FLOOD HAZARD MAPPING AND DAMAGE ANALYSIS FOR MEKI RIVER USING HEC-RAS AND HEC-FDA MODELS

Negese Roba Tufa

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

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Yilma Seleshi (Ph.D.)	____________________	____________________
Advisor	Signature	Date
____________________	____________________	____________________
Internal Examiner	Signature	Date
____________________	____________________	____________________
External Examiner	Signature	Date

DECLARATION

I, **Negese Roba** declare that this thesis is my own original work with the exception of such quotations or references which have been attributed to their authors or sources, and that this thesis has not been previously submitted to this or any other university for a degree award.

Signature: _______________

Date: __________________

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ABSTRACT

Flooding causes major damage on the economic, social and environment of the affected area. Overflow of Meki River has affected and displaced the people and destroyed farm land along the river in the flood plain area of Dugda Woreda in the summer season. In late March and early April 2016 floods destroyed 485.75 hectares farm land and damage 80 farmer houses. This research develops flood hazard maps and damage analysis along Meki River. The digital elevation model of the study area was used to extract the physical characteristics of the catchment using HEC-GeoHMS GIS extension. HEC-HMS hydrological model was used to generate flow hydrograph for different return periods at the outlet of the catchment using the design rainfall. Flood inundation and hazard maps along Meki River have been developed based on the flow hydrographs for different return periods using the HEC-RAS model, GIS for spatial data processing and HEC-GeoRAS for interfacing between HEC-RAS and GIS. Based on the output of HEC-RAS hydraulic model, using HEC-FDA, flood damages were estimated quantitatively. The areas along the Meki River simulated to be inundated for 2, 5, 10, 20, 25, 50 and 100 years return period. The flooded areas were high from Meki town to Lake Ziway for all return periods. The flood inundated area along the Meki River for a return period of 100, 50, 25, 20, 10, 5, and 2 years were 15.52, 14.99, 14.02, 13.57, 12.95, 12.50 and 11.52 km^2 respectively. The flood hazard map results were low, moderate, high and very high hazard levels based on the flood depths generated using HEC-GeoRAS GIS extension. Finally, the cost of flood damages was evaluated using HEC-FDA and mitigation measures were proposed to reduce the damages due to flooding in study area. The sum of expected annual damage for eight return period intervals was 707,193,871 birr. *The major findings in the study indicate that inundated areas in the lower part of Meki River were made economic damage on agricultural farm land and settlement. Therefore, increasing the width of the river channel or construction of levees has been proposed to reduce the economic damage of flooding in lower river parts.*

Key Words: Meki River, Flood Plain, HEC-HMS, HEC-RAS, HEC-FDA, DEM

ABBREVIATION

1-D HEC-RAS	One-Dimensional Hydrologic Engineering Center-River Analysis System
AACPS	American Council of Academic Plastic Surgeons
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
DRMFSS	Disaster Risk Management and Food Security Sector
DWANRO	Dugda Woreda Agricultural and Natural Resource Office
DWDRMO	Dugda Woreda Disaster Risk Management Office
DWTMDO	Dugda Woreda Trade and Market Development Office
EAD	Expected Annual Damage
EMA	Ethiopia Mapping Agency
ERA	Ethiopian Road Authority
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
GPS	Global Positioning System
GUI	Graphical User Interface
hac	Hectare
HEC-FDA	Hydrologic Engineering Center- Flood Damage Reduction Analysis
HEC-GeoHMS	Hydrologic Engineering Center-Geospatial Hydrologic Modeling System
HEC-GeoRAS	Hydrologic Engineering Center- Geographical River Analysis System
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center-River Analysis System
IPCC	Intergovernmental Panel on Climate Change
ITCZ	Inter Tropical Convergence Zone
JICA	Japan International Cooperation Agency
m.a.s.l	Meter Above Sea Level
MoWIE	Ministry of Water, Irrigation and Electricity
NDRMC	National Disaster Risk Management Commission

NMSA	National Meteorological Service Agency
OCHA	Office for the Coordination of Humanitarian Affairs
OFDA	Office of United States Foreign Disaster Assistance
OIDA	Oromia Irrigation Development Authority
PAs	Peasant Associations
RS	Remote Sensing
SCS CN	Soil Conservation Service Curve Number
SCS UH	Soil Conservation Service Unit Hydrograph
SMA	Soil Moisture Accounting
TIN	Triangular Irregular Network
USACE	United States Army Corps of Engineers

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1. INTRODUCTION

1.1 Background

Flooding in Ethiopia is the second major natural hazards next to drought; causes significant damages to lives, physical, natural and economic assets of the country. Flooding is mainly linked with torrential rainfall and the topography of the highland mountains and lowland plains with natural drainage systems formed by the principal river basins (NDRMC, 2016). However, intensive rainfall in the highlands causes flooding of settlements in the lowland flat parts of the country close to any stretch of river courses.

Ethiopia experiences two types of floods; river and flash floods. River floods occur due to over flow or bursting river banks and inundate areas along the banks in lowland flood plains. The floods that has occurred in late and early April 2016 in East Shoa Zone (mainly Dugda and Bora Woreda) due to Meki and Awash River and floods occurred last decades in Southern Omo zone and South Gondar zone (Fogera woreda) are typical examples of river floods. Flash floods occur in lowland areas when excessive rain fall in adjacent highland and gush downstream with massive concentration, speed and force. Often, they are sudden and appear unnoticed with little lead time for early warning. Therefore, such floods often result in a considerable toll; and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration. The disaster experienced in Dire-Dawa, Jigjiga, Adama city area typical example of flash flooding (NDRMC, 2016).

Meki River, drains into Dugda Woreda from Guraghe (Zebider) Mountain and joins Lake Ziway. Fruits and vegetables are important cash crops cultivated in flood plain area in the Dugda Woreda along the river. Overflow of the Meki River has affected the crops and vegetables land along the river during heavy rain season. Climate change and vegetation loss in the mountains area increase flood risk through changes of runoff characteristics and the drainage paths of flood water in the catchment. During an extreme flood event it is important to be able to determine quickly the extent of flooding and the land use and land cover types under water. This information can be used in developing a comprehensive relief effort (Corbley 1993). Accurate and current floodplain maps can be the most valuable tools for avoiding severe social and economic losses from floods.

In Dugda Woreda, which is along the Meki River and around Lake Ziway there is fertile land for the production of important cash crops (i.e. tomato, onion, pappy, pepper and etc.) for the inside and foreign markets. Due to fertile soil available along the river; dense population is locating surrounding the bank of river to sustain their life by producing different crops for their livelihood and markets. But, in rainy season Meki River flow over the banks and damages the crops and vegetables, materials used for crops and vegetables production and submerged farmer houses along the bank of river.

Previous studies conducted in the area focus more on groundwater hydrology, hydrogeology, climate, water balance, water resource potential assessment and land use land cover. Although flood is a severe problem in the area, no significant attempt has done to alleviate the problem. Therefore, in order to cope with the problem developing of flood hazard map, estimation of flood damage and identification of flood prone areas for the safety of the population, crop produced and the natural environment are mandatory.

1.2 Problem of Statement

Floods occur whenever the capacity of the natural or manmade drainage system is unable to cope with the volume of water generated by rainfall. Flood is a hydrological event which is characterized by high discharges and/or water levels that could lead to inundation of land adjacent to streams, rivers, lakes and other water bodies. Nowadays, extraordinary floods are common to many parts of Ethiopia every year causing a lot of losses to human lives as well as damage to property. This problem is more acute in highland areas of Ethiopia under strong environmental degradation due to population pressure. Soil erosion, land degradation, vegetation loss, over utilization of fuel wood, exotic weeds and trees and rainy season flooding are some of the environmental problems along Meki River and surrounding of Lake Ziway. Overflow of Meki River has affected and displaced the people live along the river in the summer season. During the rainy season excess water flow over the banks of Meki River; damage the crops produced close to any section of river, made economic failure and hunger of the people locating along the river. In late March and early April 2016, Meki

River overflows and burst the bank due to heavy rains and up to 440 people were affected, 80 houses were damage, 485.75 hectares of crop land, fruit and vegetation land was destroyed and estimated more than 16,455,127 birr was lost (DWDRMO, 2016). Therefore, this issue needs the research in the area in order to design long-lasting solutions for the safety of the population and the natural environment.

1.3 Objective

1.3.1 General Objective

The general objective of this research is to develop flood hazard maps and estimate flood damages for Meki River to alleviate risks occur on property and life.

1.3.2 Specific Objectives

The specific objectives of the study are;

- ✓ To develop flood inundation map for a particular return period of 2, 5, 10, 20, 25, 50 and 100 years,
- ✓ To delineate flood hazard map,
- ✓ To estimate the flood damage and
- ✓ To recommend mitigation measures for the recurrent floods.

1.4 Structure of the Thesis

This thesis is organized in six chapters. Chapter one deals with the general introduction, statement of the problem and objective of the study. Chapter two gives the literature review on previous research in the study area, floods on study area, flood hazard mapping and flood damage estimation. Chapter three gives an overview on methodology of the thesis; it includes location of the study area and data collection. Chapter four is the processing and analysis of rainfall, flow data and HEC –HMS model. Chapter five is the result and discussion part of the work namely flood inundation maps, flood hazard maps and flood damage estimation. Chapter six is about conclusion and recommendation.

2. LITERATURE REVIEW

2.1 Review of Previous Studies in the Meki River Catchment

The Central Ethiopia Rift Valley has been the interest of many researcher and organization, thus a number of essential works carried out over the hydrology, groundwater hydrology, water resource potential assessment and hydrogeology, climate and land use change of the catchment. Among them the following work listed below was reviewed for the benefit of the research.

Dagnachew (2002) in his journal of hydrology, analysis the hydrological response of Ziway-Shalla catchment to climate and land use changes; Dagnachew et al. (2004) had done the analysis of the hydrological response of a tropical terminal Lake, Lake Abiyata (Main Ethiopian Rift Valley) to changes in climate and human activities; Hawi (2007) in her MSc. thesis study the impact of land use change and climate variability on catchment runoff which is a modeling study on Meki River basin; Tadele (2009) in his Msc. thesis study environmental impacts of floriculture industries on lake Ziway: with particular reference to water quality; Legesse et al. (2010) in their journal of hydrology and earth system sciences, stream flow sensitivity to climate and land cover changes: Meki River, Ethiopia.

Italo consult in (1970) has made water resources assessment in the Ziway-Langano-Abijata-Shalla basin. The main aim of the study was to divert Meki River into Awash River for extension of irrigation in the Amibara area; JICA and OIDA (2002) in the project study of Meki irrigation and rural development, the primary emphasis was given to the assessment of water resource potential in Meki- Abjiata basin; Tenalem (2007) had done the water management problems in the Ethiopian Central Rift Valley; Tibebu (2007) studied on his Msc. thesis effects of irrigation practices and lacustrine aquifer development on water availability in Ziway-Abijata basin; Temesgen (2008) studied on his Msc. thesis hydrological analysis and lake water balance study and application of physically based distributed hydrological model for estimation of major components of the hydrologic cycle of Meki River basin; Amare (2008) studied on his Msc. thesis assessment of Lake Ziway water balance; *Edo (2014)* on his MSc, thesis studied determinants of water utilization for small-scale irrigation among rural households in Dugda Woreda; Mulugeta et al. (2015) in their journal of hydrology, characterization of water level variability of the Main Ethiopian Rift Valley Lakes; Abebe and Kassa (2016) on their international journal of waste resources studied assessing the impact of existing and future water demand on economic and environmental aspects of Meki-Ziway sub basin; Daniel (2016) in his Msc. thesis studies the impact of existing and proposed irrigation scheme on hydrology of Lake Ziway.

Halcow (1989) analyzed groundwater and surface water potential of the area in the work entitled “Rift Valley Lakes Integrated Natural Resource Development Master Plan”; Tenalem (1998) in his Ph.D, thesis analyzed general hydrology and hydrogeology of Ziway-Shalla basin, the study includes evaluation of groundwater and surface water interaction, water balance and recharge estimation of sub catchments; Tenalem (2001) had done numerical groundwater flow modeling of the Central Main Ethiopian Rift Valley lake basin; Tenalem (2003) also had done evapotranspiration estimation using thematic mapper spectral satellite data in the Ethiopian Rift Valley and adjacent highlands; Nestanet (2007) in her Msc. thesis study the groundwater resources evaluation and management in Dugda Woreda, Central Rift Valley of Ethiopia; Tenalem (2008) studied hydrological system analysis and groundwater recharge estimation using semi-distributed models and river discharge in the Meki River basin; Dereje (2011) on his MSc. thesis study numerical groundwater flow modeling of the Meki River catchment.

Previous studies conducted in the area as discussed above, more work is done on hydrology, groundwater hydrology, irrigation potential assessment, hydrogeology, and water resource potential assessment, and climate and land use change. There is no consideration of the role of flood hazard mapping of the catchment in all studies. Moreover, the current research is expected to describe flood hazard mapping and flood damage analysis for Meki River catchment so that it will increase the knowledge on understanding of flood hazard mapping, delineate flood risks area and flood damage assessment.

2.2 General Overview of Flood

Flood is a temporary covering by water of land normally not covered by water. Flood is the overflowing of the normal confines of a stream or other body of water, or the accumulation of water over areas that are not normally submerged (IPCC, 2012). Flood is the worst weather-related natural hazard, causing loss of life and excessive damage to property (Abdo and Nasr, 2008; Brych et al., 2002; Carpenter et al., 1999; Getahun and Gebre, 2015 and Silvestro et al., 2011). It is occur as a result of triggered precipitation; most devastating natural hazards and one of the most prevalent hydro-meteorological disasters in the world (Li et al., 2009). Flooding is a threat to many communities and businesses, and flood risk is increasing in some locations due to development on floodplains, climate change through changes in the frequency and severity of storms, migration to urban areas at risk from flooding, rising sea levels and artificial influences on flow regimes (Carpenter et al., 1999; Sene, 2008).

Floods have many classifications in which their type decides method of mitigation measures and extent of damage. According to intensity they are classified as low, medium, high and very high floods. According to their duration: slow-onset floods (usually last for longer period mostly weeks or months), rapid - onset floods (relatively shorter usually take from one up to three days), and flash floods (usually occur after minutes or hours of heavy rainfall).

2.3 Floods in Ethiopia

Ethiopia is highly vulnerable to a wide range of natural hazards, including drought, floods, landslides, human and animal diseases, pests, earthquakes, and urban and forest fires. Recurrent drought and floods in particular have the most severe impacts on people’s lives in Ethiopia (GFDRR, 2011).

Floods are the most common phenomenon in Ethiopia next to drought and causes significant damages to human lives and livelihood, destroying roads and widespread damage to crops, houses and infrastructures (NDRMC, 2016). Flash floods and seasonal river floods are becoming increasingly due to deforestation, land degradation, increasing climate variability, and settlement patterns. During the past two decades, major floods in 1988, 1993, 1994, 1995, 1996 and 2006 have caused significant loss of life and property (GFDRR, 2011). In April 2016, heavy spring rains have caused floods and landslides, resulting in 100 deaths and up to 120,000 people have been displaced in six regions of all over the country (ACAPS, 2016).

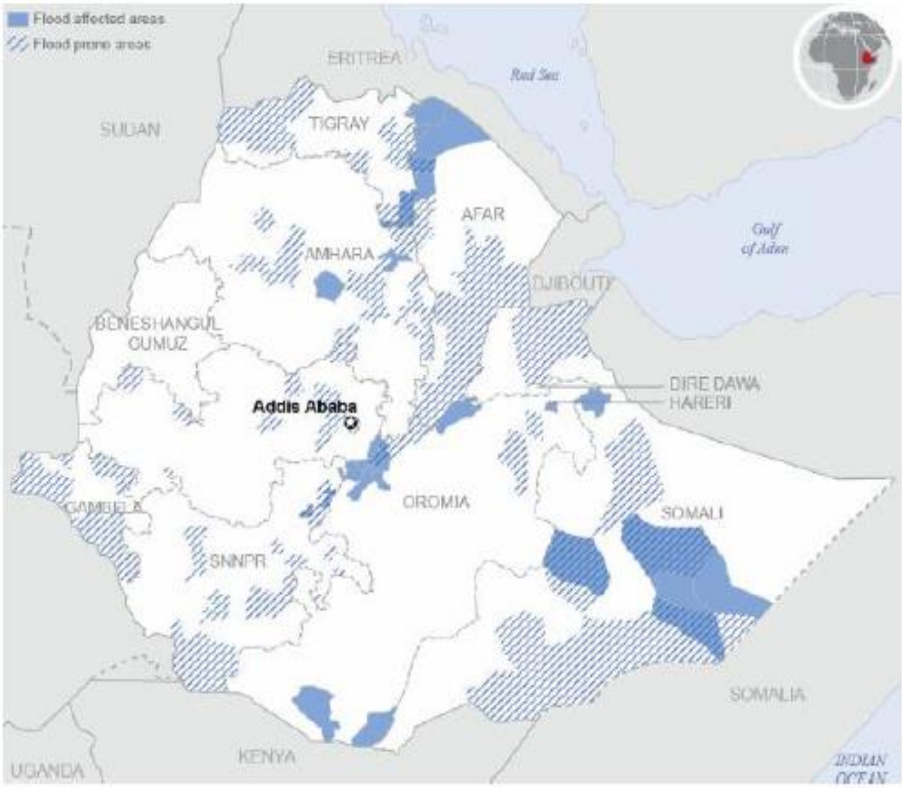
During the last decades, major floods in 2006 in Oromia have affect a total of about 22,000 households and 112,000 people in 106 peasant associations. From those affected people 13 people were died and displaced about 2,400 households of 12,000 people. As a result of this flood 225 livestock died, destroyed 8,100 ha of cropland, 220 houses and other household items (DPPA, 2007).

The 2006 floods events also affect Dugda and Bora woreda due to overflow of rivers, runoff, Ziway lake expansion and change of river courses induced by accumulation of silt in rivers beds. The root cause for the runoffs is mainly deforestation of highlands and absence of conservation measures. Due to flooding spreading of malaria and upper respiratory tract infection were observed in the woreda (DPPA, 2007). However, due to absence of disaster preparedness and prevention offices at woreda level lack of flood emergency intervention and early warning. In late March and early April 2016, Meki River overflow and 440 people were affected in four peasant associations, 80 houses and 485.75 hectares of crops and vegetation land were destroyed and loss of millions birr (DWDRMO, 2016).

Table 1 Flood disasters in Ethiopia form 1999-2016

No	People Affected	Date
1	79,000	October, 1999
2	45,000	October, 1999
3	110,000	April, 2003
4	235,418	April, 2005
5	38,000	August, 2006
6	361,600	October, 2006
7	239,586	July, 2007
8	120,000	May, 2016

Source: EM-DAT: The OFDA/CRED International Disaster Database, Universite catholique se Louvain, Brussels, Belgium and OCHA 09/05/2016

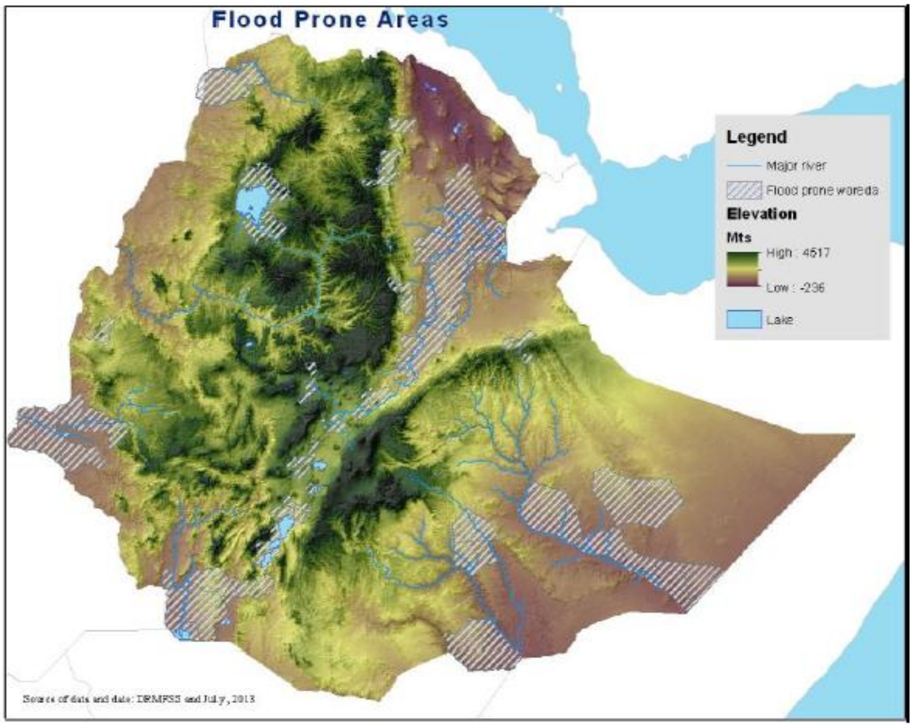


Source: OCHA 09/05/2016

Figure 1 Flood affected and flood prone areas

The rainy season in the country is concentrated in the three months between June and September, when about 80% of the rains are received. However, intense rainfall in the highlands causes flooding of settlements close to any stretch of river courses. A major river basin that has serious flood problems is the Awash River basin located in the Rift Valley. Irrigation development in the river basin is quite advanced and is located in the flood plains on either side of the Awash River. High economic damage occurs during flooding along this river basin. Therefore, flood protection practices and river training are limited to this river basin. It is estimated that in the Awash Valley almost all of the area delineated for irrigation development is subject to flood. An area in the order of 200,000-250,000 ha is subject to be flooded during high flows of the Awash River. In the Baro-Akobo Plain, (known as Gambella Plain) an area of about 300,000-350,000 ha is prone to flooding during the wet season and in the Wabi-Shebelle Basin some 100,000 ha may be flooded (Kefyalew, 2006).

Flash floods occur in lowland areas when excessive rains fall in adjacent highland areas. Flash floods mostly affect areas including Central, Southern and Western Tigray region; North and South Wollo, West Gojjam and Oromia zones in Amhara region; parts of Zone 1, Zone 2 and Zone 4 in Afar region; North Shewa zone in Oromia region; Wolayita, Hadiya, Siltie, Guraghe and Sidama zones in SNNPR; Jigjiga Town in Somali region and Dire Dawa City Administration. This type of flood is characterized by sudden onset with little lead time for early warning and often resulting in considerable damage on lives, livelihoods and property (NDRMC, 2016).



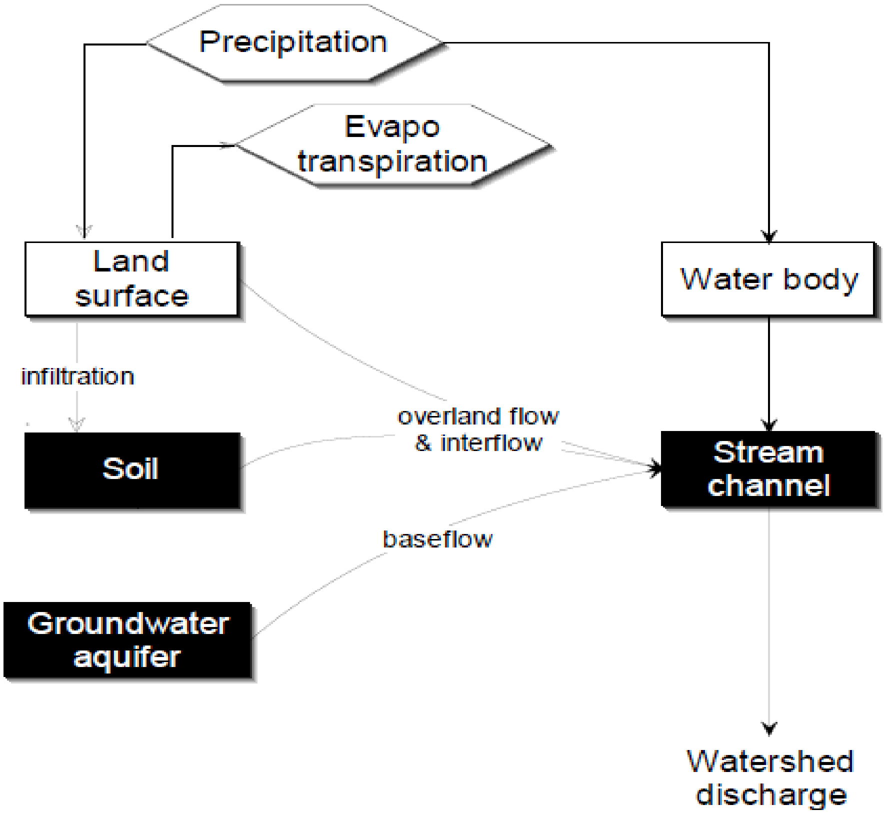
Source: DRMFSS July, 2013

Figure 2 Ethiopia flood prone areas

In Ethiopia, flood usually takes place at the peak of the rainy season (July and August) in most flood-prone areas. In Gambella flooding often occurs during August and September. In Somali region, heavy rains in the neighboring highland areas of Oromia usually cause flooding in the rainy season. Unseasonal and above-normal rainfall during October to January could also cause flooding in areas along Wabe Shebelle and Genale Rivers in Somali region and Omo River in SNNPR. Similarly, heavy rainfall in the surrounding highlands of Guraghe and Arsi mountain result overflow of Meki and Katar River and flooded people living in areas along the river in Dugda and Bora Woreda in East Shoa zone and Dodota and Ziway Dugda woreda in East Arsi Zone (NDRMC, 2016).

2.4 HEC-HMS Hydrological Model

HEC-HMS (Hydrologic Engineering Center's Hydrological Modeling System) is a comprehensive hydrologic model computer program developed by Hydrologic Engineering Center (HEC) of United States Army Corps of Engineers (USACE). HEC-HMS improves up on the capabilities of HEC-1 and provides additional capabilities for distributed modeling and continuous simulation (USACE, 2000). It is conceptual semi distributed model designed to simulate the precipitation-runoff processes of dendrite watershed systems (USACE, 2016^{a}).



Source: *USACE, 2000*

Figure 3 Typical representation of precipitation- runoff process in HEC-HMS

HEC-HMS hydrological model is tools used for studying hydrologic processes in a river basin for estimation of its resource (Chatterjee et al, 2014). It is the physically based and conceptual semi distributed model designed to simulate the rainfall-runoff processes in a wide range of geographic areas such as large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology (USACE, 2016[a]).

HEC-HMS model component is used to simulate the hydrologic response in a watershed. It is include basin models, meteorological models, control specifications, and input data. A simulation calculates the precipitation-runoff response in the basin model given input from the meteorological model. The control specifications define the time period and time step of the simulation run. Input data components, such as time-series data, paired data, and gridded data are often required as parameter or boundary conditions in basin and meteorological models (USACE, 2016[b]).

HEC-HMS hydrological model merits is that the model is physically based, spatially distributed and it belongs to public domain. It is freely available software download from the HEC website (http://www.hec.usace.army.mil/software/hec-hms/) and is supported by the US Army Corps of Engineers. The model can help to save time and money in obtaining the runoff data rather than measurement of runoff in the watershed. Moreover, it may help to simulate runoff in un-gauged watershed where there is no gauging station to measure runoff.

The main limitations of such models are selecting a loss model and estimating the model parameters are critical steps in developing HEC-HMS input. The other model limitation are HEC-HMS model is deterministic model, uncoupled model, no aquifer interactions, constant parameter values, dendrite stream systems-flow splits possible but limited capability and no downstream flow influence or reversal-backwater possible but only if contained within a reach.

The analytical components of HEC-HMS model is composed of several different modeling components that make up the entire watershed model including: infiltration loss method that calculates runoff, transform method for transforming excess precipitation into runoff, base flow models, routing methods that accumulates modeled flow from each of the distributed sub basins, creating a stream flow hydrograph, meteorological model that handles precipitation inputs, watershed stream network and size and the time span of the simulation (USACE, 2016[a]).

The infiltration loss is computed by subtracting from precipitation depth and the remaining depth is referred to as precipitation excess. Methods available in HEC-HMS to estimate infiltration loss include Initial and Constant, Deficit and Constant, Exponential, SCS Curve Number, Green and Ampt, Smith Parlange and Soil Moisture Accounting. Deficit and Constant and SMA loss models are used for continuous simulation and SCS CN, Green and Ampt and Initial and Constant loss models are applicable for event based simulation (USACE, 2000).

Different researchers used different infiltration loss method based on the available data, applicability of the method to their study area and simplicity of the method. Alemseged et al., (2016); Chatterjee et al, (2014) and Sintayehu, (2015) was used deficit and constant loss method to model infiltration loss and the method uses a single soil layer for continuous simulation of soil moisture dynamics. Tamirat and Adane, (2016) was used initial and constant loss method; is simple and applicable for the watershed lack of detail information for event simulation model. The SCS CN loss method is the most common and widely used across the world for event based simulation and used by (Abushandi and Merkel, 2013; Amini et al., 2014; Asadi and Boostani, 2013[a]; Asadi and Boostani, 2013[b]; Choudhari et al., 2014; Hashemyan et al., 2015; Knebl et al., 2005; Yang and Yang, 2014 and Yasin et al., 2015). The soil moisture accounting algorithm is the preferred method and used to simulate continuous movement of water through and storage of water on vegetation, on the soil surface, in the soil profile and in groundwater layers (Bhuiyan et al., 2017and Singh and Jain, 2015).

The transform methods in HEC-HMS are SCS unit hydrograph, Clark unit hydrograph, Snyder unit hydrograph, Kinematic wave, Mod-Clark and User specified unit hydrograph. These methods are used to simulate the process of direct runoff of excess precipitation on a watershed and transform this excess precipitation to a point runoff. The SCS UH is the most commonly used transform method applied for estimating direct runoff based on a relationship between time of concentration and lag time (Abushandi and Merkel, 2013; Amini et al., 2014; Asadi and Boostani, 2013[a]; Asadi and Boostani, 2013[b]; Bhuiyan et al., 2017; Choudhari et al., 2014; Alemseged et al., 2016; Yang and Yang, 2014 and Yasin et al., 2015). The Synder unit hydrograph method had developed for analysis of ungauged watersheds by providing relationships for estimating the UH parameters from the watershed characteristics (Sintayehu, 2015 and Tamirat and Adane, 2016). Chatterjee et al. (2014); Knebl et al. (2005) and Singh and Jain (2015) are used Clark unit hydrograph method to transform excess precipitation to stream flow hydrograph.

Base flow is the sustained runoff of prior precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from the current storm. They are different methods available for modeling the base flow includes Bounded Recession, Exponential Recession, Constant Monthly, Liner Reservoir and Nonlinear Boussinesq. Bhuiyan et al. (2017); Choudhari et al. (2014); Sintayehu (2015); Tamirat and Adane (2016); Alemseged et al. (2016); Knebl et al. (2005); Singh and Jain (2015) and Yang and Yang (2014) are used the most common method of exponential recession base flow method. Asadi and Boostani (2013[a]); Asadi and Boostani (2013[b]) and Chatterjee et al. (2014) are used the constant monthly (varying only monthly) base flow method.

The channel flow routing model is used to route the downstream hydrograph based on the upstream hydrograph as the boundary condition. The routing methods in HEC-HMS for channel flow are Kinematic Wave, Lag, Modified Puls, Muskingum, Muskingum-Cunge and Straddle Stagger. Muskingum model is very common method for channel routing and easy to use and used by (Asadi and Boostani, 2013[a]; Asadi and Boostani, 2013[b] ; Bhuiyan et al., 2017; Choudhari et al., 2014; Alemseged et al., 2016 and Singh and Jain, 2015). Yasin et al. (2015) used Muskingum-Cugne model to overcome the difficult in the Muskingum model for channel flow routing.

On the above reviewed studies researchers use HEC-HMS software for different application in their studied area by performing event and continuous simulation model. Most of them use event based simulation model of SCS CN and initial and constant loss method and others use deficit and constant and soil moisture accounting continuous simulation methods to model infiltration loss. SCS CN is one of the event based simulation models with allowable CN value ranges between 1 and 100; however the reported value on reviewed past studies here is between 51.1 and 69. The initial abstraction values range between 0mm to 500mm. In the reviewed studies reported that the value is range between 13.1 mm to 54.2 mm. The deficit and constant loss method is long term simulation model having two calibration parameters. The allowable range of initial deficit and maximum deficit both are range between 0mm and 500mm. However, the reviewed past studies value varies between 2.31 mm to 4.52 for the initial deficit and 265 mm for maximum deficit were reported. The other long simulation model is soil moisture accounting having of thirteen calibration parameters and all those parameters reported on the past studies are varies with the allowable range Table 2.

The lag time for SCS unit hydrograph estimated in previous reviewed studies vary from 2.95 minute to 396 minute; the values is depend on the longest flow path, slope and area of the studied catchment. The base flow initial discharge value is estimated using the minimum dry season flow and recession constant reported in the studies are with allowable limit Table 2 below. Ratio-to-peak refers to the ratio of the dry season minimum flow to the wet season peak flow value. The Muskingum model parameter K can be estimated based on the travel time of the flood wave through a reach. In the previous reviewed studies in the table 2 K parameter estimated based on the reach length and catchment area; large catchments have higher value of K. The allowable range of x is between 0 and 0.5. The value is depends on the shape of the modeled wedge storage. However previous reviewed studies reported the value of x is range from 0.25 to 0.48 for Muskingum channel routing.

Table 2 below shows the calibrated parameter by different authors for different loss, transform, base flow and routing of HEC-HMS model. All optimized parameters area within the allowable range.

Table 2 Optimized parameters for HEC-HMS model in reviewed past studies

Model-ing	Model	Parameter	Parameter range value	Authors
Runoff Volume	Deficit & Constant	Initial deficit (mm) Maximum deficit (mm)	2.31-4.52 265	Alemseged et al., 2016
	SCS CN	CN(-) Initial abstraction (mm)	51.1-69 13.10-54.2	Asadi and Boostani, 2013[a]; Asadi and Boostani, 2013[b]; Amini et al., 2014; Choudhari et al., 2014 and Yang and Yang, 2014
	SMA	Max. infiltration, mm/hr Soil storage, mm Tension storage, mm Soil percolation, mm/hr GW1 percolation, mm/hr GW2 percolation, mm/hr Storage coefficient, hr	4.58-73.01 416.2-514.9 60.6-175.1 0.1-2.432 0.1-1.95 0.113-1.95 2.04-27.5	Singh and Jain, 2015
Direct Runoff Transformation	SCS UH	Lag time (min)	2.95-396	Asadi and Boostani, 2013[a] ; Asadi and Boostani, 2013[b]; Amini et al., 2014; Choudhari et al., 2014; Alemseged et al., 2016 and Yang and Yang, 2014
Base Flow	Recessi-on	Initial discharge (m^3/s) Recession constant (K_r) Ratio to peak (m^3/s)	0.02-39.34 0.35-0.946 0.055-0.35	Choudhari et al., 2014; Alemseged et al., 2016; Singh and Jain, 2015 and Yang and Yang, 2014
Routing	Muskin-gum routing	K(hr) X(-)	0.25-250 0.2-0.48	Asadi and Boostani, 2013[a] ; Asadi and Boostani, 2013[b]; Choudhari et al., 2014; Alemseged et al., 2016 and Singh and Jain, 2015

2.4.1 Application area of HEC-HMS hydrological model

HEC-HMS model is designed to simulate the precipitation-runoff process in a river basin. It is applicable to simulate flood for 10, 20, 50 and 100 years return period (Hashemyan et al., 2015; Khaghan and Mojaradi, 2016). HEC-HMS has been used for performing various studies including setup flood forecasting and flood inundation models (Knebl et al., 2005).

