FLOOD MAPPING ON GREAT AKAKI RIVER IN ADDIS ABABA,

AKAKI KALITY SUB-CITY

MSc. THESIS

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HAWASSA UNIVERSITY, INSTITUTE OF TECHNOLOGY

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FLOOD MAPPING ON GREAT AKAKI RIVER IN ADDIS ABABA, AKAKI KALITY SUB-CITY

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ADVISORS' APPROVAL

This is to certify that the thesis entitled "FLOOD MAPPING ON GREAT AKAKI RIVER IN ADDIS ABABA, AKAKI KALITY SUB-CITY" as MSc. thesis in Hydraulic Engineering submitted to department of HYDRAULIC AND WATER RESOURCES ENGINEERING and has been carried out by BERHANU BALTA ID. No PGHY 005/10 under our supervision. Therefore, I recommend that the student has fulfilled the requirements and hence hereby can submit the MSc. THESIS to the department.

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DEPARTMENT OF HYDRAULIC AND WATER RESOURCES ENGINEERING

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EXAMINERS' APPROVAL

We, the undersigned, members of the Board of Examiners of MSc. thesis defense by BERHANU BALTA have read and evaluated his MSc thesis entitled "FLOOD MAPPING ON GREAT AKAKI RIVER IN ADDIS ABABA, AKAKI KALITY SUB CITY", and examined the candidate. This is, therefore, to certify that the MSc thesis has been accepted.

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LIST OF ABBREVIATIONS AND ACRONYMS

1D	1 dimensional
2D	2 dimensional
Arc GIS	Aeronautical Reconnaissance Coverage Geographic Information System
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
DTM	Digital Terrain Model
EV1	Extreme Value Type I
EV2	Extreme Value Type II
EV3	Extreme Value Type III
FEMA	Federal Emergency Management Agency
FLO-2D	Two-dimensional flood routing model
GIS	Geographical Information System
HEC-DSS	Hydrologic Engineers Center - Data storage system
HEC-RAS	Hydrologic Engineers Center - River Analysis system
ISDR	International Strategy for Disaster Reduction
LN (2P)	Two-Parameter Log-normal Distribution
LN (3P)	Three-Parameter Log-normal Distribution
POT	Peak Over Threshold
TIN	Triangular Irregular Network
TUFLOW	Two-dimensional Unsteady Flow
USACE	United State Army Corps of Engineers
USGS	United State Geological survey
WETSPro.	Water Engineering Time Series Processing tool

LIST OF NOMENCLATURES AND SYMBOLS

ha	hectare
m	meter
m^3	cubic meter
m^3/s	meter cube per second
mm	millimeter
m/s	meter per second
km	kilometer
m^2	square meter
km^3	cubic kilometer

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DECLARATION

I, the undersigned person, declare that this thesis is my original work and that all source of materials used for thesis haven been duly acknowledged.

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Signature _________________

Place Hawassa University

Date of submission _________________

ABSTRACT

*In recent years, the patterns of flood across all continents have been changing and becoming more frequent, intense and leading the people to face risks. Therefore, the risk should be investigated and quantified properly. The objective of this thesis was to develop flood inundation maps of Great Akaki river in Addis Ababa, Akaki Kality sub-city. Streamflow, digital Elevation model (12.5*12.5 m) resolution and land use data were used as an input for the RAS mapper in HECRAS model. The 2D-HECRAS and ArcGIS models were used for mapping the flood extent, depth and velocity for various return periods. The Mann-Whitney and Wald-Wolfowitz statistical tests were used to hydrological data test. The basic assumption in statistical flood frequency analysis for its homogeneity, independency and stationarity of the time series at 5% significance level. The Easy fit 5.0 software was used to fit and identify the parent probability distribution for the streamflow data. The frequency analysis result depicts that Log-Normal probability distribution with 3 parameters best fitted the flood time series. The estimated quintiles for 2, 5, 10, 25, 50 and 100 years return periods were found to be 210.29, 333.04, 453.16, 626.19, 769.75, and 925.41* m^3/s *respectively. The 2D-HECRAS model output indicated that about 86,123,156,228,285, and 350 ha land has been inundated for an event of 2, 5, 10, 25, 50 and 100 years of return period respectively. The 100 years flood magnitude inundated about 78, 272 and 34 ha of irrigated command area, swamp area and population settlement respectively. Flood risk map was developed based on hazard and vulnerability indicators. A preliminary alignment of structural flood protection dike was identified with length of 1.5km at downstream and 0.5 km at upstream of bridge which would make 95% of the settlement area on the left bank safe. The study has shown that the middle and lower part the study area is more inundated than upper parts. Therefore, the affected areas were whether to be free of infrastructure development, investment and residence of people or construct flood protection structure in order to avoid the risk of flooding in the area especially closer to the Great Akaki River.*

Key words: *HEC-RAS, Flood Inundation, Quintile estimation, ArcGIS, and Great Akaki River.*

1. INTRODUCTION

1.1. Background

Most of the living things are affected by either too less or too much of water compared to the normal requirement. The scarcity of water situation leads to drought and the surplus of water to flood. Both are equally alarming. Flood phenomenon is considered as one of the worst hazards in terms of magnitude, occurrence, geographical spread, loss of life and property, displacement of people and socio-economic activities. (Makakov et al.2017)

The study of the cause and effect of flooding has begun since flooding has become a problem to society when people and their properties become affected. Flooding is a temporary layering of water on land that may be caused by dam breach or high rainfall. Flood hazards are the most common and harsh of all naturally occurring disasters. The major causes of flood disasters include the combining effect of land inundation from heavy rainfall, climate change, and blockage of drainages with refuse, construction of buildings across drainages, inadequate drainage networks, and population increase in urban areas. These factors independently do not cause floods but the combination of several of these usually cause flood disaster. All over the world, it is acknowledged that floods are the most serious natural hazards and destroy lives and property (Farish, 2017). Structural and non-structural measures are required to mitigate these disaster situations (Nquot & Kulatunga, 2014).

Among the important headwaters of the Awash is the Akaki River, which flows through the city of Addis Ababa. The river consists of two main branches, the confluence of which was the Aba-Samuel reservoir. The western branch of the river, the Little Akaki, rises northwest of Addis Ababa on the slopes of Wechacha Mountain and flows for 40 km before it reaches the reservoir. The eastern branch of the river, the Great Akaki, rises northeast of Addis Ababa and flows into Aba-Samuel Reservoir after 53 km. The important tributaries of the Great Akaki include Ginfile, Kebena, Kechene, Kurtume, Bantyketu and Bulbula. Combinations of all tributaries to Great Akaki river is lead to flooding in the area (Feyissa et al., 2018).

