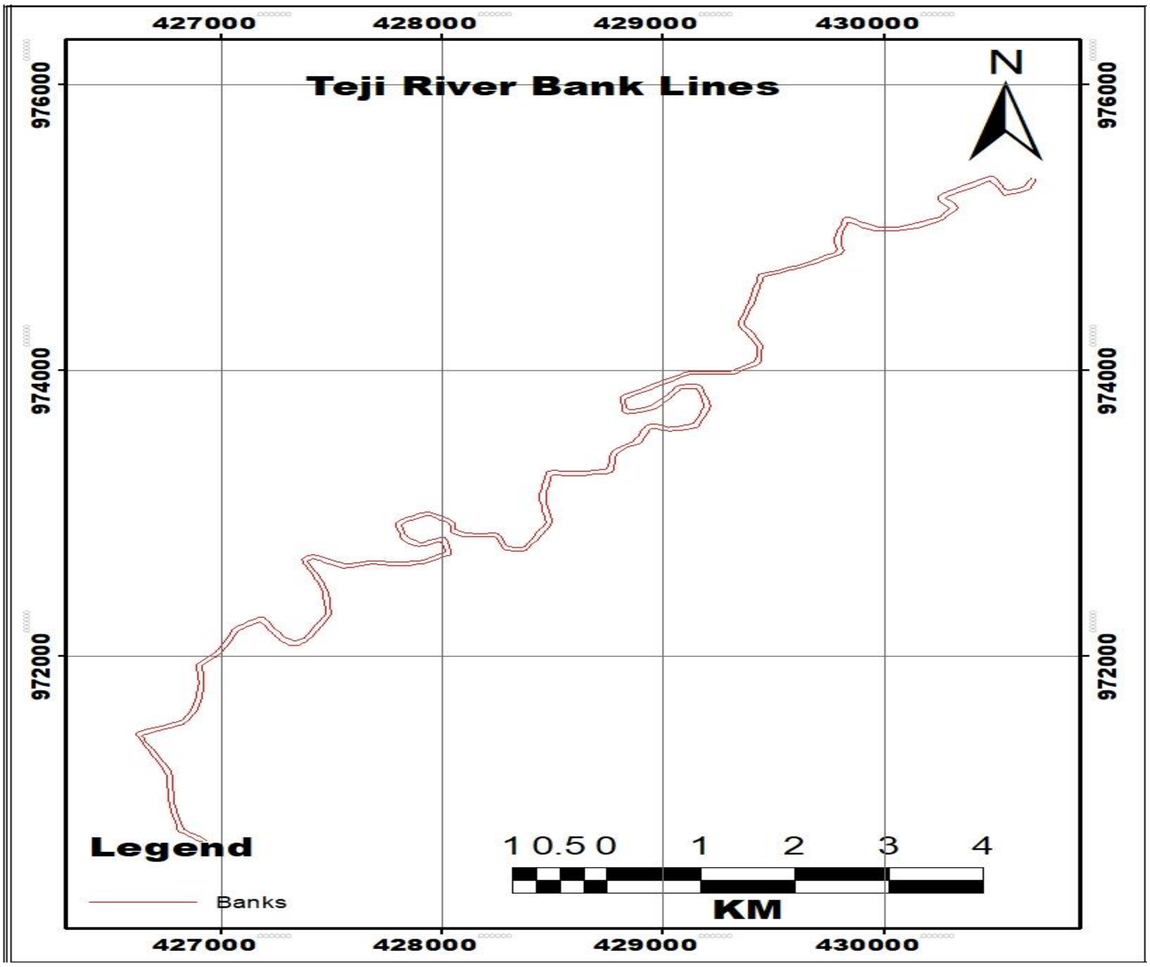


Figure 4.14: Teji river bank lines schematic view

Generally, the bank lines help for: -

- To allocate bank stations
- Calculate the overbank flow path, and
- Assist as the difference between channel and floodplain roughness

4.3.3 Flow Path Center Lines

The flow path centerline is the line that travels to the lowest point of each cross-section of the main channel. It has to pass for every particular cross-section point. Flow path lines are used to describe the lengths of the downstream reach between cross-sections in the main channel and bank areas.

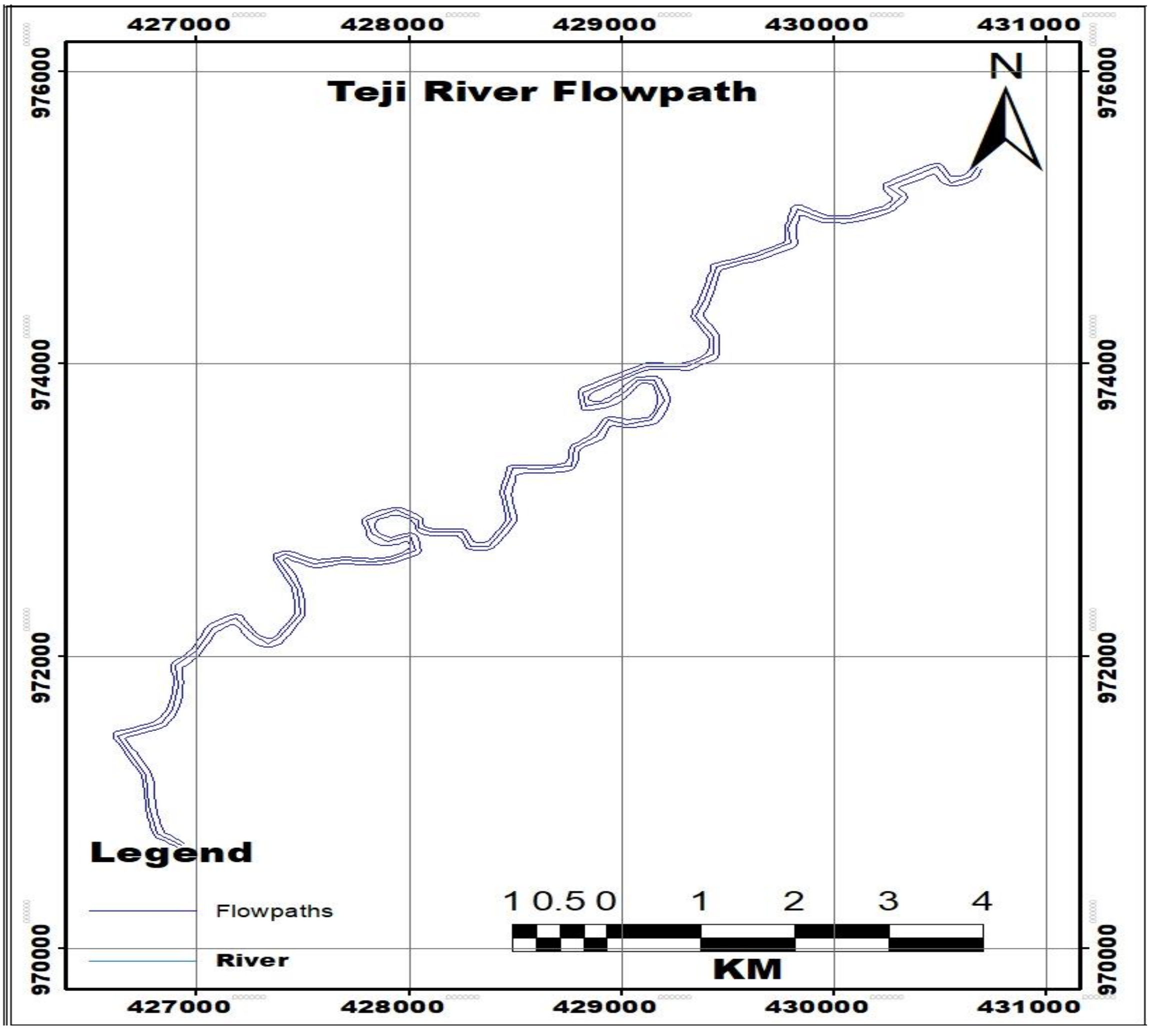


Figure 4.15: Flow path schematic view

4.3.4 Cross-Section Cutlines

Cross-section cut lines are used to collect elevation data from field data to establish a ground profile through the channel flow. The intersection of cut lines with other RAS layers, such as stream centerline and flow path lines, is used to measure HEC-RAS attributes, such as bank stations (locations that distinguish the main channel from the flood plain), downstream reach lengths (distance between the cross-section) as well as manning's coefficient n. It is therefore important to establish a sufficient number of cross-sections to provide a reasonable representation of the channel bed as well as the floodplain.

Guidelines for the formation of cross-section cut lines

- Cross-section cut lines are perpendicular to the direction of flow
- Cross-section cut lines should reach over the entire flood extent and
- All the time digitize from left to right (to downstream)

While it is not mandatory, it is a good practice to ensure a continuity of spacing between cross-sections.

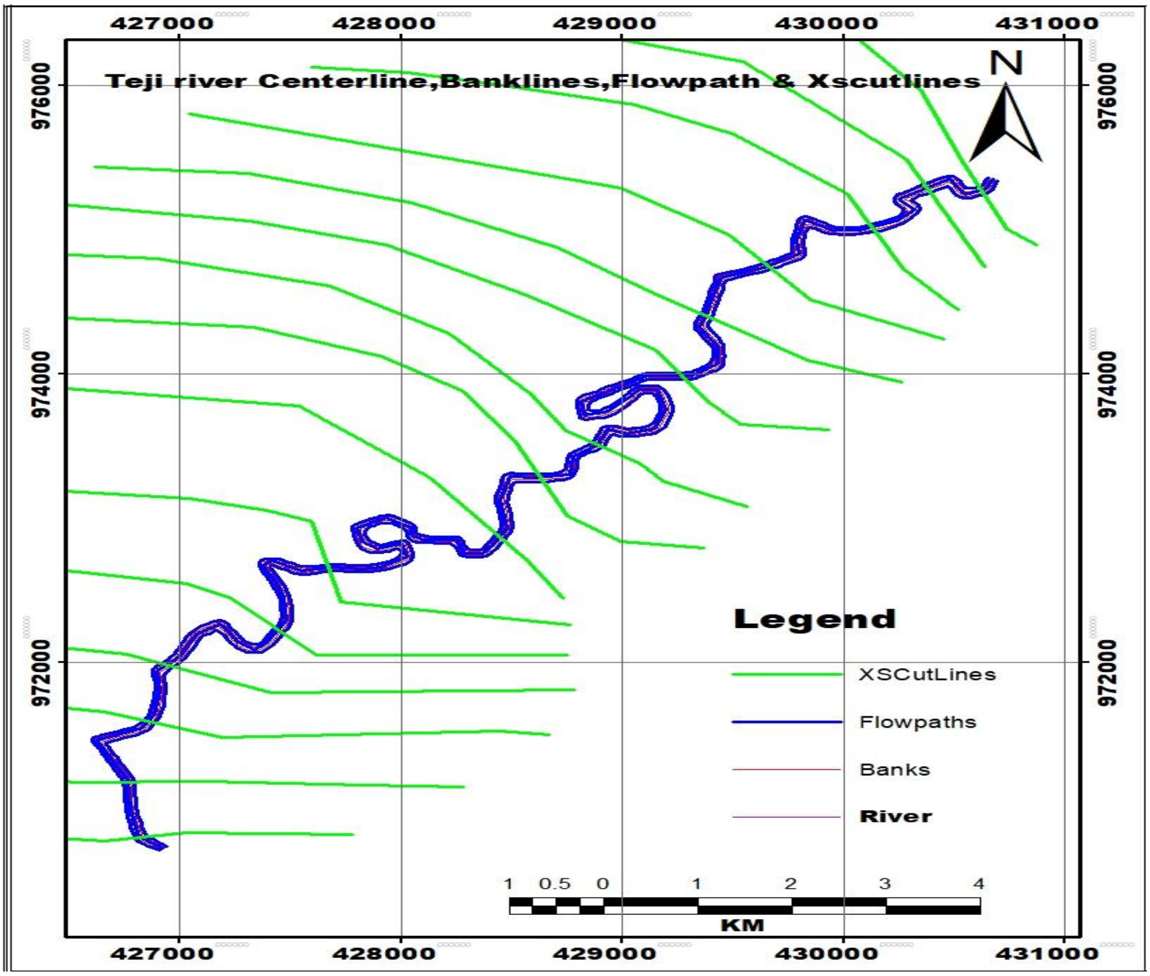


Figure 4.16: Teji river cross-sectional cut lines

4.4 HEC-RAS Output

In the HEC-RAS model, using seventeen years of meteorological data of the study area, flood discharges for different return periods 2, 5, 10, 25, 50, 100, 200, 500 years were calculated. Manning roughness coefficient is estimated/obtained/ using the Cowen method according to equation 3.10.1. Boundary conditions of the model are taking into account considering the upstream and downstream slopes of the Teji river in the study area. Finally, the model is implemented for the return period. The model output will be used as input to the HEC-FDA model. Representative graphical outputs of the model are shown in fig below, and the complete graphical and tabular outputs are shown in Appendix C.