Tamirat and Adane (2016) used initial and constant loss method of HEC-HMS model for estimating probable maximum flood in Tendaho embankment dam for spillway adequacy; the total catchment area of 112,211 km^2. The model is calibrated using five years flow data and then four years flow data used for validation purposes for the lower course of Awash River catchment. The result of the study shows HEC-HMS model produce probable maximum flood in the catchment with a higher precision of average computed Nash-Sutcliffe efficiencies (NSE) and coefficient of determination (R^2) of 0.839 and 0.873 for calibration and 0.874 and 0.913 for validation respectively.

Asadi and Boostani (2013^a) studied application of HEC-HMS model for flood forecasting in Iran, for catchment area of 16.3 km^2 and 846.5 km^2. The authors applying 3 flood events that occurred during the three-year period of 2009-2011 in were used for model testing, simultaneously. The authors test objective functions by determination coefficients and coefficients of agreement for all the flood events and obtained good model performance.

Yang and Yang (2014) used HEC-HMS model integral uncertainties for magnitude and timing of peak flow and cumulative reservoir inflow forecasting, Shihmen Reservoir catchment. It has a 761.05 km^2 catchment area and 233 million cubic meters of effective storage capacity. The study combines ensemble quantitative precipitation forecasts and a hydrological model to provide a 3-day reservoir inflow. The results showed that using the ensemble precipitation forecasts with the hydrological model would have the advantage of extra lead time and serve as a valuable reference for operating reservoirs.

Choudhari et al. (2014) studied simulation of rainfall-runoff process of Bailjore Nala watershed of Odisha, India. Randomly twenty four rainfall storm events selected for rainfall-runoff simulation. Out of these, twelve rainfall events are selected for model calibration and another twelve rainfall events are used for validation purposes. For calibration of model the statistical tests of error functions like mean absolute relative error (MARE) and root mean square error (RMSE) between the observed and simulated data are conducted. Satisfactory performance of model in rainfall-runoff simulation is defined by these error functions. After examined the mathematical error functions it is concluded that the HEC-HMS model can be effectively use for rainfall-runoff simulation in the Baijore Nala Watershed.

2.5 Flood Hazard and Inundation Map

Flood hazard maps allow delimiting and classifying the different areas according to the hazard, the vulnerability and the risk associated to the flood (Cancado et al., 2008). Flood hazard maps are identify the probability of occurrence of a specific flood events, in specific future time, as well as its intensity and identify area of impact (potentially damaging phenomenon) along streams and lakes using design flood levels (Cancado et al., 2008; Getahun and Gebre, 2015 and Jedhe et al., 2014) and flood inundation map displays the spatial extent of probable flooding for different scenarios and can be present either in quantitative or qualitative ways (Getahun and Gebre, 2015).

Flood modeling is one of the engineering tools which provide accurate information of the flood profile. The rainfall, runoff, catchment characteristics, and return period are the parameters which govern the flood (Ahmad et al., 2016). A number of efficient and cost-effective flood hazard and inundation map model have been developed and put in place in river basins, with an aim of saving lives and protecting property including infrastructures. These include MIKE, INFOWORK, ISIS, SOBEK, GIS and HEC-RAS hydraulic model.

At present time, using GIS software and HEC-RAS hydraulics model are the most commonly method used to develop flood hazard map, flood inundation map and describe the relationships between surface flooding and the depth of flow according to return period (Karimain et al., 2013). GIS software is used to delineate flood hazard area and inundation map based on the secondary data available in combination of high resolution DEM and by extracting spatial analysis of the catchment area (Jedhe et al., 2014). Forkuo (2011) develops flood hazard map of the northern region of Ghana using Aster image by GIS with an approach of synthesize the relevant database in a spatial framework. Therefore, GIS is the cost effective and efficient way to create a moderate resolution database for identifying human settlement that is highly vulnerable to flooding.

HEC-RAS hydraulic model is used to develop flood hazard and flood inundation map of the studied area by considering both steady and unsteady flow, and sub and supercritical flow regimes. The application of this models and procedure provide effective results within less time consumption and little resources. 1-D HEC-RAS hydraulic model used to develop flood hazard maps of urban area of the Orlice River valley (Czech Republic) corresponding to a 100-year flood (Brych et al., 2002). HEC-RAS/HEC-GeoRAS used to develop flood inundation maps of Awash River basin based on DEM (digital elevation model) processed to create TIN (triangular irregular network) by extracting the river-sections, stream centerlines, stream bank lines and other river geometry information for different return periods. They also develop flood hazard maps of Awash River basin using GIS software by considering the flood generating factors such as slope, elevation, drainage density, land use and soil type (Getahun and Gebre, 2015). HEC-RAS model is a powerful tool can be used for both steady and unsteady flow, yet easy-to-use software package for determining water surface profiles in a wide variety of streams.

2.5.1 HEC-RAS hydraulic model

HEC-RAS (Hydrologic Engineering Center- River Analysis System) is a hydraulic model developed by the Hydrologic Engineering Center (HEC) of the U.S. Army Corps of Engineers. It is designed to perform one-dimensional steady flow, one and two-dimensional unsteady flow hydraulic calculations for full network of natural and constructed channels, overbank/floodplain areas, sediment transport/mobile bed computations and water quality modeling. HEC-RAS is an integrated system of software, designed for interactive use in a multi-tasking environment and comprised of a graphical user interface (GUI), separate analysis components, data storage and management capabilities, graphics and reporting facilities (USACE, 2016[c]). The system is capable of modeling subcritical, supercritical, and mixed-flow regimes for streams consisting of a full network of channels, a dendritic system, or a single river reach. The model results are typically applied in floodplain management and flood insurance studies in order to evaluate the effects of floodway encroachments (USACE, 2016[c]).

HEC-RAS uses a number of input parameters for hydraulic analysis including the stream channel geometry and water flow. These parameters are used to establish a series of cross-sections along the stream. In each cross-section, the locations of the stream banks are identified and used to divide into segments of left floodway, main channel, and right floodway. At each cross-section, HEC-RAS uses several input parameters to describe shape, elevation, and relative location along the stream such as; river station number, lateral and elevation coordinates for each terrain point, left and right bank station locations, reach lengths between the left floodway, stream centerline, and right floodway of adjacent cross-sections, manning's roughness coefficients, channel contraction and expansion coefficients, geometric description of any hydraulic structures, such as bridges, culverts, and weirs (USACE, 2016[c]).

The merits of HEC-RAS has, notably its support by the US Army Corps of Engineers, the future enhancements in progress, and its acceptance by many government agencies and private firms. It is in the public domain, peer-reviewed, and it can be downloaded free of charge from the Hydrologic Engineering Center's website (http://www.hec.usace.army.mil/software/hec-ras/). The use of HEC-RAS includes extensive documentation, and scientists and engineers versed in hydraulic analysis should have little difficulty utilizing the software.

HEC-RAS is the software package predominately used in the field of hydraulic analysis for developing flood inundations maps for a variety of applications. It has the ability to model flood events and produce water surface profiles for different flow scenarios over the length of the modeled stream. HEC-RAS model can be used for both steady and unsteady flow, and sub and supercritical flow regimes (Beilicci and Beilicci, 2014 and Goodell and Warren, 2006) and with its companion utility, HEC-GeoRAS extension of ArcView, seamless integration with GIS makes both the construction of the model geometry and the post-processing of the output very easy.

Khattak et al. (2016) studied the application of HEC-RAS model, in combination with Arc-GIS, to simulate water surface profiles and to develop flood plain maps or extent of inundation area under different return-period floods for Kabul River in Pakistan. The maximum instantaneous discharge available at Warsak dam and Nowshera Bridge used to estimate peak discharges for different return periods using frequency analysis to estimate water surface profiles and extent of inundation area. Water surface profile data were extracted from HEC-RAS through HEC-GeoRAS and then were incorporated into a floodplain map through GIS. Using the water surface data and DEM created for the basin, the flooded area 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.

Nut and Plermkamon (2015) study delineation of flood plain area of Nam Phong River in northeast of Thailand; with the integration hydraulic simulation one-dimensional model, HEC-RAS/HEC-GeoRAS and GIS for different return periods. They used steady flow hydraulic model used to simulate flood along 148 km with an area of 2993.95 km^2. Peak flow data of the basin was simulated by SWAT model with 12-year rainfall records from 2000-2012 water year, and with the daily model calibration from 2004-2007 (R^2=0.93). After evaluation of the accuracy of the data, Gumbel distribution method was employed for flood frequency analysis. The flooded area obtained with the HEC-GeoRAS model for 5, 10, 25, 50 and 100 years return period was 202.78, 238.10, 240.28, 242.75 and 250.01 km^2 respectively.

Al-Zahrani et al., (2016) study flood hazard analysis using HEC-RAS hydraulic model in Hafr Al-Batin city, Saudi Arabia. The city lies in the dry valley of Wadi Al-Batin, which leads inland towards Medina and formerly emptied into the Arabian Gulf. Hafr Al-Batin is located in an area where three valleys meet, which makes the city under high risk of flooding, especially when intense rain occurs during short duration as in the case of arid and semi-arid regions. HEC-HMS models area used to simulate flood occurrence in the city for different return period. And HEC-RAS hydraulic model uses output of hydrograph from HEC-HMS to simulate unsteady flow condition. Then export the HEC-RAS file to the HEC-GeoRAS extension to calculate and analysis the floodplain hydraulics. The flood hazard maps for different return period were delineated based on the water elevation simulated using HEC-GeoRAS extension. The result of the average depths within Hafr Al-Batin city were 3.02 m, 3.26 m, 3.45 m, 3.76 m, 4.04 m and 4.34 m for the simulated 2, 5, 10, 25, 50 and 100-year design floods, respectively.

Gunasekara, (2008) study flood hazard mapping in lower reach of Kelani River, Sri Lanka; with the integration of HEC-RAS hydraulic model and HEC-GeoRAS GIS extension for a return period of 10, 20 and 50 years. HEC-GeoRAS GIS extension used to prepare the geometric data and delineate flood hazard map using the imported data from HEC-RAS. Steady flow simulation condition was performed for the return period of 10, 20 and 50 years using HEC-RAS in the lower reach of Kelani River. The flood hazard maps was delineating based on the flood depths in the lower reach of Kelani River for these return period. The result of flood hazard was low, moderate, high and very high hazard levels for flood depths less than 1m, between 1-3 m, between 3-5 m and greater 5m respectively.

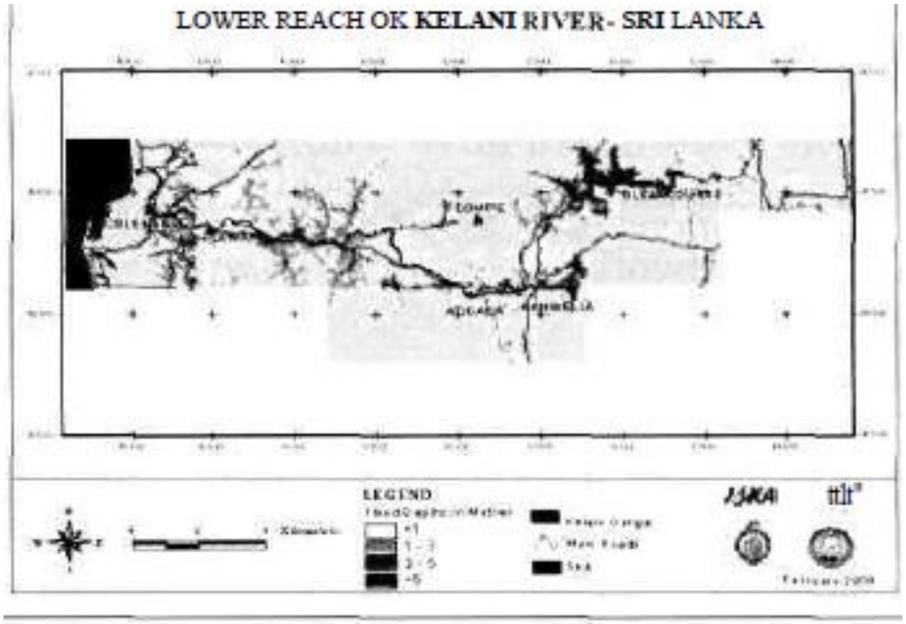


Figure 4 Flood hazard map of 20 year return period floods

Martin et al. (2012) study flood hazard modeling of River Sironko, Uganda using HEC-HMS/RAS model. The Sironko River catchment has 325 km^2 areas. The design flood for this catchment were 71.8 m^3/s, 123.0 m^3/s, 138.5 m^3/s, 163.9 m^3/s, and 183.4 m^3/s for return period of 10, 50, 100, 250 and 500 years simulated using HEC-HMS frequency storm meteorological model. HEC-RAS hydraulic model determine water surface profiles using the imported flow data from HEC-HMS and geometric data from HEC-GeoRAS. Flood hazard maps were generated by importing the HEC-RAS model output results to HEC-GeoRAS for different return period. From the result of flood hazard maps some villages located in the flood plain would be affected more especially with the 50, 100, 250 and 500 year floods.

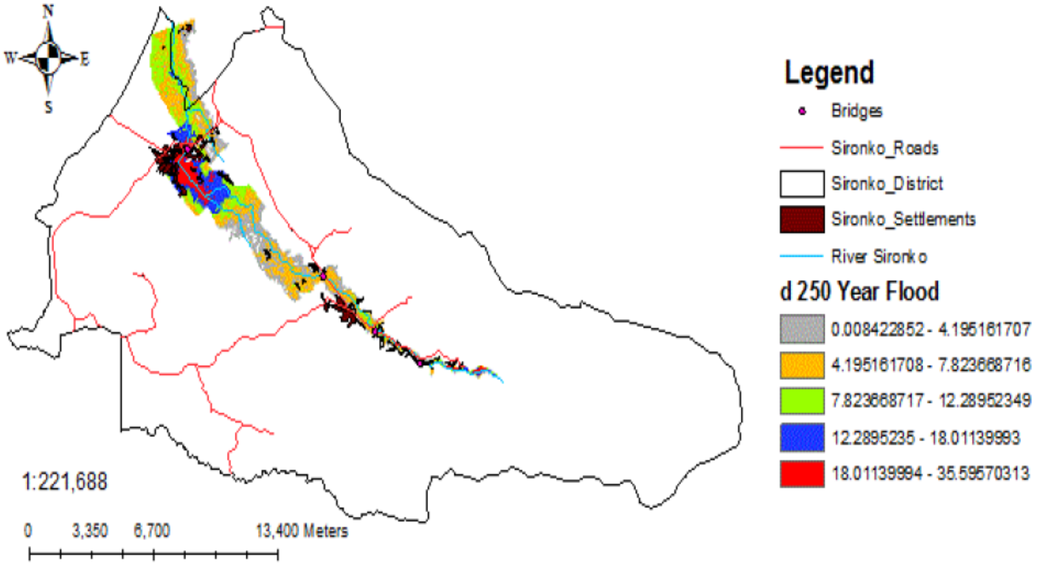


Figure 5 Sironko district flood hazard map for 250 year floods

Adewale et al. (2010) used HEC-RAS hydraulic model to evaluate flood routing and water flow activity of the Ogunpa River, Nigeria situated in densely populated town of Ibadan. They study modeling of the steady flow water surface profile and obtained the result of 1.87m^3/s and 2.8 m^3/s discharges for 50 year and 100 year return period respectively. The discharge was roughly constant between the distances of 1.21 - 2.02 km along the channel. The discharge was directly proportional to the stream length (between 7.9 km and 11 km). The difference between the 50-year and 100-year profiles results confirmed the urbanization in this region, which leads to increases in runoff and chemical and waste pollution. The channel velocity in the lower course tends to zero, which is a result of the stagnant nature of the river in the lower course due to the accumulation of heavy refuse. This particular region of the river channel is susceptible to flooding during peak rainfalls.

Khaleghi et al. (2015) simulated flood risk assessment of Lighvan Chai River using the integrated application of HEC-RAS and GIS and RS. Lighvan basin has a total 15.8 km length of river reach and 142 km^2 area. Topographic maps of 16 km of Lighvan Chai River were used for flood zoning; geo-referencing the maps and digitalizing using Arc-GIS software, geometric data of the river cross section profiles were extracted from these maps.

And the maximum flood discharge at different return periods was obtained using Fuller empirical formula. After obtaining the discharge with different return periods, these data with cross-sections were inputted to HEC-RAS model. The simulation results obtain the flood levels in cross sections and calculation of flood zoning and its area was performed in GIS. Flood levels area 0.21, 0.31, 0.40, 0.51, 0.60, 0.69 and 0.76 km^2 with a return period of 2, 5, 10, 25, 50, 100 and 200 years respectively. Overall accuracy was assessed 96% and 95% for 2000 and 2012 also Kappa coefficient was 0.95 and 0.94 for 2000 and 2012 respectively.

Awad (2016) studied hydraulic model development and determination of manning roughness value for Shatt Al-Runmaith using HEC-RAS. Calibration of Mannnig's "n" coefficient was performed by comparing the computed water surface profiles with observed one, using HEC-RAS steady flow model for Shatt Al-Rumaith channel. For calibration, the flow for the year 2014 has been considered. It is found that the value of Manning's roughness coefficient for Shatt Al-Rumaith shows a good agreement between the computed with observed water surface profiles, is n=0.023and n= 0.04 for main channel and floodplain respectively.

Mardookhpour and Jamasbi (2017) application of HEC-RAS and GIS model to prepare flood zoning for different return period and river management of Sardabrud River that lies in Mazandaran province, Iran. The catchment area of Sardabrud River is 419.25 km^2, length of the river is 48.53 km and the average discharge of the river is 3.6m^3/s. The design discharges for a return period of 2, 5, 10, 20, 25, 50, 100, 500 and 1000 years were obtained 12, 18, 24, 29, 36, 50, 65, 150 and 190m^3/s respectively. The geometrical plan of the river was prepared with the aid of Arc-GIS software with the help of regional topography data and analysis flood zoning maps for floods with return periods of 2, 5, 10, 20, 25, 50, 100 and 1000 years using HEC-GeoRAS . Every width of the stream bed is increased, width of the flood plain is also increased and water is spread over a large surface with increasing return periods. The maximum surface flooding and depth of flow is happened in 1000 year return period, 168 km^2 and 163 m respectively. Having this result regional warning system to reduce the risk and also identify the places which is need structural measures along the river.

2.6 Flood Damage Assessment

Flood damage assessment is a very important issue which is considered in water engineering science (Merz et al., 2010 and Mohammadi et al., 2014). And it is used for supporting policy analysis and flood insurance (Wagenaar et al., 2016) or to compare the impact of different flood risk management strategies (Kind et al., 2014). Flood damage assessment has a wide domain and depending on various factors can expect different results. In macro management level, the first step in defining the water engineering projects is economic analysis of projects. Although in many engineering projects it is sufficed to flood zone with specific return periods but by doing these types of studies, cost-benefit ratio of the different project is studied well and this causes the implementation of the projects which flood control will be its outcome (Mohammadi et al., 2014).

Flooding damage appraisal can been obtained by interpolating real damage data caused by historical flooding events or accounting the effects of a flood in terms of the depreciation of assets or a percentage of the market value of the flooded properties (Notaro et al., 2014). In many cases flood damage estimation will be difficult and following many errors. Uncertainties of hydrologic, hydraulic, economic, social and multiplies errors of this estimations. In some cases, the severity of damage caused by flooding is much higher than previously estimated. Thus, economic studies of flood and comparing flood control projects need to select indicators for assessing their flood damage. Whole estimation of flood damage is difficult and impossible and therefore each part of the damage is estimated by classifying flood damage to its constituent parts in term of need (Mohammadi et al., 2014).

Quantitative evaluation of flood damage is done in different ways. One of these methods is software modeling of flood damage analysis HEC-FDA. Based on hydraulic and hydrologic data of the study area, can calculate the expected annual damage (EAD). A point that should be noted is that this model can estimate the economic amount of flood damage and flood damage assessment index is flood depth (Mohammadi et al., 2014).

2.6.1 HEC-FDA model

HEC-FDA (Hydrologic Engineering Center- Flood Damage Reduction Analysis) is a computer program developed by U.S. Army Corps of Engineers. The program provides the capability to perform an integrated hydrologic engineering and economic analysis during the formulation and evaluation of flood damage reduction plans. Both economic flood damage and hydrologic engineering analysis are performed using a consistent study configuration; streams, damage reaches, plans and analysis years. The three types of available evaluations are analysis of damage, project performance by analysis years and equivalent annual damage (USACE, 2015).

HEC-FDA is an integrated system of software that is designed for interactive use. The model was developed by U.S Army Corps of Engineers and is acceptable for international resources. It is belongs to public domain and freely available software download from the US Army Corps of Engineers website (http://www.hec.usace.army.mil/software/hec-fda/). The program consists of a graphical user interface (GUI), hydrologic engineering and economics components, database and management capabilities, graphics and reporting facilities (USACE, 2015). Flood damage reduction analysis, standard for measuring risk is expected annual damage. This index represents long-term average annual flood damage for a given structure or area and compute the index by integrating a probability-damage function (Briant, 2001 and Pingel and Watkins, 2010).

Mohammadi et al. (2014) studied flood damage estimation using HEC-FDA model in the residential area of Neka River, north of Iran. The river basin in the Neka city is located in intersection of the foothills and coastal zone (Caspian Sea) and the basin is potentially at the high risk of flooding. The Neka River drainage area of 2004 km^2, river length of 130 km, with average width of 14.8 km and longitudinal slope of 1.9%. Flood discharges and flood depths for a return period 2, 5, 10, 20, 25, 50, 100 and 200 years were calculated using hydrological and hydraulic model. Then using the HEC-RAS model output is stored in the FDA format estimate flood damage of the basin. The result flood damage analysis using HEC-FDA model is quantify and EAD over the eight studied interval was 3,076,105,000 Rails.

2.7 Flood Mitigation Measure

Flooding is a natural and recurring phenomenon *(Ramkrishna and Chaudhari, 2014).* Flood risk is one of the most devastating natural hazards that cause loss of lives, damage to properties, resources and environmental degradation in urban areas *(Forkuo, 2011).*

Flood losses can be categorized as;

- ✓ Direct losses- Losses due to direct contact with flood water, to buildings and infrastructure such as roads, railroads; crops and animals.
- ✓ Indirect losses-Losses resulting from the event but not from its direct impact, i.e. transport disruption , business losses that can't be made up, losses of family income, utility supplies and communication losses etc.
- ✓ Tangible losses- Loss of things that have a monetary value, for example, buildings, livestock, infrastructure, crops etc.
- ✓ Intangible losses- Loss of things that cannot be bought and sold, for example, lives and injuries, heritage items, increase in ill health, homelessness, loss of live hood (*Merz et al., 2010)*

It is estimated that on average almost 200 million people in more than 90 countries are exposed to catastrophic flood events every year and it is expected to rise in future due to climate change and the steady demographic growth, as well as of urbanization *(UNESCO, 2008).* A crucial concern for world natural hazards is the generation of efforts, strategies, policies and programs of the global governments at various levels to mitigate the flood occurrences (*Idris and Dharmasiri, 2015).* Therefore, the ultimate aim of flood mitigation measure is to minimize human losses and economic damages, while making use of the natural resources for the benefit and well being of the people. There are two types of flood mitigation measure, structural and non-structural measure as shown in table below (*Ramkrishna and Chaudhari, 2014).*

Table 3 Structural and non-structural mitigation measures

S .No.	Structural flood mitigation measures	Non-structural flood mitigation measures
1	Storage and detention reservoirs	Flood plain zoning
2	Flood embankment	Flood forecasting/warning
3	New flood channels	Evacuation and relocation
4	Channel improvement	Flood insurance
5	Watershed management	

Ramkrishna and Chaudhari (2014) evaluate non-structural and structure flood management measures for Nasik city on the Godavari River and its tributaries in Maharashtra state. The total area of Nasik city is 264.23 km^2 and in almost all areas of the river width is less than 60m. The main flooding problem in Nasik city is due to large discharge of water from the Gangapur dam. And shifting of affected people and submergence of houses is every year's problem. The total costs of the flood affected area 48520000.00 Indian Rupee us the evaluation of the non-structure management measures. For the study area it is essential to increase the width of river channel and construct retaining wall between Ahilyabai Holkar Bridge and Talkuteshwar Mandir Bridge as structural flood management measure. The maximum proposed height of retaining wall is 10 m where river width is less than 40m and minimum is 3m near Ramwadi Bridge. Therefore, this study demonstrates the impact of non-structural measures on community and this lead to search of structural flood management measure as Gabion wall.

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

Meki River catchment is located in the Main Central Rift Valley of Ethiopian. Meki town is located about 130 km from the capital city of the country, Addis Ababa to south. Meki River crosses the town in to two, flow to east and join Lake Ziway. The area stretches from the edges of the western escarpment of the rift valley in the west and to Lake Ziway in the east. Geographically, it is located approximately between 7^{0}48’59” & 8^{0}28’37” E Longitude and 38^{0}13’21” & 38^{0}54’11” N Latitude (UTM 414308-489359 E and 864022-936956 N, Zone 37, Northern Hemisphere) respectively. The total area of Meki River catchment is about 2187.59 km^2.

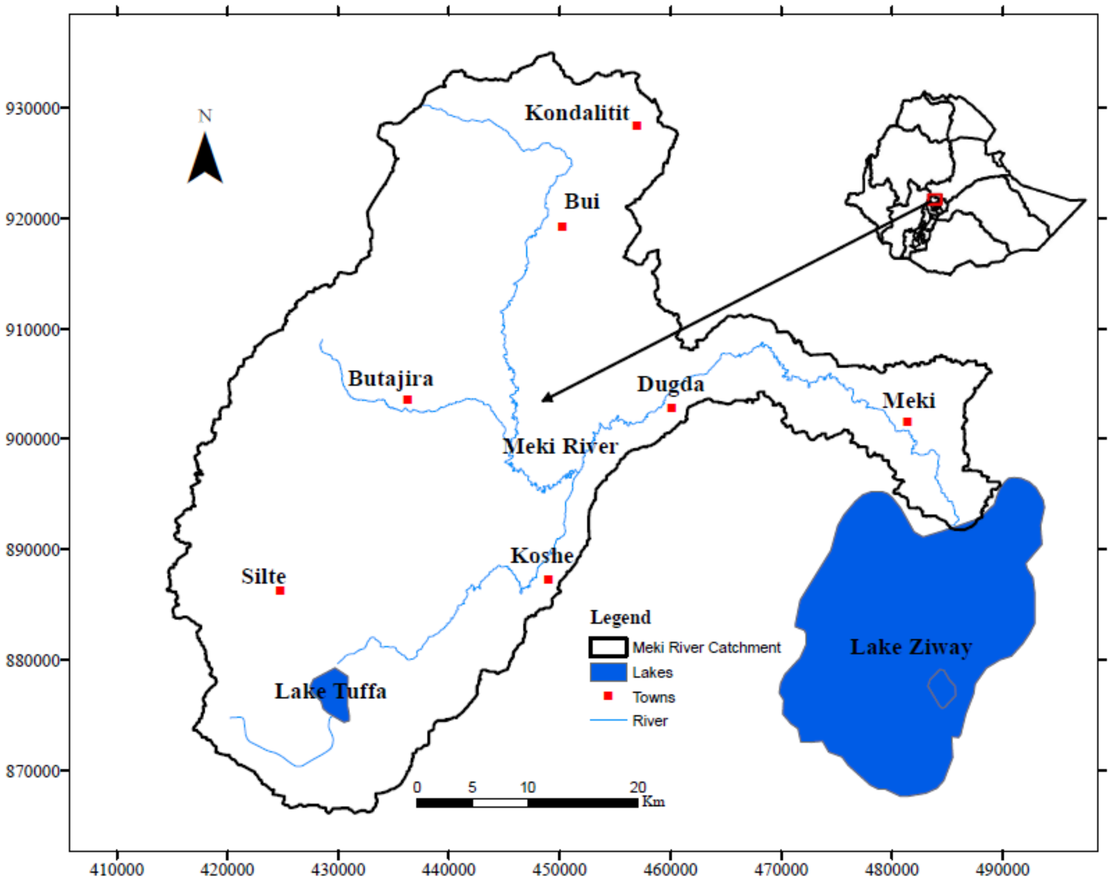


Figure 6 Location map of Meki River catchment

3.1.2 Topography and drainage

The Meki River catchment, which is part of the Ziway-Shalla basin, is located in the northern part of the Main Ethiopian Rift. The area extends from a chain of mountains upstream, called the Guraghe (Zebider) Mountains, to the low-lying Ziway Lake. Topography of the area is primarily determined by the rift system of faulting (Legesse, et.al, 2010). The study area lies within altitudes ranging from 3605m a.s.l. in the west to 1610m a.s.l. in the rift floor with a mean elevation of 2605 m a.s.l. The upper riches of the basin are steep and mountainous while the lower basin is flat with a broad valley.

The western plateau of the Guraghe highlands with elevation ranging from 3500 to 3605 m a.s.l. are the perennial sources of the Meki River while the tributaries in the escarpment and rift floor are intermittent sources. The Meki River drains from the western mountains and escarpments including a vast swampy area and travels for about 116 km before draining to Lake Ziway. The highland is characterized by higher drainage density than the escarpments and the flat rift floor areas.

3.1.3 Climate

Climate of the study area consists of three ecological zones: humid to dry humid, dry sub-humid or semi-arid and semiarid or arid lands (Makin et al., 1976). Accordingly, highland areas west of Butajira are categorized under humid to dry sub-humid land. The areas north of Butajira around the perennial sources of Meki River are humid to dry sub-humid lands. The rest of the area which is around the lake is in semiarid or arid zone. Rainfall and temperature in the Meki River catchment strongly varies with the altitude. The rainfall pattern is increase as increasing the altitude from the rift floor to the western highlands. The average annual rainfall varies spatially and ranges from 733 mm/year around the rift floor in the east to 1133 mm/year at extreme highlands areas in the west. Figure 7 shows four selected meteorological stations within the catchment and distribution of rainfall patterns in the study area.

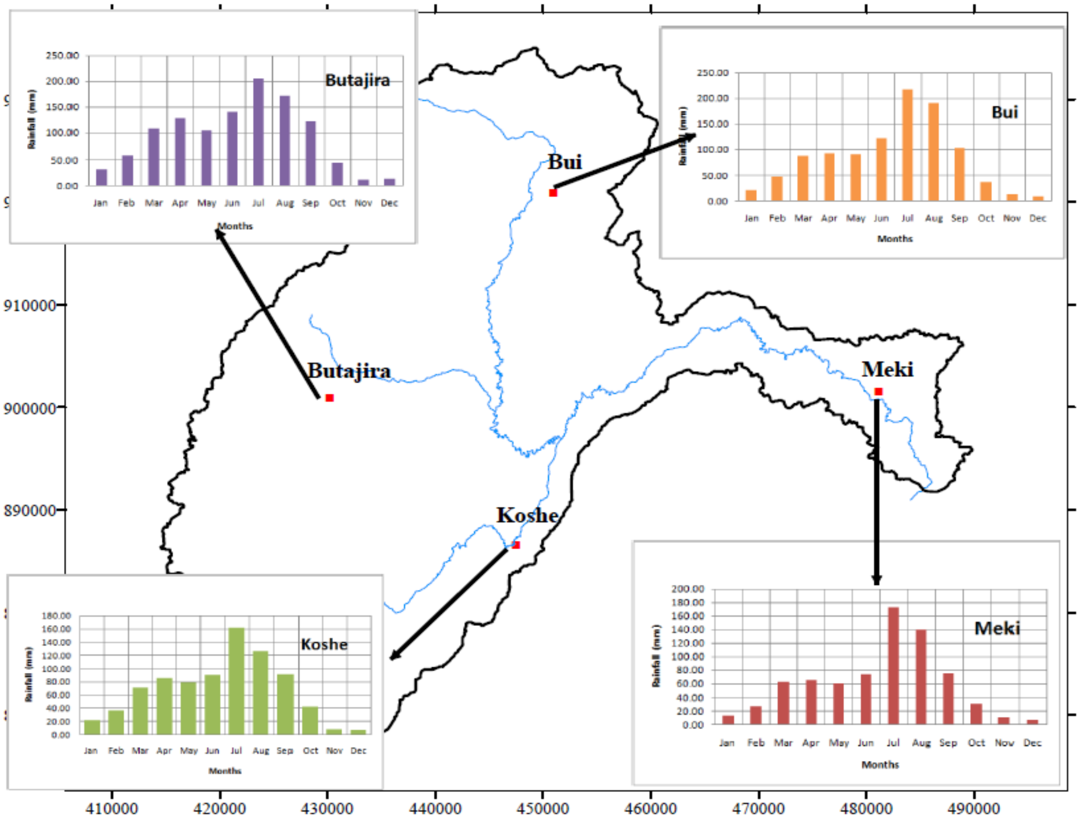


Figure 7 Meteorological stations and rainfall distribution patterns in the study area (1987-2016)

Indian and Atlantic Oceans are the sources of moisture for almost all rains in Ethiopia (Degefu, 1987). The study area is characterized by three main rainy seasons. The first one is the long rainy season in summer, which lasts from June to September and locally known as “kiremt”. The “kiremt” season is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone, which lies to the north of Ethiopia at that time. The “kiremt” rain have covers 55-70 % of the average yearly total rainfall. The second season is the dry period, which extends between October to February and locally known as “bega”. In “bega” the ITCZ lies to the south of Ethiopia when the northeasterly trade winds traversing Arabia dominates the region. The “bega” season is the main harvest period in the area and it is indicated that occasional rains during this period bring 10–15% of the yearly average. The third season, which is locally known as “belg” is of a “small rain” season accounting for 20–30% of the annual amount, and stays from March to May. Figure 8 shows observed mean monthly rainfall distribution for stations in the Meki River catchment.

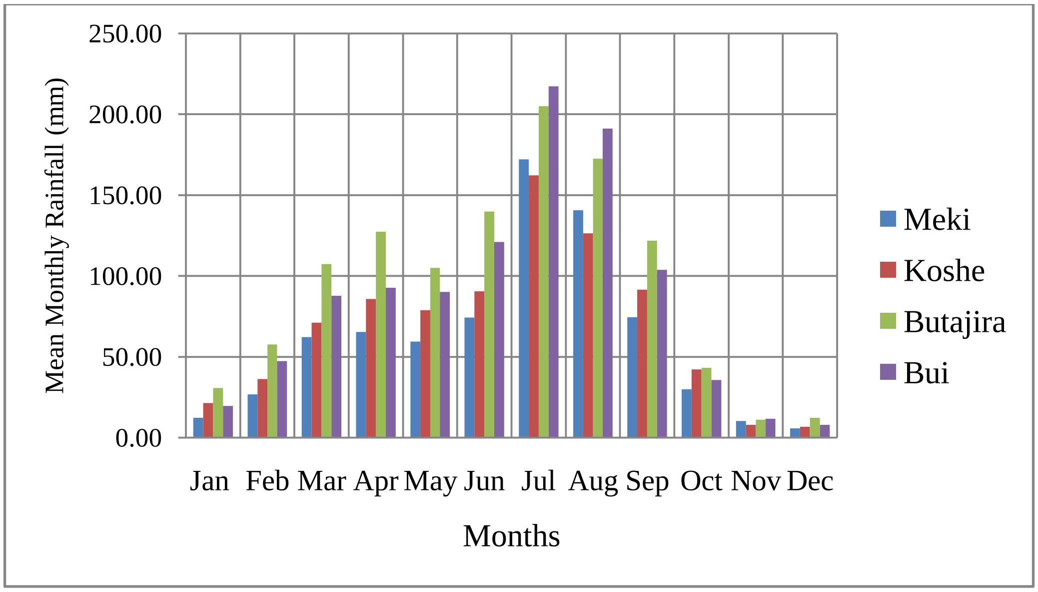


Figure 8 Mean monthly rainfall of four different topographically stations (1987-2016)

The mean annual temperature in the study area varies from 21 ^{0}C on the rift floor to 17 ^{0}C on the humid plateau. The magnitude of temperature increases as the elevation decreases. Figure 9 shows plots of mean monthly temperature at three selected stations in the Meki River catchment and near stations (Ziway in the rift floor and Butajira and Bui on the plateau; data from Ethiopian NMSA).