Flood damages can be reduced by applying hydraulic modeling to map flooded areas and implementing the remedial measures based on the model outputs. Flooding phenomena is becoming a serious issue in most places of Ethiopian urban center due to increase in imperviousness land. The recent floods on Aug 23,2018 out of Great Akaki river in Akaki Kality sub-city is a good example whereby the community were affected. The magnitude, depth and areal extent of such floods have to be quantified and preparation of flood hazard maps is vital from the perspective of safeguarding the community, economic viability of infrastructures and environmental sustainability. Flood hazard maps can be used for construction and development of flood overstressed areas. The application of hydraulic modeling for rapid flood mapping and monitoring is a significant tool of information for decision makers. Flood and flood damage are possible to monitor using HEC-RAS and GIS Software for emergency response and efficient relief work. DEMs are the major basis to generate land topography. It gives elevation information that is useful for various environmental purposes including hydrologic modeling and flood management planning. The use of DEM has extensive applications in geomorphologic and hydrological purposes. It allows the extraction of topographic features of the earth surface and displays all-natural features for both the vertical and horizontal resolutions. Using the elevation of the area, flow accumulation analysis was carried out to discover the natural drainage pattern of the area and the terrain representation and flow direction of water that enters into an area can be obtained from DEM. It was used to create data on flow direction, flow accumulation, stream segmentation in Arc GIS. Physical factors of the sub-basins were extracted from DEM. It was used to create flood inundation map (Farish, 2017). All these inputs were used and put it into HEC-RAS 2D software to produce flood hazard maps for various return periods on Great Akaki river, Kality sub city in order.

1.2. Statement Problem

Many countries worldwide, whether in Europe, America, Asia, Oceania, Australia or in Africa, are experiencing heavy rains and river overflows, causing unexpected floods which destroy entirely or partly some localities in all over the world. Floods are among the most recurring and devastating natural hazards, impacting human lives and causing severe economic damage throughout the world (Sadiq et al, 2011, p 85).

Flooding, as a natural phenomenon, has been occurred in many parts of Ethiopia. “By the end of August 2006, at least 75 woredas in eight regions had been affected by the flood according to report by Ethiopian government disaster prevention and preparedness agency. During that time more than 500,000 people were vulnerable and about 200,000 people had been affected, with 639 deaths. Thousands of live stocks were killed, 228 tons of harvested crops were washed away, 147 tons of export coffee beans were lost (and machinery ruined), 42,229 ha of crop land were inundated.

Flooding is prevalent in Addis Ababa because of the topography with steep mountains and low-lying flood plains and the heavy rainfall that occurs in July and August. The flood risk is exacerbated by uphill deforestation, urban land use change with increased impervious surface cover and the scarcity and clogging of formal drainage systems in the city (Nigusse & Adhanom, 2019). Stormwater flash floods and river flooding are the most predominant types of flooding, but flooding also occurs when excess water is released from reservoirs into the city’s rivers. Encroachment on flood plains, channelization of rivers, sedimentation, and the leveling of slopes alongside watercourses continuously increase the risk of local and downstream flooding and erosion. Residents of informal settlements inhabit river banks and steep slopes, putting themselves at risk from river flooding and landslides. With population growth, the risk of property loss, health impacts and deaths resulting from flooding will increase if urban development and faulty construction methods continue on marginal lands (Backhaus et al.,2013).

Recently on the 23 August 2018, a major flood swept through Addis Ababa, Akaki Kality sub city, resulting in 4 cattle death and significant damage to the flood defenses, public infrastructure, housing and livelihoods. Although this was the most severe flood for many years, flash floods occur in the Addis Ababa that pass through the Akaki Kality sub city every year, often causing loss of life and damage to property and infrastructure. Even though flooding is frequently observed in the Akaki floodplain, the magnitude, its areal extent of inundation and depth of water have not yet explored. Besides, the flood management strategy has not done to minimize loss of life, property and environment. So, this study has explored the flood inundation maps of Great Akaki river in Addis Ababa using advanced new technology on flood modeling such as the 2D hydraulic modeling (2D HEC-RAS) and ArcGIS software with 12.5m*12.5m DEM for topographical representation of floodplain.

Figure 1.1: Images of Great Akaki river flooding in Addis Ababa in Akaki Kality sub city(https://ethio.news/wp-content/uploads/2018/08/Untitled-design-22768x402.png). (Accessed on 17 Dec., 2018).

1.3. Objective

1.3.1. General Objective

The main objective of this study was to develop flood inundation maps of Great Akaki river in Addis Ababa Akaki Kality sub city.

1.3.2.Specific Objectives

- To select Peak over threshold (POT) values from annual maximum values using WETSPro. software
- To identify parent probability distribution which fits the flood time series generated based on Peak over threshold (POT)
- To generate inflow run off hydrographs for different return periods for 2D flood area
- To estimate the flood water depth, velocity, WSL, and flood inundation area for various return periods
- To identify potential risks of flooding and propose possible mitigation measures and preliminary alignment of protection work to reduce risk

1.4. Research Questions

- How to select POT values from annual maximum values?
- What is best fitted probability distribution to analysis river flow data
- How to generate inflow run off hydrographs for various return periods?
- How big is the inundated flood area due to the various return period flood magnitude?
- How to identify potential risks of flooding?
- What are possible mitigation measures to flood risks?

1.5. Scope of The Study

The study aimed at assessing flood mapping on Great Akaki river in Addis Ababa Akaki Kality sub city. This was mainly because of the flood hazards highly occurred in Addis Ababa on Akaki Kality sub city. In this study the inflow runoff hydrograph for different return periods was determined using Log-normal (3p) distribution, inundation mapping has been prepared on RAS Mapper, which is GIS tool of the HEC-RAS 5.0.5 2D and on ARC GIS 10.3. Appropriate alignment of flood protection works was proposed.

1.6. Significance of The Study

The study of flood mapping using HEC RAS 2D software helps to reduce flood risks by taking nonstructural and structural flood protection measures on flood hazard area.

The study will be contributing the following issues. These are: -

- Provide Flood map that give valuable information to Area officials, emergency managers, and local residents for planning an emergency response.
- Identify flood zones and to put into consideration while investing huge projects on the area.
- Identify potential risks of flooding
- Propose possible mitigation measures and alignment of protection work to reduce flood risks

2. LITERATURE REVIEW

2.1. Flooding

Flooding is the most common natural disasters around the world in terms of lost lives and damage to properties and infrastructures (Javadnejad, 2017). Dilley et al., (2005) estimated that more than one-third of the world's land area is flood prone affecting 35 percent of the world's population.

During the past 20 years, worldwide natural disasters have resulted in the death of at least 3 million people, while also adversely affecting nearly 800 million people. It has been determined that 30 out of 40 natural disasters occur in Iran, where flooding has been highlighted as the most damaging one(Safaripour et al, 2012). In world 2.3 billion people were affected by floods between 1995-2015 (Serra-llobet, 2018).

In Africa, floods of different kinds are one of the most common type of disastrous events, and they account for the biggest losses inflicted by natural disasters. The UN Office for the Coordination of Humanitarian Affairs (OCHA) recently stated that, compared with previous years, 2010 has seen the largest number of people affected and dying from flooding. This is consistent with the dramatic rise in flood events that have battered the world, with West Africa being a case in point (Sadiq, 2011, p 85).

According to the Ethiopian Government Disaster Prevention and Preparedness Agency (DPPA)(2006), the leading government agency in disaster management, more than 500,000 people are vulnerable, and more than 200,000 people have been affected, with 639 people deaths (364 people in South Omo, 256 people in Dire Dawa, and 19 people in other parts of the country). Thousands of livestock were killed, 228 tons of harvest were washed away, 147 tons of export coffee beans were lost (and machinery ruined), and 42,229 hectares of crops were inundated.

In Ethiopia, rainfall attributed to the Kiremt rains, which began on 8 June to 15 August 2017 has led to extensive flooding. The Ambeira zone in Afar region, and special zones surrounding Addis Ababa (the capital), Jima, South-east Shewa, and South-west Shewa in the Oromia region have been worst affected by the rains and flooding. It is estimated that a total of 18,628 households (HHs) (93,140 people) have been affected, of which 7,270 HHs (36,350 people) have been displaced(Mdret, 2018).