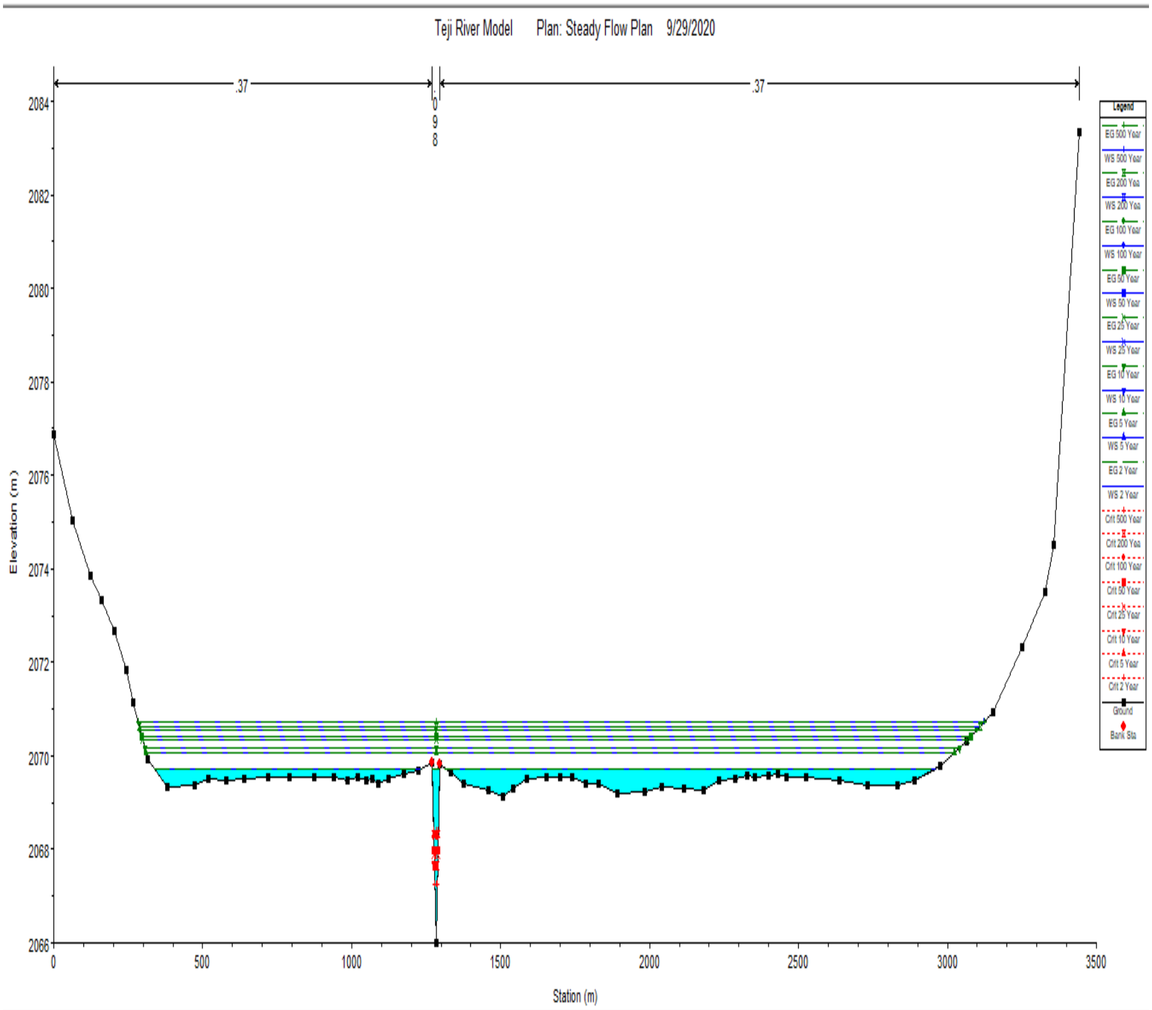


Figure 4.17: Section of Teji river reach HEC-RAS model

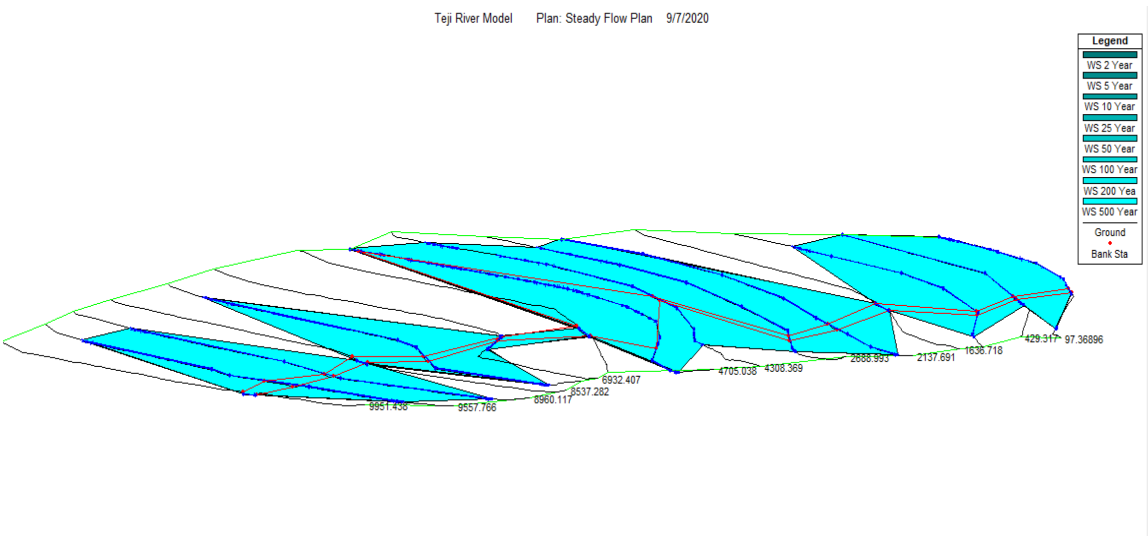


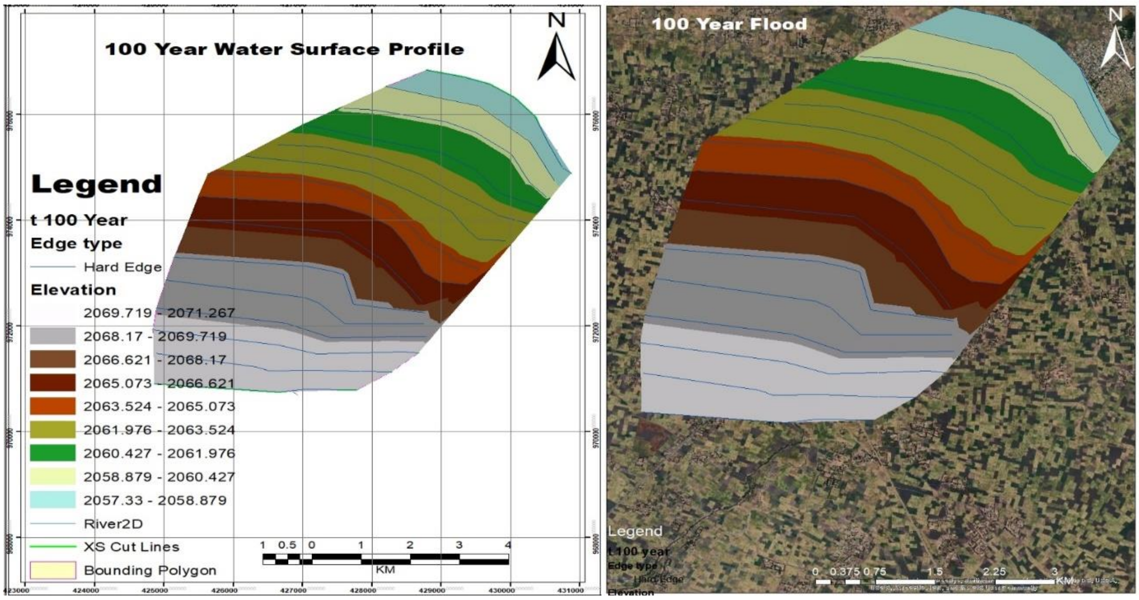
Figure 4.18: Profile of Teji river HEC-RAS model

4.5 Flood Plain Mapping

To obtain maps of the flood plain, according to earlier stages we can obtain flood plain maps in the HEC-GeoRAS model, for any return period and compare these flood plain in Arc-GIS. The detailed procedures are set out in sections 4.3.1 and 4.3.2 respectively.

4.5.1 Water Surface TIN Generation

Water surface elevation, as well as terrain-water surface interface position data for each flood event, were extracted from HEC-RAS and transferred to GIS cross-section files to produce a TIN water level. Flooded regions, where water surface elevations surpass ground elevations, can then be viewed in a 3-D format by overlaying the TIN terrain in Arc-Scene. The name of the water surface TIN was established. The water surface TIN created was named as the "t" concatenation and the name of the water surface profile (e.g. t100 years) and saved to the output directory defined in the layer configuration. After the water surface TIN has been produced with the elevation of the water surface for the selected profile, it is now applied to the map.



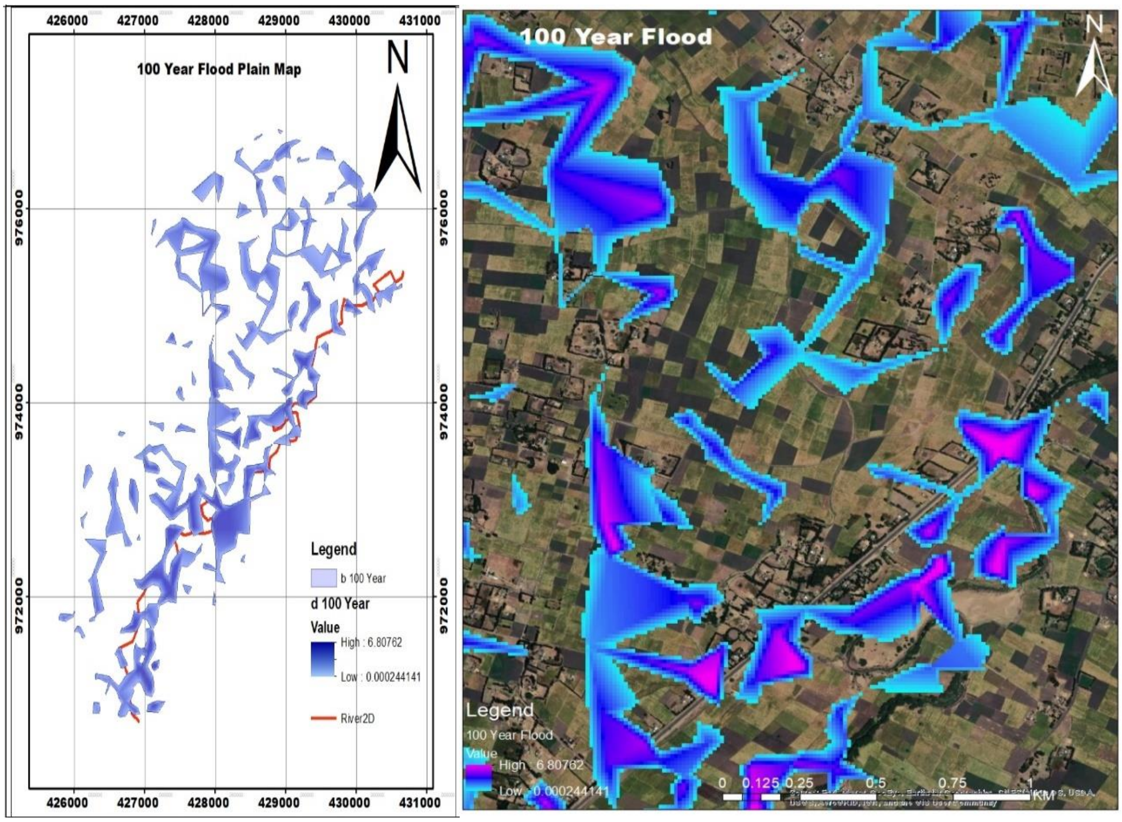
a) Bounding Polygon Water Surface b) Water Surface Google Earth Overlay

Figure 4.19: Water surface generated for t100 Year with Study area overlay

As shown in the above figure Arc-GIS triangulation method creates the surface TIN using cross-section cut lines and connecting the outer points of the bounding polygon, so that the TIN was included in the area outside the possible inundation.