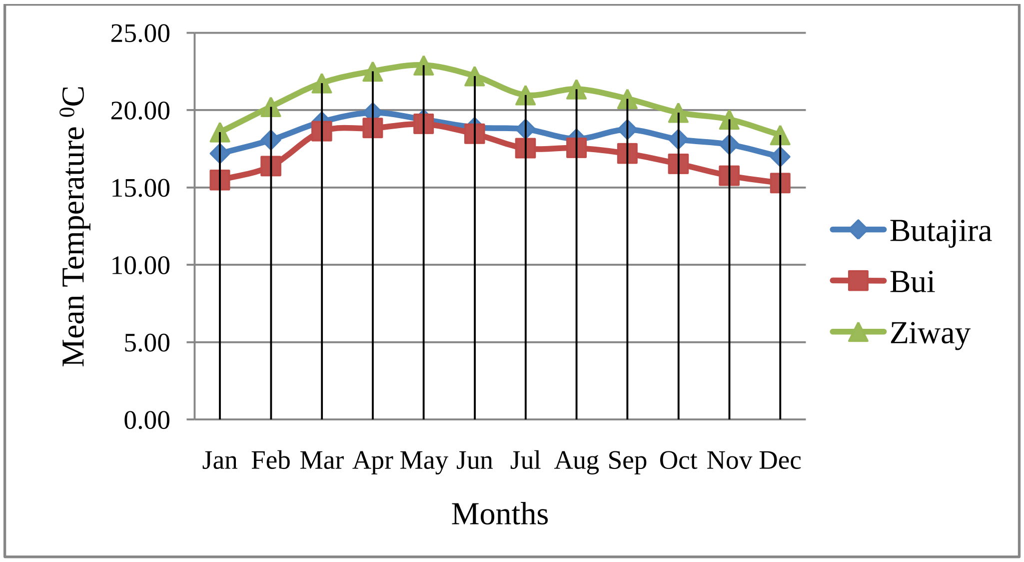


Figure 9 Mean monthly temperatures at stations within the catchment and near (2000-2005)

3.1.4 Soil

Soil map of the study area is obtained from rift valley lakes master plan study report by Halcrow Consulting group report in the form of shape file which is collected the data from Ministry of Water, Irrigation and Electricity. According to the Halcrow Consulting the dominant soil types of the study area are Chromic Luisols, Eutric Cambisol, Eutric Vertisol, Eutric Fluvisols, Fibric Histosols, Humic Nitisols, Lithic Leptosols, Luvic Phaeozems, Vertic Cambisols and Vitric Andosols. The spatial distribution of the dominant soil types of the catchment Figure 10.

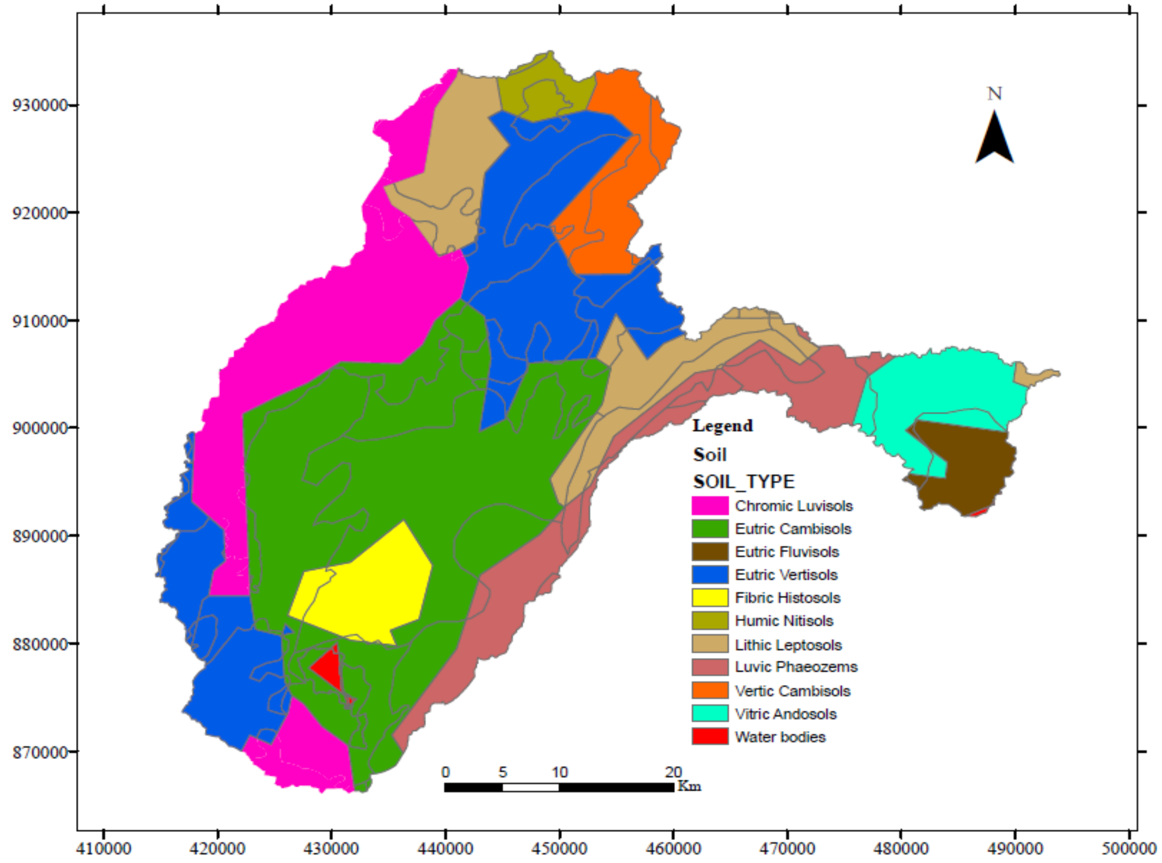


Figure 10 Dominant soil types of study area

3.1.5 Land use and cover

The land use and cover of the catchment has made dramatic change with the past years in association with the population growth of the rift valley catchment. Land use and cover of the study area is obtained from Ministry of Water, Irrigation and Electricity in the form of shape file. There are different land uses and cover types in Meki River catchment, namely crop land, herbaceous cover, tree cover, shrub land, bare areas, urban and water body that covers 94 %, 3.2%, 1.7%, 0.17%, 0.03%, 0.2% and 0.7% of the study area respectively.

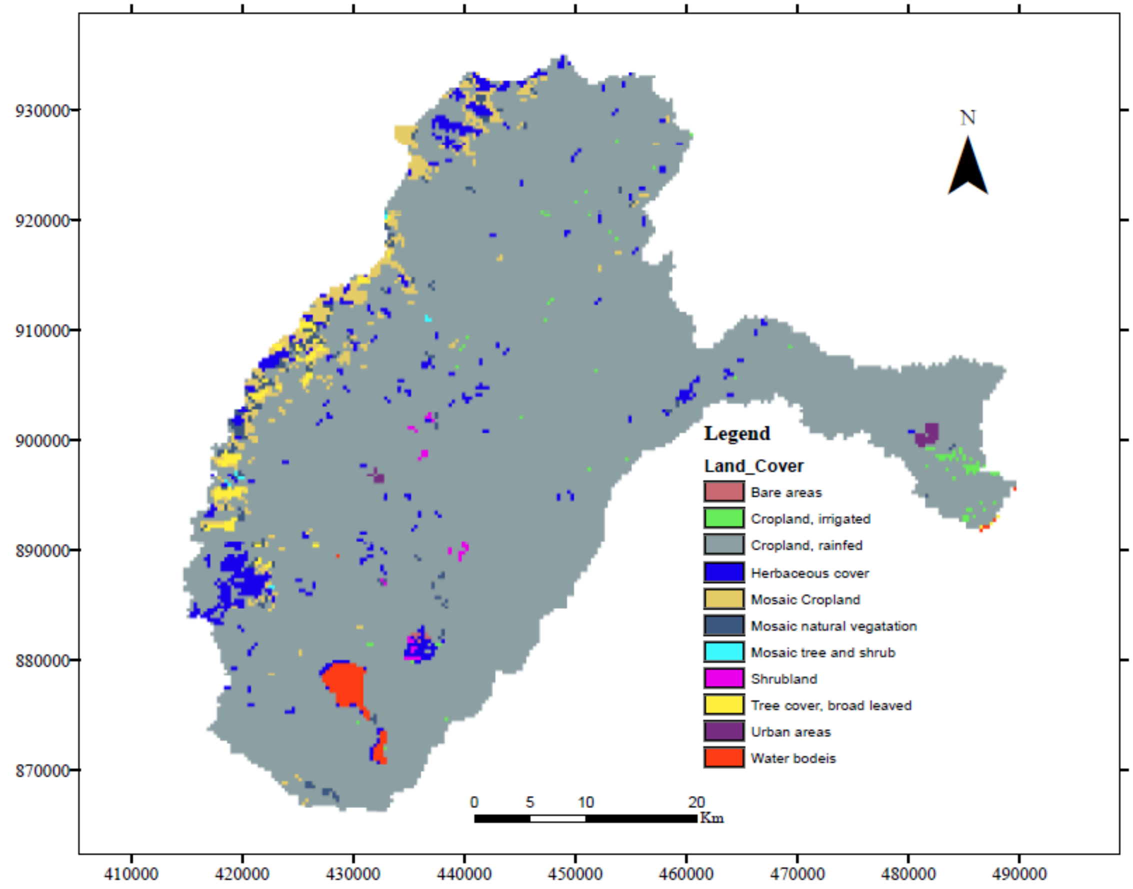


Figure 11 Land use/cover of study area

3.1.6 Agriculture

The framing practice in the east section of Meki town in the flood plains area, and which gets flooded during the rainy season, is cultivated through farm irrigation and rain fed mainly maize, wheat, teff, tomato, onion, pappy, pepper and livestock. The main crop cultivated near and around Meki town is maize. With increasing altitude, the catchment is mainly characterized by traditionally cultivated with wheat, maize, teff, ensete and livestock. Wheat is the major crop cultivated in the west part of Meki town in rift floor and escarpment, whereas teff and ensete is the major crop cultivated in the western highlands part of the catchment.

3.1.7 The 2016 flood event in study area

Flooding regularly occurs in the particular PAs of Bakele-Girisa, Weldiya-Mekdal, Weldiya-Kelina and Shube-Gamo along Meki River in the flood plain area. The aforementioned PAs have been suffering from flooding due to over flow of Meki River into adjacent areas.

According to DWDRMO, the 2016 flood event affects four PAs area located between Meki town and Lake Ziway in the flood plains. About 440 farmer were affected and 80 of were displaced from their homes.

Table 4 Affected and displaced population of Dugda Woreda due to 2016 floods

S. No	PAs	Affected Farmers		
		M	F	Total
1	Bakale-Girisa	70	24	94
2	Weldiya-Mekdal	74	30	104
3	Weldiya-Kelina	77	37	114
4	Shube-Gamo	89	39	128
	Total	**310**	**130**	**440**

Source: DWDRMO, 2016; Annual Report

Figure 12 Flooded land of Weldiya Mekdal in 2017

3.2 Dataset

In order to realize the designed objectives reliable input data is required. The main data required in the study area was time series hydrological and meteorological data including stream flow data, precipitation, temperature and others data such as land use/cover data, soil data, DEM, yield per hectares and price per kilo gram. These data were collected as secondary data from different institution. And primary data were collected from field survey using GPS instrument including cross section of the river, bridges data and flood affected area field visit. The collected data from different sources is presented in Table 5.

Table 5 Required data and sources

S. No	Data Types	Purpose	Source
1	Meteorological data	Daily precipitation data is an input to the hydrological model for flood estimation	NMSA
2	Hydrological flow data	Daily observed stream flow data is used for model calibration and validation	MoWIE
3	Soil data and land use/cover data		MoWIE
4	DEM	Generate catchment physical characteristics using HEC-GeoHMS	MoWIE
4	Crops and vegetables types in flooded area and their yield per hectares	Estimate total yield in the flooded area	DWANRO
5	Price of crops and vegetables per kilo gram	Quantify the flood damage	DWTMDO
6	1:5000 scale top-map	For cross checking the geo-spatial data and river characteristics	EMA

3.3 Materials and Models

Materials and models used in this research were selected based on the capability to work on the existing problems in achieving the predetermined objectives. To answer per-seated objectives the following materials and models have been used;

- ✓ Arc-GIS were used to prepare raw data for which to delineate sub basins to extract the physical characteristics of the catchment using HEC-GeoHMS.
- ✓ HEC- GeoHMS was used to sub-divide the catchment to more manageable form, construct inputs, and provides connection for translating GIS spatial information into hydrologic models and determine the catchment characteristics for use in HEC-HMS model.
- ✓ HEC-HMS was used to simulate the precipitation-runoff processes of the catchment and determine the peak flood discharges for different return period which have been used as an input for HEC-RAS hydraulic model.
- ✓ HEC-GeoRAS/HEC-RAS were used to delineate the flood inundation and hazard map of the study area in concert with Arc-GIS.
- ✓ HEC-FDA was used to estimate flood damage of the inundated area.
- ✓ GPS was used to collect the river cross sections and agricultural land survey data which is critically affected by the 2016 flood and information of structures constructed on the river

These models selected because of they are freely available software supported by US Army Corps of Engineers, widely used and accepted by scholars, has clear and criticizes operation steps on its manual and less time consuming.

3.4 Methodology

3.4.1 Data quality assessment

The quality and continuity of the data were analyzed to identity any kind of abnormities or missing.

A. Filling rainfall data

Rainfall data play a central role in developing rainfall-runoff models. Before using the recorded rainfall of a station, it is necessary to check first the data for continuity and consistency. The continuity of a record may be broken with missing data due to many reasons such as damage of instrument or fault in a rain gauge, failure of the observer to make the necessary visit to the gage during a period. The missing data can be estimated by using the data of neighbouring stations (Subramanya, 2008).

In this research, normal ratio method was selected to fill missing data. It is selected because of the normal annual precipitation is exceed 10% of the neighbouring station for all stations in the study area. Normal ratio method is estimating daily missing data rely on the data from any adjacent stations.

$$Px = \frac{N_x}{M}(\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots + \frac{P_M}{N_m})$$

Where P_x = is the missing annual precipitation at a station X not included in the above M stations

P_1, P_2 and P_m are the annual precipitation at neighbouring M stations

N_1, N_2… N_m the normal annual precipitations at each of the above (M+1) stations including station X are known

B. Consistency test of rainfall data

A consistent record is one where the characteristics of the record have not changed with time. Adjusting for gage consistency involves the estimation of an effect rather than a missing value. An inconsistent record may result due shifting of a rain gauge station to a new location, change in the ecosystem due to calamities, such as forest fires, landslides, and occurrence of observational error from a certain date (Subramanya, 2008).

Double-mass curve was used for this research in order to check inconsistency of the record. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent.

$$Pcx = Px\frac{M_c}{M_a}$$

Where P_{cx} = corrected precipitation at any time period t_1 at station X

Px = Original recorded precipitation at time period t_1 at station X

M_c =corrected slope of the double-mass curve

M_a = original slope of the double-mass curve

C. Statistical test of hydrological data

The quality of hydrological data was evaluated with statistical test. Independence and stationarity test, homogeneity test and outliers test were made in this research to check the quality of flow data.

Independence and stationarity test is used to determine whether the mean values and variances of a series vary with time (Rao and Hamed, 2000). Wold-Wolfowitz (W-W) test was selected in order to check independence and stationarity test.

For a data set x_1, x_2 … x_n the statistic R is calculated as

$$R = \sum_{i=1}^{N-1} x_i x_{i+1} + x_1 x_N$$

The normal distribution mean and variance calculate by

$$\bar{R} = \frac{S^2{}_1 - S_2}{N-1} \text{ and}$$

$$Var(R) = \frac{S^2{}_2 - S_4}{N-1} - \bar{R}^2 + \frac{S^2{}_1 - 4S^2{}_1 S_2 + 4S_1 S_3 + S^2{}_2 - 2S_4}{(N-1)(N-2)}$$

Where S_r =Nm_r and m_r is the r^{th} moment of the sample about the origin

$$m_r = \frac{1}{N}\sum(x_i)^m$$

The statistic $|u| = \frac{R-\bar{R}}{\sqrt{Var\,(R)}}$

Homogeneity test is used to check the recorded flow data comes from the same parent population or not (Rao and Hamed, 2000). Mann-Whitney (M-W) test was used for this research to check homogeneity test. The Mann-Whitney (M-W) method was tested by splitting the data set into two subsets of sizes p and q with p is less than or equal to q. The combined data series N= p+q is ranked in increasing order.

Then, V and W are calculated from R as

$$V = R - \frac{p(p+1)}{2} \;\; ; W = pq - V$$

R is the sum of the ranks of the elements of the first sample (size p) in the combined series (sizes N).

The M-W statistic U is defined by the smaller of V and W. The mean and variance Var (U)

$$Var(U) = \left[\frac{pq}{N(N-1)}\right]\left[\frac{N^3-N}{12} - \sum T\right]$$

$$\bar{U} = \frac{pq}{2} \quad and$$

$$The\ Statistic\ |u| = (U - \bar{U})/\sqrt{Var\ (R)}$$

Where $\bar{U}$ = mean

Var (R) = variance

U = the smaller from V and W

$\sum T$ = summed over all groups of tied observations in both samples of sizes p and q.

Outliers test are data points that depart significantly from the trend of the remaining data (Rao and Hamed, 2000). Dixon-Thompson test was selected to detect outliers. It can be used for short and long data series. The data series can be rank from the smallest to the largest (x_1, x_2, x_3…, x_n). For 3 to 7 sample size the test statistic R calculated as

$$R = \frac{X_2-X_1}{X_n-X_1} \quad \text{for low outlier}$$

$$R = \frac{X_n-X_{n-1}}{X_n-X_1} \quad \text{for high outlier}$$

3.4.2 Determination of areal rainfall

Rainfall is measured using rain gauge on the specific point in the catchment. However, hydrological convert the point rainfall values at various stations in the catchment into an average value over that catchment is necessary (Subramanya, 2008). Thiessen polygon areal rainfall determination method was selected due its sound theoretical basis and availability of computational tools.

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

Where $\bar{P}$ average rainfall over the catchment

P_1, P_2 , …P_n are the rainfall magnitudes recorded by the stations of 1, 2, … n

A_1, A_2 …A_n areas of the Thiessen polygons

n is the number of stations

GIS software was used to create Thiessen polygon area for determination of areal precipitation Figure 13.

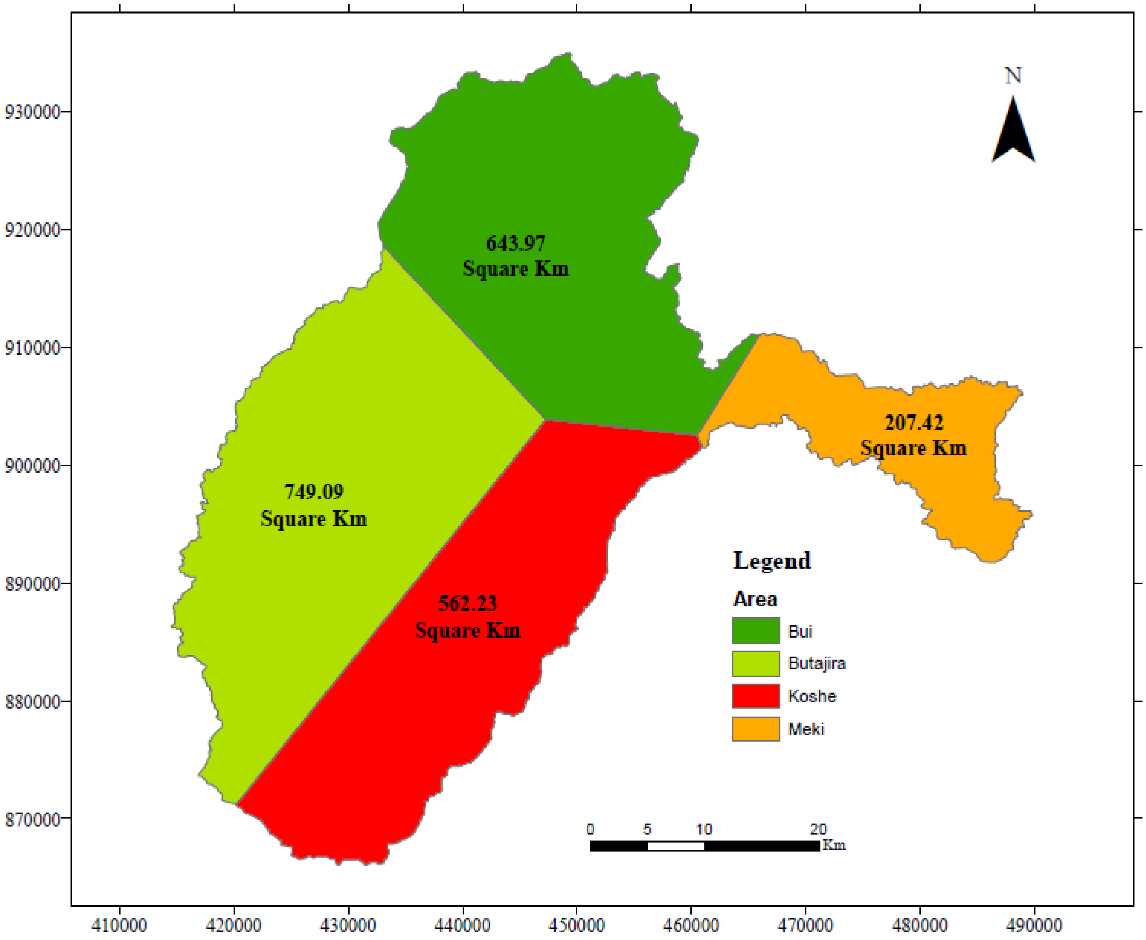
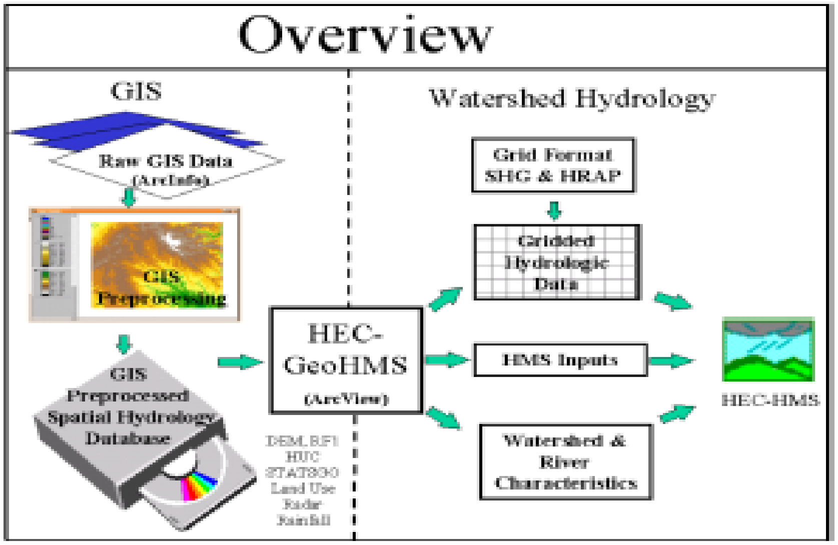


Figure 13 Created Thiessen polygon area using GIS

3.4.3 HEC-HMS/GeoHMS model

Figure 14 shows the general interrelation between GIS, HEC-GeoHMS and HEC-HMS. Input data to HEC-HMS can be pre-processed using HEC-GeoHMS extension under GIS environment. In this research, HEC-GeoHMS was used to derive river network of the sub-basins, delineate sub basins and extract the physical characteristics of the sub basins including sub basins area, river length and others catchment characteristics from the digital elevation model of the catchment.



Source: USACE, 2013

Figure 14 Overview of GIS, HEC-GeoHMS and HEC-HMS interrelations

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

The following major steps were used in this research in starting a project and GeoHMS development of a hydrologic model using DEM. These are;

i. Terrain preprocessing includes fills sink, flow direction determination, flow accumulation, stream definition, stream segmentation, catchment delineation, development of catchment polygon, drainage line processing and catchment aggregation in steps wise.
ii. Project setup
iii. Catchment characteristics
iv. Hydrologic parameter estimation and HMS model files

HEC-HMS hydrological model simulate rainfall-runoff process of the catchment and defined by three components includes basin models, meteorological models, control specifications, and input data (time series, paired data and gridded data) (USACE, 2016[a]). The basin model stores information about the properties and connectivity of the objects in the schematic such as basin areas and river reach connectivity. The meteorological model contains time series information consisting of rainfall and observed flow data. The control specifications component defines simulation time of starting and end time step. To run the system, the basin model, the meteorological model, and the control specifications were combined. A daily step data was used for the simulation based on the time interval of the available observed data. The main input data used for HEC-HMS are precipitation, observed flow, base flow and different watershed characteristics derived from HEC-GeoHMS process.

3.4.4 Calibration and validation of HEC-HMS model

Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data. And it is estimates some model parameters that cannot estimate by observation or measurement, or have no direct physical meaning. Model validation is the process of testing model ability to simulate observed data other than used for the calibration, with acceptable accuracy (Cunderlik and Simonovic, 2004). During this process, calibrated model parameters are not subject to change, their values are kept constant.

In this research, rainfall and runoff simulation was done with initial and constant loss method, Clark's unit hydrograph transform method, constant monthly base flow and Muskingum routing approach. The initial and constant loss method is very simple and appropriate for the catchment that lack of detail data. It has been used successfully in other studies (Tamriat and Adane, 2016), easy to setup and use and not demanding too much data.

In the initial and constant loss method the excess precipitation is given by

$$pe_t = \begin{cases} 0, if \ \sum pi > Ia \\ p_t - f_c, if \ \sum pi > Ia \ and \ pt > fc \\ 0, if \ \sum pi > Ia \ and \ pt < fc \end{cases}$$

Where pe_t excess precipitation, pt mean annual precipitation depth, fc maximum potential rate of precipitation loss, Ia initial loss and pi accumulated precipitation

Clark’s unit hydrograph method was selected to determine direct runoff. This method requires two parameters which is time of concentration and storage coefficient in hour. The time of concentration can be estimated based on sub basin characteristics including topography and the length of the reach (Kirpich’s formula)

$$T_c = 0.0078 * \left(\frac{L^{0.77}}{S^{0.385}}\right)$$

Where T_c is time of concentration in hr, L is reach length in feet, and S slope in %

Base flow has been estimated using constant monthly method from recorded flow at Meki Gauge station. It was selected the minimum recorded flow of months January to December.

Muskingum routing method was selected to model the river reaches. This method uses simple conservation of mass approach to route flow through the stream reach and requires three parameters *K*, *X* and number of sub reaches (n). The *X* parameter affects attenuation travel time through reaches of stream flow volume, ranges from 0 to 0.5. The *K* parameter simulates a delay in stream flow (in hours) as it moves through the channel. In this research Muskingum *x* parameter was set 0.15 for natural channel and the Muskingum *k* parameter was determined through calibration depends on catchment characteristics.

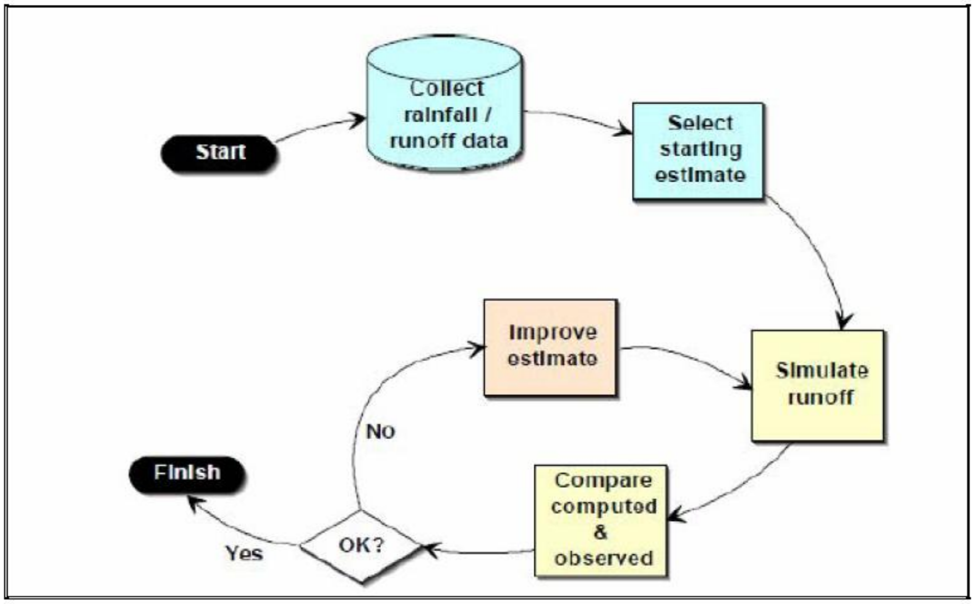
Table 6 HEC-HMS model parameters and their allowable ranges

Modeling	Model	Parameter	Ranges
Runoff Volume	Initial and constant rate loss	Initial loss (mm) Constant rate loss (mm/hr)	0-500 0-300
Direct Runoff Transformation	Clark's unit hydrograph	Time of Concentration (hr) Storage Coefficient (hr)	0.1-500 0-150
Routing	Muskingum routing	K (hr) X(-)	0.1-150 0-0.5

The quantitative measure of the goodness-of-fit between the computed result from the model and the observed flow is called objective function. An objective function measures the degree of variation between computed and observed hydrographs. It is equal to zero if the hydrographs are exactly identical. The key to automated parameter estimation is a search method for adjusting parameters to minimize the objective function value and find optimal parameter values. There are six different functions are provided that measure the goodness-of-fit in different ways in the optimization manager these are; peak-weighted root mean square error function (PWRMSE), sum of squared residuals function (SSR), sum of absolute residuals function (SAR), percent error in volume function (PEV) and percent error in peak flow function(PEQ) (USACE, 2000).

Two search methods are available in HEC-HMS model for minimizing the objective function and finding optimal parameter value. The first one is univariate gradient method (UG):- evaluates and adjusts one parameter at a time while holding other parameters constant. The second one is nelder and mead method (NM):- uses a downhill simplex to evaluate all parameters simultaneously and determine which parameter to adjust. The tolerance determines the change in the objective function value that will terminate the search. That is, when the objective function changes less than the specified tolerance, the search terminates (USACE, 2000).

In this research peak-weighted root mean square error function (PWRMSE) with univariate gradient search algorithm were selected to search optimal parameter value and minimize the objective function.



Source: USACE, 2000

Figure 15 Schematic representation of calibration procedure

3.4.5 Model performance evaluations

The performance of the model must be evaluated for the extent of its accuracy (Goswami et al., 2005) and should be evaluated before it receives any application. The model performance was evaluated through a set of objective functions that measure the goodness-of-fit between simulated and observed hydrograph.

The model performance simulation has been evaluated using efficiency criteria such as Nash and Sutcliffe simulation efficiency (NSE), coefficient of determination (R^2) and percent difference (D%) for this research. In general, NSE and R^2 are used to evaluate the model ability to reproduce the pattern of the observed hydrograph.

Nash-Sutcliffe Coefficient of Efficiency (NSE)

The Nash and Sutcliffe coefficient (NSE) is a measure of efficiency that relates the goodness-of-fit of the model to the variance of measured data. NSE can range from $-\infty$ to 1 and an efficiency of 1 indicates a perfect match between observed and simulated discharges. NSE value between 0.9 and 1 indicate that the model performs very well while values between 0.6 and 0.8 indicate the model performs well (Abeyou, 2008), whereas values NSE=0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance. Moriasi et al. (2007) recommended for monthly time steps that NSE values between 0.75 and 1 is very good and NSE-value between 0.65 and 0.75 is good. The NSE is estimated by;

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_{obs,i} - Q_{sim,i})^2}{\sum_{i=1}^{n}(Q_{obs,i} - \bar{Q}_{obs,i})^2}$$

Where, *NSE* is Nash-Sutcliffe coefficient of efficiency, $Q_{obs,i}$is the observed discharge at the time step i, $\bar{Q}_{obs,i}$, is the mean of the observed discharge, $Q_{sim,i}$ is the simulation discharge at the time step *i* and *N* is the number of observations.

Coefficient of Determination (R^2)

The coefficient of determination is defined as the squared value of the coefficient of correlation. It is estimated as

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(Q_{sim,i} - \bar{Q}_{sim,i}\right)(Q_{obs,i} - \bar{Q}_{0bs,i})\right]^2}{\sum_{i=1}^{n}[\left(Q_{sim,i} - \bar{Q}_{sim,i}\right)]^2 \sum_{i=1}^{n}[\left(Q_{obs,i} - \bar{Q}_{0bs,i}\right)]^2}$$

Where all terms area defined previously and $R^2 = 1$ is the target value

Percent of Difference, D

The percent of difference over a specified period with total days calculated from measured and simulated values of the quantity in each model steps as

$$D = 100\ \% * \left[\frac{\sum_{i=1}^{n} Q_{obs,i} - \sum_{i=1}^{n} Q_{sim,i}}{\sum_{i=1}^{n} Q_{obs,i}}\right]$$

Where terms are defined previously

The percent difference can be varying between $\infty\ to - \infty$, it is acceptable performance of model range between +15% to -15% (Abeyou, 2008).

3.4.6 Frequency analysis

Frequency analysis was used as a key input for estimation of flood frequency and magnitude. Certain hydrologic procedures use rainfall and rainfall frequency as the basic input rather than flood frequency. It is commonly assumed that the 10-year rainfall will produce the 10-year flood and 25- year rainfall for 100- year flood. The rainfall frequency analysis was carried out using the available 24 hour annual maximum rainfall data for the rain gauge stations situated in the nearby areas (ERA, 2002).

There are different types of frequency analysis methods that are used to describe the pattern of hydrologic phenomena and predict future behavior from past records of the events in that particular area or watershed. Log normal distribution method was selected based on the Chi-Square best fit test to estimate design rainfall for different return periods as;

$$Y_T = \bar{Y} + K_T * Sy$$

Where Y_T logarithm of design rainfall for return period T, K_T frequency factor for corresponding return period T with zero coefficient of skewness, $\bar{Y}$ logarithm of mean and Sy logarithm of standard deviation (Chow et al., 1988).

The design rainfall obtained using frequency analysis was used as input for HEC-HMS models to simulated flow hydrograph for different return periods. HEC-HMS model was used calibrated parameters and simulating flow for 2, 5, 10, 20, 25, 50 and 100 years using frequency storm meteorological model.

3.4.7 Flood inundation area delineation and flood hazard mapping

Flood inundation and hazard maps are the representation of the hydrologic and hydraulic processes in the catchment, river channel and floodplain. Accurate representation of the actual process is of paramount significance in predicting flood extent and depth. Determining the variation of flow characteristics in spatial and temporal resolution enables to design flood evacuation plan quite efficiently.

HEC-RAS/GeoRAS were used for flood inundation area delineation and flood hazard mapping in this research. The GIS extension of HEC-GeoRAS and HEC-RAS hydraulic model were used one after another (i.e. first HEC-GeoRAS then HEC-RAS then back GIS extension of HEC-GeoRAS) to determine flood extent and depth.

The main data required for HEC-GeoRAS to develop the input data for the RAS geometry is Triangular Irregular Network. The TIN of study area was developed from clipped 30m x 30m DEM of the study area using 3D-anaylst tools extension in the Arc-GIS Figure 16.