2.2. Flood Frequency Analysis

According to Chow et al (1988), hydrologic systems are sometimes impacted by extreme events, such as severe storms, floods, and droughts. The magnitude of an extreme event is inversely related to its frequency of occurrence, very severe events occurring less frequently than events that are more moderate. Estimating flood magnitudes and their frequencies need knowledge related to distributions of flood flow series. Probability for future events can be predicted by fitting past observations to selected probability distributions. The primary objective is to relate the magnitude of these extreme events to their frequency of occurrence through the use of probability distributions (Chow et al, 1998). In this case, flood frequency analysis is the most suitable method in order to determine a robust probability distribution that fits to stream flow data at a certain location of interest. The most widely used methods in predicting the flood magnitudes are at-site and regional flood frequency analyses (Zahrahtul, 2012). When the stream flow selected for flood frequency analysis, there are two method of compiling flood peak data, annual maximum and partial duration serious. Annual maximum serious takes the single maximum peak discharge in each year of record so that the number of data values equals the record length in years whereas partial duration takes all the peak over a selected level of discharge, a threshold (Raghunath, 2000). However, the partial duration is limited by the fact the observation may be dependent which violets the assumption of independence of flood peak for statistical analysis (Cunnane, 1989).

2.3. Probability Distributions of Hydrologic Variables

According to Chow et al (1988), there are a number of distributions in hydrology used to analyze the probability of occurrence of a stream flow.

2.3.1. Log-Pearson type III distribution

The Log-Person Type III distribution is a member of the family of Pearson III distribution, and is also referred to as the Gamma distribution. Log-Person Type III distribution is derived by change of variable on the logarithms of this variable. This is the current required method to be used for frequency analysis in the United State. The location of the bound ϵ in the log-Pearson Type III distribution depends on the skewness of the data. If the data are positively skewed, then $\log X \geq \epsilon$ and ϵ is a lower bound, while if the data are negatively skewed, $\log X \leq \epsilon$ and ϵ is an upper bound. The log transformation reduces the skewness of the transformed data and may produce transformed data that are negatively skewed from original data that are positively skewed. In that case, the application of the log- Pearson Type III, it arises a problem that is the tendency to give low upper bounds on the magnitude of the data (Cunuane, 1989).

2.3.2. Extreme value distribution

The General Extreme Value is the family of continuous probability distribution that combines the Gumbel (EV1), Weibull (EV2) and Frechet distribution (EV3). GEV makes use of three parameters; location, scale and shape. The location parameter describes the shift of distribution in a given direction on the horizontal axis. The scale parameters describe how spread out the distribution is and defines where the bulk of the distribution lies, as the scale parameter increase, the distribution will become spread out. The third parameter in the GEV family is the shape parameter which strictly affect the shape of the distribution and governs the tail of each distribution. The shape parameter is derived from skewness, as it represents where the majority of the data lies. Which creates the tail of the distribution when shape parameter (K) = 0, this is the EV1distribution, for which the EV2 is when K> 0, and for K<0 the distribution is EV3. The Gumbel (EV1) and Weibull (EV2) distribution are used for extreme (maxima and minima values) respectively of hydrological variables. The EV1 distribution is used in the frequency analysis of floods and EV2 distribution in the analysis of low flow values observed in a river (Cunuane, 1989). Gumbel extreme value distribution aims to build the relationship between the probability of the occurrence of a certain event, its return period and its magnitude (El-Naqa and Zeid, 1993).

2.3.3. Exponential distribution

Some sequences of hydrologic events, such as the occurrence of precipitation, may be considered Poisson processes, in which events occur instantaneously and independently on a time horizon, or along a line. The time between such events, or inter arrival time, is described by the exponential distribution whose parameter λ is the mean rate of occurrence of the events. The exponential distribution is used to describe the inter arrival times of random shocks to hydrologic systems, such as slugs of polluted runoff entering streams as rainfall washes the pollutants off the land surface. The advantage of the exponential distribution is that it is easy to estimate **λ** from observed data and the exponential distribution lends itself well to theoretical studies, such as a probability model for the linear reservoir (**λ** = l/k, where k is the storage constant in the linear reservoir). Its disadvantage is that it requires the occurrence of each event to be completely independent of its neighbors, which may not be a valid assumption for the process under study for example, the arrival of a front may generate many showers of rain and this has led investigators to study various forms of compound Poisson processes, in which λ is considered a random variable instead of a constant (Kavvas at al., 1981).

2.3.4. Gamma distribution

The time taken for a number ß of events to occur in a Poisson process is described by the gamma distribution, which is the distribution of a sum of ß independent and identical exponentially distributed random variables. The gamma distribution has a smoothly varying form like the typical probability density function and is useful for describing skewed hydrologic variables without the need for log transformation. It has been applied to describe the distribution of depth of precipitation in storms.

According to Abramowitz & Irene (1970), the two-parameter gamma distribution (parameters ß and υ) has a lower bound at zero, which is a disadvantage for application to hydrologic variables that have a lower bound larger than zero.

In determining correct distributions, the concern is to find the one that would be capable of describing the recorded sample and more importantly, extrapolating correctly to large return periods. Many distribution functions forms have been proposed for describing flood occurrences. However, previous studies have reported in their literature that there is no „universal" distribution function that is best representing flood trends at all steam flow locations of interest (Zahrahtul,2012).

2.3.5. Normal distribution

The normal distribution is used in frequency analysis for fitting empirical distributions to hydrological data, and in simulation of data. As many statistical parameters are approximately normally distributed, the normal distribution is often used for statistical inferences. An early application of the normal distribution to hydrologic variables was by(Adeboye & Alatise, 2007),who introduced the normal probability paper for analysis of hydrologic data. Markovic, (1965) found that the normal distribution could be used to fit the distribution of annual rainfall and runoff data. Haghighat, (2014) demonstrated that, in the absence of information about the distribution of floods and economic losses associated with the design of flood reduction measures, the use of the normal distribution is better than other distributions such as extreme value, log-normal or Weibull.

2.3.6. Three-Parameter Log-normal (LN (3P)) Distribution

The Log-normal (3p) distribution is a member of the family of Normal distribution. It is the most widely used distribution function for determination of flood. It also a standard method to compute peak flood in United State (Busby, 2017).

According to Yilma (2009) in large-scale studies, many countries adopted standard methods that can be used by scholars or agencies in order to produce uniformity in conducting flood frequency analysis. For instance, United State Water Resource Council recommends the three-parameter lognormal distribution where as in similar study. United Kingdom and Ireland proposed the GEV distribution as a standard. The Person III and Log Person III distribution where generally recommended in Germany.

2.4. Model Selection

Selecting the best and appropriate model is an essential part in any research work. There are various criteria for choosing the most suitable model. According to (Cunderlik & Simonovic, 2007), the choice depends mainly on the requirement and needs of the research or project under interest. (Cunderlik & Simonovic, 2007) were put the following as criteria: the required output of the model, Availability of input data, Prices and availability of the model and the model structure. Some of the factors and criteria involved in the selection of model for this study includes: free, simple to use, the importance of the required model output, availability and quality of data, the hydraulic and hydro geological characteristics of the basin, the availability and size of computers for model development and operation. 2D Flood Modeling is selected due to no need to predefine the flow routes, Easy to setup, can be more accurate, Velocity variation on flood plain, Flood maps and depth grids at direct output. In this research the 2D hydraulic model (HEC-RAS) with ArcGIS was used. The model has the capacity to simulate plain areas with high accuracy.