4.5.2 Floodplain Delineation Using Raster

Flooding occurs to a depth equal to the difference between the water-surface TIN and surrounding terrain TIN. Converting both TIN themes into grids allows for the subtraction of the elevation data using the raster calculation in GIS. Then the theme of terrain raster is subtracted from the theme of the water surface grid to construct a map of the flood depth. The flow depth at this point is given by using the query tool in GIS and clicking on any point within the floodplain. To develop an integrated data query model, the cross-section geometry data and for each event considered are extracted from the cross-section mapping results and the water surface TIN model. Using the GIS data query method, a data query is achieved by simply clicking on the cross-section cut-line. Fig below is an example of the kinds of information that can be collected by using these query models at a specific station on the river.



a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure 4.20: A portion of the inundated plain area of Teji river for the 100-year flood event

From the attribute table of the polygon of the flood extent, the inundation area was displayed and used for the analysis of the flooding effect with crop yield/ha. The extent of inundation areas for the floods of different return period's floods is shown in the table below. Flood inundation map for each return period tabulated in Appendix C.

Table 4.2: Flood inundation area

Return Period	2	5	10	25	50	100	200	500
Flow(m^3/s)	62	115	138	173	195	233	258	288
Inundated area(ha)	308.02	422.68	459	507.39	535.49	574	598	622.50

By superimposing the return period-wise flood inundation map on the land use map of the study region, the affected areas have been estimated for the above-mentioned return periods. Usually, for all return times, most agricultural land and settled areas would be affected.

4.6 Flood Damage Analysis

Houses in the study area construct from wood, grasses, and mud walls that are simple to reconstruct. The surveyed houses were seriously damaged by the 2011 E.C flood, and inundated for hours and days. On the other hand, the surveyed households said that as a result of the flood their properties were seriously damaged. The households also said that the flood cause health problems and causalities. The households in the focus group also mention that due to flood many elderly people and children got sick during the flood, particularly due to diarrheal disease, caused by the intrusion of river water into wells.

The study of flood damage in the Teji River Teji region, for present (current) structures in the model, in particular, the model is run under existing conditions. First, we divide the damage type into two according to damage report from the woreda flood risk management and preparedness office into agricultural and residential. The hydraulic and hydrological flow data shall be entered for the return periods of 2, 5, 10, 25, 50, 100, 200, and 500 years. The output of the HEC-RAS model is then stored in the HEC-FDA format and the product of the FDA model is used as input. In other words, these flood depth values are used for different areas.

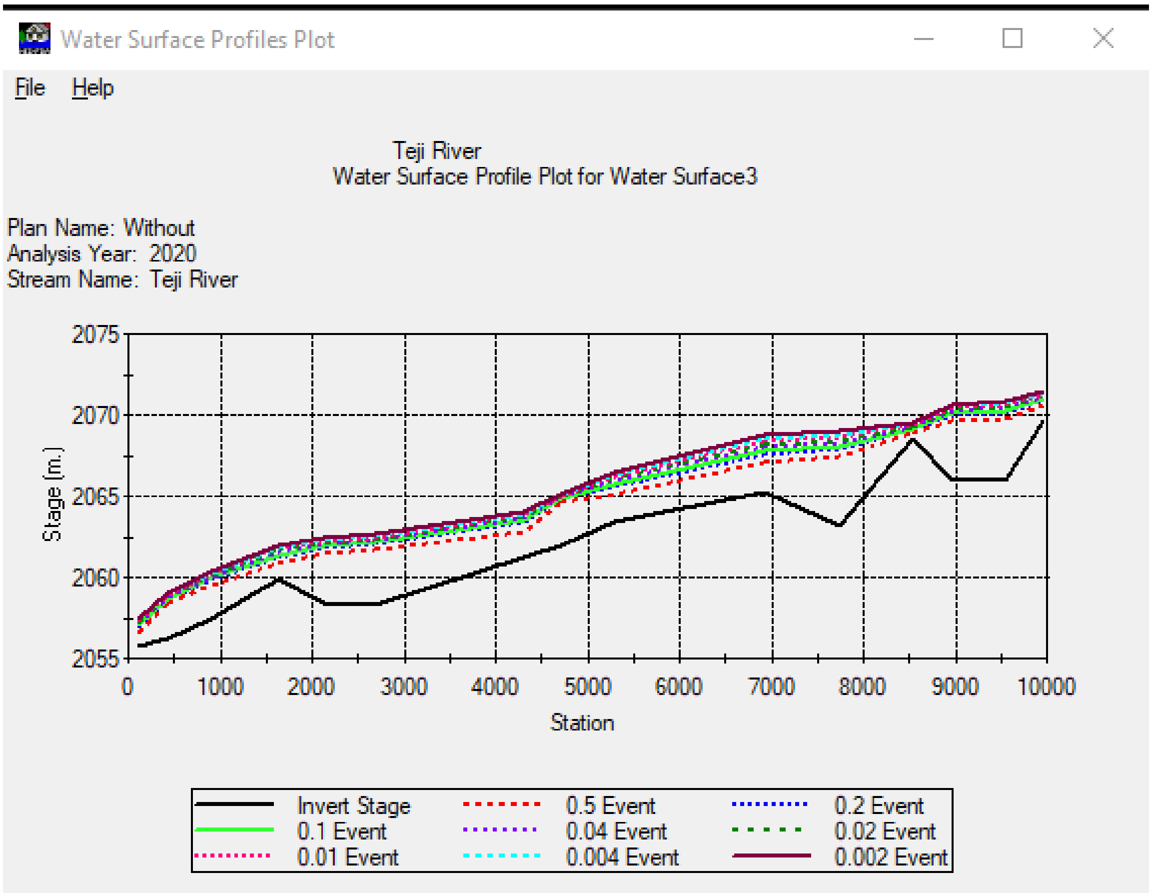


Figure 4.21: HEC-FDA model water surface profile plot

4.6.1 Structural Damage Analysis

Structural damage is related to a class of structures with the same average economic loss. The data used for structural damage shall be extended to all structures related to that type of structure. All systems are divided into area one and area two based on the counter variable. The total houses of 867 for area one located in Buti Talgo and Alango Tulu Keble and 309 located in Bill and Wasirbi Basii Teji Region are estimated to be ground level during the survey with GPS, the counter of Arc-GIS and also google earth.

Table 4.3: Structural occupancy ground level estimation

Type of Occupancy	Number Houses	Contour level	Average Ground Level	Standard Deviation
Area1	867	2072-2058	2065	4.32
Area2	309	2079-2065	2072	4.32

Figure 4.22: Contour interval used to estimate structural ground level.

4.6.2 Estimation of Structural Damage Cost

The cost of structural damage is the maintenance cost of poorly damaged mud walls, and mud disposal deposited in the home due to flood is estimated by randomly sampling homes in the USA dollar. According to random sampling of fifteen (15) households in each keble namely Buti Talgoo, Alangoo Tulluu, Wasarbi Basii, and Bilii (Table 3.2), the average structural damage is 112$ for one household. Fifteen household is selected due to time constraint, economic constraint, the density of household, and the scope of the study. The estimation considers the current market value of structure maintenance.

4.6.3 Estimation of Content Damage Cost

Content damage cost is the estimation of damaged content of household during a flood that includes household food, animal meal, and home material lost. According to random sampling of fifteen households, the average content damage is 365$.

4.6.4 Estimation of Other Damage Cost

The estimation of other damage cost considers mainly the agricultural land loss to crops. According to equation 3.12, the major crops cultivated in the woreda with cost/ha are calculated for different return periods. The yield per/ha is tabulated in Appendix A.

Taking into account the collected data file referred to above, by running a flood damage analysis model with HEC-FDA, the expected annual damage (EAD) over the full range analyzed, which is the amount of the expected annual damage, as follows: EAD:

2,962,832.59$(Two Million Nine Hundred Sixty-Two Thousand Eight Hundred Thirty-Two Point Five Nine Dollar).

File Help

Teji River
Equivalent Annual Damage by Damage Categories and Damage Reaches
for the Without (Without project condition Default) plan
(Damage in $'s)

Discount Rate: 4.000
Analysis Period: 30 Years
Plan was calculated with Uncertainty
Version 1.4.2, July 2017; Less Simple Method (0.010)

Stream Name	Stream Description	Damage Reach Name	Damage Reach Description	Equivalent Annual Damage or Damage Categories		Total Damage
				Agricultural	Residence	
Teji River	Teji River Flood Damage Analysis	Reach	Teji River Flood Damage Analysis	1078.34	2961754.25	2962832.59
	Total for stream: Teji River			1078.34	2961754.25	2962832.59

Figure 4.23: HEC-FDA model output equivalent annual damage

4.7 Flood Plain Management

4.7.1 Levee Assigning

A levee is primarily used to stop the floods by controlling the river and not by training the river. In the HEC-FDA model, levee was applied to the river and flood control system (USACE, 2016). The levee size, the failure characteristics, and the relationship between the inside and the outside of the levee point have been defined in the levee features.

4.7.2 Levee Height

The levee height was calculated by adding a 100-years flood level to a required freeboard (equation 3.14). The 100-year flood stage in the river is 2068.25 m above sea level. Recommended freeboard for 233 $m^{3/}s$ was 0.8 m. Top levee height becomes 2069.05 m above sea level. A levee height is 3.05 m above the average ground level. The average ground level is about 2066 above sea level.

4.7.3 Characteristics of Levee Failure

Levee failure characteristics were determined by the type of levee and structural stability. Levee failure may happen due to characteristics of with a probability of technical failure of the Geo-technical. Levee was constructed a year ago or required a detailed design levee to estimate the failure characteristics. The scope of this analysis was limited to the estimate of damage minimized by the provision of levee. In this analysis, a levee was not likely to have a geo-technical failure is considered.

4.7.4 Levee Water Stage

The water surface stage in the outer side of the levee is determined by the water surface profile computed by HEC-RAS. Interior water stage was happened due to inland flooding. Inland floods were caused by localized torrential rain, which could not be drained by gravity due to the high water level in the river.