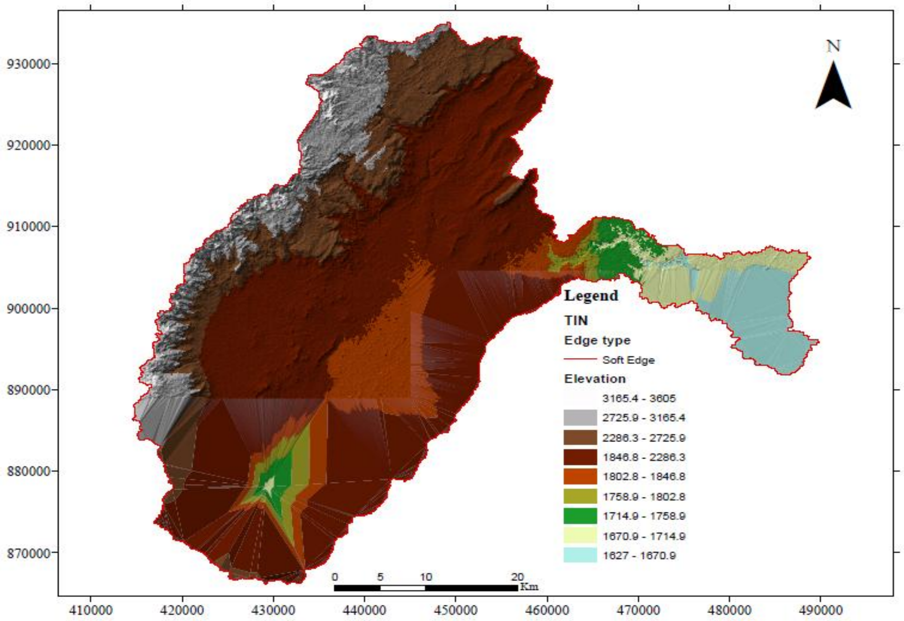


Figure 16 Meki River catchment TIN

1. **Pre RAS (HEC-GeoRAS)**

HEC-GeoRAS Arc GIS extension was pre processing the preparation of RAS layers including stream center line, bank lines, flow path lines, cross sectional cut lines and other layers. The combination of actual field data and TIN were generating river and floodplain of study area. The surveyed data contains information about the river layers (center line, right bank and left bank) and flood plain area. Shape file of the stream centerline and bank lines were digitalized in Arc-GIS with the help of collected field survey data and TIN. To export RAS GIS data, 3D stream centerlines and 3D cross sections line with elevation values were created from the TIN. Geometric data from the 3D stream center line and cross section line shape file is copy to RAS export file includes river data, reach, station identifiers, cross-section cut lines, cross-section surface lines and main channel bank stations.

The main aim of Pre RAS is to develop the spatial data required to generate a HEC-RAS import file. The process is divided in three steps;

- ✓ Create RAS layers defining stream centerline, stream banks, flow path lines, cross sections and bridge.
- ✓ Attributing RAS layers using RAS geometry menu functions of the previously defined stream centerlines, cross sections, stream banks, flow path lines and bridge by extracting the spatial data from TIN.
- ✓ Generate HEC-RAS import file containing geometric attribute data from an existing TIN and complementary data sets.

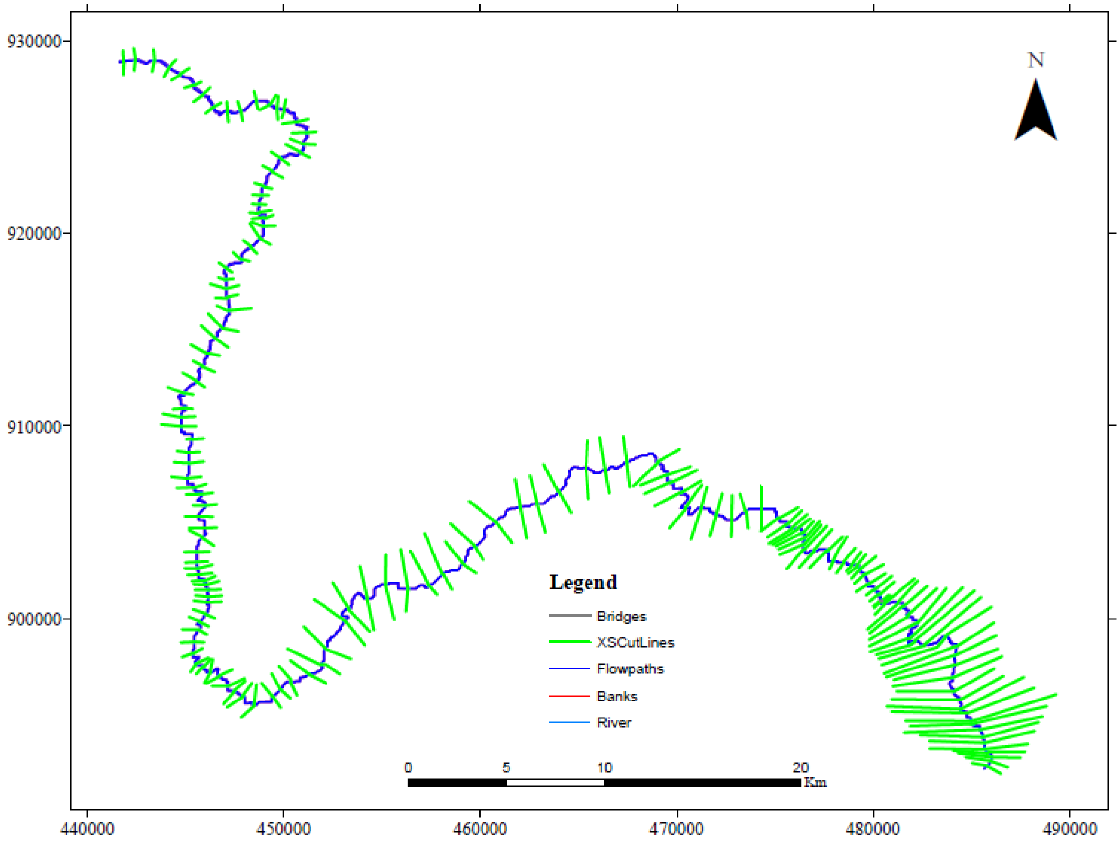


Figure 17 Digitalized Meki River catchment RAS layers

2. HEC-RAS

HEC-RAS hydraulic model was used to determine the flow profiles and flood plain profiles for different return periods by importing the flow hydrograph from HEC-HMS model and geometric data from HEC-GeoRAS.

For each HEC-RAS project, there are three required components; the Geometry data, Flow data, and Plan data. The geometry data consists of a description of the size, shape, and connectivity of stream cross-sections. Likewise, the flow data contains flow hydrographs. Finally, plan data contains information pertinent to the run specifications of the model, including a description of the flow regime (USACE, 2016[d]). Each of these components is explored below individually.

First HEC-RAS was import geometric file that is exported from HEC-GeoRAS of Arc-GIS extension. Geometry data contains physical parameters describing cross-sections of the reach. On HEC-RAS editing series of cross sections along the channel, manning's roughness coefficient and analysis bridges on the geometric data were made. Manning's roughness coefficient of the main channel and flood plains area determined based on surface roughness, vegetation, channel irregularities and material transported. For this research, the manning roughness coefficient was selected by comparing the study area river characteristics with the standard table in the reference manual 2016.

Second the flow data has been extracted from HEC-HMS hydrologic model. Since Meki River is a natural channel chose unsteady flow simulation condition. Unsteady data are required to perform an unsteady flow simulation. Unsteady flow data is comprised of boundary conditions and initial conditions. Boundary conditions must be specified for each modeled constituent at all locations where flow enters the system, including the upstream boundaries of the main channel. Several different types of boundary conditions are available; flow hydrograph, stage hydrograph, stage and flow hydrograph, rating curve, and normal depth (USACE, 2016[d]). In this research select flow hydrographs for the boundary conditions since they can be directly exported from the HEC-HMS model and used the normal depth assumption as the downstream boundary condition. Normal depth values used the energy slope, but the energy slope is unknown, used the slope of the channel bottom.

The average bed slope of Meki River is 0.009248. Continuity and momentum is the governing equation to simulate unsteady flow condition in the HEC-RAS model. The one-dimensional equations of motion can be combined into a single set and shows below (USACE, 2016^{d});

$$\frac{\partial A}{\partial t}+\frac{\partial(\varphi Q)}{\partial x_c}+\frac{\partial[(1-\varphi)Q]}{\partial x_f}=0$$

$$\frac{\partial Q}{\partial t}+\frac{\partial\left(\frac{\varphi^2 Q^2}{A_c}\right)}{\partial x_c}+\partial((1-\varphi)^2 Q^2/A_f)/\partial x_f+gA_f[\frac{\partial Z}{\partial x_c}+S_{fc}]+gA_f[\frac{\partial Z}{\partial x_f}+S_{ff}]$$

Where the subscripts c and f refer to the channel and flood plain respectively, t is time, Q is total flow, A is cross sectional area, S is storage from the non- conveying portions of cross section, x is the element longitudinal length and g is gravity

$$\varphi = K_c/(K_c+K_f)$$

Where K_c is conveyance in the channel and K_f is conveyance in the floodplain

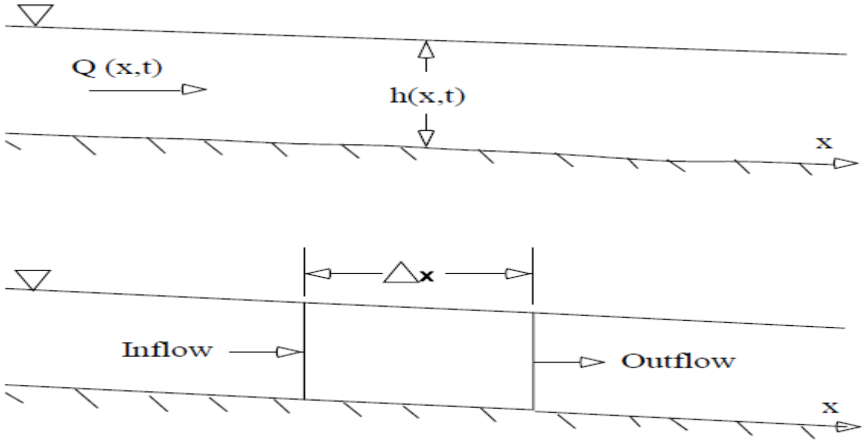


Figure 18 Elementary control volume for derivation of continuity and momentum equations

3. Post RAS (HEC-GeoRAS)

Post RAS is the last steps to visualize the inundation extent, boundaries and generate flood depths of hazard map. Flood hazard maps and inundation area delineation were generating using GeoRAS on GIS environment in this research.

The general method adopted for flood inundation and flood hazard mapping are consists of basically four steps.

i. GeoRAS pre-processing to generate a HEC-RAS import file
ii. Running of HEC-RAS to calculate water surface profiles
iii. Post-processing of HEC-RAS results using GeoRAS and
iv. Flood hazard mapping

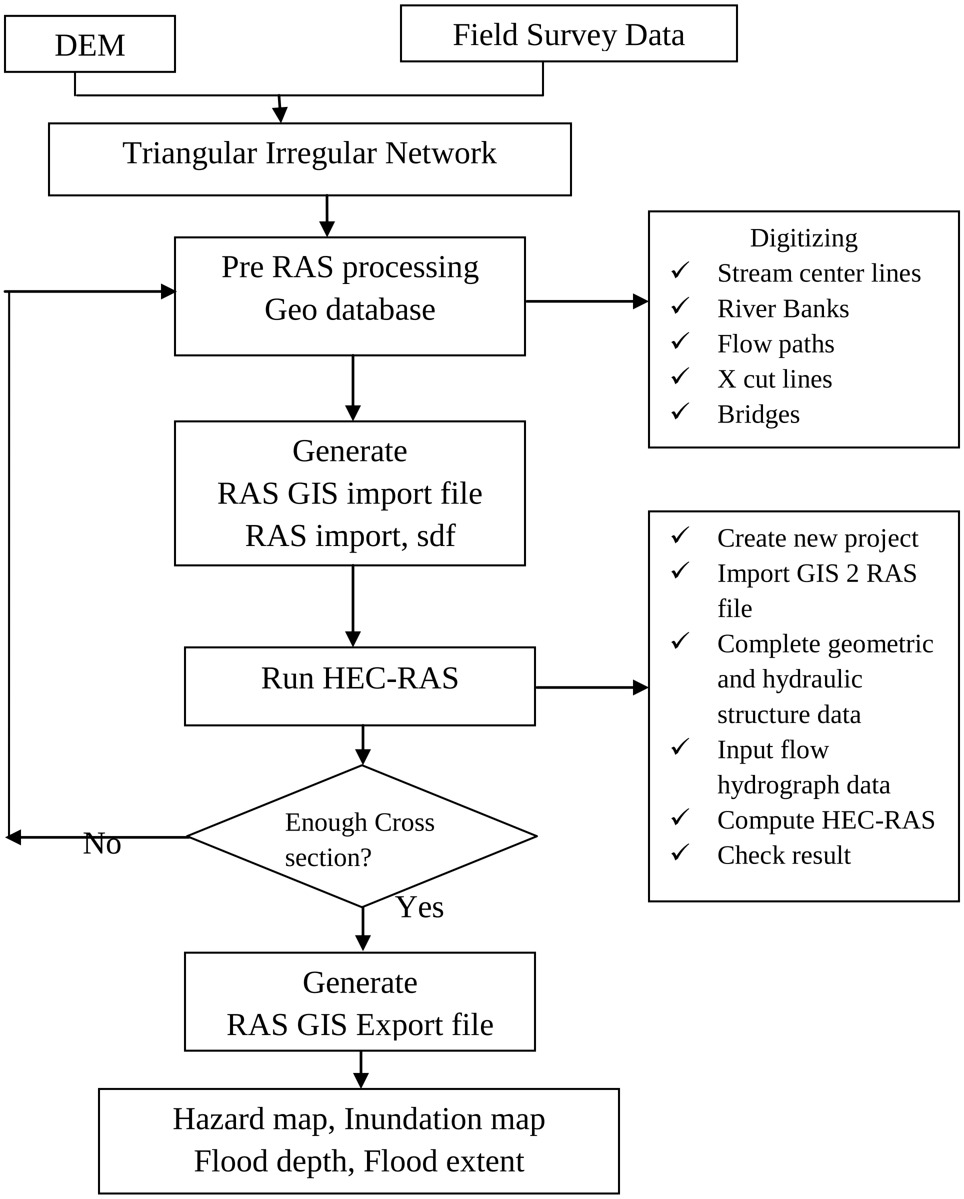


Figure 19 Flow chart for flood hazard and inundation maps

3.4.8 Estimation of flood damage

HEC-FDA program provides state-of-the-art analysis for formulating and evaluating flood damage reduction plans using risk-based analysis methods. It is calculations took into account information and uncertainties from interrelated hydrologic, hydraulic, geotechnical and economic information (USACE, 2015).

In this research, HEC-FDA software program was used to quantify the flood damage of the inundation area based on the output of hydraulic and hydrological result. The program applies Monte Carlo simulation of numerical analysis procedure that computes the expected value of damage used to determine flood inundation damage. A stage-damage function describes the amount of economic damage that might occur given certain flood plain stages.

Flood damage estimation passes through two procedures. First, determination of inundation area and flood depth using HEC-RAS hydraulic model was performed. Second, the sum of expected annual damage of 2, 5, 10, 20, 25, 50, 100 and 200 years return period interval were estimated using HEC-FDA model. When, estimated all valuable property located within the endangered area i.e. the damage potential, needs to be quantified. The expected damage was calculated by using depth-damage-functions, which show the total damage of the valuable property (e.g. crop, famer house, vegetables, etc) or its relatively damaged share as a function of inundation depth.

The following major steps were used in HEC-FDA to estimate flood damage of inundated area.

i. Define the study and enter configuration data (i.e. study stream name, damage reaches, analysis years and plans)
ii. Develop exceedance – probability function and stage – discharge using HEC-FDA by importing hydraulic and hydrologic data from HEC-RAS hydraulic model
iii. Enter economic data and produce stage – damage function
iv. Compute sum of expected annual damage for eight return period intervals of 2, 5, 10, 20, 25, 50, 100 and 200 years.

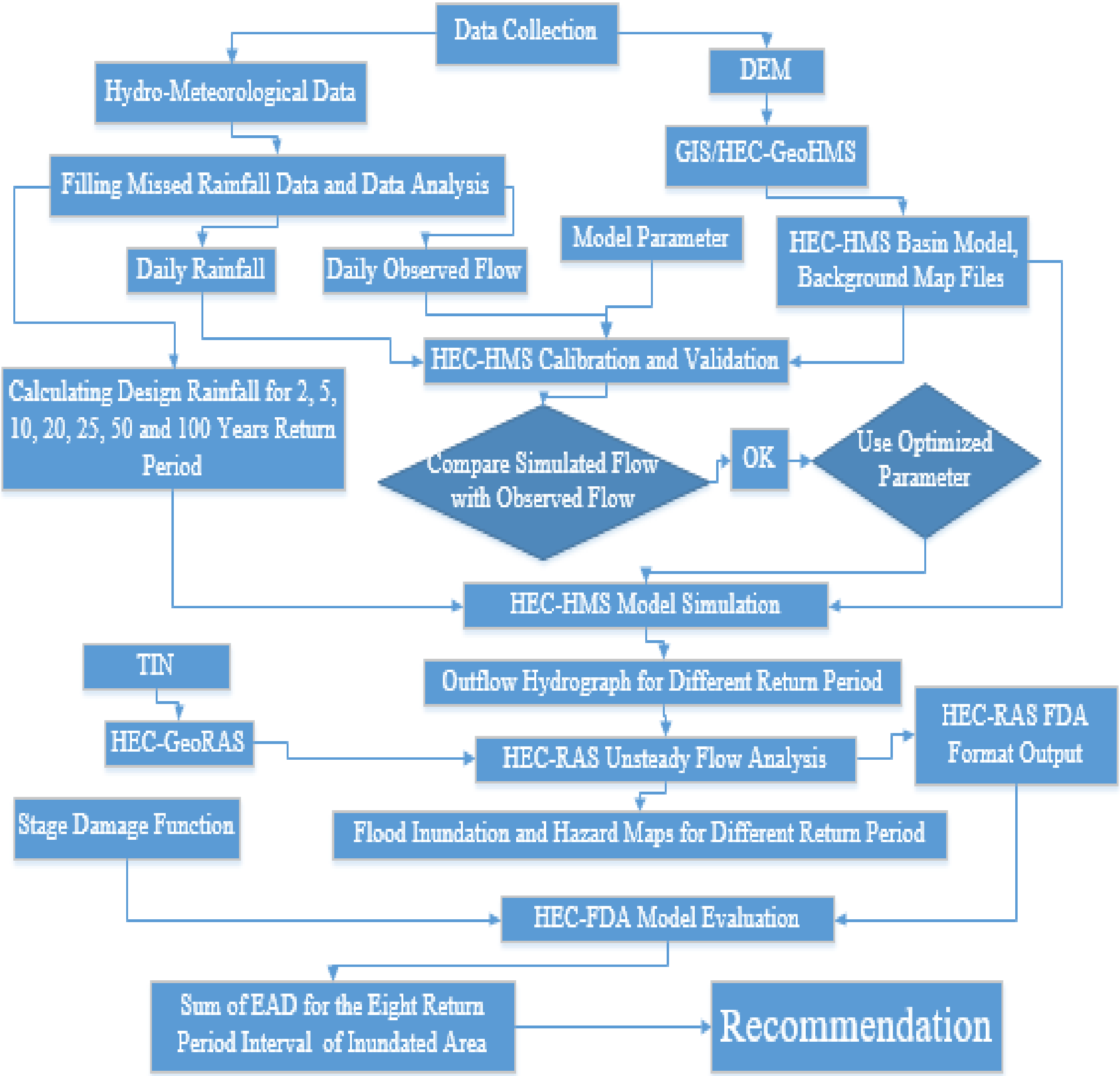


Figure 20 Conceptual frame work of the overall methodology followed in this research

4 DATA PROCESSING AND ANALYSIS

The available data were organized and processed for the analysis. After the models are selected, collecting the necessary required data in field and offices, infilling the missing data and checking the quality of the hydro-meteorological data is mandatory.

4.1 Filling Missing Rainfall Data

Thirty years meteorological data (rainfall, maximum and minimum temperature, wind speed, relative humidity) were collected from NMSA of Ethiopian. In this research normal ratio method was used to fill the missing data at the station. The percent of missed precipitation for Meki, Koshe, Butajira and Bui stations were 18.4%, 9.8%, 16.4%, 14.5% respectively.

Table 7 Meteorological stations and collected data in the river catchment

Stations	Elevation (m)	Longitude	Latitude	Data (daily)	Stations Types
Meki	1662	38.82	8.15	Precipitation	Rainfall recording station
Koshe	1878	38.53	8.01	Precipitation	Rainfall recording station
Butajira	2000	38.37	8.15	Maximum temperature Minimum temperature Precipitation	Ordinary station
Bui	2054	38.55	8.33	Maximum temperature Minimum temperature Precipitation Wind Speed Relative humidity Sunshine hour	Principal station

4.2 Consistency of Rainfall Data

Double-mass curve was used to check for inconsistency of the record. This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent.

To check the consistent of Meki River catchment only consider four rainfall stations located within the catchment and as it can be seen from the figure below the rainfall is consistent.

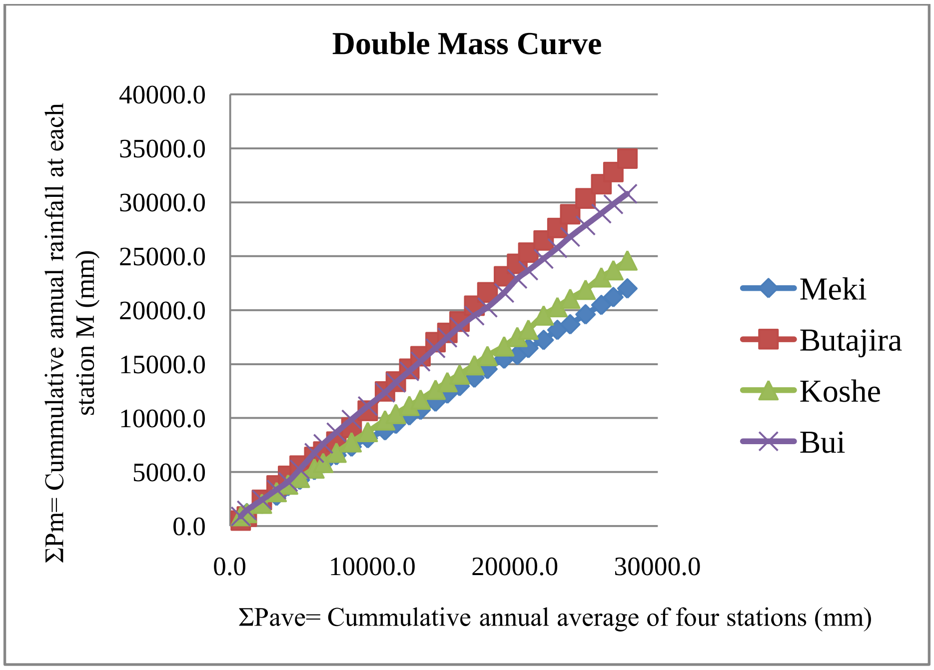


Figure 21 Double mass curve of Meki River catchment

4.3 Flow Data

Daily flow data of the study area were collected from Ministry of Water, Irrigation and Electricity (Department of Hydrology) from 1990 to 2013 years. The gauge station is located at Meki town near main bridge on the road of Addis Ababa to Hawassa where the downstream end is considered flood prone area.

The stream flow data for this specific research were used for calibration and validation of the model and it's used to specify the model parameter. For the calibration (2007-2010) data was used for the validation the next two years data was used (2011-2012). The calibration and validation of the model is under taken by the full year available flow data. Meki River catchment has continuous full year recorded stream flow data for the years of 2007 to 2012.

The quality of hydrological data was performed before using the collected observed stream flow data for calibration and validation for the year of 2007 to 2012 using statistical test.

4.3.1 Test for independence and stationarity

The test was under taken by selecting the annual maximum time series data for the specify years of (2007-2012) of full data set. Independence and stationarity test were checked using Wold-Wolfowitz (W-W) test.

Thus, using W-W test the following results were obtained;

R =22329

$\bar{R} = \frac{363.33^2 - 23473.57}{6-1}$ =21706.298

$Var(R)$=146608.58

$|u| = \frac{22329 - 21706.298}{\sqrt{146608.58}} = 1.63$

The test statistic value U =1.63 is less than the critical value at 5% significance level $U_{0.025}$ =1.96. Therefore, accept the hypothesis of independence and stationarity.

4.3.2 Test for homogeneity

The homogeneity test was made by Mann-Whitney (M-W) test and the following results were obtained;

R= 6, p=3 and q=3; $V = 6 - \frac{3(3+1)}{2} = 0$; $W = 3 * 3 - 0 = 9$; $\bar{U} = \frac{3*3}{2} = 4.5$

Statistic U smaller of V or W = 0; $\sum T = 0$

$$Var(U) = \left[\frac{3*3}{6(6-1)}\right]\left[\frac{6^3 - 6}{12}\right] = 5.25$$

$The\ Statistic\ |u| = \frac{0 - 4.5}{\sqrt{5.25}} = 1.95$

The test statistic value U =1.95 is less than the critical value at 5% significance level $U_{0.025}$ =1.96. From this result, it can be conclude that the recorded flow data comes from the same parent population and homogeneity at the 5 % significance level.

4.3.3 Test for outliers

Dixon-Thompson test was used to detect outliers. It can be used for short and long data series. Since, the selected stream flow data is six year continuously recorded. For 3 to 7 sample size the test statistic R obtained after arranging the data in ascending order;

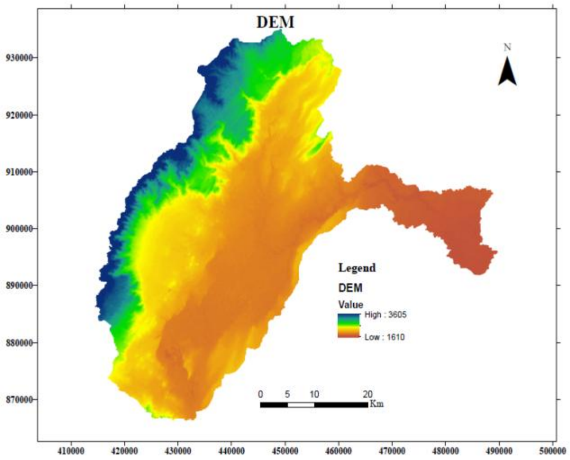
$$R = \frac{54.395-29.977}{80.101-29.977} = 0.487 \qquad \text{low outlier}$$

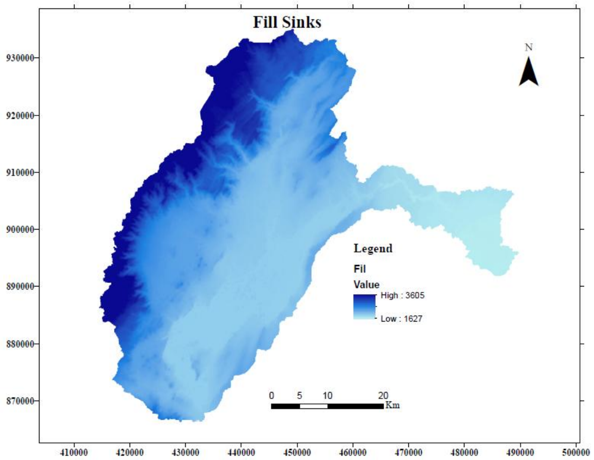
$$R = \frac{80.101-69.849}{80.101-29.977} = 0.205 \qquad \text{high outlier}$$

The critical statistic R_c for six sample size data was 0.560 at 5% of significance level. The low and high test statistic R value is less then critical statistic R_c value at 5% of significance level. Thus, the flow data concluded that there are no low and high outliers in the samples.

4.4 HEC-GeoHMS Data Processing

HEC-GeoHMS (version that works with Arc-GIS 10.1) was used to process a 30-meter DEM to extract basic physical characteristics of the study area. Digital Elevation Model of Rift Valley basin found from Ministry of Water, Irrigation and Electricity. Grid Machine toolbox was used to clip the Meki River catchment DEM from Rift Valley Basin DEM. And terrain data preprocessing was perform in sequential steps using HEC-GeoHMS.





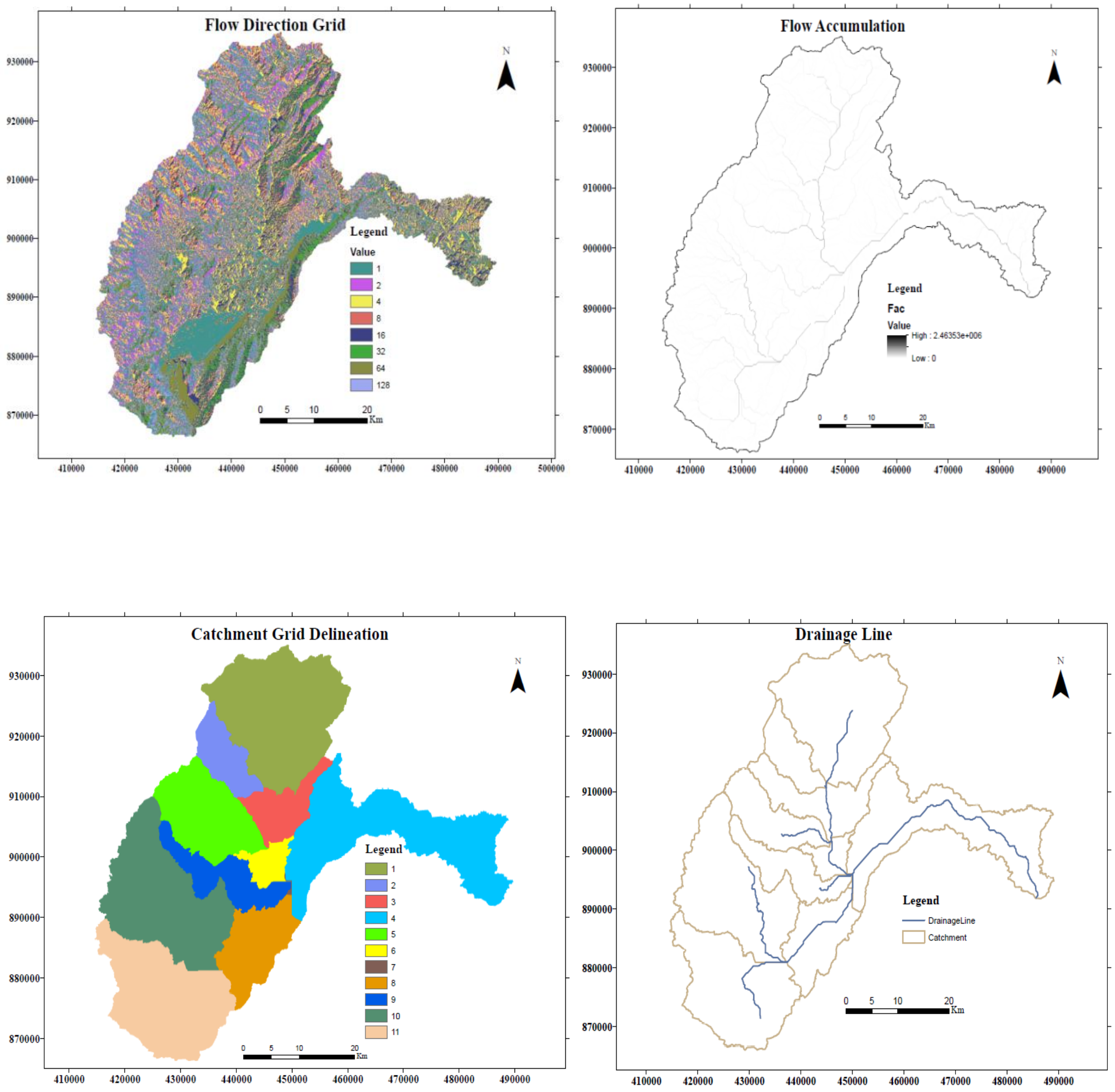


Figure 22 Terrains preprocessing of Meki River catchment

Table 8 Meki River catchment sub- basin parameters obtained from GeoHMS

Sub- basin name	Sub-basin length (Km)	Sub-basin area (Km^2)	Sub-basin lag time (hr)	Area-HMS
W120	131.54	398.32	4.48	398.32
W130	67.59	90.45	2.98	90.45
W140	79.67	92.12	3.83	92.12
W150	226.10	404.65	13.09	404.65
W160	93.31	203.25	3.33	203.25
W170	54.78	44.80	3.20	44.80
W180	11.97	1.20	1.37	1.20
W190	93.49	145.85	5.87	145.85
W200	114.15	114.97	5.62	114.97
W210	146.54	357.80	4.28	357.79
W220	121.54	330.41	4.68	330.41

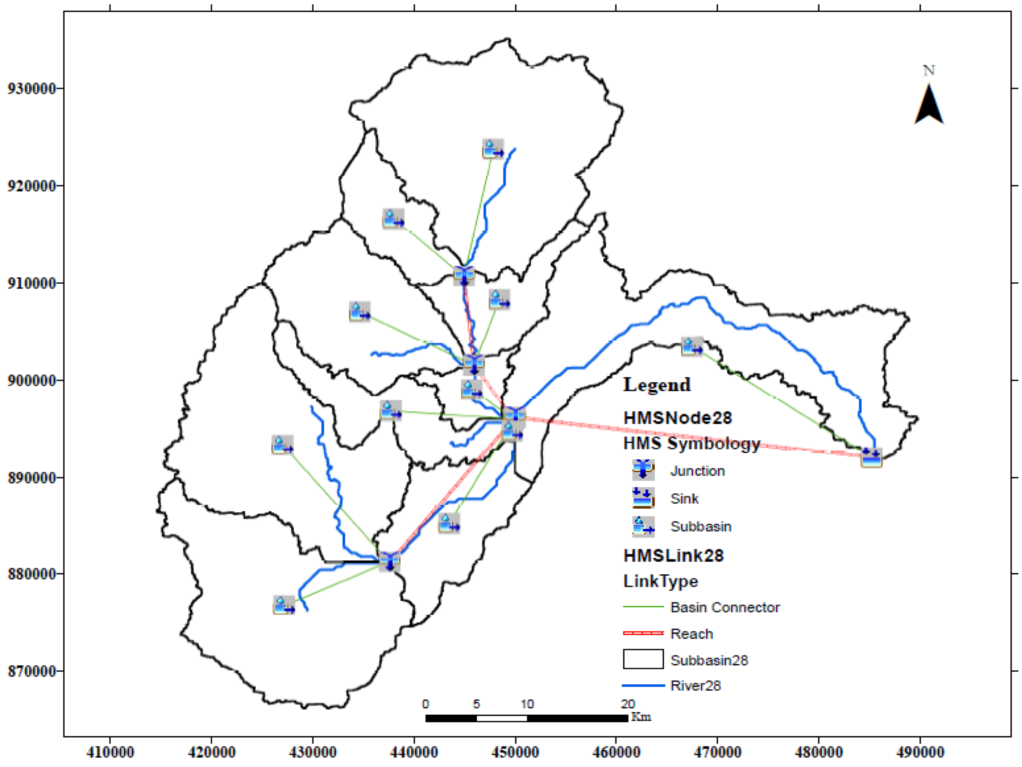


Figure 23 Hydrological elements of Meki River catchment in HEC-GeoHMS

4.5 HEC-HMS Model Calibration and Validation

The HEC-HMS model is calibrated and validated for the daily observed flow data of six years (2007-2012) period and the best fit parameters were obtained. Daily rainfall and flow data for the period Jan 1, 2007 to Dec 31, 2010 was used for calibration and from Jan 1, 2011 to Dec 31, 2012 was used for validation of model. The peak-weighted root mean square method objective functions and univarate search algorithm were adopted.