2.5. Software's used for the study

2.5.1. Geographic Information System

Geographic information system (GIS) is a tool that can be used in every step of the flood risk assessments for visualization, data management and modelling(Yusoff et al, 2008)

According Somaiyeh et al (2015) GIS is a system for capturing, storing, checking, identifying, manipulating analysis and displaying data, which are spatially referenced to the earth. Using GIS to the large extent facilitate in providing accurate information as it can handle the digital data along with their associated attribute information on physical and environmental aspects. The capability of applying GIS to the flood simulation assists in analyzing the flood level or extents spatially. It helps in visualizing flood simulation in an interactive setting, where the spatial impact of various scenarios can be viewed along with the location of critical facilities and thus to assess the regions vulnerability towards a flood event efficiently (Sudha, 2012).

2.5.2. Water Engineering Time Series Processing tool (WETSPro.)

The WETSPRO – tool is available in two versions: a zip file with MATLAB p-files to run the tool in MATLAB (MathWorks, 2012a) and an executable file that can be run on computers without the MATLAB software. Users without a MATLAB license can use the executable file to run the WETSPRO – tool. However, to make this possible version 8.1 (or higher) of the MATLAB Compiler Runtime (MCR) needs to be installed. It is used to select POT values (Division, 2014).

2.5.2.1. POT – selection

In water engineering applications, extremes are often analyzed for time series. Those extremes have to be extracted first as peak-over-threshold values from the time series in a preliminary study. They can take the form of instantaneous or aggregated values (averaged values in a fixed time duration) or cumulative values in events (e.g. storm volumes). As the extremes in an extreme value analysis have to be independent, an 'independency criterion' has to be used in the extraction. Two methods to select (nearly) independent discharge peaks (or any other quantity) out of a time series are provided in the WETSPRO tool.
The selection of POT-values out of a time series is done in the second tab of the WETSPRO–tool, called "POT selection". The POT values will be selected from the time series provided in the first tab. If the user wants to extract POT-values from a different time series, he must load this new time series in the first tab (Division, 2014).

2.5.3. Easy fit software

Easy fit is a data analysis and simulation software, which enables us to fit and simulate statistical distribution with sample data, choose the best model and use the obtained result of analysis to take better decisions. The software can function as a standalone window application or an add on for Excel spreadsheet. The basic idea behind the software is that the distance between data and the distribution under test is measured; and is compared to a certain threshold value. If the distance (called "test statistics") is lower than thresholds value, the distribution is considered as "good" (Hossien and Alireza, 2014). The software uses well-known goodness of fit test statistics. These are chi-square test and Kolmogorov-

Smirnov test. The chi-square test is used to determine if a sample comes from a population with specific distribution. Easy fit computes the test statistics and compare to the critical value with the chosen significant level, the test is rejected if and only if the test statistics is greater than or equal to the critical value at the chosen significance level.

2.5.4. Hydraulic Modeling (HEC-RAS)

The HEC-RAS proposed by the U.S. Army Corps of Engineers Hydrology Engineering Center has the steady flow solver, unsteady flow solver, the sediment transport calculus, as well as the water temperature simulation. In the 2D approach, there are no cross-sections, as with 1D modeling. Instead, the riverbed is defined by a network field, single grids or mesh, in which the shape can be square (cell based with regular elevation intervals) or polygonal (with irregular intervals) where each individual element has an associated elevation. The flexible mesh has an irregular representation that can be square, rectangular, triangular, or a combination of these shapes; also, the size of the shapes can vary. The Manning coefficient can be variable and applied at every element location or cell. Typical modeling software used for calculating two-dimensional flood flows includes FLO- 2D, WOLF 2D, MIKE 21, TUFLOW, SOBEK, and HEC-RAS (Changzhi et al., 2014). Model selection could be an issue when there are a lot of available numerical models. Verification and validation, handling of 2D flows, and speed are some criteria used to select one particular model (Reinaldo, 2015). Universality and usability (Changzhi et al., 2014) and modification by developers (owners) through time (FERC, 2014) are also considered in selection.

US Army Corps of Engineer’s hydrology Engineering Center have developed the hydrologic engineering center river analysis system (HEC-RAS) in 1995. It is an integrated system of software, designed for interactive use in a multitasking, multi-user network environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, and reporting facilities. It is designed to perform 1D and 2D hydraulic calculations for a full network of natural and constructed channels. The new version of HEC-RAS supports Steady and Unsteady Flow Water Surface Profile calculations, perform sediment transport simulation and perform water quality simulation (USACE, 2010). The basic computational equations for computing water surface profile for HEC RAS 2D modelling are 2D energy equation, Diffusion-Wave equation and the momentum equation (Saint-Venant Equations).

2D models avoid many of the assumptions required by their 1D counterparts and, as a result, provide a more accurate representation of complex hydraulic conditions encountered in the real world. Additionally, the high visual graphic output of 2D models makes it easier for engineers to convey their results and concepts to nontechnical stakeholders.

2.5.4.1.Benefits of 2D models:

- Fewer modeling assumptions and less user judgment yield results that are representative of actual conditions.
- Enhanced communication with stakeholders with engaging graphics, videos of flow paths, and georeferenced results.
- Accurate representation for complex conditions, including wide floodplains, sinuous channels, multiple channels, bends and confluences, bridge/roadway crossings, roadway overtopping, skewed roadway, tidal waterways, and bridge scour, among other conditions.

2.5.4.2.Current Limitations of the 2D modelling Capabilities in HEC-RAS

According to HEC-RAS 5.0.5 2D modelling user manual, the following is a list of the current limitations of the HEC-RAS 2D flow modeling software. These are items activity being worked on to improve the software, and will be available in future versions:

- More flexibility for adding internal hydraulic structures inside of a2D flow areas.
- Cannot currently perform sediment transport erosion/deposition in 2D flow areas.
- Cannot current perform water quality modeling in 2D flow areas.
- Cannot connect pump stations to 2D flow area cells.
- Cannot use the HEC-RAS bridge modeling capabilities inside of a 2D flow area. It can do culverts, weirs. and breaching by using the SA/2D Area Conn tool.

2.6. Flood Inundation Mapping

Flood inundation maps indicate flooded areas that are affected by or vulnerable to a particular hazard. Flood inundation maps were generated using ArcGIS (Asnaashari et al., 2014). It helps to prevent serious damage and deaths. It is a vital component for appropriate land use planning in flood prone areas. It creates easily-read, rapidly-accessible charts and maps which facilitate the administrators and planners to identity areas of risk and prioritize their mitigation/response efforts as nonstructural measure. (Dakota s., 2017)

An inundation map displays the spatial extent of probable flooding for different scenarios and can be presented either in quantitative or qualitative ways. The inundation or hazard assessment mapping delineates flood hazard area in the river basin by integrating local knowledge, hydrological, meteorological and geomorphologic data using different approaches. The inundation or hazard mapping is an essential component of emergency action plans; it supports policy and decision makers to decide about how to allocate resources, flood forecasting and significant land use planning in flood prone areas (Getahun and Gebre, 2015).

Inundation maps can have a different use including emergency action plans, mitigation planning, emergency response, and consequence assessment (FEMA, 2013).