Table 4.4: External and internal water levels in the suggested levee

Exterior Stage (m)	Interior Stage (m)
2058.13	2066
2059.75	2066
2061.01	2066
2062.59	2066
2063.29	2066
2064.66	2066
2065.72	2066
2066.86	2066
2069.30	2066
2069.54	2066
2070.20	2066
2071.19	2066
2071.35	2066
2072.07	2066

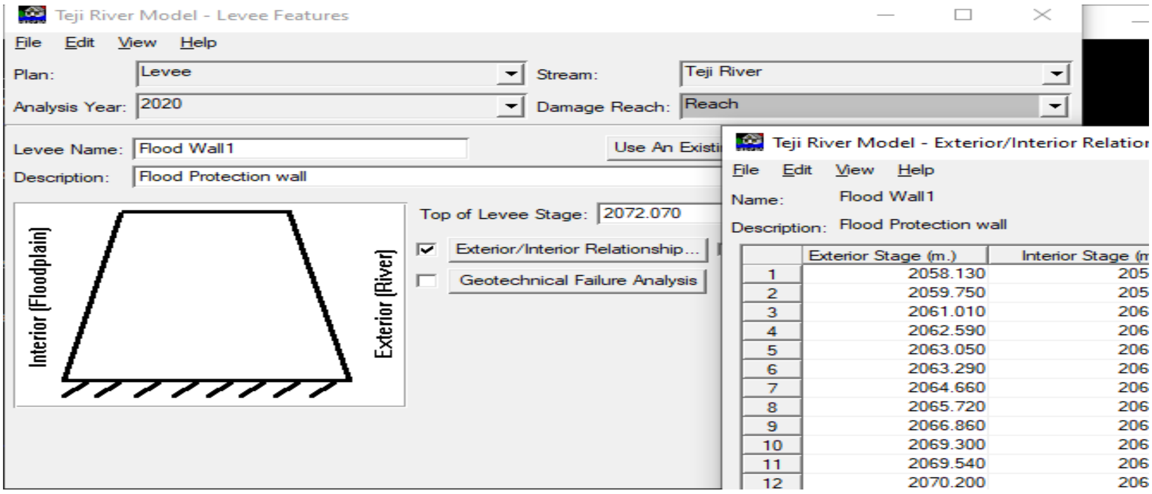
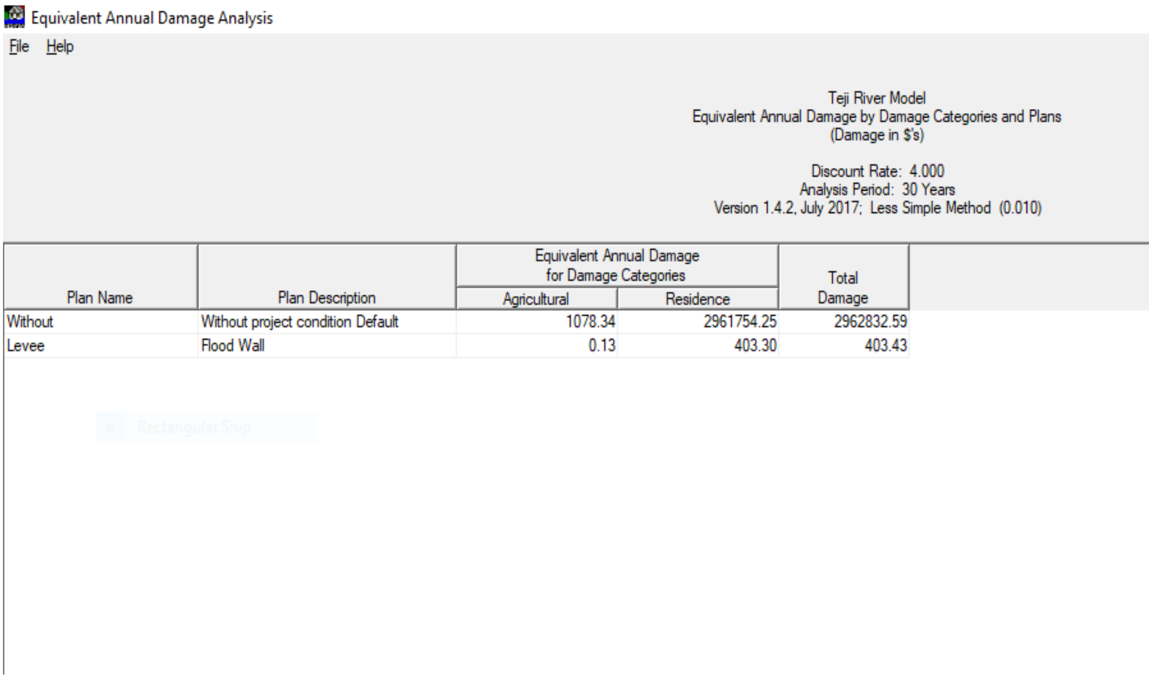


Figure 4.24: Assignment of the levee to the river in the HEC-FDA model

Using the HEC-FDA model the Expected and Equivalent, the annual amount of damage was reduced for various overrun probabilities calculated. Total economic loss \$2,962,832.59 estimated annual damage without a project. By having a levee, we will reduce the loss to \$403.43 annually.


Equivalent Annual Damage Analysis

Teji River Model
Equivalent Annual Damage by Damage Categories and Plans
(Damage in \$'s)

Discount Rate: 4.000
Analysis Period: 30 Years
Version 1.4.2, July 2017; Less Simple Method (0.010)

Plan Name	Plan Description	Equivalent Annual Damage for Damage Categories		Total Damage
		Agricultural	Residence	
Without	Without project condition Default	1078.34	2961754.25	2962832.59
Levee	Flood Wall	0.13	403.30	403.43

Figure 4.25: HEC-FDA model schematic view reduction of economic loss by the levee

By incorporating levee, the HEC-FDA statistics indicate that damage occurred was reduced to 403.43\$.

Chapter 5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In the Illu woreda Teji area, the major source of the flood is the Teji River over flooding due to rainfall in the upper catchment. The flood happens because of accelerated showers as well as sloped of the upper catchment.

This study provides a systemic approach to flood damage analysis and flood plain management. The main model used in this study is ArcGIS, HEC-GEORAS, HEC-GeoHMS, HEC-HMS, HEC-RAS, HEC-FDA, Google Earth, and easy curve fit. Flood plain mapping, one-dimensional steady flow analysis, and flood damage analysis, and flood plan assessment are powerful tools to produce more reliable, accurate, and standardized results and save time and money. HEC-FDA offers a new perspective for assessing flood damage and analyzing flood structure

Study of the damage caused by flooding in the Teji River Teji area, existing structures in the direction of flow, is considered in the model. In other words, the model is run on current conditions. Coming up I divided the damage categories into two, agricultural and residential, according to the flood risk management and preparedness office survey. The hydraulic and hydrological flow data shall be entered for the return periods of 2, 5, 10, 25, 50, 100, 200, and 500 years. Thus, the HEC-RAS model output is stored in the FDA format and the HEC-FDA model is used as input. Considering the input data for the model, the next steps would automatically estimate the economic damage. Taking into account the data set, by running the flood damage analysis model with HEC-FDA, the estimated annual economic damage (EAD) for the entire study period, which is actually the amount expected annual damage, is $2,962,832.59. In the meantime, flood control measures were done. Using the HEC-FDA model levee is considered and the damage is reduced to 403.43$. Formerly there is no flood management plan in the area. Therefore flood control plans, are required.

5.2 Recommendation

Depending on the outcome of this study, the next recommendation and suggestions were made.

- DEM of the study area has low-resolution quality therefore Ministry of Water Irrigation and Energy should revise if possible
- According to my study result by assigning a levee to the flood plain area the economic damage reduced from 2,962,832.59$ to 403.43$, therefore constructing a levee is proposed to take care of the society.
- Future studies should consider climate change impact as well as adaptation to climate change.
- The government should help the affected community to re-construct their houses and distribute seed and agricultural inputs to communities whose crops have been washed away by the floods.

REFERENCES

1. ALASKA Satellite Facility website (https://vertex.dac.asf.alska.edu)
2. A. R. Rao And K. H.Hamed,(2000) Flood Frequency Analysis. Boca Raton: Crc Press Llc,
3. Applied Hydrology Course Manual by Dr. Agizew Nuguse, (2017)
4. Chow, V. T., Maidment, D. R. and Mays, L. W., (1998) Applied hydrology. New York: McGraw Hill.
5. Corria F.N. (1999), Flood plain management in urban developing areas. Part II. GIS based flood analysis and urban growth modelling, Berlin.doi.10.1023/A:1008045419517.
6. David Butler and John W.Davies, (2011), 3rd Edition Urban Drainage
7. DPPA, (2006) Joint Government and Humanitarian Partners: Flash appeal for the flood disaster in Ethiopia.
8. El-Naqa, A. and N.A. Zeid (1993) "A program of frequency analysis using Gumbel's Method." Ground Water 31(6): 1021-1024.
9. Ethiopian Roads Authority Drainage Manual (ERA, 2013).
10. Ethiopian Roads Authority Drainage Manual (ERA, 2002).
11. Federal Democratic Republic of Ethiopia (2018) National Disaster Risk Management Commission, Early Warning, and Emergency Response Directorate (revised flood alert).
12. Floods and health in Gambella region, Ethiopia: An Assessment of the strength and weakness of the coping mechanism May 2008)
13. Geohazards (2009). "Applied earth sciences: Geo hazards, process modeling multi hazard risk assessment. enschede :ITC".
14. G.W.Brunners "calibration of unsteady flow models" Vol.10.No.May,Pp.1-42,(2008)
15. Illu Woreda Agricultural and Rural Development Office, (2011 E.C) Report.
16. Illu Woreda Flood Risk Management and Preparedness Office, (2011E.C) Report.
17. International Journal of Engineering Research and Technology (IJERT), (2015)
18. Joint Government–Humanitarian Partners National Flood Contingency plan, (2018 kiremt).
19. Journal of Water Resources and Hydraulic Engineering (Sep 2014)

20. K. Subramania, (2008) Engineering Hydrology. 3 rd Edition New Delhi McGraw Hill.
21. Manual on Flood Control Planning, March 2013
22. Negese Roba, (2017) Flood Hazard Mapping and Damage Analysis for Meki River Using, HEC-RAS and HEC-FDA models, MSc thesis, Addis Ababa University, Ethiopia.
23. Okirya Martin, Albert Rugumayo and Janka Ovcharo Vichova, (2012), Global Journal of Engineering, Design, and Technology.
24. OECD, 2016, Financial management of flood risk, http://dx.doi.org/10.1787/9789264257689-en
25. OECD (2016), Financial Management of flood risk.
26. Report from UN Office for the Coordination of Humanitarian Affairs Published on 18 Oct 2017.
27. Robson, A. and D.Reed (1999). Flood estimation hand book: FEH: statistical procedures for flood frequency estimation: FEH flood peak data. Walling ford, Institute of hydrology.
28. Santos Kumar Garg, (2005) Irrigation Engineering and Hydraulic Structures
29. S.A. Mohammadi et al, (2014) flood damage estimate, using the HEC-FDA model Journal.
30. Smyth, G.K. (2003). "Pearson's goodness of fit statistic as a score test statistics. Science and statistics".
31. USACE, (2008) HEC-FDA, User's Manual. California: US Army Corps of Hydrological Engineering Center.
32. USACE, (2000) HEC-GeoHMS Geospatial Hydrologic Modelling Extension.
33. USACE, (2009) HEC-GeoRAS, User's Manual. California: US Army Corps of Hydrological Engineering Center.
34. USACE, (2013) HEC-HMS Hydrologic Modeling System User Manual
35. Yilema Seleshi (Dr), (2005), Engineering Hydrology.
36. USACE, (2016). HEC-RAS River, Hydraulic Reference Manual. California: US Army Corps of Hydrological Engineering Center.
37. United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/)
38. Urban Drainage 3rd Edition David Butler and John W.Davies, (2011)

39. Webeshet Hailu, (2019), Flood Damage Analysis Using HEC-FDA Software (In case of Upper Awash Sebata - Awas Woreda), MSc thesis, Addis Ababa University, Ethiopia.
40. Wondwosen Dejenne, (2011), Flood Modelling Using 2D Hydrodynamic Model in the Fogera Flood Plain, MSc thesis, Addis Ababa University, Ethiopia.
41. Zelalem Abera, (2011), Flood Mapping and Modeling on Fogera Flood Plain: A case study of Ribb River, MSc thesis, Addis Ababa University, Ethiopia.

APPENDIX A

Table1: Study Area Crop Types, Cultivated land, and yield per ha of 2012 E.C Year

No.	Illu Woreda Crop Types, Cultivated land and Yield Per Ha of 2012 Year																
	Kebele	Teff		Weat		Barly		Maize		CheackPea		GrassPea		Lenti		Bean	
		ha	Kun	ha	Kun	ha	Kun	ha	Kun	ha	Kun	ha	Kun	ha	Kun	ha	Kun
1	Tulu Manguraa	856	21400	337	10110	4	20	50	1900	340	8160	154	4004	9	150	8	160
2	Alango Tulluu	767	15340	60	2220	2	32	37	1369	401	9624	126	3150	106	1696	2	40
3	Billi	923	25844	256	9728	4	160	41	1968	240	6720	80	2640	98	1960	9	198
4	Wasarbii Naaddoo	619	15475	164	5904	0.5	8.5	33	1584	159	3975	71	2272	37	481	8	168
5	Wasarbii Baasii	720	15840	350	10850	1	14	42	1344	300	8700	134	4154	77	1386	4	80
6	Kulee Asgorii	800	21600	312	9984	1	18	60	3300	305	7917	125	3250	23	450	5	18
7	Butii Talgoo	589	11780	196	6664	2	30	30	1230	364	8736	194	5044	80	1520	3	60
8	Amdoo Quncoo	542	9756	327	12418	10	36	46	1838	335	8375	219	5694	125	2375	3	60
9	Kulee Gafarsaa	915	19215	342	15310	2	81	52	3380	265	6360	193	5018	93	1767	10	210
10	Bantuu Aliitoo	790	15800	208	7488	3	57	33	1155	346	8304	207	5175	76	1520	6	126
11	Wareersoo Qaliina	326	6520	15	120	3	30	44	1056	431	9482	170	3910	190	4180	3	66
12	Jigduu Midaa	630	12600	31	1302	2	42	38	2432	424	13568	68	2244	305	6710	4	92
13	Muloo Sattey	725	13500	45	895	12	160	64	1747	385	9625	248	6248	130	2450	14	93
14	Duwaa Bisee	1006	23944	289	13601	2	42	30	1140	164	3936	65	1625	15	270	15	3100
15	Dugdaa Luugoo	890	16910	335	8040	1	22	45	1215	310	7750	122	3172	95	1900	1	15

Source: Woreda Agricultural and Rural Development Office

APPENDIX B

Figure1: Teji River characteristics View March, 2020

Figure2: Taking Teji River Cross-Section March, 2020

Figure3: Taking Teji River Depth and Width, March 2020

Table2: Manning Roughness for the river (channel)

	Channel Condition	"n"	Description, Example
Degree of Irregularity (n_1)	Smooth	0.00	Compares to the smoothest channel attainable in a given bed material
	Minor	0.01- 0.005	Compares to carefully dredged channels in good condition but having slightly eroded or scoured side slopes.
	Moderate	0.006-0.010	Compares to dredged channels having moderate to considerable bed roughness and moderately sloughed or eroded side slope
	Severe	0.011-0.020	Badly sloughed or scalloped banks of natural streams; Badly eroded or sloughed sides of canals or drainage Channels: unshaped, jagged, and irregular surfaces of the canal in rock
Variation In Channel	Gradual	0.000	The size and shape of channel cross-sections change gradually.