The rainfall and runoff modeling for catchment was conducted using initial and constant loss, Clark's unit hydrograph transformation, constant monthly base flow and Muskingum routing. The initial value of parameters was obtained from the catchment characteristics which area extracted using Arc-GIS software and HEC-GeoHMS tool and critical review of various studies that use HEC-HMS.

Table 9 Optimized parameters value during calibration

Sub basin name	Constant loss rate (mm/hr)	Time of Concentration (hr)	Storage Coefficient (hr)	Reach Name	K (hr)
W120	1.98	7.46	11	R30	66.19
W130	1.97	4.97	7.5	R50	65.08
W140	1.97	6.38	11.5	R60	91.33
W150	1.97	21.83	8.5	R80	85.64
W160	1.97	5.54	8	R100	71.12
W170	1.97	5.34	9		
W180	2.95	2.28	8.5		
W190	1.97	9.78	11		
W200	0.23	9.36	7		
W210	1.97	7.13	10		
W220	0.15	7.80	6.5		

Note: Muskingum X value is 0.15 for all reach and initial loss is 0.00 mm for all sub basins assuming that the catchment is saturated during extreme event.

Figure 24 below shows the observed stream flow and simulated hydrograph for the calibration period. The model is produced good observed hydrograph pattern. The peak is well captured in all year.

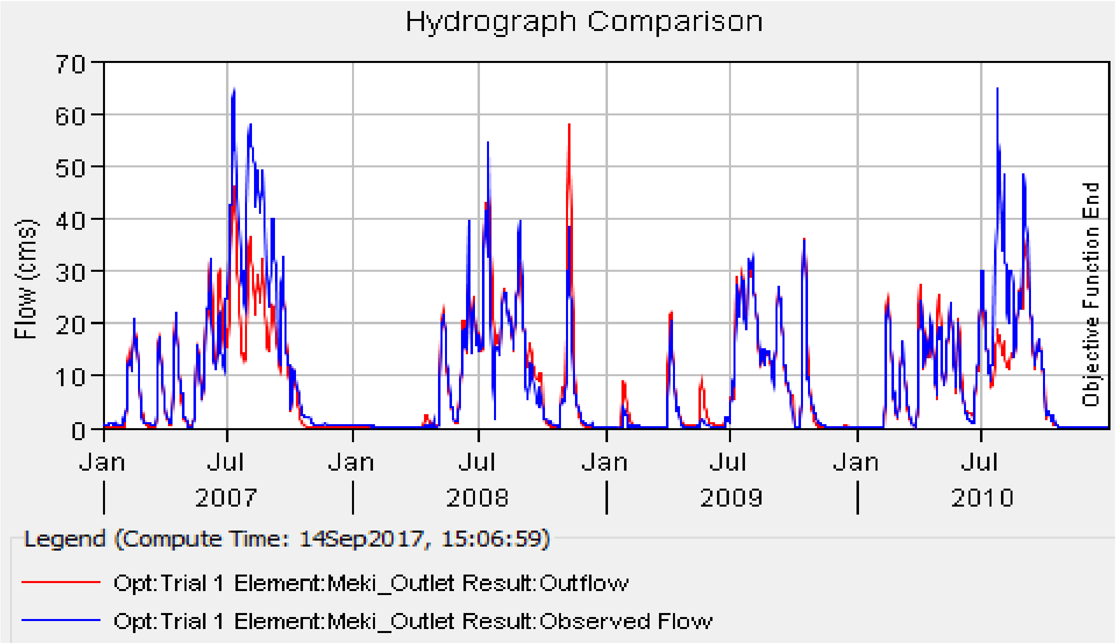


Figure 24 Daily observed and simulated hydrographs for the calibration period (2007-2010)

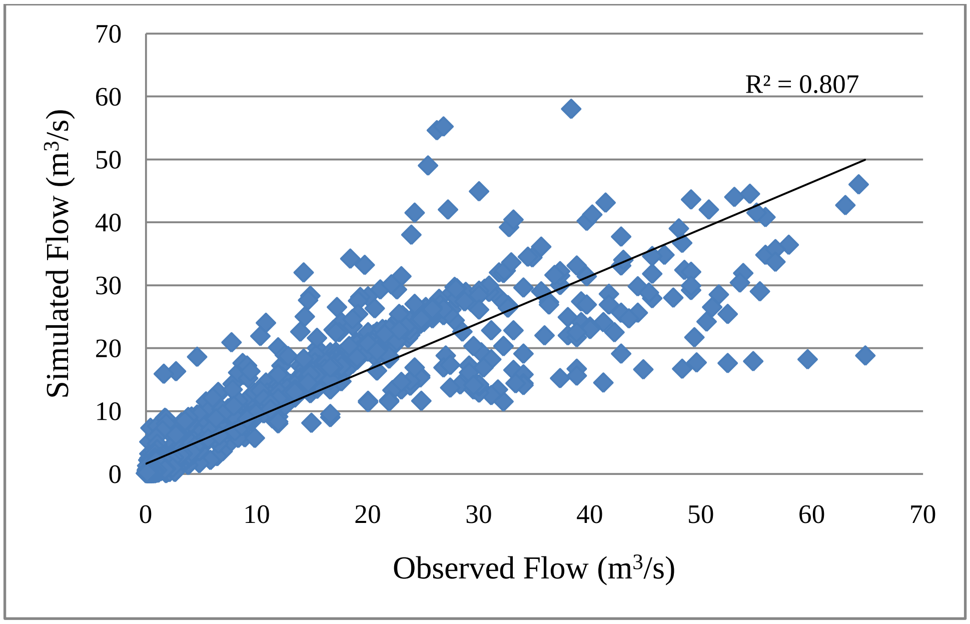


Figure 25 Simulated versus observed scatter diagrams during calibration

Model validation was used to determine the effectiveness of the calibrated HEC-HMS model parameters in reproducing hydrograph outside of the calibration period and used 1/3 of total data set, Jan 1, 2011 – Dec 31, 2012.

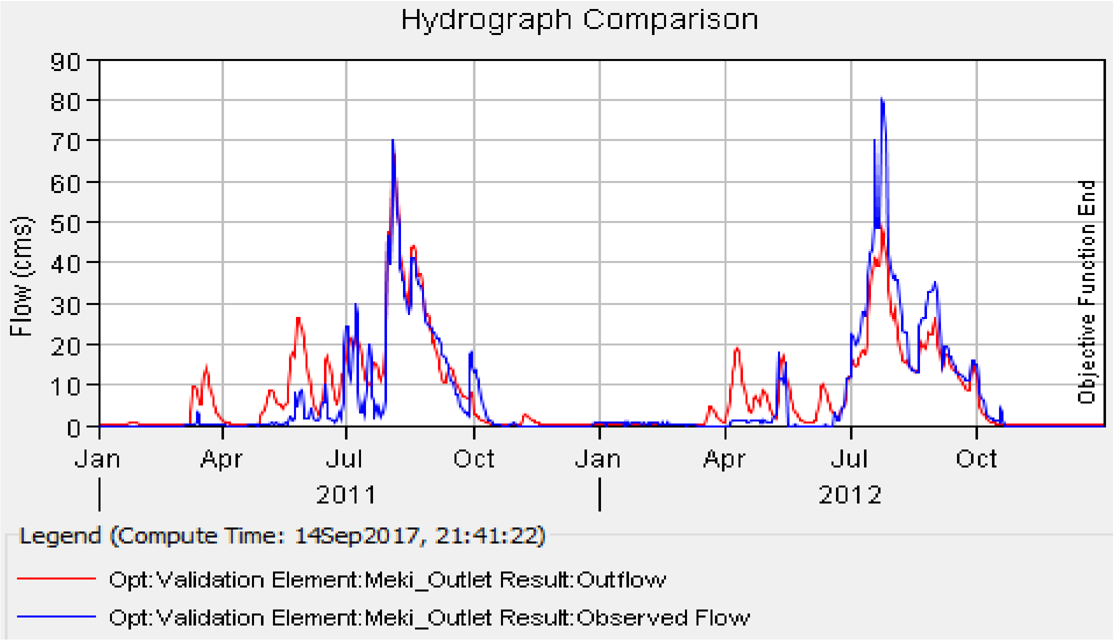


Figure 26 Daily observed and simulated hydrograph for validation period (2011-2012)

The model performance during calibration and validation period is very good when evaluating in terms of objective functions. The percent of difference during calibration was –10.5 % which within the allowable range ± 15 %. The model was calibrated and validated using the collected data and the values of objective functions are shown Table 10. The model performance results of objective functions during calibration and validation period is shows slightly similar.

Table 10 Model performance during calibration and validation

Objective Function	Calibration	Validation
NSE (-)	0.799	0.810
R^2 (-)	0.807	0.816
D (%)	-10.5	-14.9
Period	Jan 1, 2007 – Dec 31, 2010	Jan 1, 2011 –Dec 31, 2012

4.6 Rainfall Frequency Analysis

The rainfall frequency analysis was estimated for the point precipitation data collected from NMSA. Thirty years rainfall data was collected from four stations in the catchment. The design rainfall estimated using log normal distribution for different return period at selected meteorological station Table 11.

Table 11 Extreme rainfall magnitude (X_T) of T year's for rainfall station.

Return Period T (year)	Rainfall Magnitude X_T (mm)			
	Meki	Koshe	Butajira	Bui
2	52.61	52.24	53.30	52.84
5	70.74	72.66	73.35	71.47
10	82.58	86.34	86.67	83.69
20	92.18	97.59	97.58	93.63
25	97.39	103.76	103.53	99.03
50	108.34	116.84	116.14	110.40
100	119.22	129.98	128.76	121.71
200	130.17	143.36	141.56	133.13

From the above results selected the highest design rainfall to estimate flood for different return period using HEC-HMS models. Alternate block method was used to generate rainfall hyetograph. Figure 27 shows generated rainfall hyetograph for rainfall depth of Butajira station.

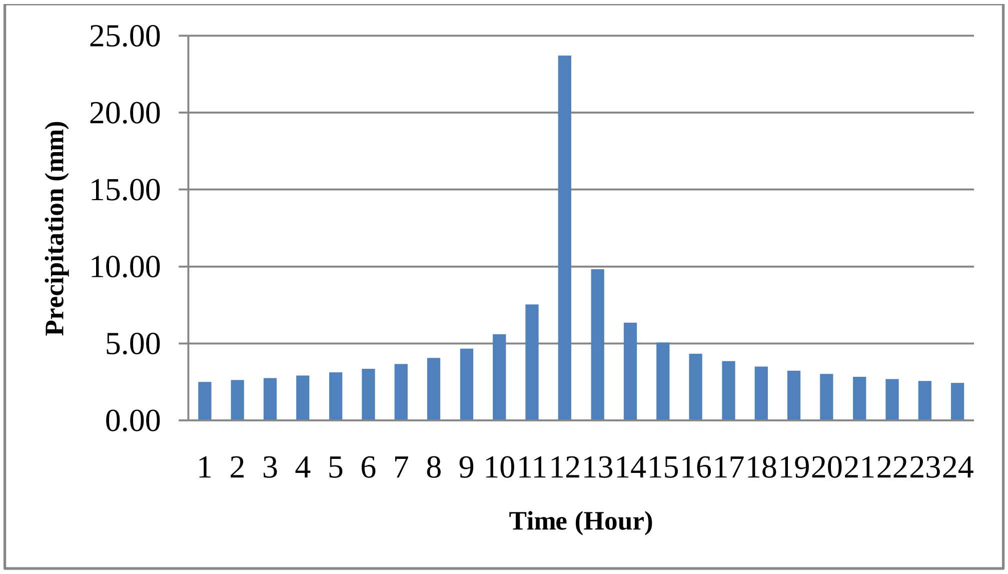


Figure 27 Butajira station rainfall hyetograph for 50 year return period

HEC-HMS meteorological model need frequency storm for flood estimation and was developed 24 hours' frequency storm with 15 minute intensity duration. Table 12 shows the frequency storm of Butajira station for different return period.

Table 12 Frequency storm for different return period

Duration (hr)	Rainfall depth in mm with return period							
	2	5	10	20	25	50	100	200
0.25	5.44	7.49	8.85	9.96	10.57	11.85	13.14	14.45
1	10.88	14.97	17.69	19.92	21.13	23.71	26.28	28.90
2	15.39	21.17	25.02	28.17	29.89	33.53	37.17	40.86
3	18.85	25.93	30.64	34.50	36.60	41.06	45.52	50.05
6	26.65	36.68	43.33	48.79	51.77	58.07	64.38	70.78
12	37.69	51.87	61.28	69.00	73.21	82.12	91.04	100.10
24	53.30	73.35	86.67	97.58	103.53	116.14	128.76	141.56

4.7 Results of HEC-HMS by Frequency Strom

Using the optimized parameters obtained from the daily basis of calibration the model simulate for the return period of 2, 5, 10, 20, 25, 50 and 100 years and the flow values are found accordingly in Table 13.

Table 13 Peak discharge for different return period using HEC-HMS

Return Period (Years)	Flow (m^3/s)
2	66.2
5	125.9
10	173.9
20	216.0
25	239.2
50	288.9
100	339.2

The above table shows the peak flow is increase as the return period is increased.

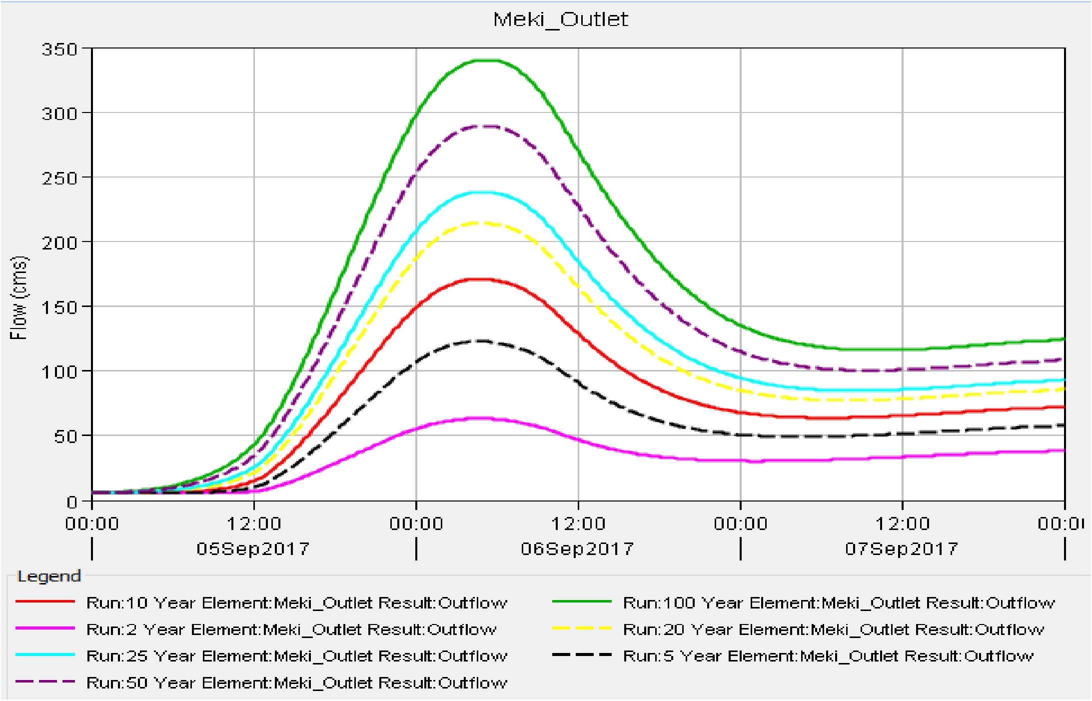


Figure 28 Outflow hydrograph of Meki River for 2, 5, 10, 20, 25, 50 and 100 year return periods

Figure 28 shows the flow hydrograph value for a return period of 2, 5, 10, 20, 25, 50, and 100 years. The graph of flow hydrograph is also increase as the return period increases. The flow hydrograph obtained here in HEC-HMS model used in the HEC-RAS unsteady flow simulation to determine the water surface profile.

4.8 HEC-RAS Hydraulic Model Output

Flood inundation and flood hazard maps were processed using hydraulic model (HEC-RAS/HEC-GeoRAS). Hydraulic modeling was convert the flow hydrograph values estimated using HEC-HMS previously into water surface elevations along the stream reach.

HEC-RAS model was determine the water surface profile within the channel and flood plain; using the inputs data of flow hydrograph imported from HEC-HMS and geometric data imported from HEC-GeoRAS with supported format and geo referenced.

In the HEC-RAS window, the geometric data was editing based on the center traverse survey point data. The geometric data imported from the Arc GIS extension using HEC-GeoRAS; river system schematic, cross section data, downstream reach lengths for the left overbank, channel and right over bank and cross section cut lines (X and Y coordinates of the plan-view lines that represents the cross section).

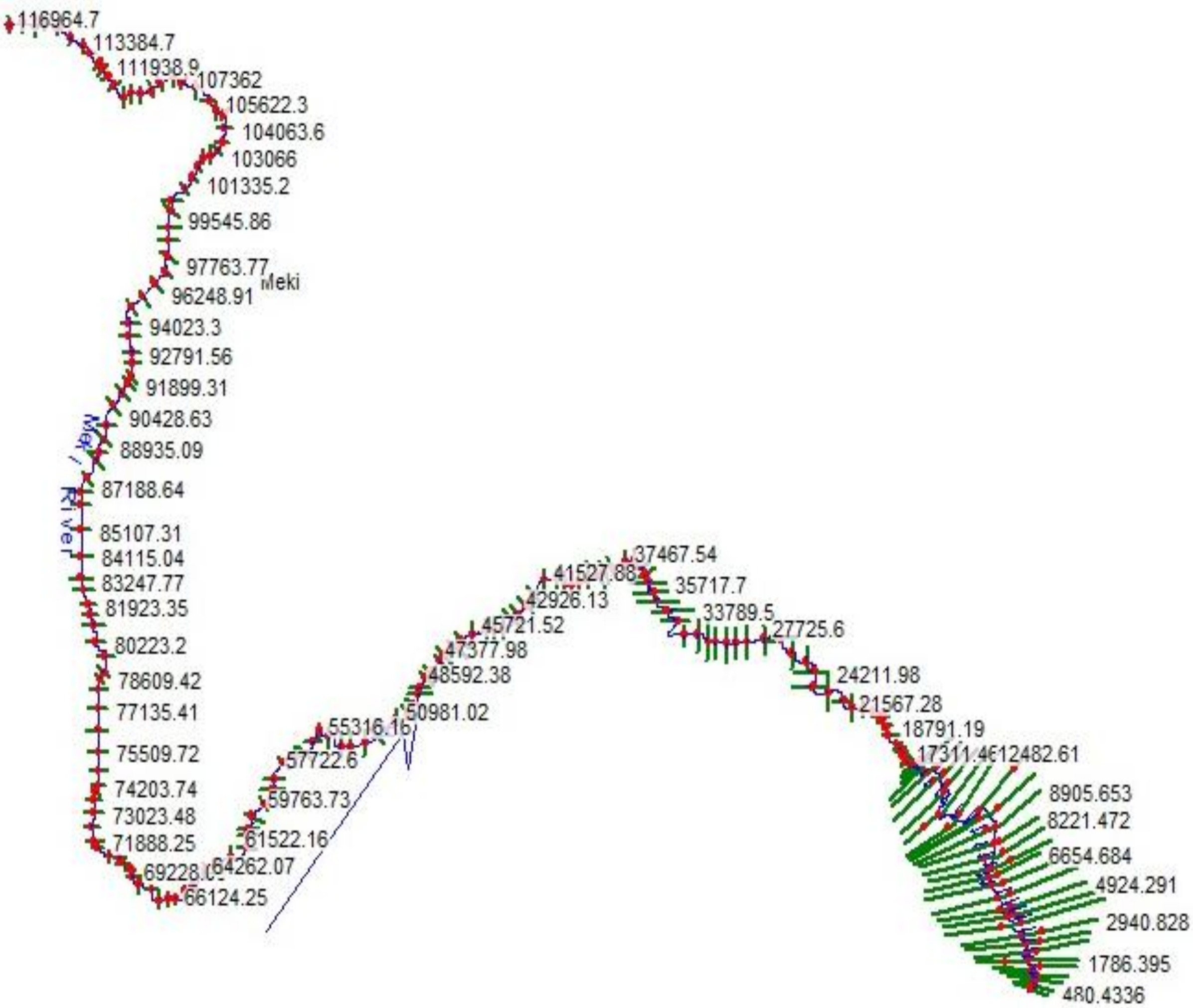


Figure 29 Geometric schematic of Meki River

Each river station has different model parameters. The model is calibrated for the cross section parameters. The calibration of model for this research was performed based on the actual field survey data collected in the site and field visit. Therefore, HEC-RAS was calibrated for the field survey data but flow data is already calibrated and validated on the HEC-HMS model no need to calibrate here.

The other parameters for the model are roughness manning coefficients and coefficient of contraction and expansion. The selection of manning roughness coefficient values involves judgment, skill and subjective. The manning roughness value was selected by comparing the study area river characteristics with the standard table. The value was between 0.035 and 0.050. Meki River reach divide into three based on the manning roughness coefficient;

upstream reach, intermediate reach and flood plain reach and their values for main channel and banks are 0.050 and 0.040 for upstream reach, 0.050 and 0.045 for intermediate reach and 0.040 and 0.035 for flood plain reach respectively.

Expansion and contraction coefficient were determine based on the physical observation of the river reach. In Meki River the cross sections of the reach change gradual. Thus, the values of expansion coefficient 0.3 and contraction coefficient 0.1 and at the bridge station the expansion coefficient 0.5 and contraction coefficient 0.3 were selected for this analysis.

The water surface profile was simulating using HEC-RAS model for a return period of 2, 5, 10, 20, 25, 50 and 100 years. Flow hydrograph data from HEC-HMS hydrologic model and geometric data of GIS format from HEC-GeoRAS extension was used for unsteady flow simulation analysis condition using HEC-RAS. Water surface at river cross section for flood of 50 year return period is show in the following figure.

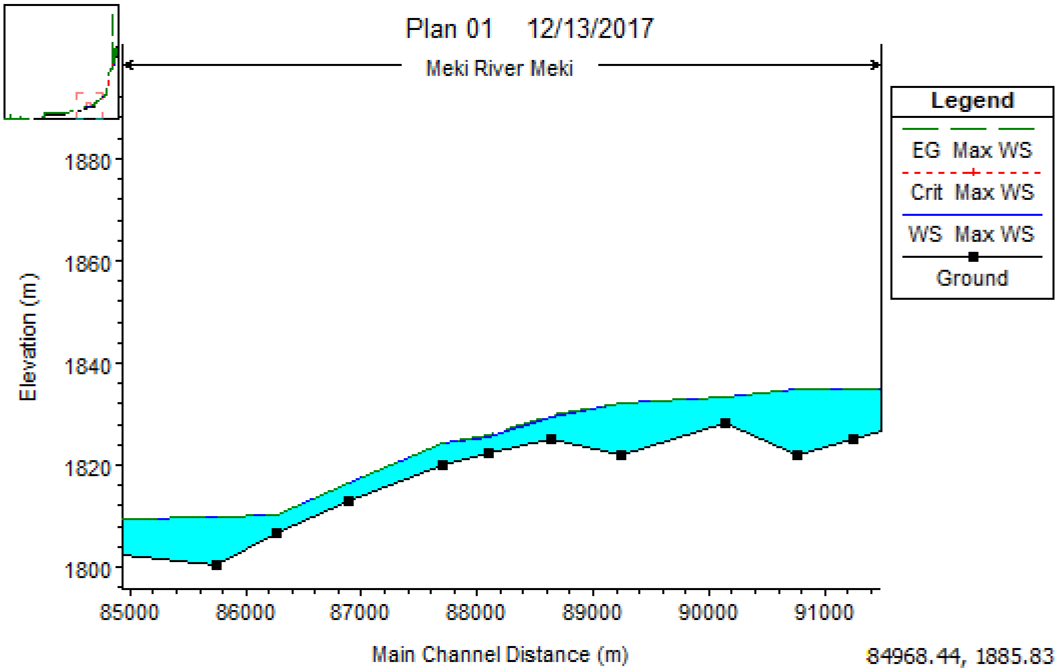


Figure 30 Water surface at river cross section for 50 year return period

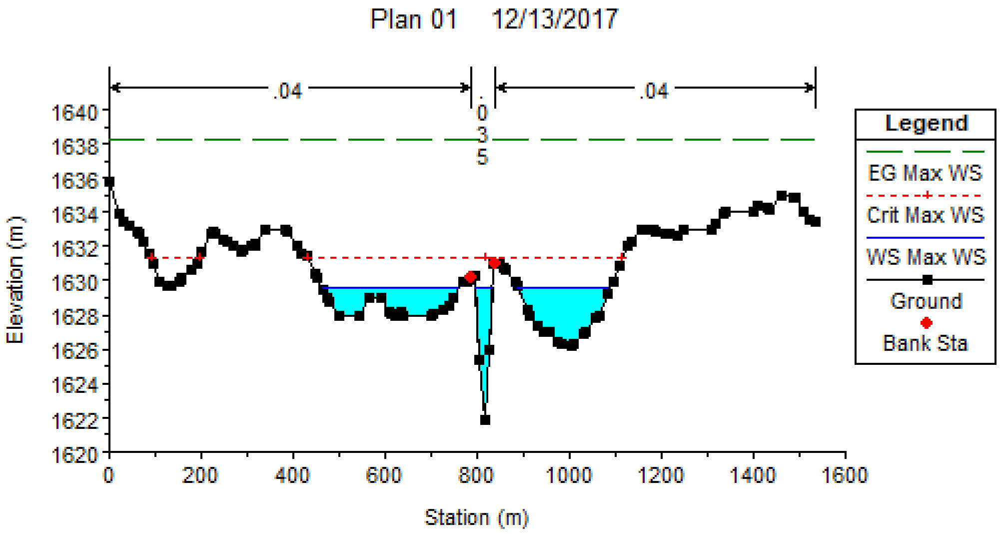


Figure 31 Cross sectional flood view

HEC-RAS model was display the 3D perspective view. Figure 32 shows the 3D perspective view for 50 year return period.

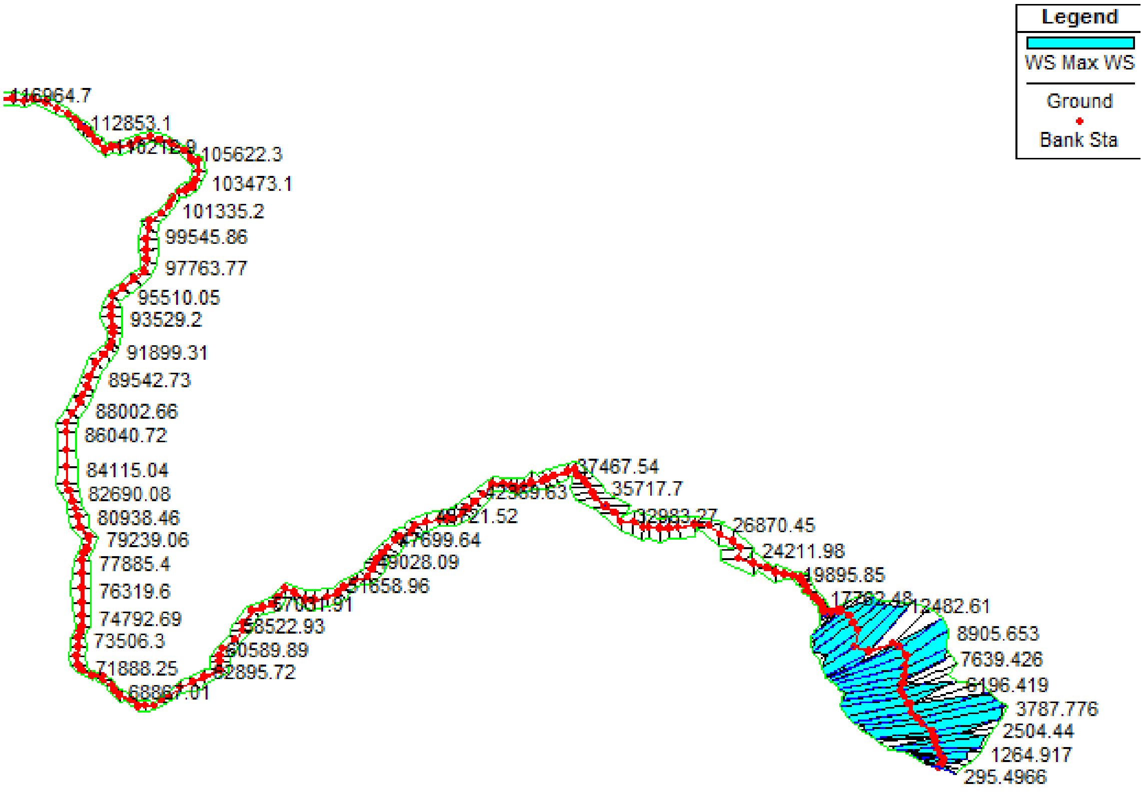


Figure 32 3D perspective view of the flood plain and the channel in HEC-RAS (50 year storm)

5 RESULT AND DISCUSSION

5.1 Flood Inundation Map

The flood inundation map shows the flood extents at peak flow hydrograph for 2, 5, 10, 20, 25, 50 and 100 years return period. Arc GIS with the extension of HEC-GeoRAS was generated the flood inundation maps by importing HEC-RAS GIS format file for different return periods. The inundated maps for 2, 5, 10, 20, 25, 50 and 100 years return period were shows Figure 33 to 39.

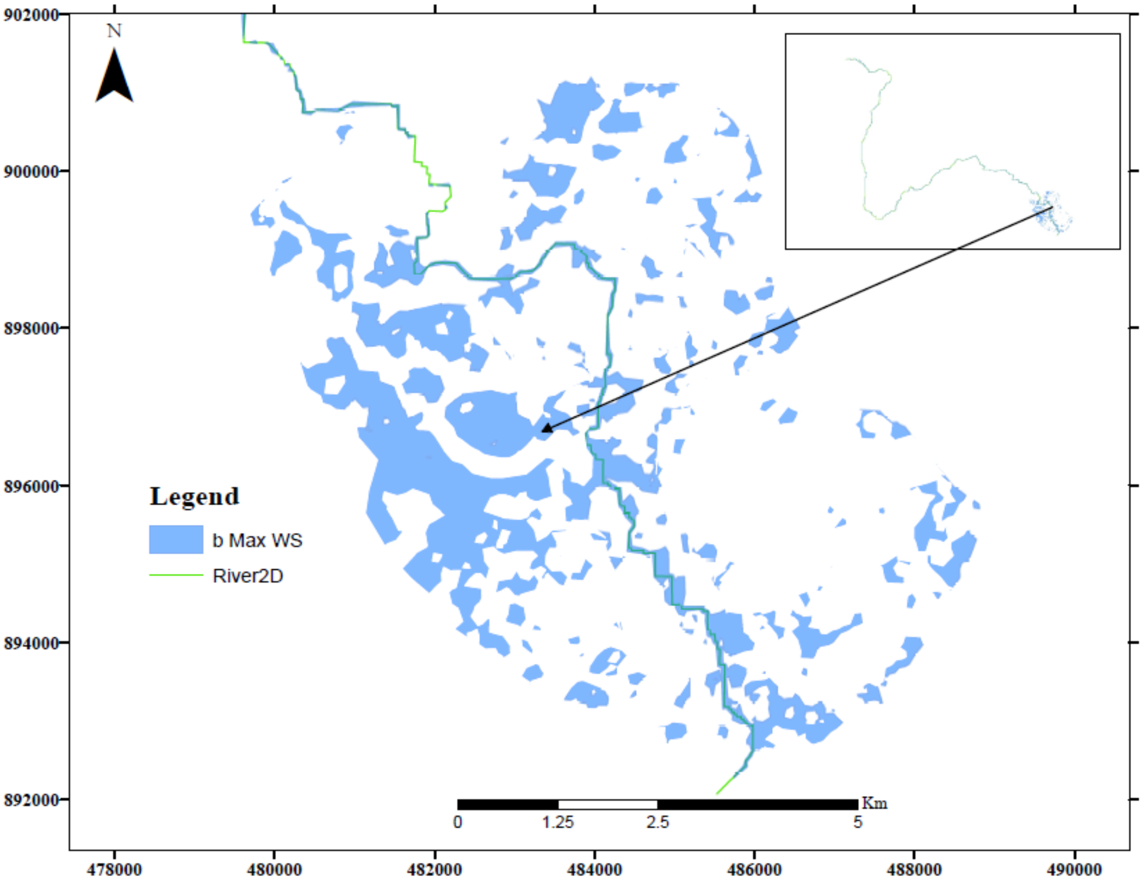


Figure 33 Flood inundation map for 2 year return period

The 2 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 11.15 km^2 especially downstream of Meki town Figure 33.

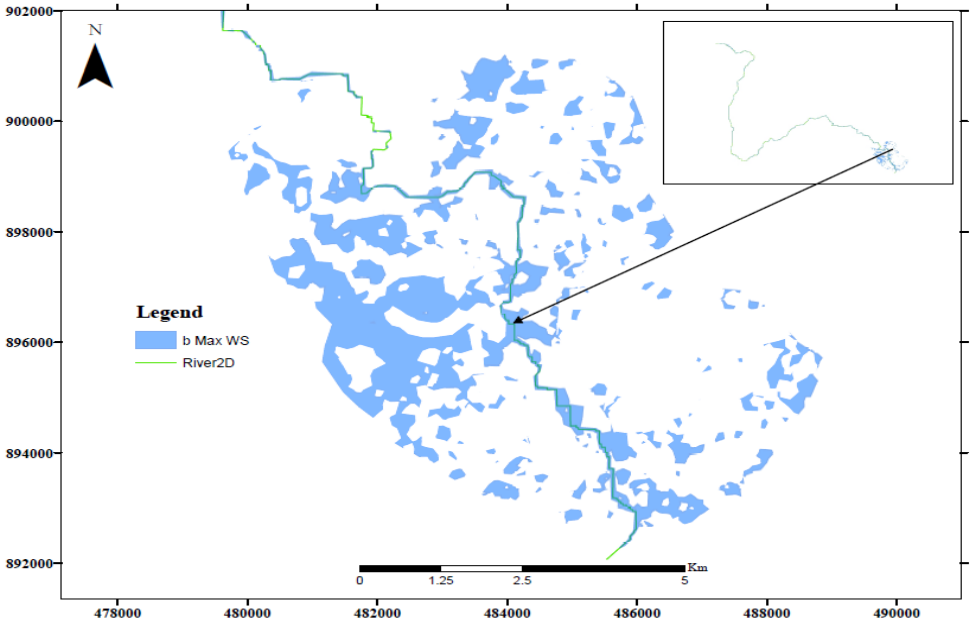


Figure 34 Flood inundation map for 5 year return period

The 5 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 11.57 km^2 Figure 34.