1. Emergency action plans (EAP): An Emergency Action Plan is used to identify potential emergency conditions at a dam and specifies preplanned actions to minimize property damage and loss of life. The downstream inundation map is the basis for developing Emergency Action Plan and used to show the emergency management authorities and the critical areas for action in case of an emergency.

2. Emergency response: Emergency response represents the actions taken in the aftermath of an incident to save and sustain lives, meet basic human needs, and reduce the loss of property and the effect on critical infrastructure and the environment. In the case of dam failures and incidents, this would be the response by the dam owner, local community emergency management to minimize the consequence of actual dam failure or incident.

3. Hazard mitigation planning: Mitigation is the proactive effort to reduce loss of life and property by understanding the effect of disasters. This is achieved through identifying hazard potentials and the risks they pose in a given area. In the case of river flooding, hazard mitigation planning involves identifying the population at risk and identifying the action to reduce their vulnerability. Information required by hazard mitigation planners includes the inundation zone boundary, depth of flooding, velocity and timing.

According to (Nquot & Kulatunga, 2014) flood risk management plan are based on five major elements: prevention, protection, preparedness, emergency response and recovery. It is important to note that the preparation of flood risk maps and risk management plans do not by themselves stop the occurrence of floods. So, appropriate mitigation measures should be taken in flood prone area. The question may rise to construct flood protection structures: how are these new structures to be built and where would they be located; and of what materials are they to be built?(Nquot & Kulatunga, 2014) argues for the need for economic, social, and environmental sustainability and the use of adaptive measures for new developments.

4. Flood consequence assessment: It includes identifying and quantifying the potential consequence of flooding or incident. While hazard mitigation planning focuses on the economic and social impacts of a potential disaster and the organizational and government action needed in the result of flooding to respond and recovery.

2.6.1. Flood Inundation Map Elements

FEMA (2013) recommends that map collar information, base map data, inundation polygons, and Inundation elevation as elements of flood inundation map.

1. Map collar information: The latitude and longitude coordinates are can be referenced at the corners of the neat line. The other important information displayed on the map collar can be horizontal reference grid ticks to help orient map users to real world coordinates.

2. Base map data: Base map data provide the background from which inundation hazard information is overlaid and interpreted. Clear, easy to interpret base maps are critical for the effective use of an inundation map.

3. Inundation polygons: Inundation polygons are used to define the horizontal limits of the inundated area for one or more breach events. The inundation polygon shows the intersection of the peak water surface elevations from the dam breach model with the ground elevation with the terrain surface.

4. Inundation elevation: Inundation elevation can be explained at key locations along the inundation polygon if desired and extracted directly from flood model. Elevations are not always a critical element for an inundation map. Elevation may be important for flood warning, if early warnings are possible.

For this study, Three-Parameter Log-normal (LN (3)) Distribution, ArcGIS10.3 and HEC-RA 5.0.5 2D modeling software are selected for catchment characteristic determination and delineation of flood mapping respectively to meet the simulation requirements set above using available DEM, topography, land use/land cover and hydrology data.

2.7. Flood Risk Analysis

Flood risk analysis is a process that analyses the nature and extent of the risk by considering the potential hazard, the vulnerability and the resilience of the community that might be affected. The vulnerability is influenced by certain processes or factors (social, economic, environmental and physical) that make the community more susceptible to the impact of the hazard. Resilience refers to the capacity of an exposed community to adapt, resist or change in order to return to their normal functioning and structure. However, the resilience of a community is determined by its ability to reorganize its social systems according to lessons learnt from past experience, in order to reduce the risk of future flood events. At the same time, this capacity of a community is influenced by its available resources, including physical, institutional and economic means, and its ability to reduce the levels of risk (ISDR 2010a).

Flood risk is a combination of likelihood of flooding and the potential consequences arising. The consequence of flooding depends on the hazard associated with the flooding and the vulnerability of people, property and the environmental potentially affected by flood (EHLG, 2009).

The term risk has been defined in several ways in the natural hazard literature. According to the definitions proposed by Kron (2002), three variables determine the “risk”: hazard, vulnerability and exposure

Hazard: the threatening natural event including its probability/magnitude of occurrence

Exposure: the values/humans that are present at the location involved;

Vulnerability: the lack (or loose) of resistance to damaging/destructive forces

Most important is the distinction that is drawn between the words hazard and risk(Elisabetta Genovese, 2006). A hazard does not automatically lead to a harmful outcome, but identification of a hazard does mean that there is a possibility of harm occurring, with the actual harm depending upon the exposure to the hazard and the characteristics of the receptor.

Vulnerability to flood disasters comes through various forms: exposure to floods because of locating in flood-prone areas, occupying a dwelling that has little resistance to floods, the quality of buildings, lack of protections from floods, weaknesses of the population related to age, gender, health status, infirmity. Inability to avoid or recover from a flood disaster and low levels of protection or assistance are also contributory social factors.

According to Badilla (2002) for planning purpose, a hazard map is not completely useful. The location of the areas where largest economic losses due to natural disasters could occur is invaluable importance. Therefore, the need of conducting natural hazard studies with vulnerability and risk assessments is recommended.

2.8. Flood Protection Measures

Flood control measures aimed at lowering the vulnerability of people and their property include list of means, i.e. river engineering works, such as dams, flood walls, embankments, or river training works, retention polders (Klijn, 2009). Netherlands as a country with long history of flood risk management using the structural mitigation measure strategy represented by protective dikes for centuries. Ideally, the trade-off between different flood mitigation measures has to be applied depending on the regional characteristics, flood type and frequency, land use of floodplain as well as the vulnerability of the region(Tsamalashvili, 2010).

2.9. Sensitivity Analysis

The 2D HEC-RAS model based on the Saint-Venant equations or shallow water wave equations has been widely used in planning and designing of river training. This software is widely used in canals flow movement, flood routing and dam-break flow. Pappenberger et al. investigated the uncertainty of Manning coefficient of roughness; The research of Aronica et al., Hankin and Beven, Hardy et al., Rameshwaran and Willetts indicated that the roughness and geometric boundary condition has a very important influence on the forecasted of flood and water quality. In actual applications, while HEC-RAS provided general recommendations for regarding of sensitivity of model parameters. Therefore, is better than obviously to select appropriate model parameters. For 2D HEC RAS model, the most sensitive parameter is roughness (Zhang et al , 2016).

2.10. Previous Studies on The Study Area

In the study area, there are different studies performed under different topics. Some of these concentrated on, assessing human impacts on the greater Akaki river, pollution status of Akaki river and its contamination effect on surrounding environment and agricultural products: etc.

In the 2015 there was a research conducted by *Elias Zeleke*, (2015) on flood mapping of Bantyeketu River and aimed to delineate and map areas located on both sides of the river that was potentially affected by flooding and determine flood levels and magnitude for Bantyeketu River by routing flow data from Akaki Gaging Station. On the basis of a topographic analysis of the Bantyeketu watershed, a simulation model for the Hydrological Modeling System (HMS). Hydrological model has been set up and 1D-Hydraulic model (HEC-RAS) have been used to flood analysis. Bantyeketu River is little tributary of Great Akaki river. Even though the Akaki area is characterized as high flood prone area, still there is no flood studies conducted on Great Akaki river. The current flood problem and lack of studies in the areas show as the importance of study in the depth. This study concentrates flood mapping for different return periods using the HEC-RAS new version of 2D unsteady flow analysis.