Cross Section (n_2)	Alternative occasionally	0.001-0.005	Large and small cross-sections alternate occasionally, or occasionally the main flow shifts from side to side Owing to changes in cross-sectional shape.
	Alternative Frequently	0.01-0.015	Large and small cross-sections alternate frequently, or frequently the main flow frequently shifts from side to side owing to Changes in cross-sectional shape.
Effect of Obstruction(n_3)	Negligible	0.000-0.004	A few scattered obstructions, which include debris Negligible deposits, stumps, exposed roots, logs, piers, or isolated boulders, that occupy less than 5 percent of the cross-sectional area
	Minor	0.005-0.015	Obstructions occupy less than 15 percent of the cross-sectional area and the spacing between obstructions are such that the sphere of influence around One obstruction Minor does not extend to the sphere of influence around another obstruction. Smaller adjustments are used for curved smooth-surfaced objects than are used for sharp edge irregular objects.
	Appreciable	0.02-0.03	Obstructions occupy from 15 to 50 percent of the cross-sectional area or the space between obstructions is Appreciable small enough to cause the effects of several obstructions to be additive, thereby blocking an equivalent part of a cross-section
	Severe	0.04-0.05	Obstruction occupies more than 50 percent of the cross-sectional area or the space between obstructions is Small enough to cause turbulence across most of the cross-section.
Amount of vegetation (n_4)	Small	0.002-0.01	Dense growths of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation; supple tree seedlings such as willow, cottonwood, arrowed, or salt cedar growing where the average depth of flow is at least three times the height of the vegetation.
	Medium	0.010-0.025	Turfgrass growing where the average depth of flow is from one to two times the height of the vegetation moderately dense steamy grass, weeds, or tree

			seedlings growing where the average depth of flow is from two to three times the height of the vegetation: brushy, moderately dense vegetation, similar to l- to 2-year-old willow trees in the dormant season, growing along the banks and no significant vegetation along the channel bottoms where the hydraulic radius exceeds 2 feet
	Large	0.025-0.050	grass growing where the average depth of flow is about equal to the height of vegetation: 8- to lo-year old willow or cottonwood trees intergrew with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 feet; bushy willows about 1-year-old intergrown with some weeds alongside slopes (all vegetation in full foliage) and no significant vegetation along channel bottoms where the hydraulic radius is greater than 2 feet.
	Very large	0.05-0.10	Turfgrass growing where the average depth of flow is less than half the height of the vegetation: bushy willow Very large trees about 1 year old intergrown with weeds alongside slopes (all vegetation in full foliage) or dense cattails growing along channel bottom; trees intergrown with weeds and Brush (all vegetation in full foliage).
Degree of Meandering (m)	Minor	1.0	The ratio of channel length to valley length 1.0 to 1.2
	Appreciable	1.15	The ratio of the channel length to valley length is 1.2 to 1.5.
	Sever	1.30	The ratio of the channel length to valley length is Greater Than 1.5.

Table3: Manning Roughness for Flood Plain Source (G.W. Brunner, 2008)

	Flood Plain Condition	"n"	Example
Degree of Irregularity(n_1)	Smooth	0.000	Compares to the smoothest, flattest flood Plain attainable in a given bed material.

	Minor	0.001-0.005	Is a flood plain with minor irregularity in Shape. A few rises and dips or sloughs May be visible on the flood plain.
	Moderate	0.006-0.010	Have more rises and dips. Sloughs and hummocks ay occur
	Sever	0.011-0.02	The flood plain is very irregular in shape. Many rises and dips or sloughs are visible. Irregular ground surfaces in pastureland and furrows perpendicular to The flow is also included.
Variation of Floodplain Cross Section (n_2)	Not Applicable	0.000	
Effective of Obstruction (n_3)	Negligible	0.000-0.004	A few scattered obstructions, which Include debris deposits, stumps, exposed roots, logs, or isolated boulders, occupy less than 5 percent of the cross-sectional area.
	Minor	0.005-0.019	Obstructions occupy less than 15 percent of the cross-sectional area
	Sever	0.02-0.03	Obstructions occupy from 15 to 50 Percent of the Cross-sectional area.
Amount of Vegetation (n_4)	Small	0.001-0.010	The dense growth of flexible turf grass, such as Bermuda, or weeds growing where the average depth of flow is at least two times the height of the vegetation: or supple tree seedlings such as willow, cottonwood, arrow weed, or salt cedar growing where the average depth of flow is at least three times the height of
	Medium	0.011-0.025	Turfgrass growing where the average depth of flow is from one to two times the height of the vegetation; or moderately dense steamy grass, weeds, or tree seedlings growing where the average depth of flow is from two to three times the height of the vegetation; brushy, moderately dense vegetation, similar to l- to 2year-old willow trees in the dormant season
	Large	0.025-0.05	Surf grass growing where the average depth of flow is about equal to the height of vegetation: or 8- to lo-year-old willow or cottonwood trees intergrew with some weeds and brush (none of the vegetation in foliage) where the hydraulic radius exceeds 2 ft.; or mature

			row crops such as small vegetables; or mature field
	Very large	0.05-0.10	Surf grass growing where the average depth of flow is less than half the height of the vegetation: or moderate to dense brush: or heavy stand of timber with few down trees and little undergrowth with depth of flow below branches: or matur field crops where the depth of flow is less than height of the vegetation.
	Extreme	0.1-0.2	Dense bushy willow, mesquite, and salt cedar (all vegetation in full foliage): or the heavy stand of timber, few down trees, depth of flow reaching branches.
Degree of Meander (m)		1.0	Not applicable

Table5: Teji River Cross Section Survey Primary data, March 2020

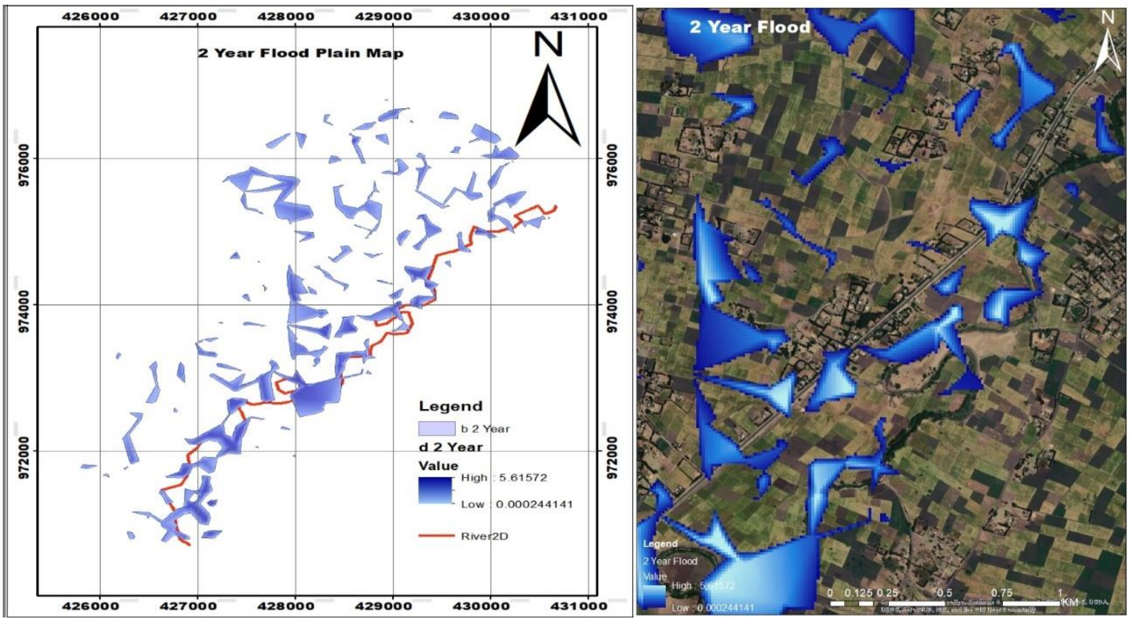
Parameter	Measurement/Value
Depth	4 – 12 m
Width	30 – 60 m
Slope	0.006 – 0.008

APPENDIX C

Figure4: Animal Food Placed 0.5m above ground during filed observation to protect from flood March 2020

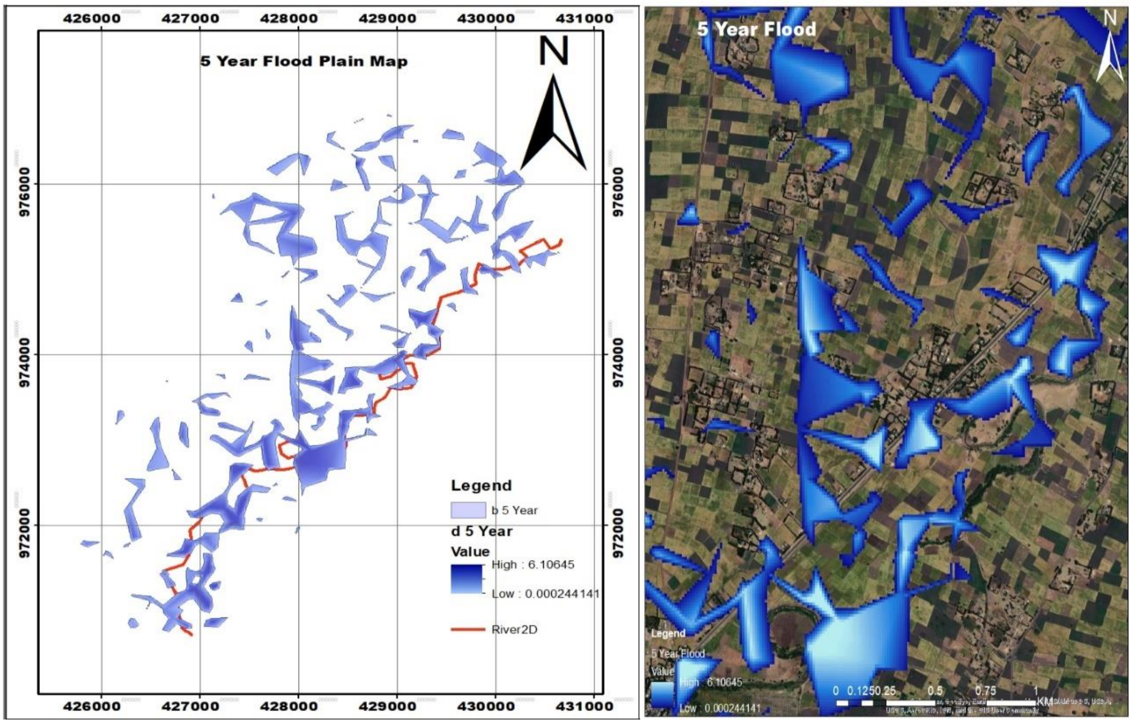
Figure5: Household Material during field observation some placed 1m above ground to protect from flood March 2020