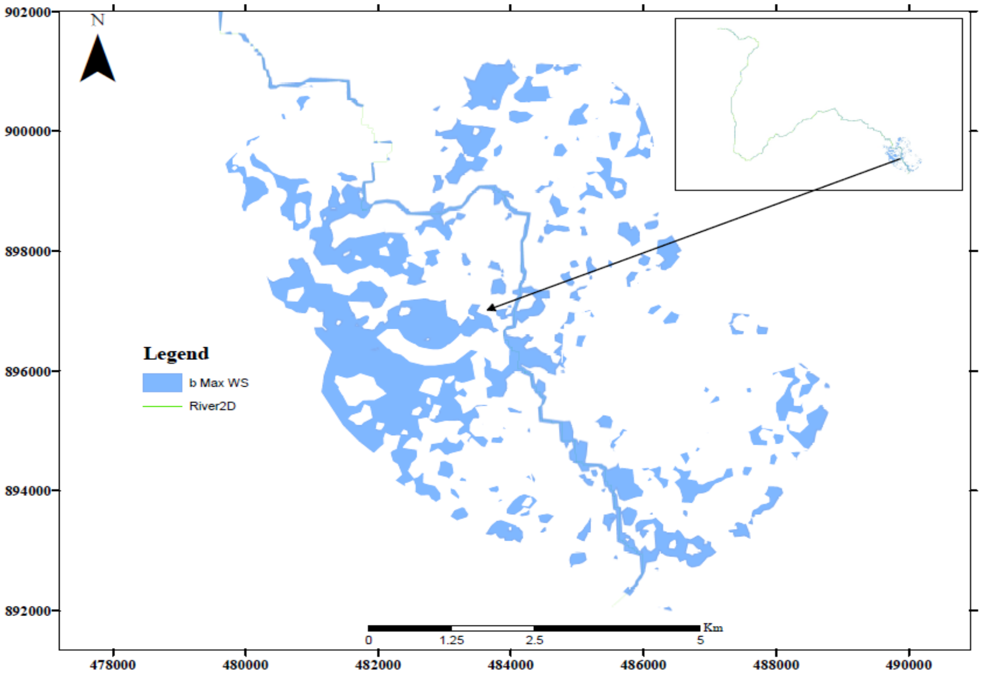


Figure 35 Flood inundation map for 10 year return period

The 10 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 11.97 km^2 Figure 35.

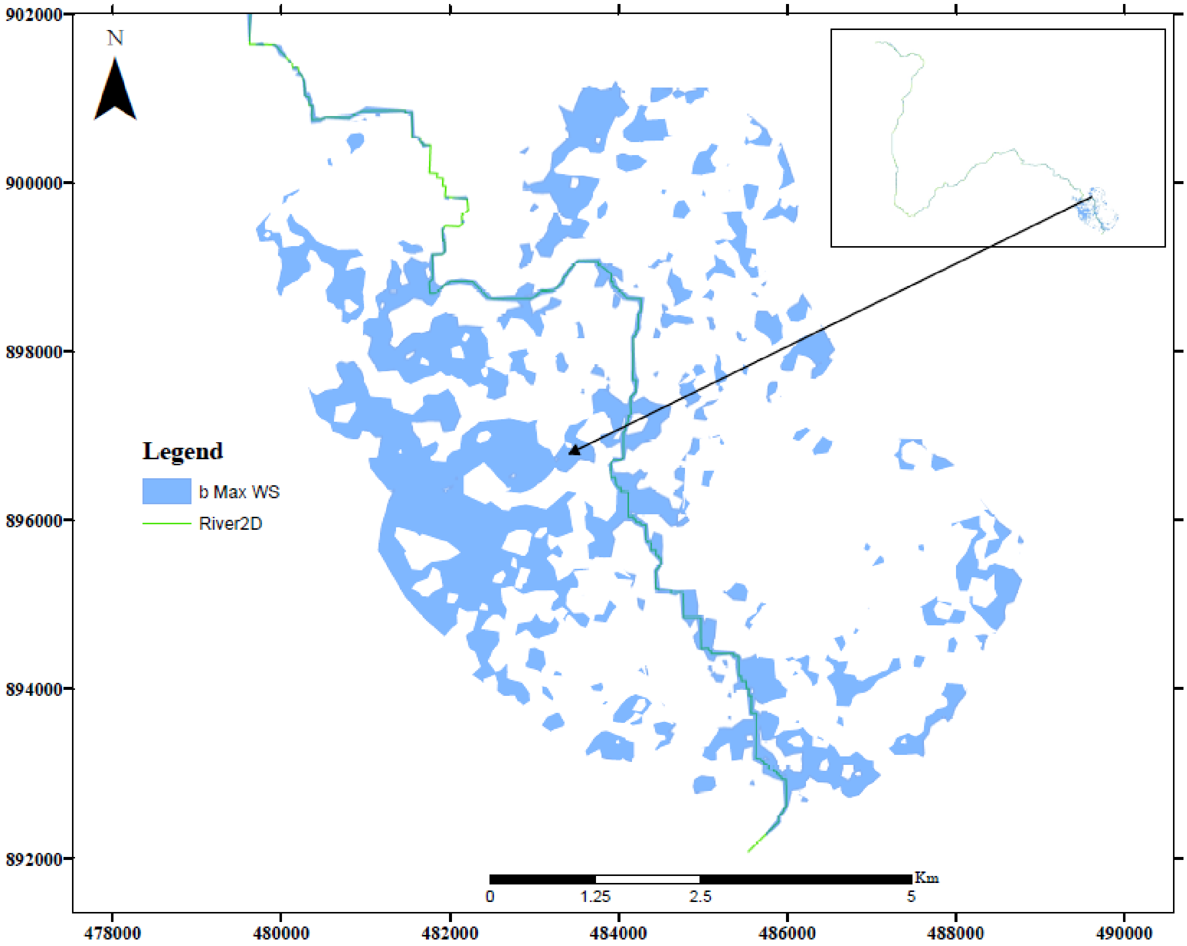


Figure 36 Flood inundation map for 20 year return period

The 20 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 13.20 km^2 Figure 36.

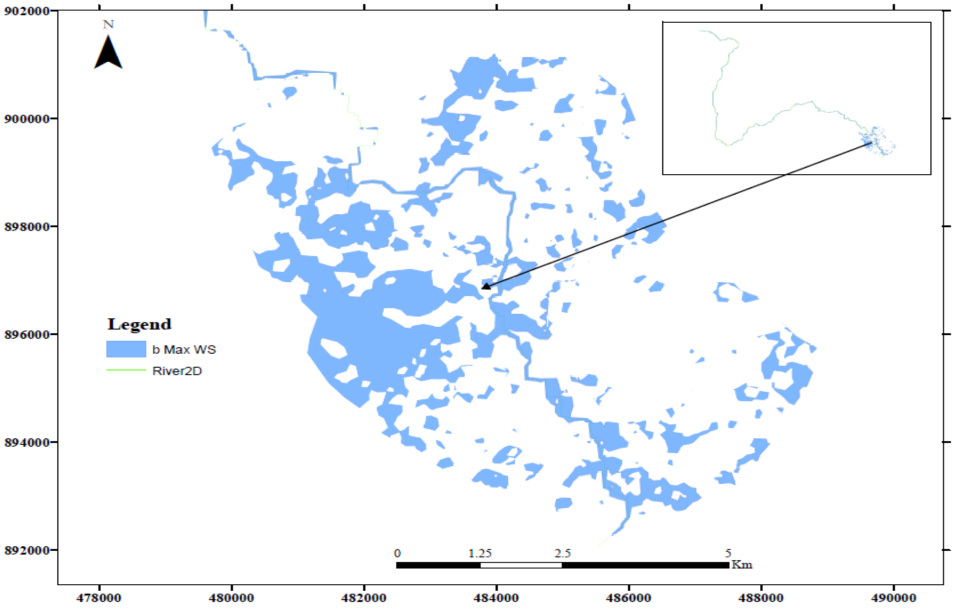


Figure 37 Flood inundation map for 25 year return period

The 25 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 13.53 km^2 Figure 37.

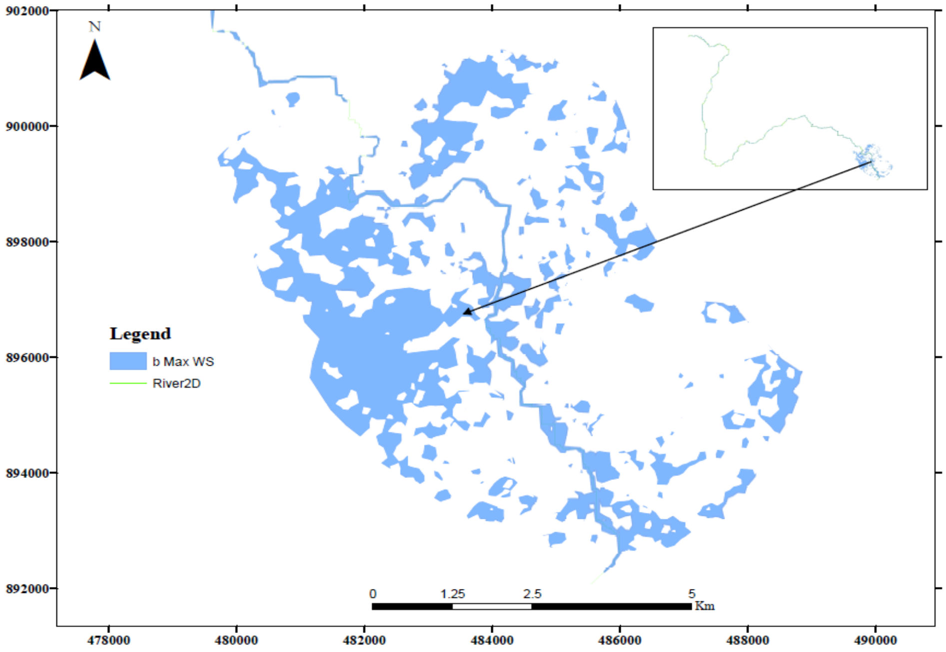


Figure 38 Flood inundation map for 50 year return period

The 50 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 14.25 km^2 Figure 38.

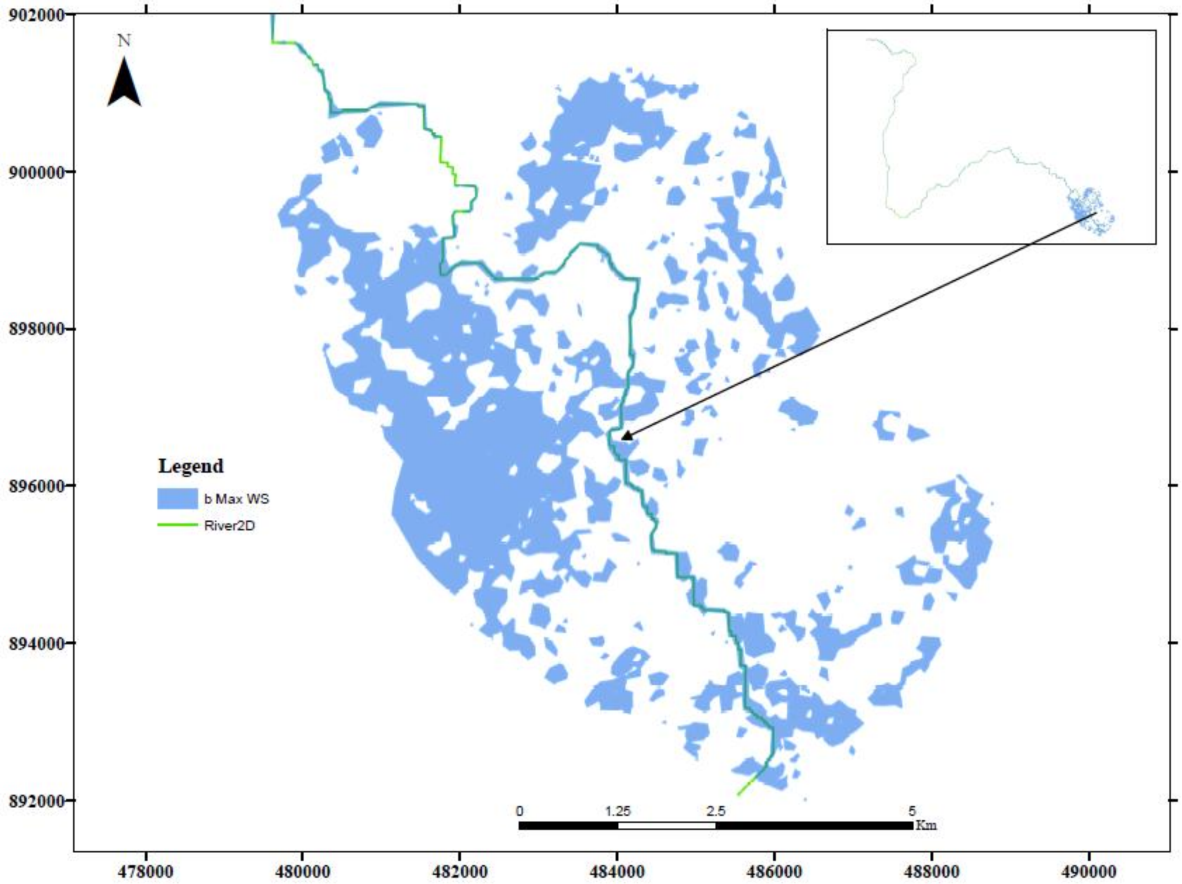


Figure 39 Flood inundation map for 100 year return period

The 100 year return period flood inundated maps using the peak flow hydrograph results obtained from HEC-HMS models and geometric data from HEC-GeoRAS GIS extension indicated that a large flooded area is in the lower part of the Meki River catchment covers 15.42 km^2 Figure 39.

The result above shows that flooded areas increases, as the return period increased. The flood inundation areas were high particulary from Meki town to Lake Ziway for all return periods. The flooded area for the 100 year return period was high relative to other return periods Table 14.

Table 14 Design rainfall, stream flow, flooded area and average inundation depth

Return Period (Years)	Design Rainfall X_T (mm)	Flow (m^3/s)	Flooded area (km^2)
2	53.30	66.2	11.15
5	73.35	125.9	11.51
10	86.67	173.9	11.97
20	97.58	216.0	13.20
25	103.53	239.2	13.53
50	116.14	288.9	14.25
100	128.76	339.2	15.42

In the Meki River catchment four PAs fall under different return period flood include Bakele Girisa, Welidya Mekdal, Shube Gamo and Welidya Kelina. The flood inundation map shows that 12.46 % of the four PAs area inundated by a 2 year flood. About 12.93 %, 13.38 %, 14.75 %, 15.12 %, 15.93 % and 17.35 % areas were covered by 5, 10, 20, 25, 50 and 100 years flood respectively. The area inundated by different return periods slight increasing in aerial coverage observed as return period increases.

The flooded area was graphically overlaid on the land use shape files genareted from Google Earth and field survey data Figure 41. Accordingly most of the area along the river in the flood plain area is agricultural land espacilly downstream of Meki town. Thus, the agricultural land is more affected by all year return period floods.

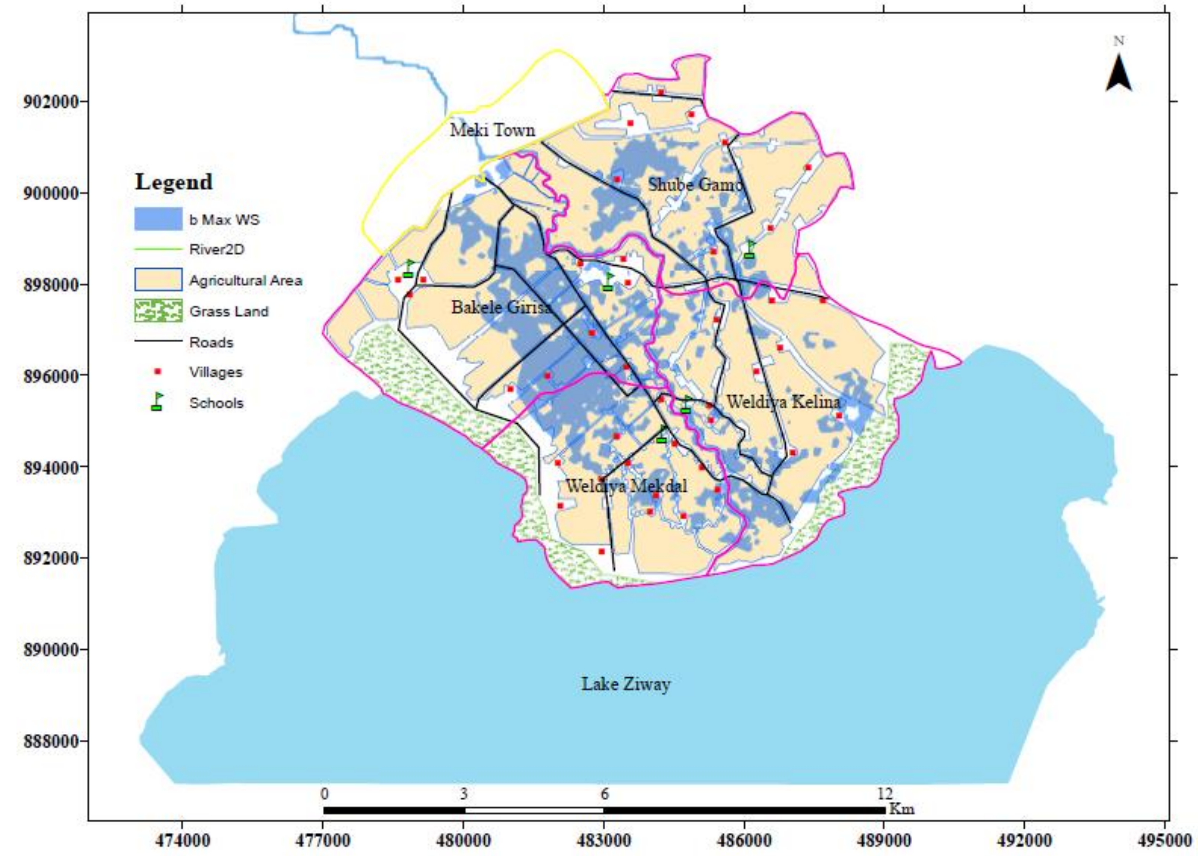


Figure 40 Flood affected PAs by 100 years flood in Dugda woreda flood plain

5.2 Flood Hazard Map

The flood hazard maps corresponding to 2, 5, 10, 20, 25, 50 and 100 years return period floods were delineated using HEC-GeoRAS on GIS environment by considering flood depths. The flood depth of all return period is found to be high within Bakele Girisa PAs. The flooded areas of Bakele Girisa PAs were found in lower elevation compared to other PAs. The flood hazard maps for 100 year return period show in Figure 41. The other years return period flood depth maps are attached in Appendix D.

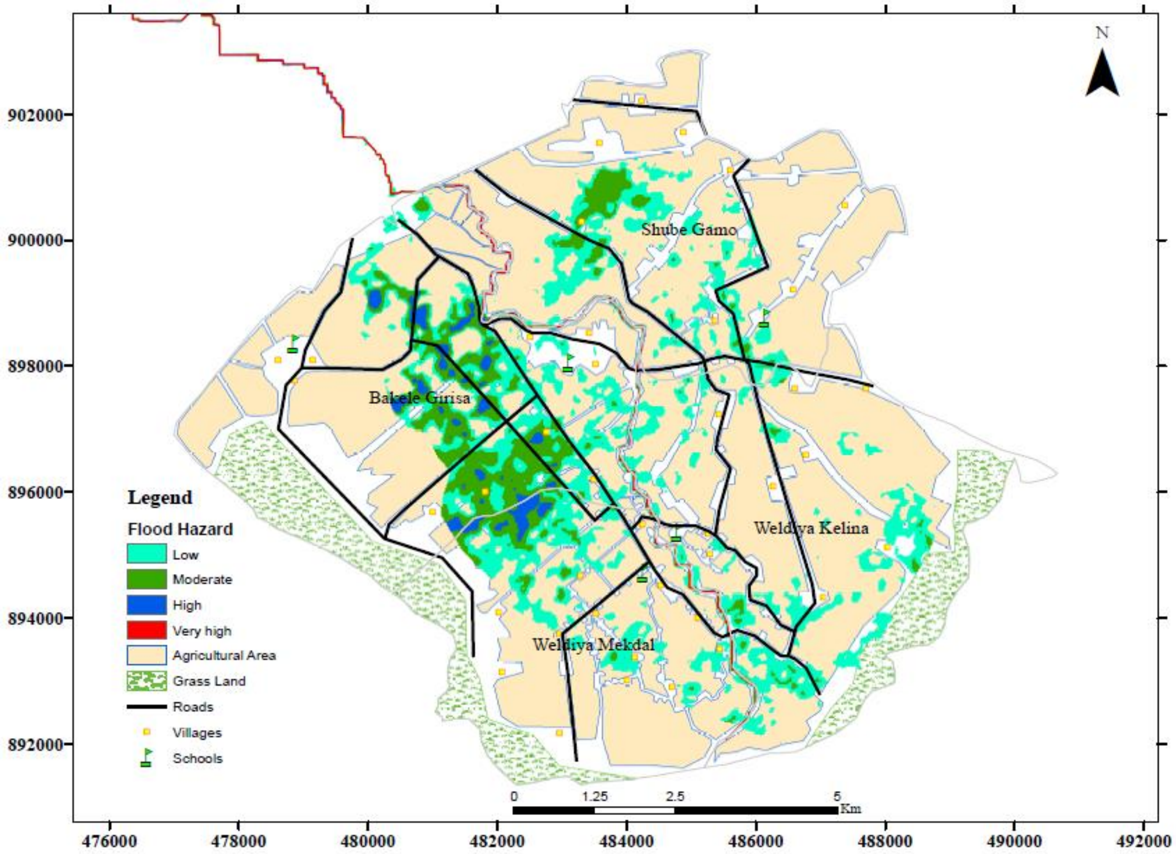


Figure 41 Flood hazard maps for 100 years return period

Figure above for 100 year return period the flood hazard maps result was classified into low, moderate, high and very high hazard levels. The maximum area was inundated for the low flood hazard level in the flood plain area found to be 9.40 km^2. The flood affected areas for 100 year return period were 4.21, 1.56, and 0.12 km^2 for the flood hazard level of moderate, high and very high respectively. The flood hazard level increases as the flood depths are increases. The higher the inundation depth, the greater the houses and agricultural parts which are damaged and the stronger the buoyancy force.

For 50 year return period the maximum depth of flood are 4.95 m and flooded Bakele Girisa, Weldiya Mekdal, Weldiya Kelina and Shube Gamo PAs of Dugda woreda. The total flooded area was 14.25 km^2 under different flood hazard levels. The flood hazard map ranges from low to very high hazard levels in the flood inundated area Appendix D. The flood depth greater than 0.5 m is sufficient to cause damages to agricultural land and farmer house in the study area.

The 25 year return period results show that 13.53 km^2 area was inundated under different flood hazard levels. The flood hazard maps levels vary from low to very high hazard levels in the flood inundated area. The maximum area was inundated for the low flood hazard levels in the flood plain area Appendix D.

The 20 year return period results show that 13.20 km^2 area is inundated under different flood hazard levels. The flood hazard maps range from low to very high hazard levels in the flood inundated area. The maximum area was inundated for the low flood hazard levels follow by moderate flood hazard levels in the flood plain area Appendix D.

The 10 year return period results show that 11.97 km^2 area is inundated under different flood hazard levels. The flood hazard maps range from low to very high hazard levels in the flood inundated area. The maximum area was inundated for the low flood hazard levels follow by moderate flood hazard levels in the flood plain area Appendix D.

The 5 year return period results show that 11.57 km^2 area is inundated under different flood hazard levels. The flood hazard maps range from low to very high hazard levels in the flood inundated area. The maximum area was inundated for the low flood hazard levels in the flood plain area Appendix D.

The 2 year return period results show that 11.15 km^2 area is inundated under different flood hazard levels. The flood hazard maps ranges from low to very high hazard levels in the flood inundated area. The maximum area was inundated for the flood hazard levels of low follow by moderate hazard levels Appendix D.

5.3 Flood Damage Estimation

The flood damage assessments were performing in the area where flood inundated in the flood plain of Meki River. The flood plain area divides into three land use class; settlement (farmer house), grass land and agricultural land further classified under two damage categories of residential (farmer houses) and agricultural areas for HEC-FDA input Figure 42. The flooded areas were largely cover by agricultural land on the left and right banks of the river Figure 41 above. Most of the areas under flooding have water depth greater than

0.5 m on average. Flood depth greater than 0.5 m is sufficient to cause economic damage to any types of agricultural land and settlement.

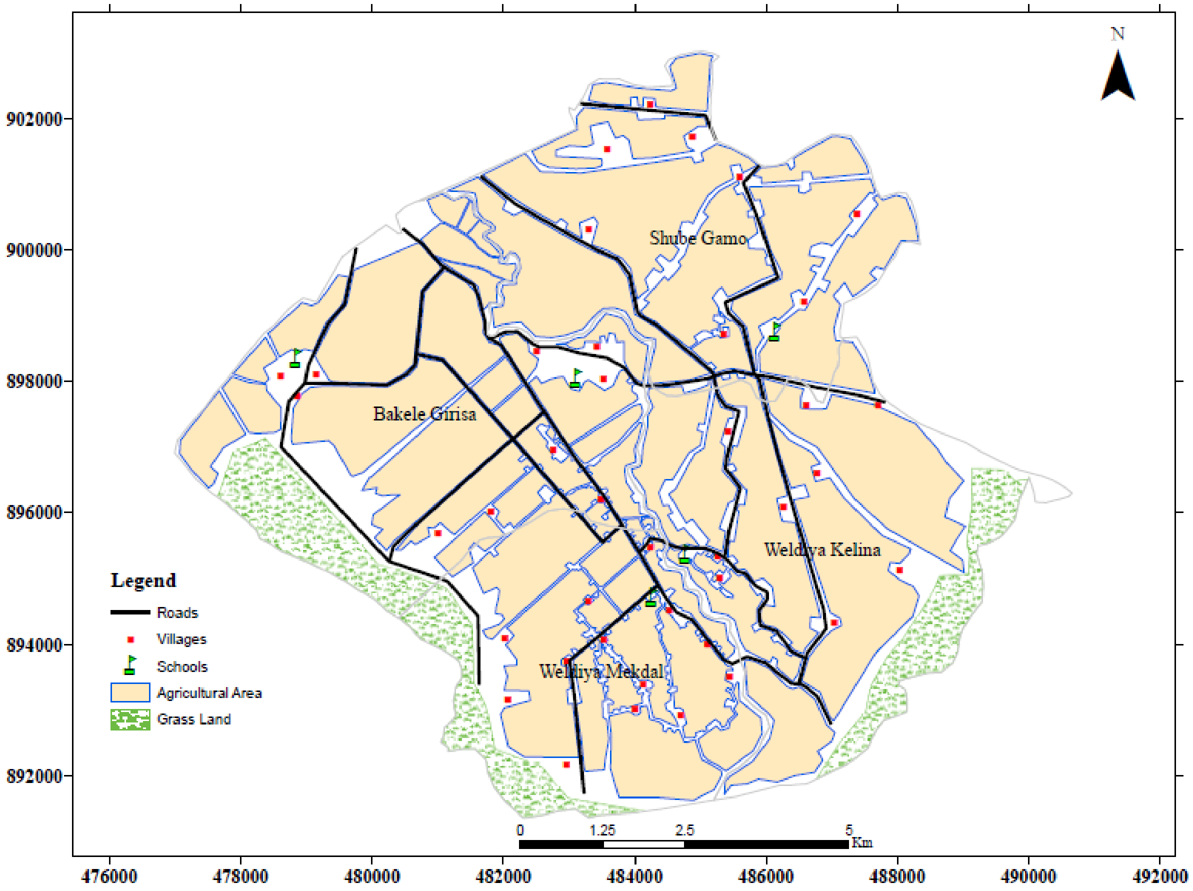
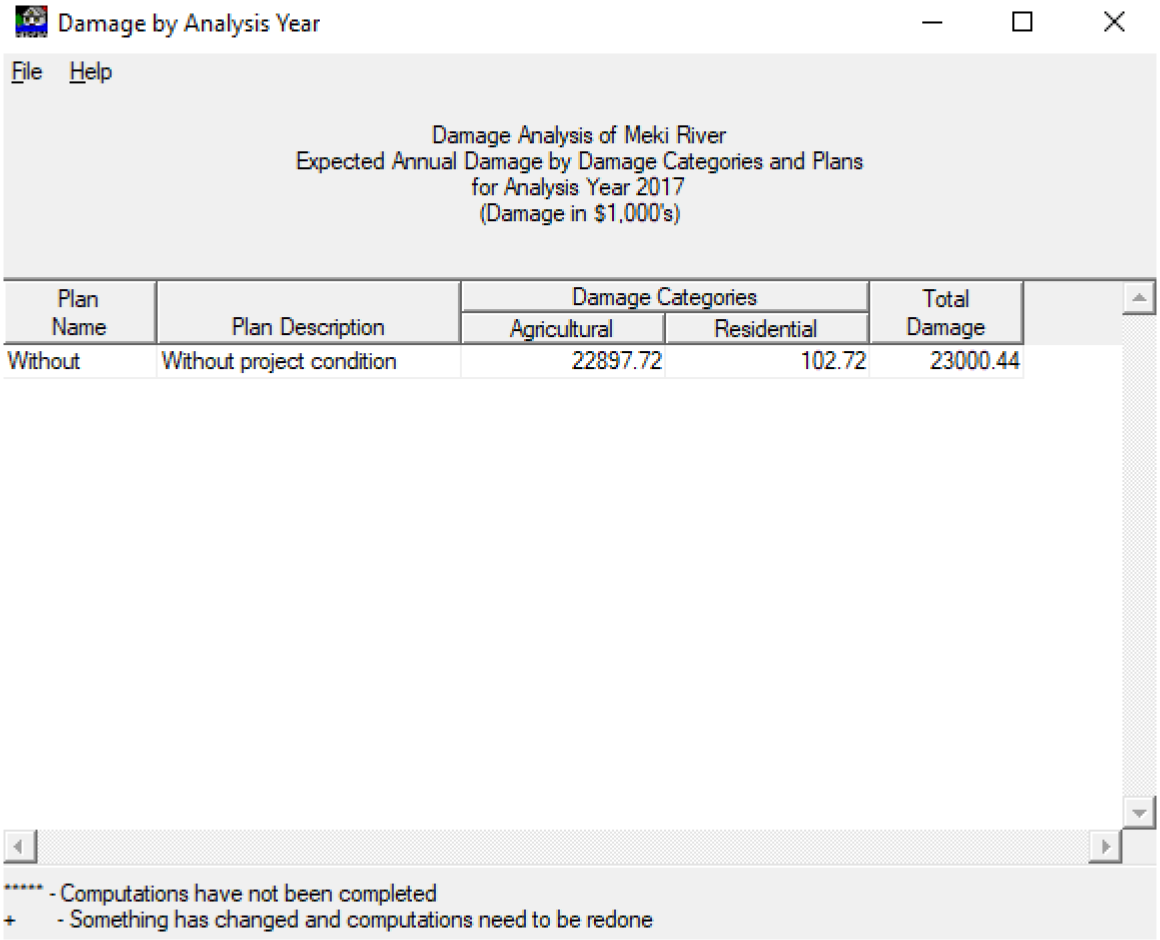


Figure 42 Map of land use of Meki River flood plain area

The hydraulic and hydrological data of the flow hydrograph for return period of eight intervals of 2, 5, 10, 20, 25, 50, 100 and 200 years have been used to estimate the flood damage using HEC-FDA model. The model was estimate flood damage using the relation of the return period of floods and their water depth. It was developed graph of exceedance probability function, stage discharge using the imported FDA format of HEC-RAS output data from HEC-RAS hydraulic model and stage damage Appendix E.

The HEC-RAS model output is stored in the FDA format, HEC-FDA model was used as input. The estimated flood damage using HEC-FDA model shows Table 15. The expected annual damage over the entire studied interval of 2, 5, 10, 20, 25, 50, 100 and 200 years which is the sum of expected annual damages in eight periods was 707,193,871 birr

Table 15 Expected annual damage (HEC-FDA)



Damage Analysis of Meki River
Expected Annual Damage by Damage Categories and Plans
for Analysis Year 2017
(Damage in $1,000's)

Plan Name	Plan Description	Damage Categories		Total Damage
		Agricultural	Residential	
Without	Without project condition	22897.72	102.72	23000.44

***** - Computations have not been completed
\+ - Something has changed and computations need to be redone

Table 15 above HEC-FDA model results show that the sum of expected annual damages of eight return periods interval; the model is not gives the individual return period flood damage values. Thus, the traditional approach of flood damage estimation was used to analysis economic flood damage for individual return period and to verify the model results.

In the study area estimation of flood damages were made to the rural areas of two land use categories: (1) farmer houses and (2) the agricultural areas.

The maximum possible economic damage of the agricultural product in flooded area is equal to the yield production per land area multiplied by the market value of the crops and vegetable type. There is no consideration for the production cost and other expenses, and therefore it is the maximum yield loss in monetary values only.

The economic flood damage of agricultural product was made for Maize, Wheat, Teff and Tomato which is cultivated in the summer season in flooded area. The yields of agricultural product per hectares were obtained from DWANRO by calculating the average yield for the last 5 years. And the market value of the each type of crops and vegetable was obtained from DWTMDO used the average market value over the last five year prices. Table 16 shows the maximum values of crop and vegetables estimated for each of the aforementioned crops and vegetable types.

Table 16 Maximum values of crops and vegetable yield in birr/hac

Crops and vegetables	Market value of crops and vegetable (birr/kg)	Crops and vegetable yield (ton/hac)	Market value of crops and vegetable (birr/hac)
Maize	4.5	4.8	21600
Wheat	7.0	3.0	21000
Teff	10.25	1.0	10250
Tomato	11.5	32	368000

Traditional approaches of computing the flood damage were made by integrating the flood inundation maps and flood depth maps with the land use map. According to local knowledge flood depth greater than 0.5 m is sufficient to damages farmer houses. The average price to constructed one farmer houses cost 4,500 birr. Table 17 gives the estimated flood damages for the individual return period based on the land use categories.

Table 17 Flood damage in birr for each land use category for different return period floods

Return period	Land Use Category					Total (birr)
	Maize	Wheat	Teff	Tomato	Farmer houses	
2	3539822	3441494	1841223	63799380	360000	72981918
5	3673160	3571128	1910578	66202585	360000	75717453
10	3800150	3694590	1976631	68491352	360000	78322723
20	4190641	4074234	2179744	75529311	382500	86356430
25	4295407	4176090	2234237	77417544	382500	88505779
50	4523988	4398321	2353133	81537324	405000	93217766
100	4946226	4808831	2572758	89147474	427500	101902790
200	5257350	5111312	2734588	94754954	472500	108330703

As shows the results above the HEC-FDA model values slight similar to the traditional approach. The areas under flood inundation in the lower part of Meki River have been made economic damage on the settlement and agricultural land. Thus, flood mitigation measures were recommended to reduce the physical extent of flooding and relieving the effect of the floods on humans, property and farm land.

Flood surface profiles are the vital components to apply flood mitigation measures because it shows more accurately where to concentrate future mitigation efforts. Flood mitigation refers to measures adopted to reduce damages to life and property by floods. Flood mitigation measures can be implemented to reduce the physical extent of flooding, relieve the effect of a flood on humans and the community and reduce the tendency towards flood damage of future floods in different areas. From the flood elevation profile of the study area, the flood is out of the banks for most of the flow scenarios.

Therefore, to keep the flood water within the extent of the bank, flood mitigation measures should be proposed. The selection of mitigation measures strongly depends on the characteristics of the area that is urban or rural. An optimal set of flood mitigation measures can be established for an area by looking at the characteristics of the flood reach and the flood magnitude. Flood mitigation measures can be classified as structural and non-structural.

In this research two alternatives structural flood mitigation measure were recommended to reduce the tendency towards flood damage of future floods by;

- ✓ **Increasing the width of river channel**

Meki River width is 20 m on average in the lower reach. These river widths have not sufficient capacity to pass the maximum flood. Thus, increasing the width of river channel in the lower parts of the river is reducing flood damage.

- ✓ **Flood protection by levee**

A levee may be defined as an embankment extending generally parallel to the stream course and designed to protect the area behind it from overflow by floodwaters. Building levees along a stream as a shield against high water level has been one of the most ancient means of flood protection. For this study, it is proposed to construct levee at areas where flood depth above the banks of the river. During maximum flood the water flow over the banks in the flood plain area and inundated the adjacent land. Constructing levee along the right and left of the river banks; where the overflow of maximum flood occurs to alleviating the flood damages on the community.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

The main source of flooding in the Meki River catchment is a result of river flood originating from the rainfall on the upper catchment. It is occur as a result of intensive showers, and steep slope of the upper catchment.