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

The study was conducted on Great Akaki River and its one tributary (bulbula river) from upstream to down Akaki Kality sub city. The Akaki catchment is located in central Ethiopia along the western margin of the Main Ethiopian Rift. The catchment is geographically bounded between 8°46´–9°14´N and 38°34´- 39°04´E, covering an area of about 1500 km2 and at altitude 2048-2600m. The entire catchment is bounded to the north by the Intoto ridge system, to the west by mount Menagesha and the Wechecha volcanic range, to the southwest by mount Furi, to the south by mount Bilbilo and Guji, to the southeast by the Gara Bushu hills and to the east by the mount Yerer volcanic center (Demlie and Wohnlich,2006).

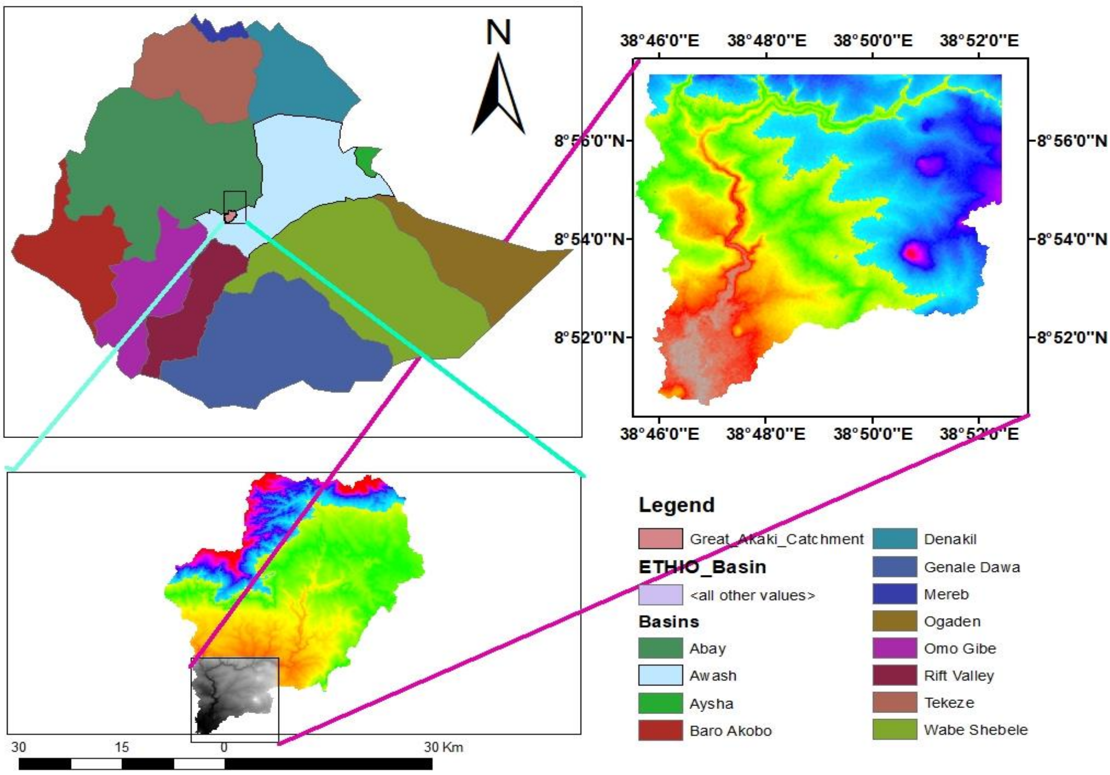


Figure 3.1: Map of the Great Akaki River catchment and the study area

3.1.2. Topography

The topography is characterized by mountains and steep slopes to the north and flat plains to the south. The city rests on a landscape of volcanic rocks such as basalt with vertosol clay soils(Backhaus et al., n.d.).

3.1.3. Climate

Despite its proximity to the equator, the study area experiences a temperate Afro-Alpine climate. Daily average temperatures range from 9.9 to 24.6 °C and annual mean rainfall is 1254 mm, as measured at Addis Ababa Observatory (Granger & Carey, 2007). The climate of the Akaki catchment is characterized by two distinct seasonal weather patterns. The main wet season, locally known as Kiremt extends from June to September, contributing about 70% of the total annual rainfall. A minor rainy season, locally known as Belg, contributes moisture to the region from mid-February to mid-April (Mechal et al., 2016). The remaining five months are dry season. Current climate change projections indicate an increase in annual precipitation by approximately 10% by 2100 and an increase in 5-day by up to 30% by 2100(Backhaus et al., n.d.). Average monthly minimum temperature varies from 12.27 to 14.09 and average monthly maximum temperatures vary from 24.71 to 27.55

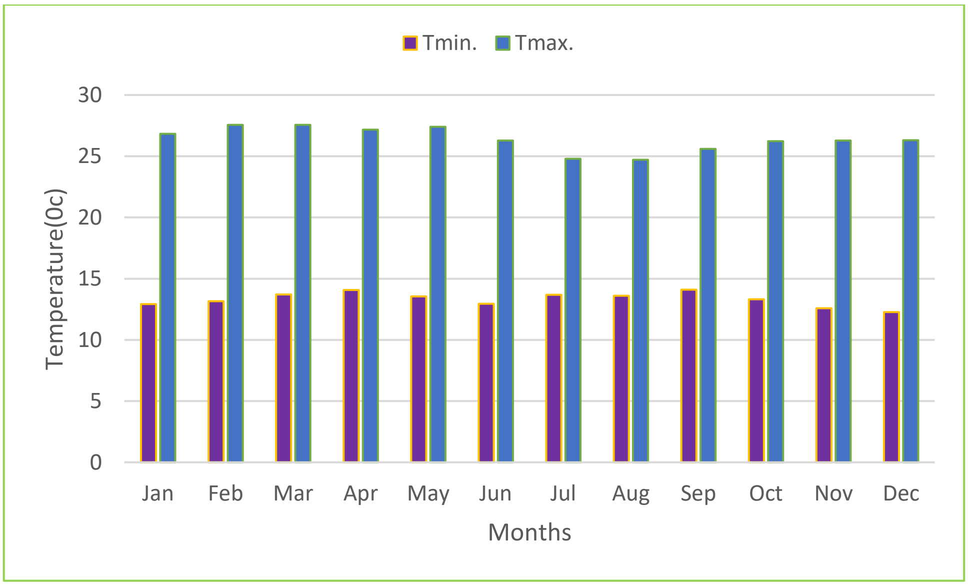


Figure 3.2: Mean monthly Min and Max temperature at Akaki station, 1997-2016

3.1.4. Soil

According to Meyer & Enzler, (2013) the major soil types of the catchment are calcaric xerosols, chromic cambisols, chromic luvisols, chromic vertosols, eutric nitisols, leptosols, orthic solonchks, pellic vertosols, and vertic cambisols. From these pellic vertosols type of soil is the most dominant one in the area.