APPENDIX D



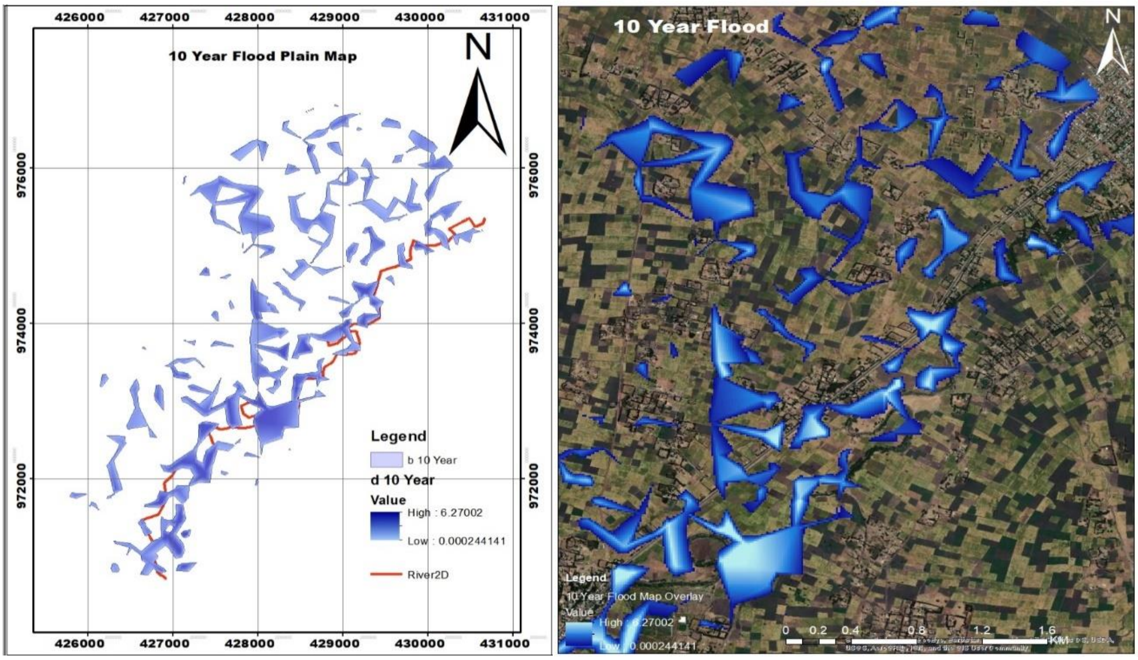
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure6: A portion of inundated plain area of Teji River for the 2-year flood event



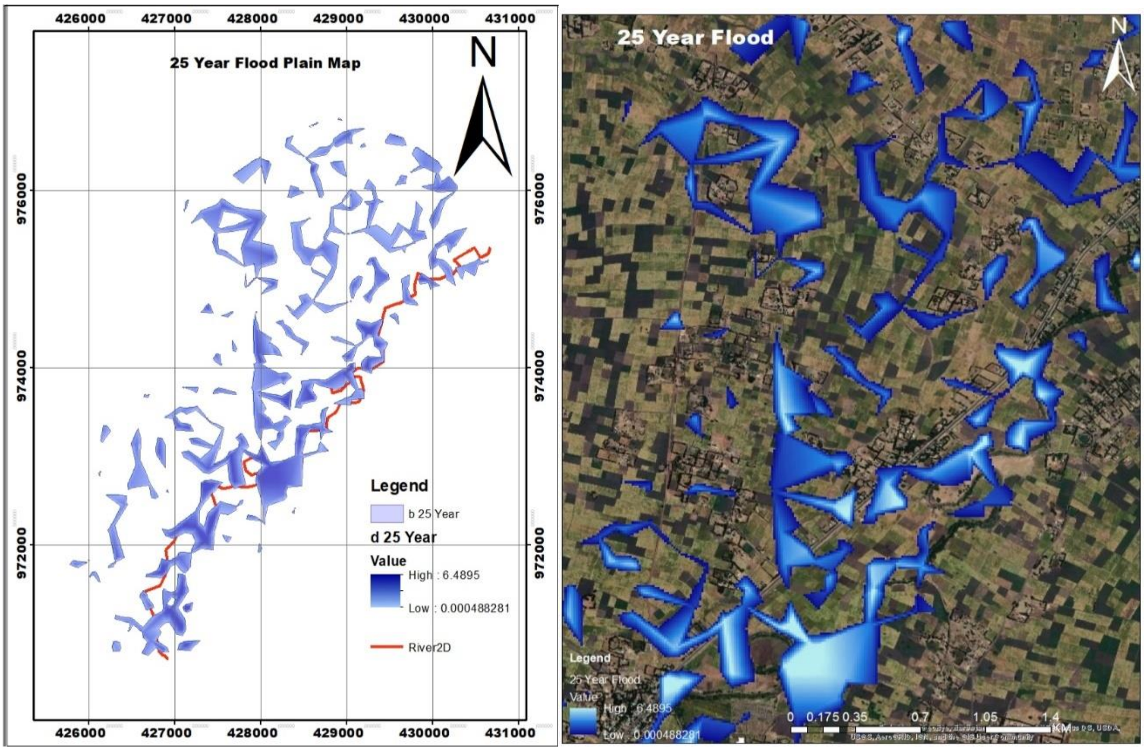
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure7: A portion of inundated plain area of Teji River for the 5-year flood event



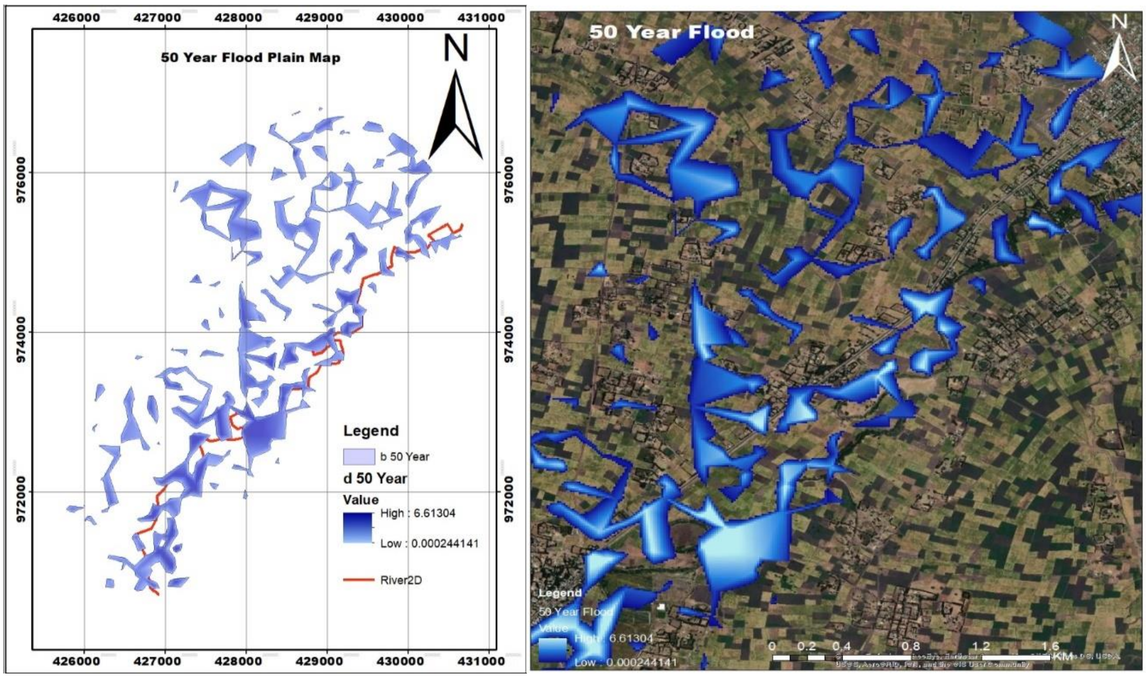
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure8: A portion of inundated plain area of Teji River for the 10-year flood event



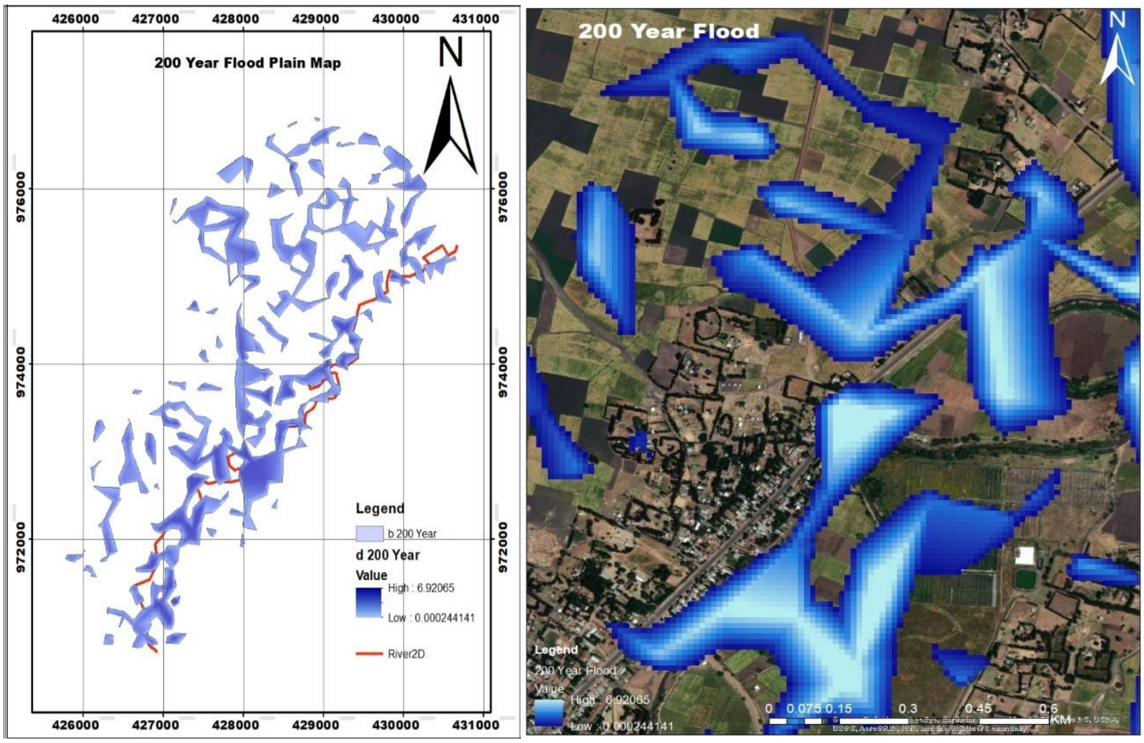
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure9: A portion of inundated plain area of Teji River for the 25-year flood event