In this research flow hydrograph was evaluated under design rainfall using HEC-HMS model. Meki River catchment was first classified in to eleven sub basins using HEC-GeoHMS GIS extension. Calibration and validation of HEC-HMS model was performed based on the Meki River flow data collected from MoWIE and rainfall data collected from NMSA. The calibration was made with four years' flow data, from 2007-2010 and validation was made with two years' flow data from 2011-2012 of calibrated parameters. Using log normal distribution method the design rainfall was determined for each rainfall stations. After calculating design rainfall for each rainfall stations select the highest to estimate the peak flow hydrograph. With optimized values of calibrated parameters, HEC-HMS was estimate peak flow hydrograph under frequency storm of meteorological model.

The flood inundation and flood hazard maps were delineated using HEC-RAS/GeoRAS (first HEC-GeoRAS then HEC-RAS and finally back to HEC-GeoRAS). HEC-GeoRAS GIS extension was create RAS layers defining the stream centerlines, cross sections, bridges and their attributing using TIN and survey data in the field. HEC-RAS was simulate the water surface profiles and 3D perspective view of flood plain using the geometric data imported from HEC-GeoRAS of GIS extension and flow hydrograph imported from HEC-HMS hydrological model. HEC-GeoRAS delineate the flood extent and flood depth of the study area in concert with Arc-GIS by importing HEC-RAS GIS format file. The flooded areas along Meki River were 15.52, 14.99, 14.02, 13.57, 12.95, 12.50 and 11.52 km^2 for return period of 100, 50, 25, 20, 10, 5 and 2 respectively.

Finally, flood damage analysis was evaluated with the hydrological and hydraulic model result output using HEC-FDA. Flood damage evaluation has several uncertainties, accurate determination of economic estimates is not possible, but it is possible to get closer estimation to the exact amount of damage by HEC-FDA. HEC-FDA estimates the expected annual damage in economic monetary units.

6.2 Recommendation

Based on the findings of this research the following recommendations can be drawn;

- Future studies should consider the effect of sedimentation deposited on the river channel on flooding
- Real time flood forecasting and emergency response centre in Meki town that has linkage with various governmental, public, nongovernmental and private organizations.
- Early warning systems and reliable communication systems (mobile phone network and radio) to facilitate information sharing.
- Installation and operation of a real-time reporting network of rainfall and river gauges

REFERENCES

Abdo, G.M. and Nasr, A.E., 2008. The sudan experience in flood forecasting and early warning. *Sudan Engineering Society Journal*, Volume 54 No.50

Abebe, G.S., and Kassa, T.M., *2016.* Assessing the impact of existing and future water demand on economic and environmental aspects of Meki-Ziway sub basin, Ethiopia. *International Journal of Waste Resources*, 6:223, doi:10.4172/2252-5211.1000223

Abeyou, W. (2008). *Hydrological balance of Lake Tana, Upper Blue Nile Basin, Ethiopia*, M.Sc. thesis, International Institute for Geo-information science and Earth observation, Netherlands.

Abushandi, E. and Merkel, B., 2013. Modelling rainfall runoff relations using HEC-HMS and IHACRES for a single rain event in an arid region of Jordan. *Journal of Water Resource Management* 27:2391–2409.

ACAPS, 2016. Ethiopia Floods

Adewale, P.O., Sangodoyin, A.Y. and Adamowski, J., 2010. Flood routing in the Ogunpa River in Nigeria using HEC-RAS. *Journal of Environmental Hydrology*, 18:25

Ahmad, H.F., Alam, A., Bhat, M.S. and Ahmad, S., 2016.One-Dimensional steady flow analysis using HEC-RAS; A case of River Jhelum, Jammu and Kashmir. *European Scientific Journal*, ISSN: 1857 – 7881 e - ISSN 1857- 7431, volume 12, Number 32

Alemseged, T.H., Fekadu, T.T. and Rientjes, T., 2016. Flood forecasting in Niger-Benue basin using satellite and quantitative precipitation forecast data. *International Journal of Applied Earth Observation and Geoinformation*, 52, 475–484

Al-Zahrani, M., Al-Areeq, A. and Sharif, H., 2016. *Flood analysis using HEC-RAS model: a case study for Hafr Al-Batin, Saudi Arabia*. FLOOD*risk* 2016 - 3rd European Conference on Flood Risk Management

Amare, M., 2008. *Assessment of Lake Ziway water balance.* MSc thesis, Addis Ababa University, Ethiopia.

Amini, A., Ghazvinei, P.T., & Javan, M. and Saghafian, B., 2014.Evaluating the impacts of watershed management on runoff storage and peak flow in Gav-Darreh watershed, Kurdistan, Iran. *Arab Journal of Geosciences*, 7:3271–3279.

Asadi, A. and Boostani, F., 2013^{a}.Application of HEC-HMS for flood forecasting in Kabkian basin and Delibajak subbasin in Iran. *IOSR Journal of Engineering***,** **e**-ISSN: 2250-3021, **p**-ISSN: 2278-8719, Vol. 3, Issue 9, PP 10-16

Asadi, A. and Boostani, F., 2013^{b}.Performance evaluation of the HEC-HMS Hydrologic Model for Lumped and Semi-distributed storm flow simulation (Study Area: Delibajak Basin). *American Journal of Engineering Research*, e-ISSN: 2320-0847 p-ISSN: 2320- 0936, Volume-02, Issue-11, pp-115-121

Awad, A.M., 2016. Hydraulic Model Development using HEC-RAS and Determination of Manning Roughness Value for Shatt Al-Rumaith. *Muthanna Journal of Engineering and Technology*, 4:9-13

Beilicci, R. and Beilicci, E., 2014. Advance hydraulic modeling using HEC-RAS, Baraolt River, Romania. *Research Journal of Agricultural Science*, 46 (1).

Bhuiyan, H. A. K. M., McNairn, H., Powers, J. and Merzouki, A., 2017. Application of HEC HMS in a cold region watershed and use of RADARSAT-2 soil moisture in initializing the model. *Journal of Hydrology*, 4, 9; doi:10.3390/hydrology4010009

Briant, M.J, 2001. Hydrologic Engineering Center- Flood Damage Analysis (HEC-FDA), Sensitivity and Uncertainty Analysis.

Brych, K., Dittrt, F. and Elias, V., 2002. *Development of flood boundary maps of urban areas using HEC-RAS software.* Proceedings of the Fourth international FRIEND Conference held at Cape Town. South Africa. March 2002. IAHS Publ. no. 274.

Cancado, V., Brasil, L., Nascimento, N. and Guerra, A., 2008. *Flood risk assessment in an urban area: Measuring hazard and Vulnerability.* 11th International Conference on Urban Drainage, Edinburgh, Scotland, UK.

Carpenter, T.M., Sperfslage, J.A., Georgakakos, K.P., Sweeneyc, T., Fread, D.L., 1999.National threshold runoff estimation utilizing GIS in support of operational flash flood warning systems. *Journal of Hydrology*, 224, 21–44.

Chatterjee, M., De, R., Roy, D., Das, S. and Mazumdar, A., 2014. Hydrological Modeling Studies with HEC-HMS for Damodar Basin, India. *World Applied Sciences Journal* 31 (12): 2148-2154, Choudhari, K., Panigrahi, B. and Paul, J.C., 2014. Simulation of rainfall-runoff process using HEC-HMS model for Balijore Nala watershed, Odisha, India. *International Journal of Geomatics and Geosciences,* Volume 5, No 2.

Chow, V.T., Maindment, D.R. and Mays, W.L., 1988. Applied Hydrology. New York, McGraw-Hill

Corbley, K., 1993. Remote sensing and GIS provide rapid response for flood relief. *Earth Observation Magazine*, September, 2, 28–30.

Cunderlik, J.M and Simonovic, S.P., 2004. "*Assessment of Water Resources Risk and Vulnerability to Changing Climatic*" Project Report IV, Calibration, Verification, and Sensitivity Analysis of the HEC-HMS: 23.

Dagnachew, L., 2002. *Analysis of the hydrological response of the Ziway–Shalla lake basin (Main Ethiopian Rift) to changes in climate and human activities*. Ph.D. Thesis, Aix en-Provence, Universite d‟Aix-Marseille III, France.

Dagnachew, L., Christine Vallet-Coulomb, C., and Gasse, F., 2004. Analysis of the hydrological response of a tropical terminal lake, Lake Abiyata (Main Ethiopian Rift Valley) to changes in climate and human activities. *Journal of Hydrological Processes*, 18, 487- 504.

Daniel, F., 2016. *The impact of existing and proposed irrigation scheme on hydrology of lake Ziway.* Msc. thesis, Addis Ababa University, Ethiopia.

Degefu, W., 1987. *Some aspects of meteorological drought in Ethiopia*. Drought and Hunger in Africa, Cambridge University Press, Cambridge, pp. 23–36.

Dereje, B., 2011. *Numerical groundwater flow modeling of the Meki River catchment, central Ethiopia.* MSc. thesis, Addis Ababa University, Ethiopia.

DPPA, 2007. *Regional Summary of Multi-Agency Flood Impact Assessment of 2006*. Early Warning Department, Addis Ababa, Ethiopia

DWDRMO, 2016. *Annual* r*eport of flood disaster risk of 2016.*

Edo, E.K., 2014. *Determinants of water utilization for small-scale irrigation among rural households in Dugda Woreda.* MSc thesis, Haramaya University, Ethiopia.

ERA, 2002. Drainage Design Manual

Forkuo, E.K., 2011.Flood hazard mapping using Aster image data with GIS. *International Journal of Geomatics and Geosciences,* Volume 1, Number 4

Getahun, Y.S. and Gebre, S.L., 2015. Flood hazard assessment and mapping of flood inundation area of the Awash River Basin in Ethiopia using GIS and HEC-GeoRAS/HEC-RAS Model. *Journal of Civil and Environmental Engineering*, 5:4. http://dx.doi.org/10.4172/2165-784X.1000179

GFDRR, 2011. *Disaster risk management programs for priority countries.*

Goodell, C. and Warren, C., 2006. *Flood inundation mapping using HEC-RAS.* Obrasy Proyectos, Edition 2

Goswami,K.M. , O‟Connor,K.P. , Bhattarai, and A.Y.Shamseldin,M.(2005).Assessing the performance of eight real-time updating models and procedures for the Brosna River, *Journal of Hydrology and the Earth System Sciences*. 9 (4): 394-411.

Gunasekara I.P.A, 2008. Flood Hazard Mapping in Lower Reach of Kelani River *The Institution of Engineers, Volume. XXXXI, No. 05, pp. 149-154, Sri Lanka*

Halcrow, Sir, & Sons, 1989. *Rift valley lakes integrated natural resources development master plan.* Ethiopian Valleys Development Studies Authority. Unpublished Technical Report of Sir Halcrow& Sons, Addis Ababa, Ethiopia.

Hashemyan F., Khaleghi M.R. and Kamyar M., 2015. Combination of HEC-HMS and HEC-RAS models in GIS in order to Simulate Flood (Case study: Khoshke Rudan river in Fars province, Iran). *Research Journal of Recent Sciences*, ISSN 2277-2502, Volume. 4:8, 122-127

Hawi, A., 2007. *Impact of land use change and climate variability on catchment runoff*; *A modeling study of the Meki river basin*. MSc thesis, Addis Ababa University, Ethiopia.

Idris, S. and Dharmasiri, L.M., 2015:A review; Flood risk inevitability and flood risk management in urban areas, *Journal of Geography and Regional Planning*, 8:8,205-209.

IPCC, 2012. *Managing the risks of extreme events and disasters to advance climate change adaptation*. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp. Retrieved March 7, 2014, fromhttps://www.ipcc.ch/pdf/special-reports/srex/SREX_Full_Report.pdf

Italo Consult, 1970. *Meki River Diversion Scheme Volume 2 Hydrology*. Imperial Ethiopian Government, Awash Valley Authority.

Jedhe, Y.S., Dr.R.N.Sankhua and Dr.K.N.Dhumal, 2014. Flood hazard mapping for Khadakwasla watershed. *International Journal of Innovative Research in Science, Engineering and Technology,* ISSN: 2319-8753, Volume 3, Issue 10

JICA & OIDA, 2002. *The study for Meki Irrigation and Rural development Project*. Main report, volume 1.

Karimain, K. R., Sadatinejad, J. and Honarbakhsh, A., 2013. Comparison of the hydraulic routing flood in Doab River. *Journal of Water Resources Engineering*, 6:15-24

Kebede, B., 2012. *Application of GIS and Remote Sensing techniques for flood hazard and risk assessment: The case of Dugeda Bora Woreda of Oromiya regional state, Ethiopia.* Paper for the 2012 Berlin Conference on the Human Dimensions of Global Environmental Change.

Keyalew, A., 2006. *Integrated flood management: Ethiopia.* The Associated Programme on Flood Management, World Meteorological Organization/Global Water Partnership.

Khaghan, A.A.M. and Mojaradi, B., 2016.The integrate of HEC-HMS and HEC-RAS Models in GIS integration models to simulate flood (Case study: the area of Karaj). Journal of *Current World Environment,* 11:1, pp 1-5

Khaleghi, S., Mahmoodi, M. and Karimzadeh, S., 2015.Integrated application of HEC-RAS and GIS and RS for flood risk assessment in Lighvan Chai River. *International Journal of Engineering Science Invention, Volume 4 Issue 4 PP.38-45*

Khattak, M.S., Anwar, F., Saeed, T.U., Sharif, M., Sheraz, K. and Ahmed, A., 2016. Floodplain Mapping Using HEC-RAS and Arc-GIS: A Case Study of Kabul River. *Arab Journal of Science Engineering,* 41:1375–1390. DOI 10.1007/s13369-015-1915-3

Kind, J., Vos, R., Tijssen, A., Jeuken A., and Slootjes, N., 2014. *Towards the evaluation of adaptive flood risk management strategies for the Rhine estuary – Drechtsteden*, 6th International Conference on Flood Management (ICFM6), 16–18 September 2014, Sao Paulo, Brazil, 2014.

Knebl, M.R., Yang, Z.L., Hutchison, K. and Maidment, D.R., 2005. Regional scale flood modeling using NEXRAD rainfall, GIS, and HEC-HMS/RAS: a case study for the

San Antonio River Basin Summer 2002 storm event. *Journal of Environmental Management,* 75,325–336

Legesse, D., Abate, H., Abiye, T.A., and Vallet-Coulomb, C., 2010. Stream flow sensitivity to climate and land cover changes: Meki River, Ethiopia. *Journal of Hydrology and Earth System Sciences*, 14, 2277–2287. doi:10.5194/hess-14-2277- 2010

Li, L., Hong, Y., Wang, J., Robert F. Adler, Frederick S. Policelli, Habib, S., Irwn, D., Korme, T. and Okello, L., 2009. Evaluation of the real-time TRMM-based multi-satellite precipitation analysis for an operational flood prediction system in Nzoia Basin, Lake Victoria, Africa. *Center for Natural Hazards*, 50:109–123. DOI 10.1007/s11069-008- 9324-5.

Makin, M. J., Kingham, T. J., Waddams, A. E., Birchall, C. J., and Eavis, B. W.: Prospects for irrigation development around Lake Ziway, Ethiopia, Land Res. Study. Division, Ministry of Overseas Development, 26, Tolworth, UK, 270 pp., 1976.

Mardookhpour, A.R. and Jamasbi, H., 2017.Flood zoning estimation and river management by using HEC-RAS and GIS model. *International Journal of Energy and Water Resources*, 1, 1: 13-18,

Martin, O., Rugumayo, A. and Ovcharovichova, J., 2012. Application of HEC-HMS/RAS and GIS tools in flood modeling; A case study for River Sironko, Uganda. *Global Journal of Engineering, Design and Technology,* volume 1(2); 19-31

Merz, B., Kreibich, H., Schwarze, R., and Thieken, A., 2010. Review article "Assessment of economic flood damage", *Journal of Natural Hazards Earth System Science*, 10, 1697– 1724.

Mohammadi, S.A., Nazariha, M. and Mehrdadi, N., 2014. *Flood damage estimate (quantity), using HEC-FDA model. Case study: the Neka River.* 12th International Conference on Computing and Control for the Water Industry, *Procedia Engineering 70: 1173 – 1182*

Moriasi,N.D., J. G. Arnold,W.M., Van Liew,LR.,Bingner,D.R., & Veithand T. L.Harmel. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. *Journal of American Society of Agricultural and Biological Engineers,* Vol. 50(3): 885−900.

Mulugeta, D.B., Diekkrüger, B. and Roehrig, J., 2015. Characterization of water level variability of the Main Ethiopian Rift Valley Lakes. *Journal of Hydrology*, 3, 1;doi:10.3390

NDRMC, 2016. *National flood alert.* Early Warning and Response Directorate. Ethiopia

Nestanet, K., 2007. *Groundwater resources evaluation and management in Dugda Woreda, Central Rift Valley, Ethiopia*. Msc. thesis, Addis Ababa University, Ethiopia.

Notaroa. V., De Marchisa, M., Fontanazzaa, C.M., La Loggiab, G., Puleob, V. and Freni, G., 2014. *The effect of damage functions on urban flood damage appraisal.* 12th International Conference on Computing and Control for the Water Industry, Procedia Engineering 70: 1251 – 1260

Nut, N. and Plermkamon, V., 2015. Floodplain mapping using HEC-RAS and GIS in Nam Phong River basin, Thailand. *International Journal of Environmental and Rural Development, 6-1*

Pingel. N. and Watkins Jr.D., 2010. Multiple flood source Expected Annual Damage computations. *Journal of Water Resources Planning and Management*, 136(3): 319-326

Ramkrishna, S.S. and Chaudhari, P.S., 2014. Evaluation of non-structural and structural flood management measures. *International Journal of Innovative Research in Advanced Engineering*, 1: 2.

Rao, A.R. and Hamed, K.H., 2000. Flood frequency analysis. London.

Sein, K.K. and Myint, T., 2016.Flood hazard mapping using hydraulic model and GIS; A case study in Mandalary City, Myanmar. *Journal of Suan Sunandha Science and Technology*

Sene, K., 2008. *Flood warning, forecasting and emergency response*. United Kingdom

Silvestro, F., Rebora, N. and Ferraris, L., 2011. Quantitative flood forecasting on small and medium-sized basins: A Probabilistic Approach for Operational Purposes. *Journal of Hydrometeorology*. Volume 12. DOI: 10.1175/JHM-D-10-05022.1

Singh, W.R. and Jain, M.K., 2015. Continuous hydrological modeling using Soil Moisture Accounting algorithm in Vamsadhara River Basin, India. *Journal of Water Resource and Hydraulic Engineering*, Volume 4 Issue 4, PP. 398-408; DOI: 10.5963/JWRHE0404011

Sintayehu, L.G., 2015. Application of the HEC-HMS model for runoff simulation of Upper Blue Nile River basin. *Journal of Hydrology Current Research*, 6:2, http://dx.doi.org/10.4172/2157-7587.1000199

Subramanya, K., 2008. Engineering Hydrology. 3rd edition, New Delhi, Tata McGraw-Hill.

Tadele, M., 2009. *Environmental impacts of floriculture industries on lake Ziway: with particular reference to water quality*. Msc. Thesis, Addis Ababa University, Ethiopia.

Tamirat, D.H. and Adane, A.A., A.A.,2016. Embankment dam spillway adequacy evaluation under Probable Maximum Flood the case of Tendaho Dam, Ethiopia. *The International Journal of Science & Technoledge*, Volume 4 Issue 9

Temesgen, A., 2008. Application of physically based distributed hydrological model for estimation of major components of the hydrologic cycle: the case of Meki river basin. MSc thesis, ArbaMinch University, Ethiopia.

Tenalem, A., 1998. *The hydrogeological system of the Lake District basin, Ethiopia*. Ph.D thesis, University of Amsterdam, Enscheda, Netherlands.

Tenalem, A., 2001. *Numerical groundwater flow modeling of the central main Ethiopian Rift Valley lake basin.*

Tenalem, A., 2003. Evapotranspiration estimation using thematic mapper spectral Satellite data in the Ethiopian rift and adjacent highlands. *Journal of Hydrology*, 279, 83-93.

Tenalem, A., 2007. Water management problems in the Ethiopian Central Rift Valley; Challenges for development. *Journal of African Earth Sciences*, 48 (2), 222–236

Tenalem, A., 2008. Hydrological system analysis and groundwater recharge estimation using semi-distributed models and river discharge in the Meki River basin. *Ethiopian. Journal Science, 31, 29-42.*

Tibebu, T., 2007. *Effects of irrigation practices and lacustrine aquifer development on water availability in Ziway-Abijata basin.* Msc. Thesis, Addis Ababa University, Ethiopia.

UNESCO (United Nations Educational, Scientific and Cultural Organization) (2008), Floods.

USACE, 2000. *Hydrologic Modeling System, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS).* Technical Reference Manual.

USACE, 2013. *Geospatial Hydrologic Modeling Extension , Hydrologic Engineering Center- Geospatial Hydrologic Modeling System (HEC-GeoHMS).* User's Manual, Version 10.1

USACE, 2015. *Flood Damage Reduction Analysis*, *Hydrologic Engineering Center- Flood Damage Reduction Analysis (HEC-FDA).* User's Manual, Version 1.4

USACE, 2016[a]. *Hydrologic Modeling System*, *Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS).* User's Manual, Version 4.2

USACE, 2016[b]. *Hydrologic Modeling System*, *Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS).* Quick Start Guide, Version 4.2

USACE, 2016[c]. *River Analysis System*, *Hydrologic Engineering Center- River Analysis System (HEC-RAS).*User's Manual, Version 5.0

USACE, 2016[d]. *River Analysis System*, *Hydrologic Engineering Center- River Analysis System (HEC-RAS).*Hydraulic Reference Manual, Version 5.0

Wagenaar, D.J., De Bruijn, K.M., Bouwer, L.M. and De Moel, H., 2016. Uncertainty in flood damage estimates and its potential effect on investment decisions, *Journal of Natural Hazards Earth System Science*, 16, 1–14.

Yang, S.C. and Yang, T.H., 2014. Uncertainty assessment: Reservoir Inflow Forecasting with ensemble precipitation forecasts and HEC-HMS. *Journal of Advances in Meteorology,* Article ID 581756, 11 pages

Yasin, Z., G. Nabi, and S. M.Randhawa, 2015. Modeling of Hill Torrent using HEC Geo-HMS and HEC- HMS Models: A case study of Mithawan Watershed. *Pakistan Journal of Meteorology*, Volume 11, Issue 22

APPENDIX

Appendix A: Double Mass Curve of Meteorological Stations of Study Area

Table A1 Annual Precipitation of Each Station (1987-2016)

Year	Annual Precipitation			
	Meki	Butajira	Koshe	Bui
1987	804	1247.9	907.7	969.5
1988	728.8	1124.5	659.4	863.5
1989	870.2	1311.5	1150	1092.6
1990	921.3	1465.5	837.1	1079.7
1991	519.5	1271.6	772.2	1025.6
1992	934.6	1156.9	776.4	995.9
1993	749.8	1129.3	1314.5	1093.4
1994	638.8	1031.2	674.5	759.8
1995	347.3	1168.8	869.7	1306.4
1996	955.8	1483.8	889.5	1348.3
1997	804.6	1240.3	859.1	759.5
1998	773	1459.9	867	1046.2
1999	697	1054.4	698.7	983.6
2000	751.5	865.6	707.9	998.4
2001	758.9	1301.3	912.9	1220.6
2002	511.6	1159.9	578.7	901.3
2003	787	1187.8	750.6	1056.1
2004	601.1	913.4	594.2	921.2
2005	728.5	1783.6	1076.5	1264.7
2006	783.1	1572.3	953.6	1229.1
2007	788	1297.1	967.5	1198.3
2008	772.8	919.2	945.1	1073.9
2009	608.5	504.7	520.8	838.6
2010	906.6	791.1	864	1523.6
2011	580.4	953.8	623.8	1150.3
2012	899.7	881.7	691.6	727.3
2013	753.2	1344.3	1083.9	942.0
2014	858.4	1542.1	860.5	967.6
2015	467.8	365.8	291	566.9
2016	695.4	488.1	923.5	875.3

Table A2: Annual Cummulative of each Station and Average of the cummulative

Year	Cummulative of each Station (mm)				Average Cummulative
	Meki	Butajira	Koshe	Bui	
2016	695.4	488.1	923.5	875.3	745.6
2015	1163.3	853.9	1214.5	1442.2	1168.5
2014	2021.7	2396.0	2075.0	2409.8	2225.6
2013	2774.9	3740.3	3158.9	3351.8	3256.5
2012	3674.6	4622.0	3850.4	4079.1	4056.5
2011	4255.0	5575.9	4474.2	5229.4	4883.6
2010	5161.6	6366.9	5338.2	6753.0	5904.9
2009	5770.1	6871.6	5859.0	7591.6	6523.1
2008	6542.8	7790.8	6804.1	8665.5	7450.8
2007	7330.9	9087.9	7771.6	9863.8	8513.5
2006	8114.0	10660.2	8725.2	11092.9	9648.1
2005	8842.5	12443.8	9801.7	12357.6	10861.4
2004	9443.6	13357.2	10395.9	13278.8	11618.9
2003	10230.6	14545.0	11146.5	14334.9	12564.3
2002	10742.2	15704.9	11725.2	15236.2	13352.1
2001	11501.1	17006.2	12638.1	16456.8	14400.6
2000	12252.6	17871.8	13346.0	17455.2	15231.4
1999	12949.6	18926.2	14044.7	18438.8	16089.8
1998	13722.6	20386.1	14911.7	19485.0	17126.4
1997	14527.2	21626.4	15770.8	20244.5	18042.2
1996	15483.0	23110.2	16660.3	21592.9	19211.6
1995	15830.3	24279.0	17530.0	22899.3	20134.7
1994	16469.1	25310.2	18204.5	23659.1	20910.7
1993	17218.9	26439.5	19519.0	24752.5	21982.5
1992	18153.5	27596.4	20295.4	25748.4	22948.4
1991	18673.0	28868.0	21067.6	26774.0	23845.7
1990	19594.3	30333.5	21904.7	27853.7	24921.5
1989	20464.5	31645.0	23054.6	28946.3	26027.6
1988	21193.3	32769.5	23714.0	29809.8	26871.7
1987	21997.3	34017.4	24621.7	30779.3	27853.9

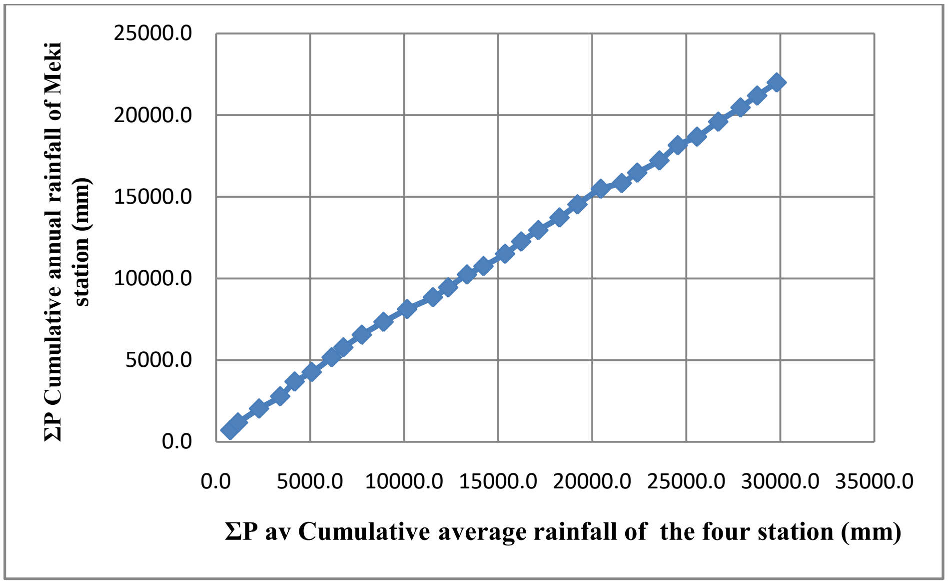


Figure A1 Double Mass Curve of Meki Rainfall Station

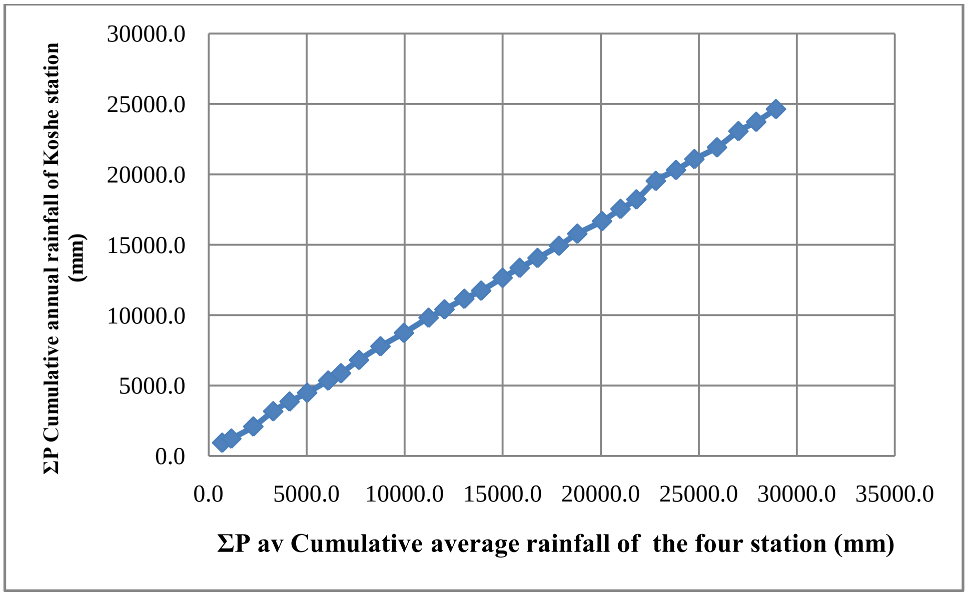


Figure A2 Double Mass Curve of Koshe Rainfall Station

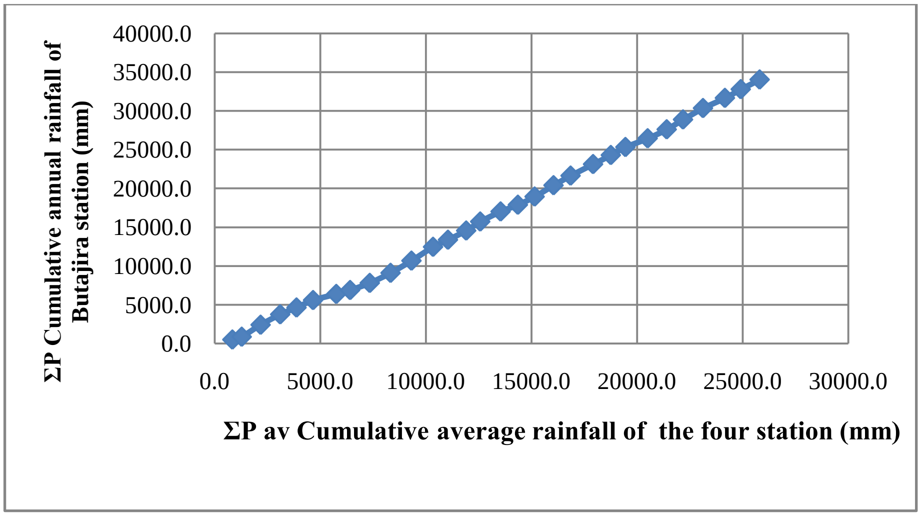


Figure A3 Double Mass Curve of Butajira Rainfall Station

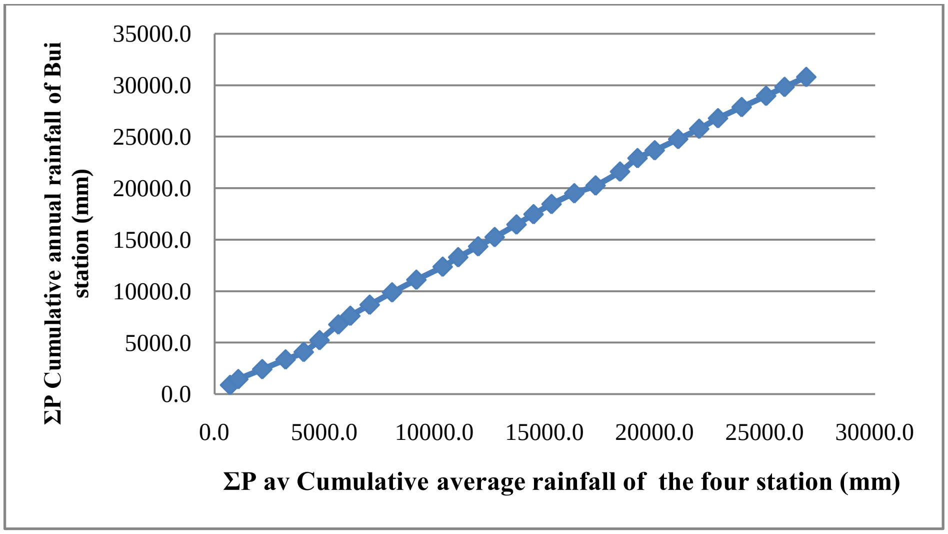


Figure A4 Double Mass Curve of Bui Rainfall Station

APPENDIX B: Annual Areal Rainfall of Study Area

Table B1 Annual Areal Rainfall of Study Area using Thiessen Polygon (1987-2016)

Year	Meki (mm)	Butajira (mm)	Koshe (mm)	Bui (mm)	Areal Rainfall (mm)
1987	804	1247.9	907.7	969.5	1033.9
1988	728.8	1124.5	659.4	863.5	887.9
1989	870.2	1311.5	1150	1092.6	1162.0
1990	921.3	1465.5	837.1	1079.7	1135.0
1991	519.5	1271.6	772.2	1025.6	996.4
1992	934.6	1156.9	776.4	995.9	988.7
1993	749.8	1129.3	1314.5	1093.4	1130.3
1994	638.8	1031.2	674.5	759.8	820.0
1995	347.3	1168.8	869.7	1306.4	1053.2
1996	955.8	1483.8	889.5	1348.3	1238.3
1997	804.6	1240.3	859.1	759.5	956.2
1998	773	1459.9	867	1046.2	1116.7
1999	697	1054.4	698.7	983.6	906.5
2000	751.5	865.6	707.9	998.4	853.2
2001	758.9	1301.3	912.9	1220.6	1124.2
2002	511.6	1159.9	578.7	901.3	869.6
2003	787	1187.8	750.6	1056.1	996.5
2004	601.1	913.4	594.2	921.2	802.8
2005	728.5	1783.6	1076.5	1264.7	1344.0
2006	783.1	1572.3	953.6	1229.1	1233.5
2007	788	1297.1	967.5	1198.3	1133.1
2008	772.8	919.2	945.1	1073.9	957.9
2009	608.5	504.7	520.8	838.6	618.2
2010	906.6	791.1	864	1523.6	1039.1
2011	580.4	953.8	623.8	1150.3	890.7
2012	899.7	881.7	691.6	727.3	788.0
2013	753.2	1344.3	1083.9	942.0	1100.1
2014	858.4	1542.1	860.5	967.6	1128.2
2015	467.8	365.8	291	566.9	416.0
2016	695.4	488.1	923.5	875.3	736.4

APPENDIX C: Hydrological Data of Study area

Table C1 Annual Maximum Stream Flow of Meki River (2007-2012)

Year	2007	2008	2009	2010	2011	2012
Stream flow (m^3/s)	64.19	54.39	29.98	64.81	69.85	80.10