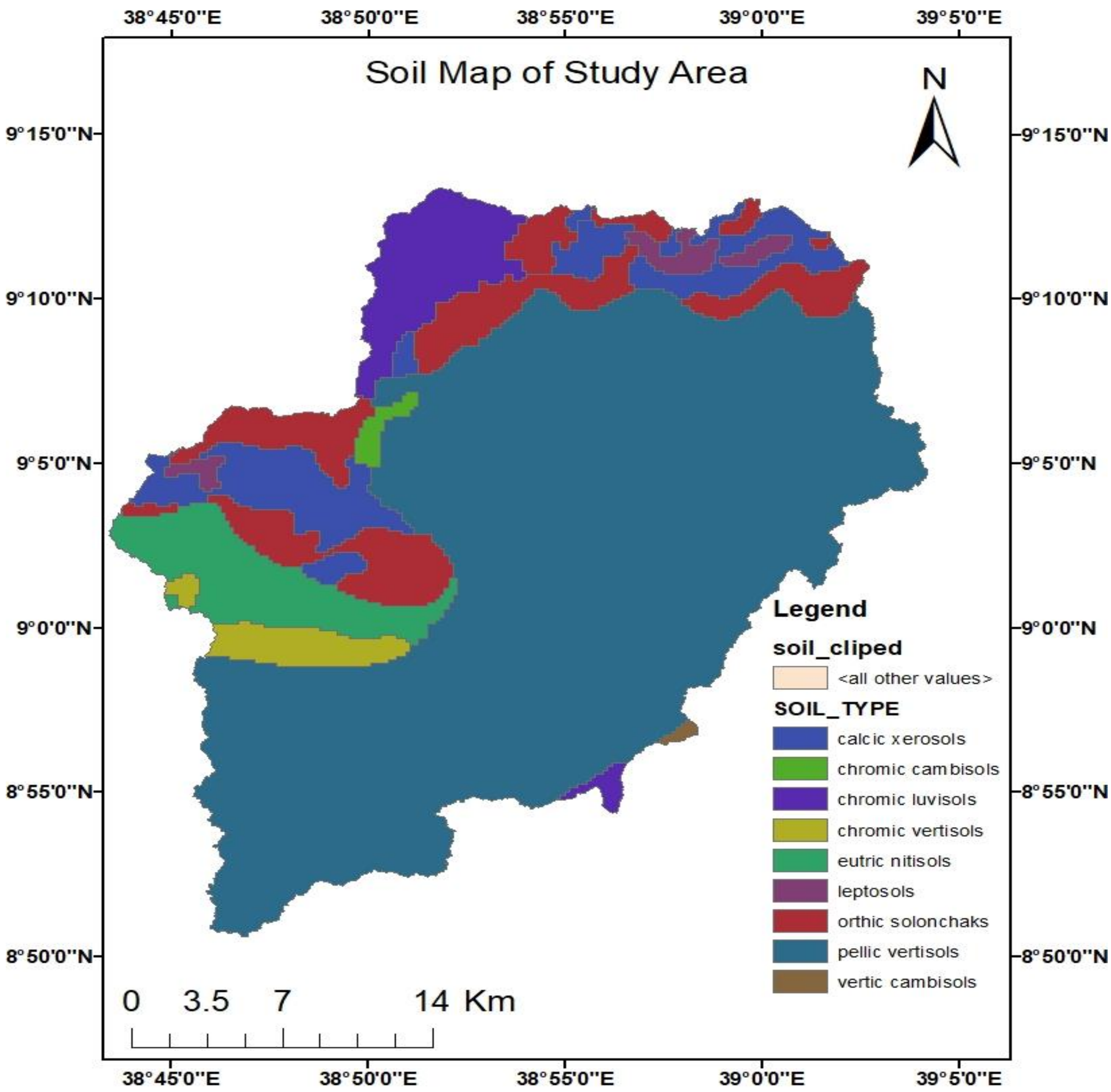


Figure 3.3: Soil map of the Great Akaki river catchment

3.1.5. Land use/Land cover

Most of the land in Ethiopia was used for permanent pastures namely 40%. The rest for annual crop production 12%, permanent crops 1%, forest and woodland 25% and others 22% (Taddese 2001). A major problem in Ethiopia was deforestation (Burju et al, 2013). This problem is related to socio-political changes, economic activities, population growth, agricultural development and local conflicts over resources. In Ethiopia the forest cover has decreased to less than 3-3.6% in the past half-century. The main land use pattern in the city holds residential areas, market quarters, industrial zones, agricultural areas ,forest and quarries.The rapid urbanization requires wide areas for varius purposes and hence the size of the city is increasing at high rate.presentlyindustrial areas are located in the southern sector along the river channels and in the borders of the city.The central part of the city includes residential quarters, governmental offices, churches, schools and colleges,airports,parks,sport grounds, and various sized markets (Shumba, 2001).

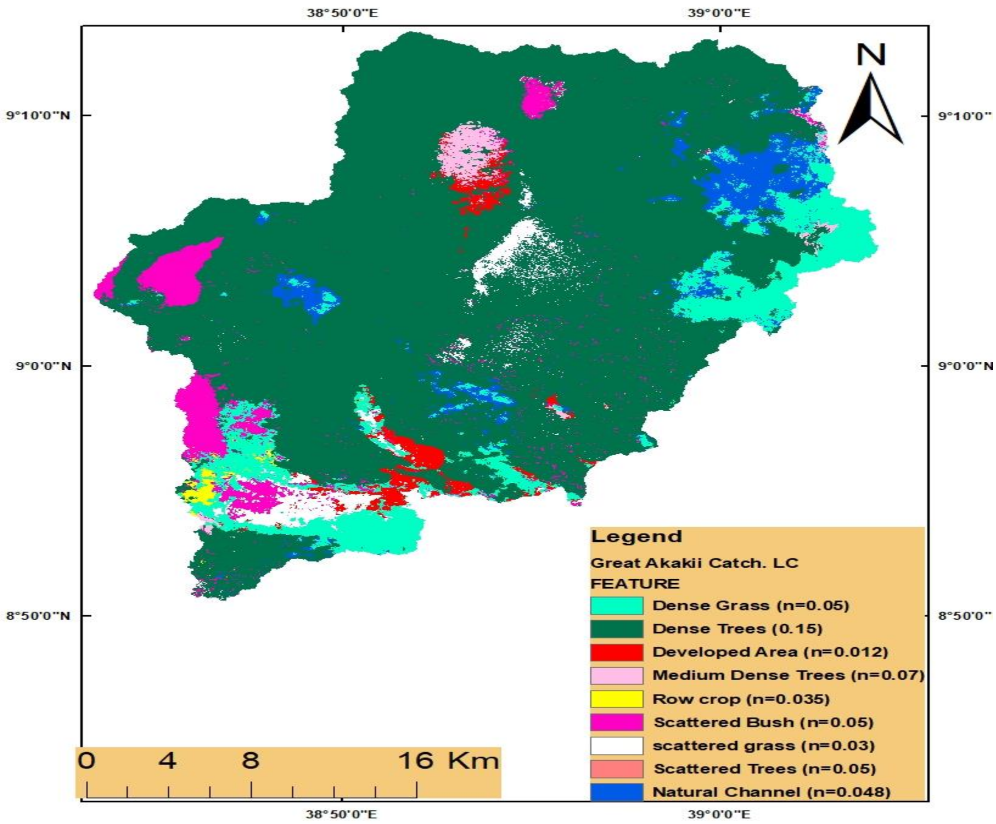


Figure 3.4: Great Akaki River Catchment Land use /cover (https://earthexplorer.usgs.gov/).

3.1.6. Population

Addis Ababa has an annual population growth rate of 2-3% and the population is expected to grow from 3.2 million in 2015 to 5.9 million in 2030. Akaki Kality, is one of the 10 sub cities of Addis Ababa, the capital of Ethiopia. As of 2011 its population was of 195,273. Formerly, Akaki Kaliti was known as Woreda 26 (Backhaus et al, 2011).