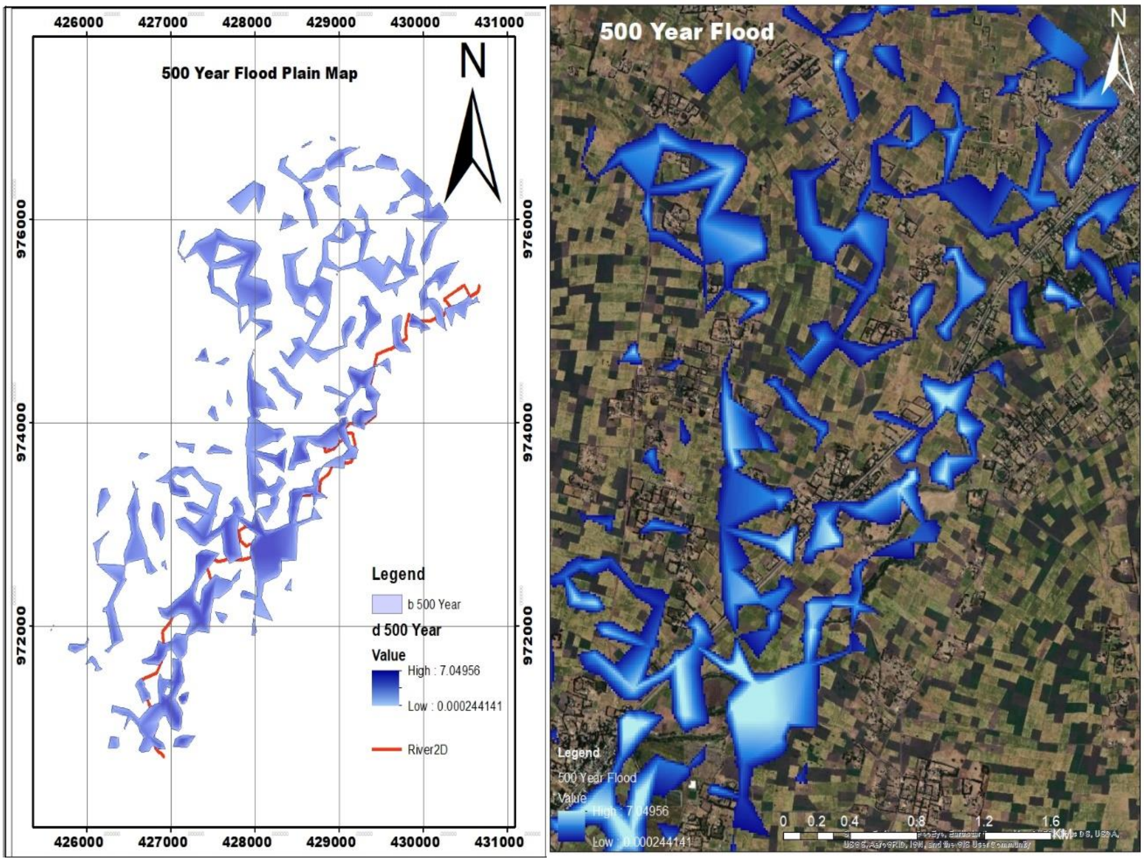
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure10: A portion of inundated plain area of Teji River for the 50-year flood event



a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

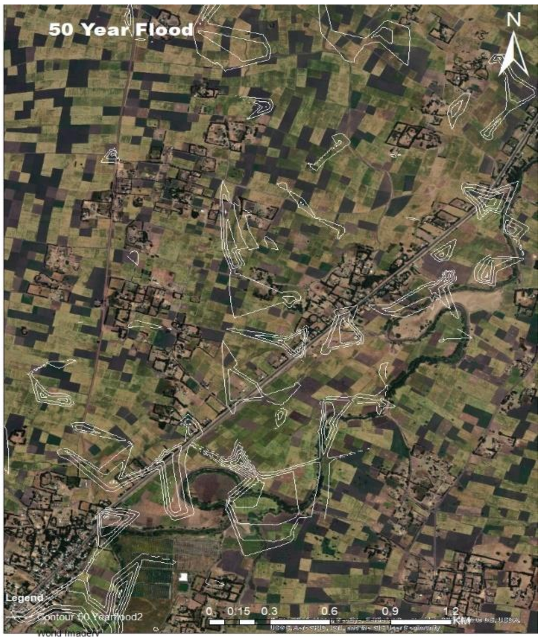
Figure11: A portion of inundated plain area of Teji River for the 200-year flood event

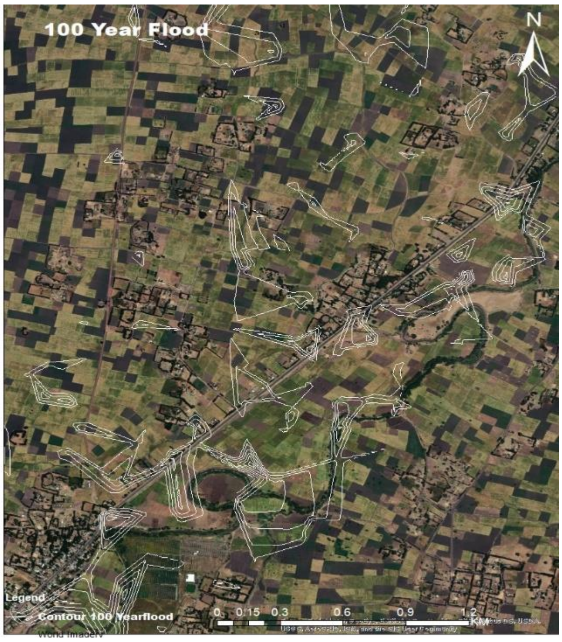


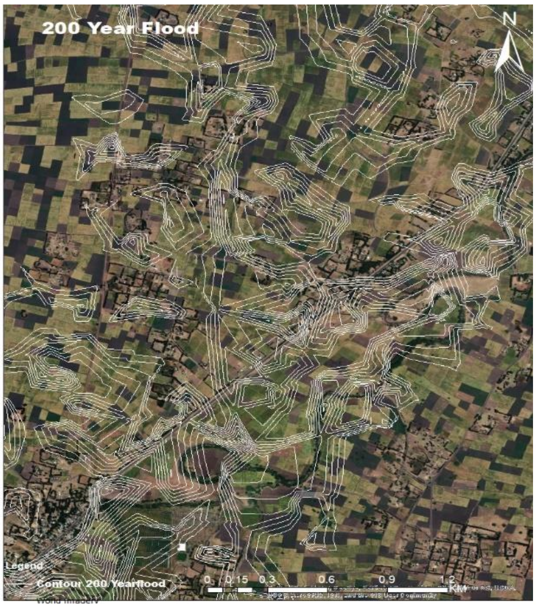
a) Flood Plain Polygon Map b) Flood Plain Google Earth Overlay

Figure12: A portion of inundated plain area of Teji River for the 500-year flood event

The figure below shows that flood depth by contour overlapping google map


50 Year Flood
N
Legend
Contour 50 Yearflood2
0 0.15 0.3 0.6 0.9 1.2
Km


100 Year Flood
N
Legend
Contour 100 Yearflood
0 0.15 0.3 0.6 0.9 1.2
Km

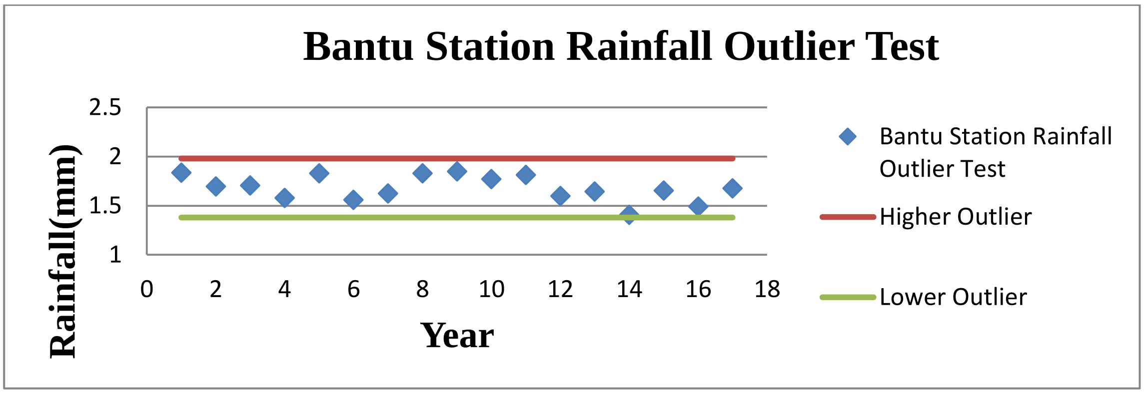

200 Year Flood
N
Legend
Contour 200 Yearflood
0 0.15 0.3 0.6 0.9 1.2
Km

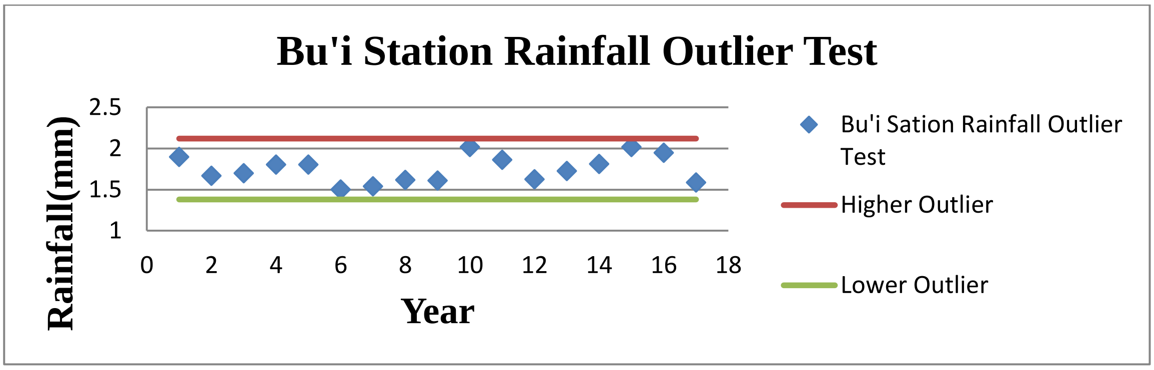

500 Year Flood
N
Legend
Contour 500 Yearflood
0 0.15 0.3 0.6 0.9 1.2
Km

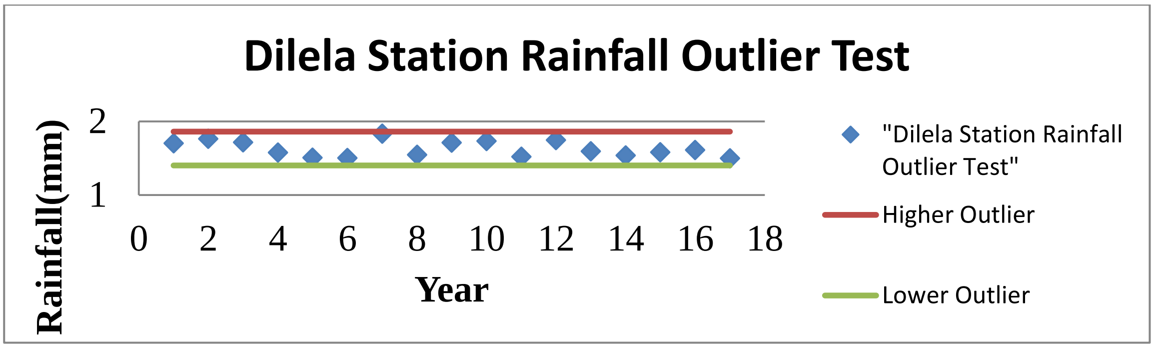

2 Year Flood
N
Legend
Contour 2 Yearflood
0 0.15 0.3 0.6 0.9 1.2
Km

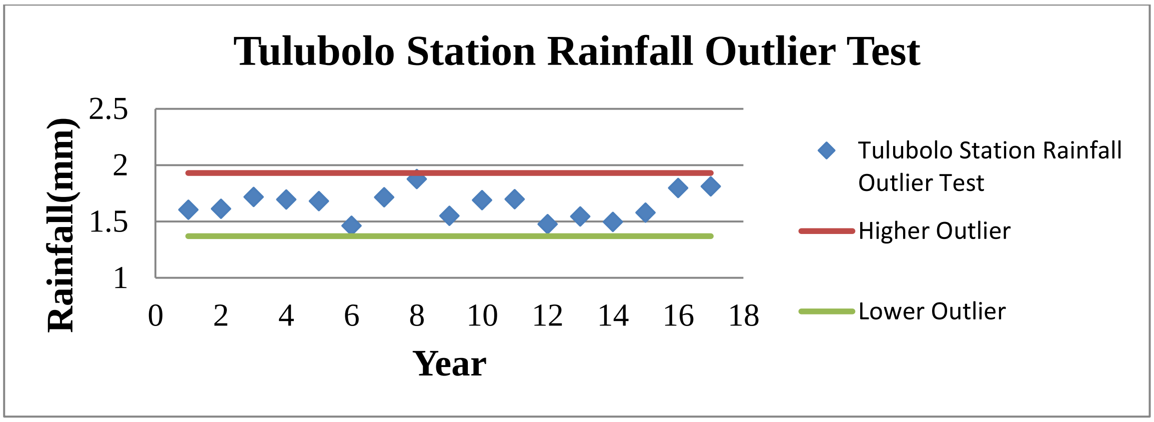

5 Year Flood
N
Legend
0 0.15 0.3 0.6 0.9
Km

APPENDIX E


Bantu Station Rainfall Outlier Test
Rainfall(mm)
2.5
2
1.5
1
0 2 4 6 8 10 12 14 16 18
Year
Bantu Station Rainfall Outlier Test
Higher Outlier
Lower Outlier


Bu'i Station Rainfall Outlier Test
Rainfall(mm)
2.5
2
1.5
1
0 2 4 6 8 10 12 14 16 18
Year
Bu'i Sation Rainfall Outlier Test
Higher Outlier
Lower Outlier