Table C2 Wald-Wolfowitz (W-W) statistical test

S.No	Year	Flow (m^3/s)	$X_i * X_{i+1}$	X_i^2	X_i^3	X_i^4
1	2007	64.19	3491.78	4120.74	264522.74	16980508.44
2	2008	54.39	1630.60	2958.82	160944.79	8754592.27
3	2009	29.98	1942.81	898.62	26937.95	807518.86
4	2010	64.81	4526.91	4200.34	272223.78	17642823.35
5	2011	69.85	5594.97	4878.88	340785.08	23803497.39
6	2012	80.10	5141.92	6416.17	513941.65	41167240.05
		S_1 =363.33	R= 22329	S_2=23473.57	S_3=1579356.00	S_4=109156180.40

APPENDIX D: HEC-GeoRAS Model Outputs

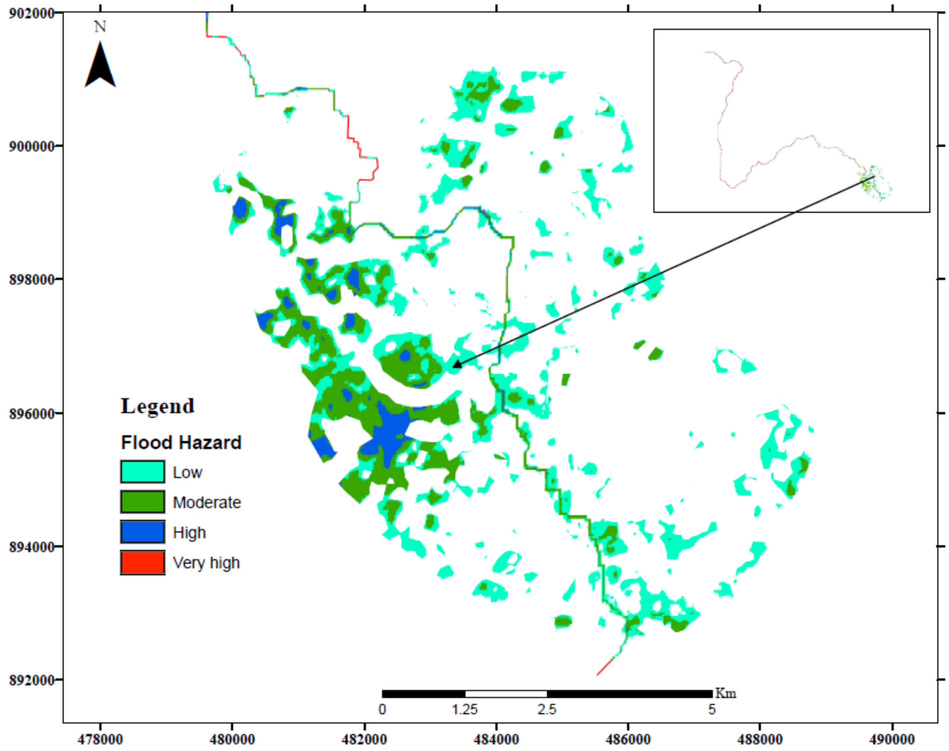


Figure D1 Flood hazard map for 2 year return period

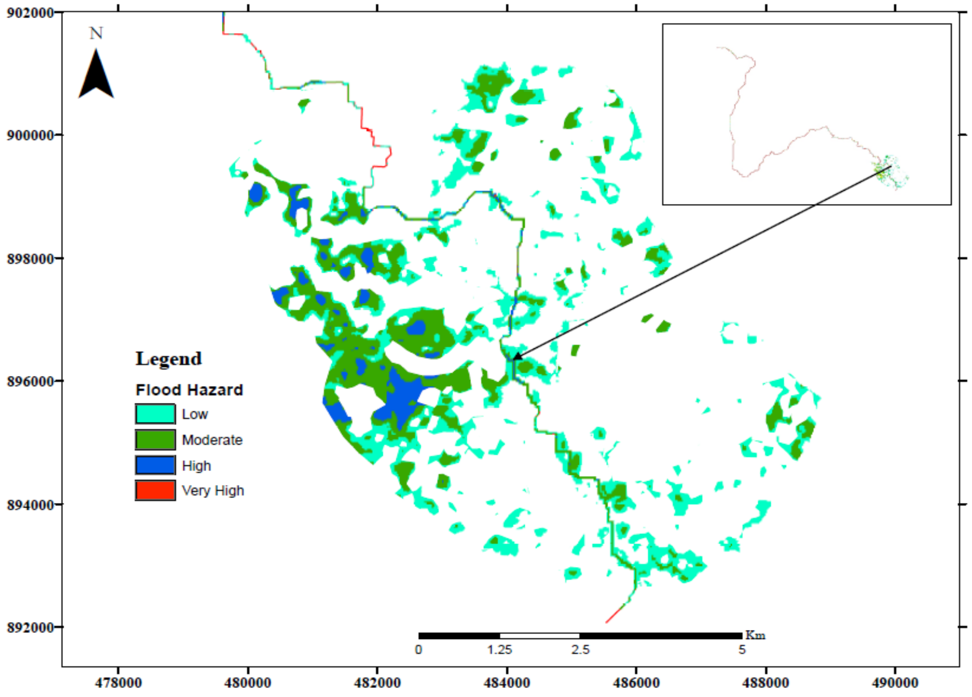


Figure D2 Flood hazard map for 5 year return period

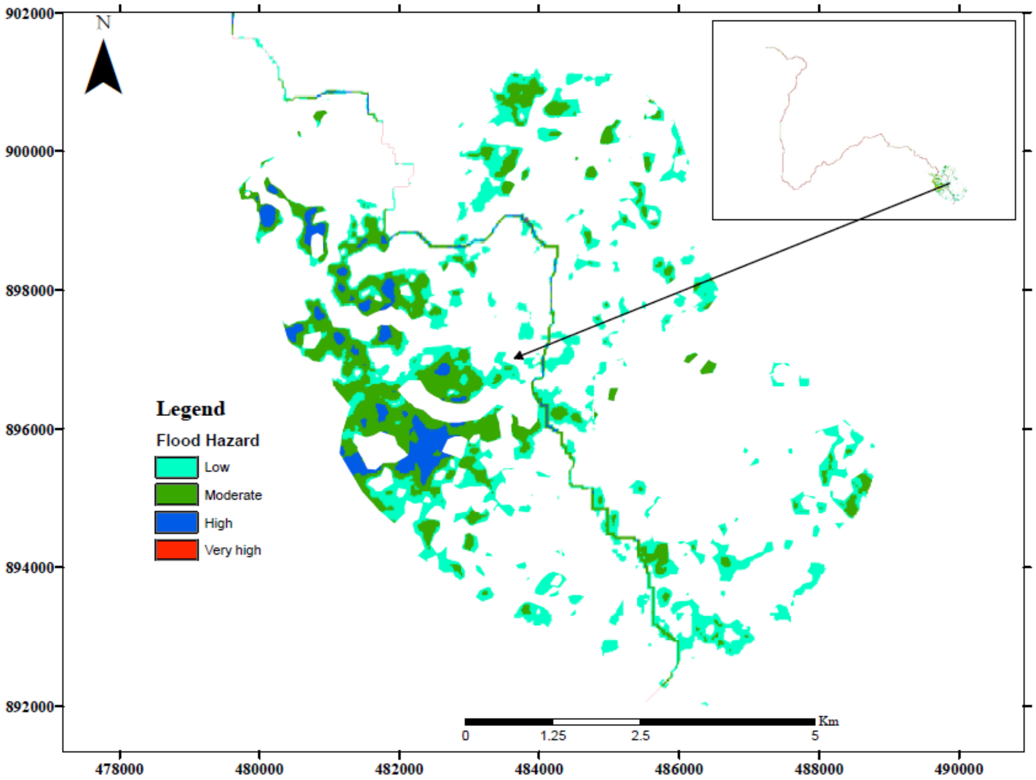


Figure D3 Flood hazard map for 10 year return period

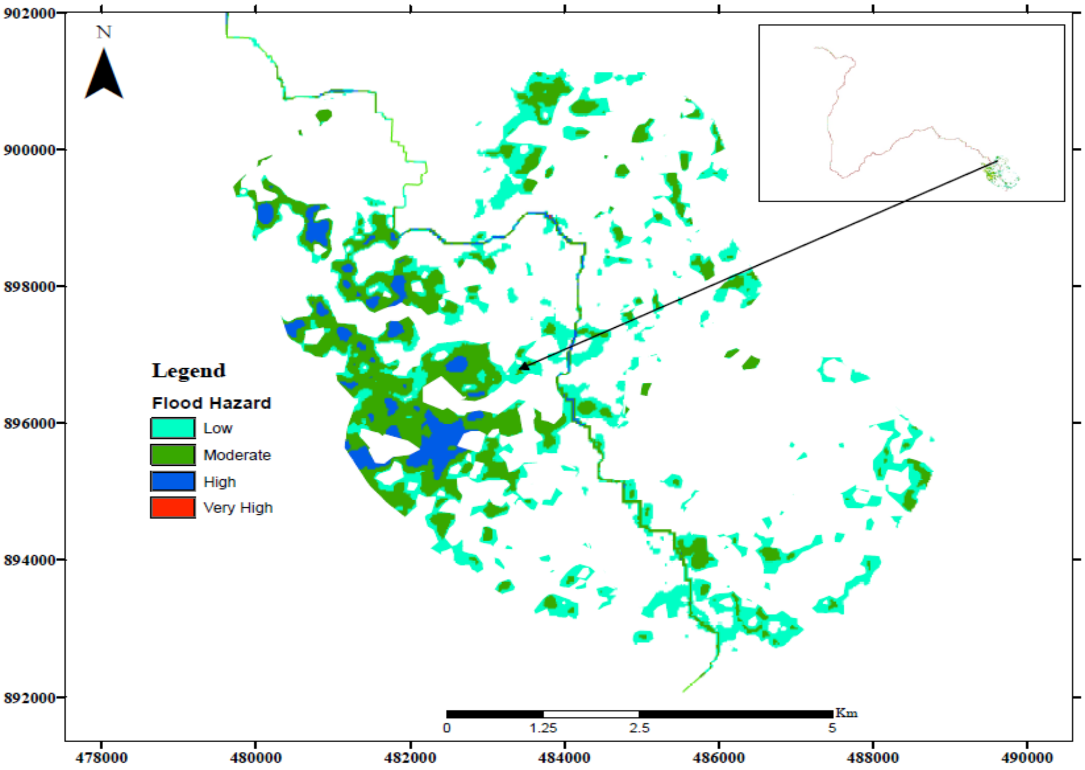


Figure D4 Flood hazard map for 20 year return period

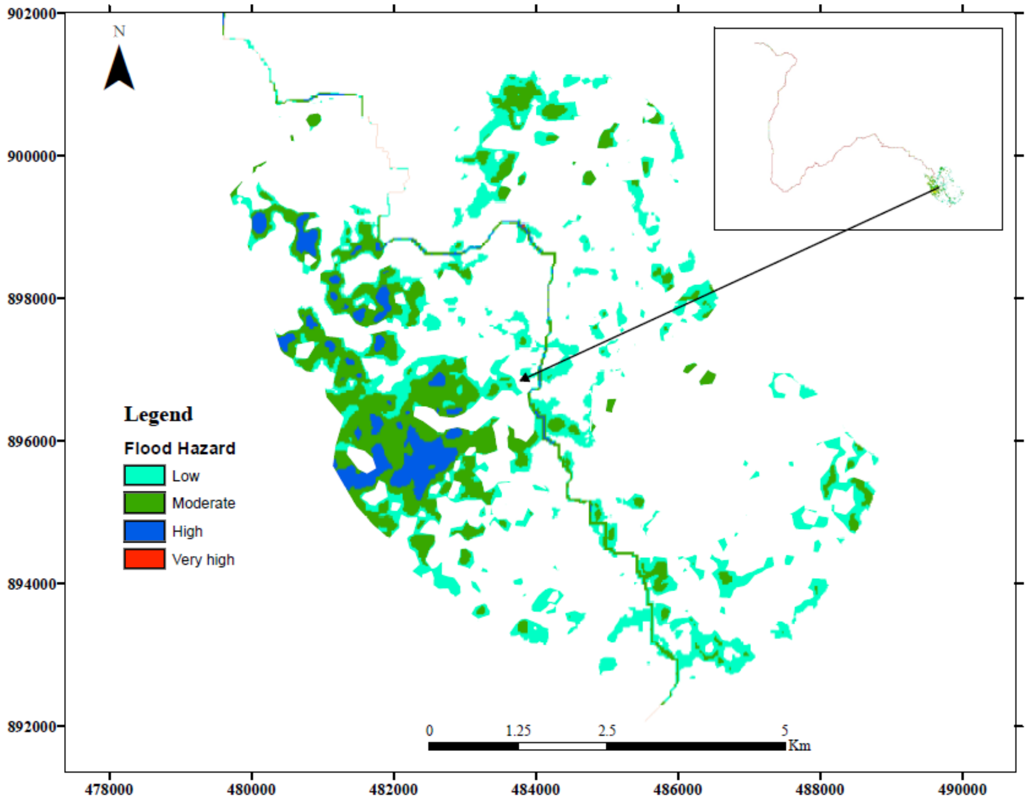


Figure D5 Flood hazard map for 25 year return period

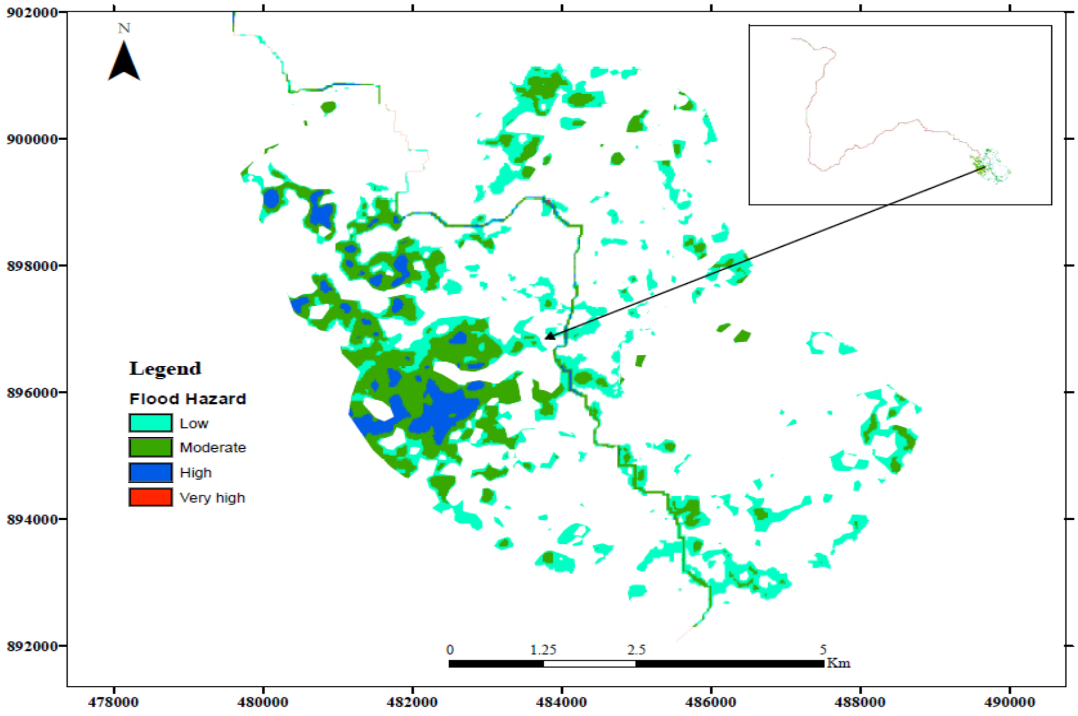


Figure D6 Flood hazard map for 50 year return period

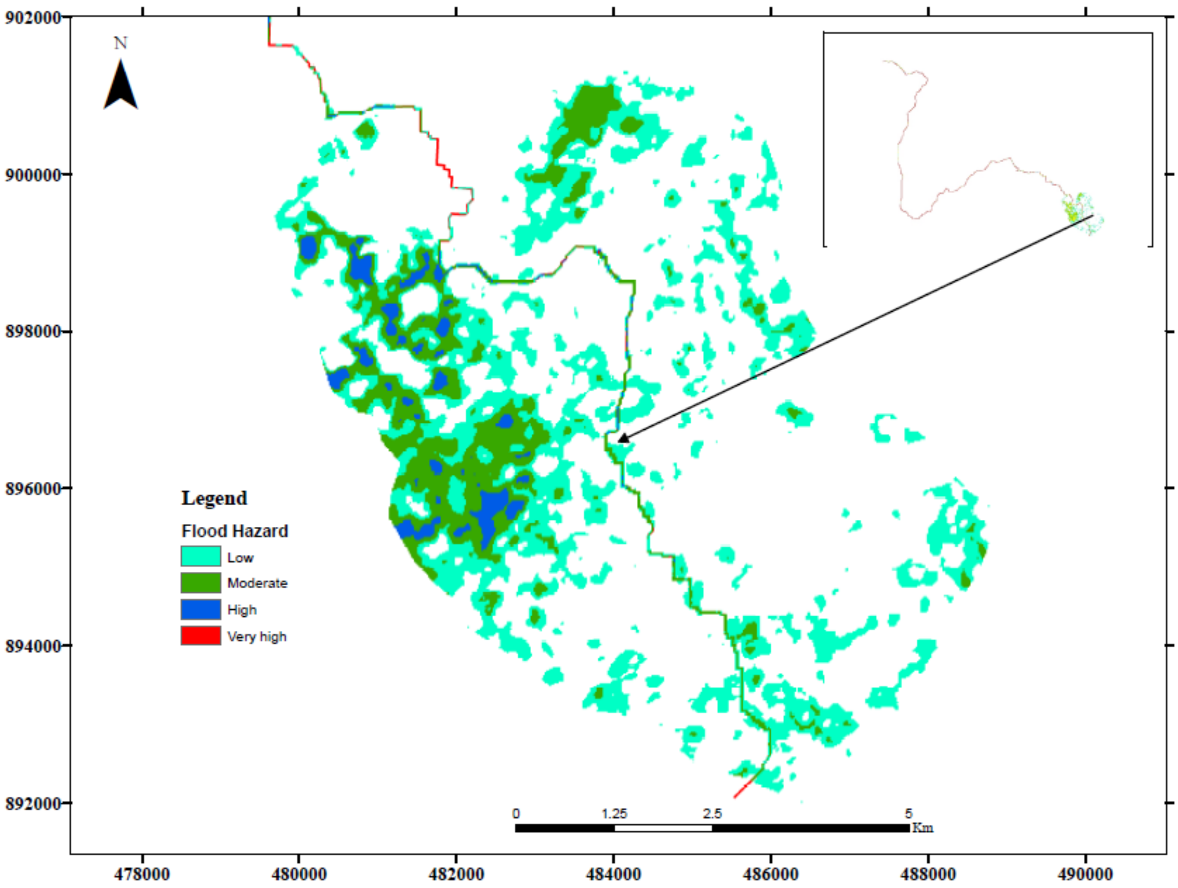


Figure D7 Flood hazard map for 100 year return period

Appendix E: HEC-FDA Model Output Graphs

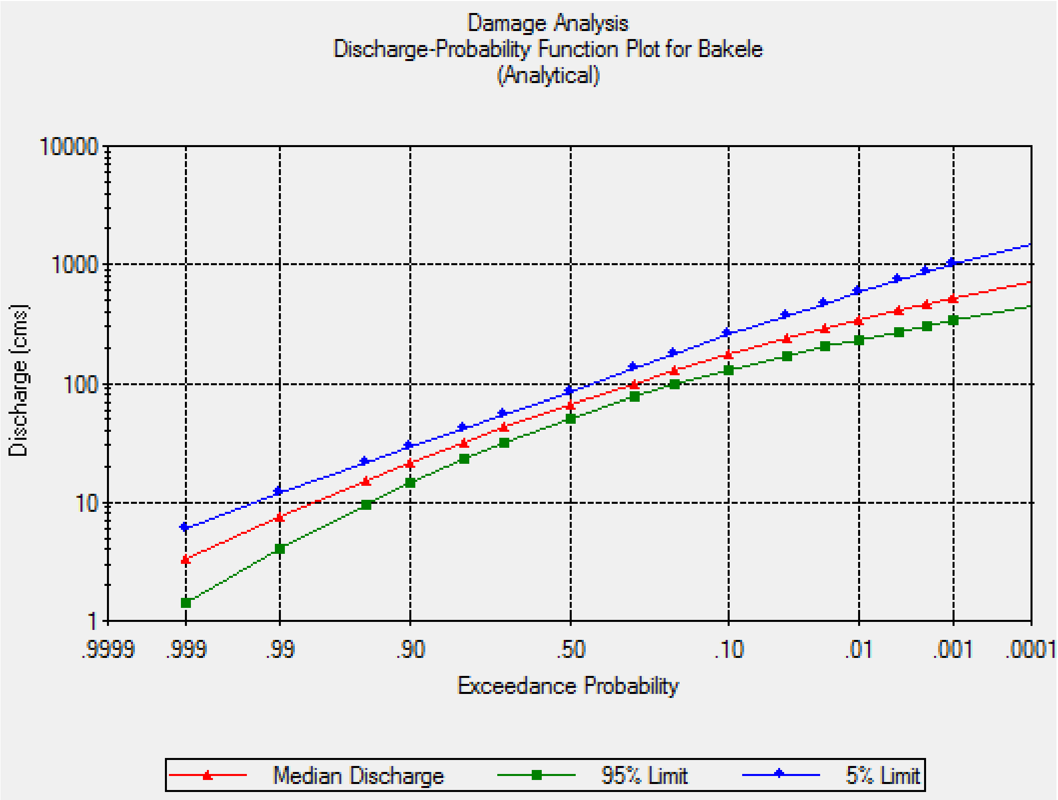
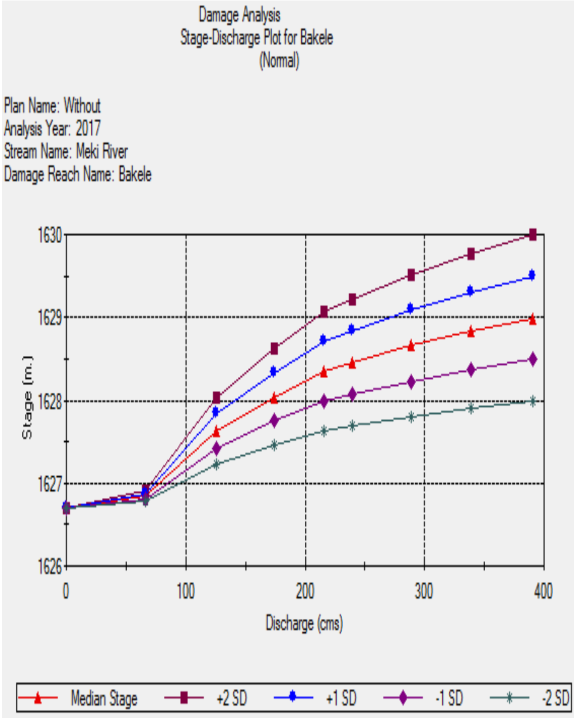
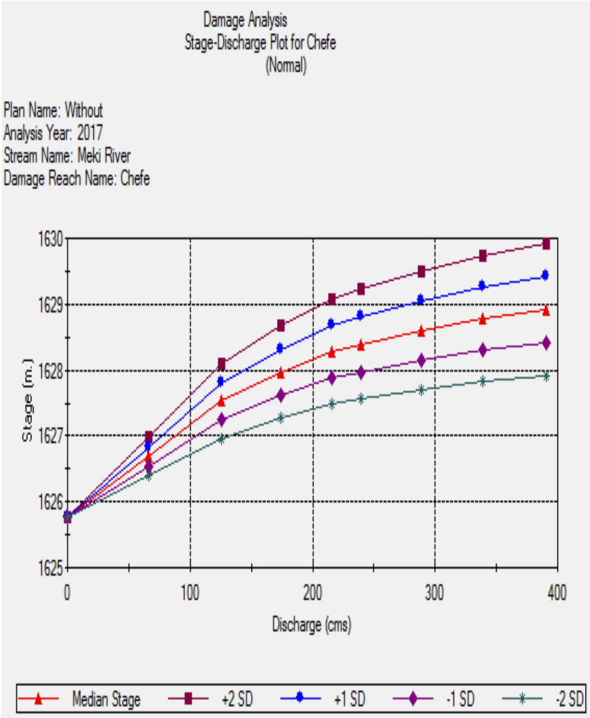


Figure E1 Exceedance - Probability function graph





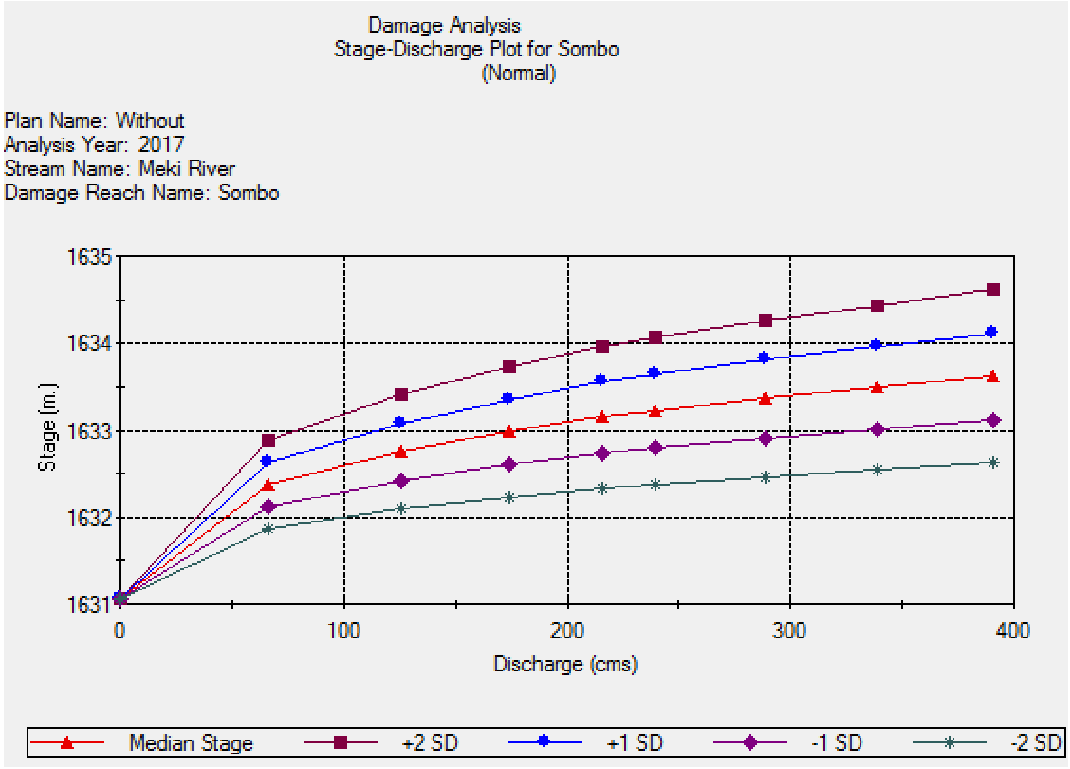


Figure E2 Stage –Discharge graph for three damage reaches

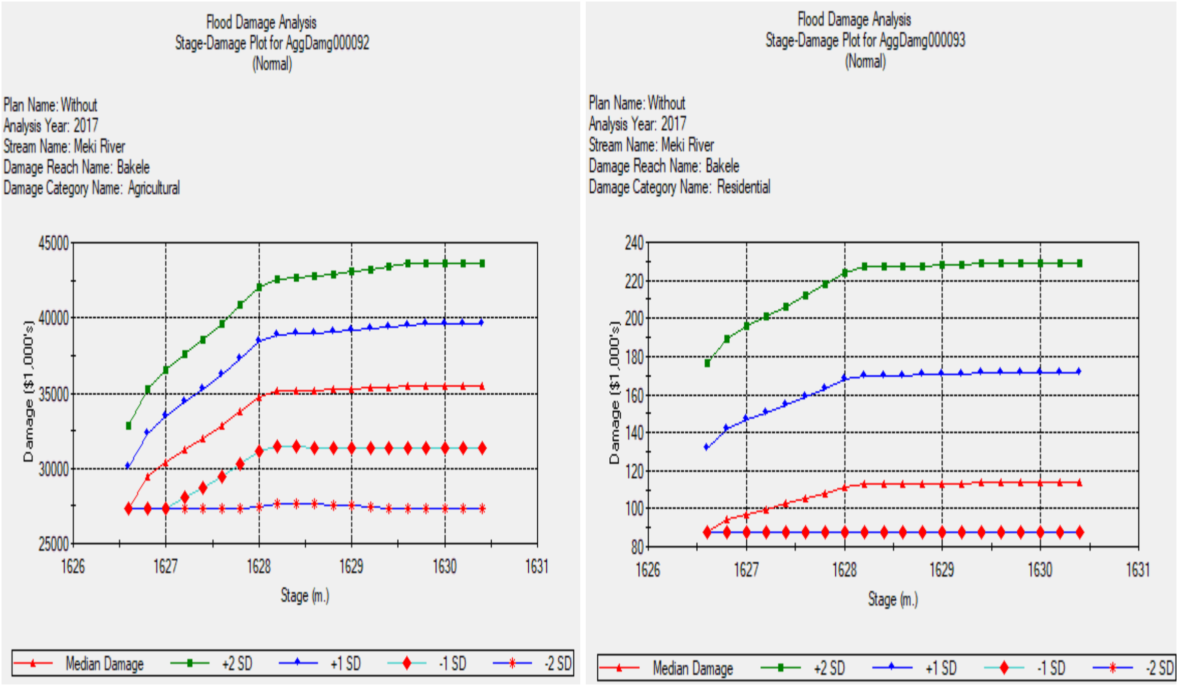


Figure E3 Stage-Damage graph for agricultural and residential damage categories

APPENDIX F: Surveyed GPS Data along the River and in Flood Plain Area

Table F1: Field surveyed GPS data along lower Meki River cross sections

So No.	X-Coordinate (m)	Y-Coordinate (m)	Elevation (m)	Stations
1	480338	900776	1651	Meki Main Bridge
2	480380	900786	1654	
3	480381	900775	1640	
4	480341	900763	1651	
5	481754	899061	1645	Sombo
6	481800	899040	1644	
7	481821	899037	1645	
8	481810	898445	1644	Roba Masa
9	481822	898598	1643	
10	481854	898720	1644	
11	482562	898483	1646	Melka Gerbi
12	482586	898523	1645	
13	482592	898562	1647	
14	484102	897802	1644	Oda Tuta
15	484187	897807	1644	
16	483986	897222	1643	Oda Jari
17	484109	897230	1642	
18	484196	897243	1643	
19	484402	895358	1647	Burka Chefe
20	484438	895337	1646	
21	484464	895302	1643	
22	484492	895275	1646	
23	485410	894008	1639	Horofe
24	485533	894028	1638	
25	485637	894047	1639	
26	485796	892663	1637	Masa Feteno
27	485959	892747	1635	
28	486050	892790	1636	
29	486216	892885	1636	

Table F2: Field surveyed GPS data of flood affected agricultural land and villages in the 2016

So No.	X-Coordinate (m)	Y-Coordinate (m)	Elevation (m)	Remarks
1	480017	899097	1640	Sombo farm land
2	480050	898852	1639	
3	480222	898872	1637	
4	480215	899136	1641	
5	480659	898144	1635	Bakele farm land
6	481631	899123	1642	
7	482048	898336	1640	
8	481398	897809	1634	
9	481271	896243	1633	
10	482546	897444	1630	
11	483171	896566	1639	
12	481435	895021	1636	
13	483572	893169	1637	Weldiya farm land
14	483929	893460	1638	
15	484127	893050	1636	
16	483195	900053	1634	Keraru farm land
17	483605	901025	1636	
18	484412	900609	1635	
19	483625	899835	1633	
20	486595	893704	1636	Kelina farm land
21	486660	894224	1635	
22	486871	894012	1634	
23	481806	895939	1637	Bakele villages
24	482752	896847	1636	
25	484126	893282	1634	Mekdal villages
26	486613	897568	1637	Kelina villages
27	483311	900214	1638	Keraru villages

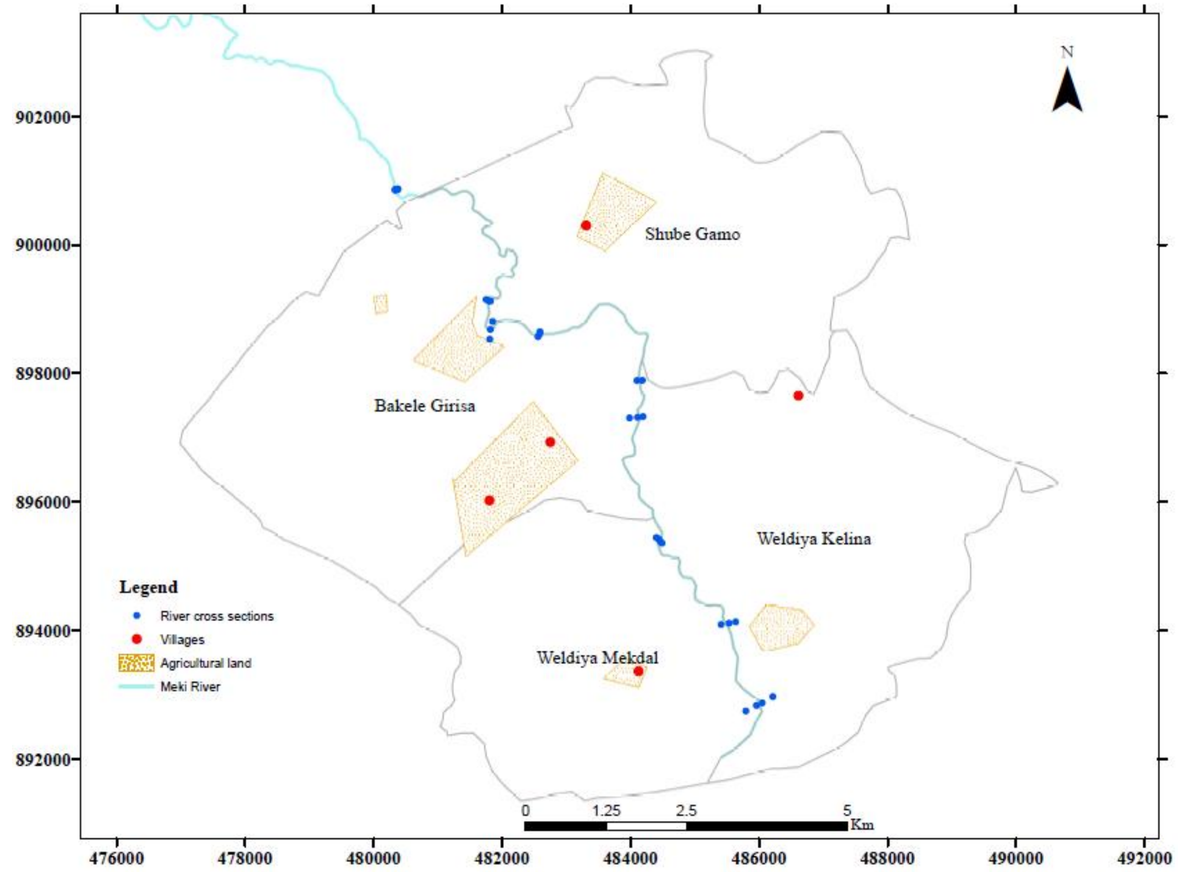


Figure F1 Maps of GPS surveyed data along Meki River and in flood plain area

APPENDIX G: Photo of Meki River channel for determination roughness coefficient

Figure G1 Photo of main river channel at flood plain

Figure G2 Photo of main river channel at intermediate reach

Figure G3 Photo of left channel at the intermediate reach