Dilela Station Rainfall Outlier Test
Rainfall(mm)
2
1
0 2 4 6 8 10 12 14 16 18
Year
"Dilela Station Rainfall Outlier Test"
Higher Outlier
Lower Outlier


Tulubolo Station Rainfall Outlier Test
Rainfall(mm)
2.5
2
1.5
1
0 2 4 6 8 10 12 14 16 18
Year
Tulubolo Station Rainfall Outlier Test
Higher Outlier
Lower Outlier

APPENDIX F

Gumbel Method Parameter Estimation

Flood forcasting for different return period			
Tr(Years)	P	KTr	XTr (flow) cumecs
2	0.5	-0.164	87.471
5	0.2	0.720	123.347
10	0.1	1.305	147.100
25	0.04	2.045	177.112
50	0.02	2.593	199.376
100	0.01	3.138	221.476
200	0.005	3.681	243.495
500	0.002	4.396	272.546

Chi-Square Test

Chi-Square Test								
Interval	Range	ni	fs(Xi)	Fs(Xi)	Zi	F(Xi)	P(Xi)	Xc^2
1	< 25	0	0.0000	0.0000	-1.704	0.044	0.0440	0.748
2	25-45	3	0.1765	0.176	-1.211	0.113	0.0692	2.831
3	45-65	2	0.1176	0.294	-0.718	0.236	0.1232	0.004
4	65-85	1	0.0588	0.353	-0.225	0.411	0.1747	1.307
5	85-105	5	0.2941	0.647	0.268	0.606	0.1946	0.866
6	105-125	2	0.1176	0.765	0.760	0.776	0.1707	0.280
7	125-145	2	0.1176	0.882	1.253	0.895	0.1184	0.000
8	145-165	1	0.0588	0.941	1.746	0.960	0.0651	0.010
9	165-175	1	0.0588	1.000	1.746	0.960	0.0000	0.000
Sum		17	1.000				0.9598	6.047

m-p-1	6			
	12.6	from table		
X6,0.95	12.6> 6.047	distribution is accepted		

Table C.3 Cumulative Chi-square Distribution with ν degrees of freedom: $F(\chi^2) = \frac{1}{2}\int_0^{\chi^2} \frac{(t/2)^{(\nu/2)-1}\exp(-t/2)}{\Gamma(\nu/2)} dt$ (entry in table is χ^2)

F =	0.001	0.005	0.010	0.025	0.050	0.100	0.250	0.500	0.750	0.900	0.950	0.975	0.990	0.995
ν = 1	0.000002	0.00004	0.0002	0.0010	0.0039	0.016	0.102	0.455	1.32	2.71	3.84	5.02	6.63	7.88
2	0.0020	0.0100	0.0201	0.0506	0.103	0.211	0.575	1.386	2.77	4.61	5.99	7.38	9.21	10.6
3	0.0243	0.0717	0.115	0.216	0.352	0.584	1.213	2.366	4.11	6.25	7.81	9.35	11.3	12.8
4	0.0908	0.207	0.297	0.484	0.711	1.06	1.92	3.36	5.39	7.78	9.49	11.1	13.3	14.9
5	0.210	0.412	0.554	0.831	1.15	1.61	2.67	4.35	6.63	9.24	11.1	12.8	15.1	16.7
6	0.381	0.676	0.872	1.24	1.64	2.20	3.45	5.35	7.84	10.6	12.6	14.4	16.8	18.5
7	0.599	0.989	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.0	14.1	16.0	18.5	20.3
8	0.857	1.34	1.65	2.18	2.73	3.49	5.07	7.34	10.2	13.4	15.5	17.5	20.1	22.0
9	1.15	1.73	2.09	2.70	3.33	4.17	5.90	8.34	11.4	14.7	16.9	19.0	21.7	23.6
10	1.48	2.16	2.56	3.25	3.94	4.87	6.74	9.34	12.5	16.0	18.3	20.5	23.2	25.2
11	1.83	2.60	3.05	3.82	4.57	5.58	7.58	10.3	13.7	17.3	19.7	21.9	24.7	26.8
12	2.21	3.07	3.57	4.40	5.23	6.30	8.44	11.3	14.8	18.5	21.0	23.3	26.2	28.3
13	2.62	3.57	4.11	5.01	5.89	7.04	9.30	12.3	16.0	19.8	22.4	24.7	27.7	29.8
14	3.04	4.07	4.66	5.63	6.57	7.79	10.2	13.3	17.1	21.1	23.7	26.1	29.1	31.3
15	3.48	4.60	5.23	6.26	7.26	8.55	11.0	14.3	18.2	22.3	25.0	27.5	30.6	32.8
16	3.94	5.14	5.81	6.91	7.96	9.31	11.9	15.3	19.4	23.5	26.3	28.8	32.0	34.3
17	4.42	5.70	6.41	7.56	8.67	10.1	12.8	16.3	20.5	24.8	27.6	30.2	33.4	35.7
18	4.90	6.26	7.01	8.23	9.39	10.9	13.7	17.3	21.6	26.0	28.9	31.5	34.8	37.2
19	5.41	6.84	7.63	8.91	10.1	11.7	14.6	18.3	22.7	27.2	30.1	32.9	36.2	38.6
20	5.92	7.43	8.26	9.59	10.9	12.4	15.5	19.3	23.8	28.4	31.4	34.2	37.6	40.0
21	6.45	8.03	8.90	10.3	11.6	13.2	16.3	20.3	24.9	29.6	32.7	35.5	38.9	41.4
22	6.98	8.64	9.54	11.0	12.3	14.0	17.2	21.3	26.0	30.8	33.9	36.8	40.3	42.8
23	7.53	9.26	10.2	11.7	13.1	14.8	18.1	22.3	27.1	32.0	35.2	38.1	41.6	44.2
24	8.08	9.89	10.9	12.4	13.8	15.7	19.0	23.3	28.2	33.2	36.4	39.4	43.0	45.6
25	8.65	10.5	11.5	13.1	14.6	16.5	19.9	24.3	29.3	34.4	37.7	40.6	44.3	46.9
26	9.22	11.2	12.2	13.8	15.4	17.3	20.8	25.3	30.4	35.6	38.9	41.9	45.6	48.3
27	9.80	11.8	12.9	14.6	16.2	18.1	21.7	26.3	31.5	36.7	40.1	43.2	47.0	49.6
28	10.4	12.5	13.6	15.3	16.9	18.9	22.7	27.3	32.6	37.9	41.3	44.5	48.3	51.0
29	11.0	13.1	14.3	16.0	17.7	19.8	23.6	28.3	33.7	39.1	42.6	45.7	49.6	52.3
30	11.6	13.8	15.0	16.8	18.5	20.6	24.5	29.3	34.8	40.3	43.8	47.0	50.9	53.7
31	12.2	14.5	15.7	17.5	19.3	21.4	25.4	30.3	35.9	41.4	45.0	48.2	52.2	55.0
32	12.8	15.1	16.4	18.3	20.1	22.3	26.3	31.3	37.0	42.6	46.2	49.5	53.5	56.3
33	13.4	15.8	17.1	19.0	20.9	23.1	27.2	32.3	38.1	43.7	47.4	50.7	54.8	57.6

2	0.0020	0.0100	0.0201	0.0506	0.103	0.211	0.575	1.386	2.77	4.61	5.99	7.38	9.21	10.6
3	0.0243	0.0717	0.115	0.216	0.352	0.584	1.213	2.366	4.11	6.25	7.81	9.35	11.3	12.8
4	0.0908	0.207	0.297	0.484	0.711	1.06	1.92	3.36	5.39	7.78	9.49	11.1	13.3	14.9
5	0.210	0.412	0.554	0.831	1.15	1.61	2.67	4.35	6.63	9.24	11.1	12.8	15.1	16.7
6	0.381	0.676	0.872	1.24	1.64	2.20	3.45	5.35	7.84	10.6	12.6	14.4	16.8	18.5
7	0.599	0.989	1.24	1.69	2.17	2.83	4.25	6.35	9.04	12.0	14.1	16.0	18.5	20.3
8	0.857	1.34	1.65	2.18	2.73	3.49	5.07	7.34	10.2	13.4	15.5	17.5	20.1	22.0
9	1.15	1.73	2.09	2.70	3.33	4.17	5.90	8.34	11.4	14.7	16.9	19.0	21.7	23.6
10	1.48	2.16	2.56	3.25	3.94	4.87	6.74	9.34	12.5	16.0	18.3	20.5	23.2	25.2
11	1.83	2.60	3.05	3.82	4.57	5.58	7.58	10.3	13.7	17.3	19.7	21.9	24.7	26.8
12	2.21	3.07	3.57	4.40	5.23	6.30	8.44	11.3	14.8	18.5	21.0	23.3	26.2	28.3
13	2.62	3.57	4.11	5.01	5.89	7.04	9.30	12.3	16.0	19.8	22.4	24.7	27.7	29.8
14	3.04	4.07	4.66	5.63	6.57	7.79	10.2	13.3	17.1	21.1	23.7	26.1	29.1	31.3
15	3.48	4.60	5.23	6.26	7.26	8.55	11.0	14.3	18.2	22.3	25.0	27.5	30.6	32.8
16	3.94	5.14	5.81	6.91	7.96	9.31	11.9	15.3	19.4	23.5	26.3	28.8	32.0	34.3
17	4.42	5.70	6.41	7.56	8.67	10.1	12.8	16.3	20.5	24.8	27.6	30.2	33.4	35.7
18	4.90	6.26	7.01	8.23	9.39	10.9	13.7	17.3	21.6	26.0	28.9	31.5	34.8	37.2
19	5.41	6.84	7.63	8.91	10.1	11.7	14.6	18.3	22.7	27.2	30.1	32.9	36.2	38.6
20	5.92	7.43	8.26	9.59	10.9	12.4	15.5	19.3	23.8	28.4	31.4	34.2	37.6	40.0
21	6.45	8.03	8.90	10.3	11.6	13.2	16.3	20.3	24.9	29.6	32.7	35.5	38.9	41.4
22	6.98	8.64	9.54	11.0	12.3	14.0	17.2	21.3	26.0	30.8	33.9	36.8	40.3	42.8
23	7.53	9.26	10.2	11.7	13.1	14.8	18.1	22.3	27.1	32.0	35.2	38.1	41.6	44.2
24	8.08	9.89	10.9	12.4	13.8	15.7	19.0	23.3	28.2	33.2	36.4	39.4	43.0	45.6
25	8.65	10.5	11.5	13.1	14.6	16.5	19.9	24.3	29.3	34.4	37.7	40.6	44.3	46.9
26	9.22	11.2	12.2	13.8	15.4	17.3	20.8	25.3	30.4	35.6	38.9	41.9	45.6	48.3
27	9.80	11.8	12.9	14.6	16.2	18.1	21.7	26.3	31.5	36.7	40.1	43.2	47.0	49.6
28	10.4	12.5	13.6	15.3	16.9	18.9	22.7	27.3	32.6	37.9	41.3	44.5	48.3	51.0
29	11.0	13.1	14.3	16.0	17.7	19.8	23.6	28.3	33.7	39.1	42.6	45.7	49.6	52.3
30	11.6	13.8	15.0	16.8	18.5	20.6	24.5	29.3	34.8	40.3	43.8	47.0	50.9	53.7
31	12.2	14.5	15.7	17.5	19.3	21.4	25.4	30.3	35.9	41.4	45.0	48.2	52.2	55.0
32	12.8	15.1	16.4	18.3	20.1	22.3	26.3	31.3	37.0	42.6	46.2	49.5	53.5	56.3
33	13.4	15.8	17.1	19.0	20.9	23.1	27.2	32.3	38.1	43.7	47.4	50.7	54.8	57.6

34	14.1	16.5	17.8	19.8	21.7	24.0	28.1	33.3	39.1	44.9	48.6	52.0	56.1	59.0
35	14.7	17.2	18.5	20.6	22.5	24.8	29.1	34.3	40.2	46.1	49.8	53.2	57.3	60.3
40	17.9	20.7	22.2	24.4	26.5	29.1	33.7	39.3	45.6	51.8	55.8	59.3	63.7	66.8
50	24.7	28.0	29.7	32.4	34.8	37.7	42.9	49.3	56.3	63.2	67.5	71.4	76.2	79.5

Source: Chow, V. T., Maidment, D. R. and Mays, L. W., (1998) Applied hydrology.