3.2.Methodology

3.2.1. Data collection

In order to achieve the objective of this study, different data were collected. These are stream flow data, DEM and land use/land cover data. The stream flow data was collected from Ministry of Water Resources, Ethiopia. The digital elevation model (DEM) and land use/land cover data were also downloaded from the Alaska satellite Facility (https://vertex-retired.daac.asf.alaska.edu/) and the United States Geological Survey (USGS) (https://earthexplorer.usgs.gov/) respectively. The manning's roughness coefficient where collected from field survey and verify it from relevant literature Chow (1959).

3.2.2. Stream flow data

The flow data was used to know the magnitude of the flood with perspective to its return period and areas inundated because of this flood. The flow data were available for one station; the name of the station is Akaki. The station had data ranging in time from 1986 to 2004, though it had data no missing gaps during the period.

3.2.3. Digital Elevation Model (DEM)

Digital Elevation Model (DEM) is a square grid of regular spaced elevation data for hydrology, agricultural planning, soil mapping and so on. Unfortunately, the use of DEM surface is generally not suitable for large scale terrain representation for hydraulic analysis of the river channels. Because they cannot vary in the spatial resolution, it may poorly define the land surface in areas of complex relief. Therefore, for hydraulic modeling of river channels, the triangular irregular network (TIN) model is preferable so the Digital Elevation Model (DEM) with spatial resolution 12.5m by 12.5 m was downloaded from the Alaska satellite Facility (https://vertex-retired.daac.asf.alaska.edu/) is converted to TIN. A TIN is a triangular mush constructed on the X, Y and Z location of the set of data points. The TIN model allows for a dense network of points where the land surface is complex and detailed, such as river channels, for a lower point density in flat or gentle sloping areas. For this research the TIN of the study area is derived from 12.5m resolution DEM of the study area using the 3D-special analysis extension in the Arc GIS.

3.3. Satellite Image Data

Satellite image of the study area was obtained from Google Satellite, and it was geo-referenced by using Arc-GIS. Fig.3.5 shows geo-referenced satellite image of the study area.

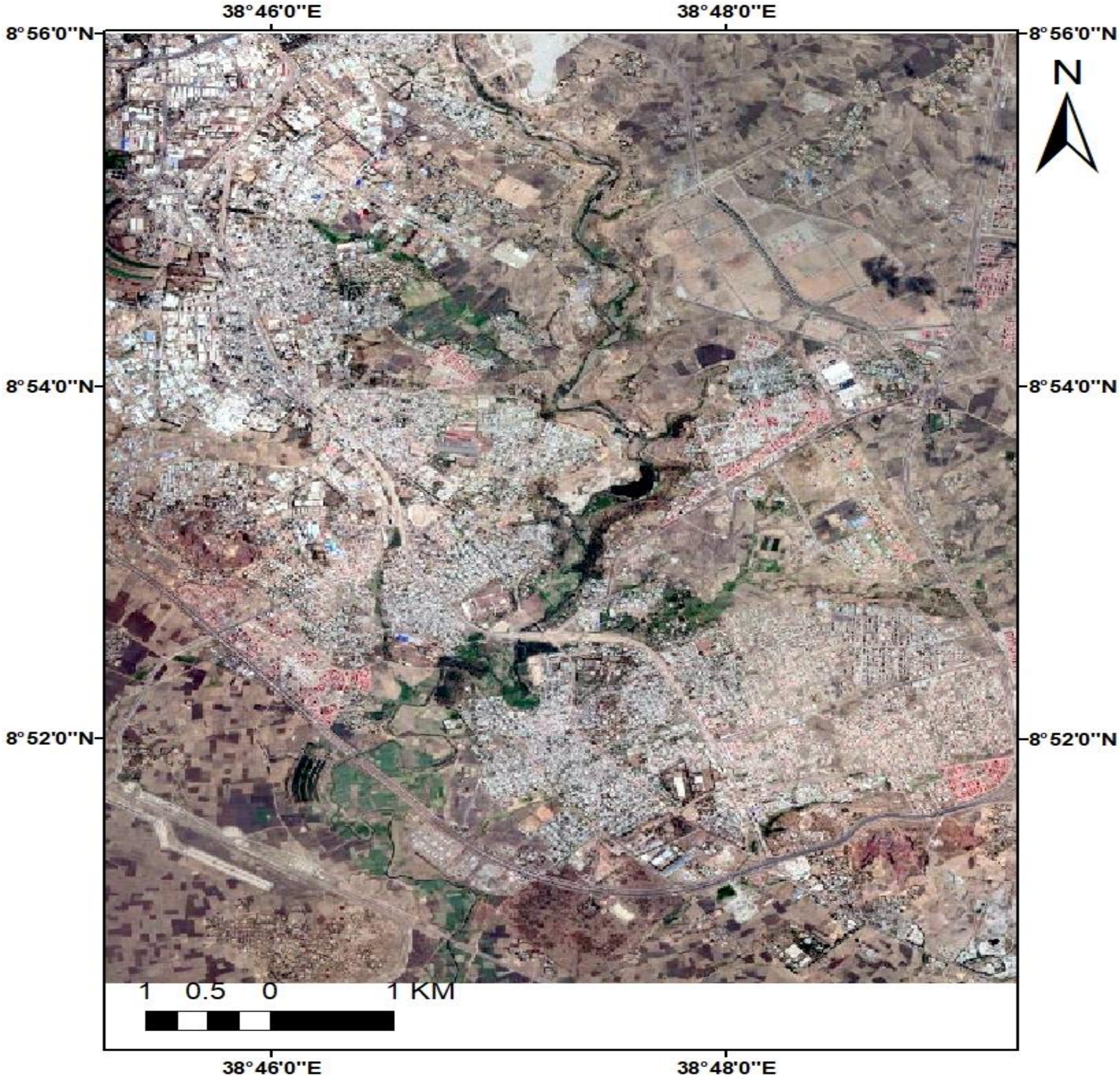


Figure 3.5 : Satellite image of study area in 2019 GC.

3.4. Data analysis

3.4.1. Tests on hydrologic data

The basic assumptions in statistical flood frequency analysis are the independence and stationarity of the data series and that the data come from the same distribution homogeneity and outlier, it is better to check the flow data at five percent significance levels to reach an accurate estimate.

3.4.1.1. Test of independence and stationarity

Wald-Wolfowitz (1943) (W-W) test was used to test for the independence of a dataset and to test for the existence of trends in a given sample of size N. For a dataset X1, X2 .... Xn the statistic R was calculated

$$R = \sum_{i-1}^{N-1} X_i X_{i+1} + X_1 X_n \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (1)$$

Where: - X_i – Magnitude of flow at i period

X_{i+1} – Magnitude of flow next to i period

X_1 – Magnitude of flow at first period

X_n – Magnitude of flow at last period

N– Total number of flows

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

$$\bar{R} = \frac{S_1^2 - S_2}{N - 1} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (2)$$

$$Var(R) = \frac{S_1^2 - S_2}{N - 1} - \bar{R}^2 + \frac{S_1^4 - 4S_1^2 S_2 + 4S_1^2 S_3 + S_2^2 - 2S_4}{(N-1)(N-2)} \dots \dots \dots \dots \dots (3)$$

Where; $S_r = Nm'_r \ and \ m'_r = \frac{1}{n} \sum_{i-1}^{n} x_i^r$

$$m'_r \ is \ the \ rth \ moment \ of \ the \ sample \ about \ the \ origin$$

The statistic U is approximately normally distributed with mean zero and variance unity. In this thesis, the test of independence was at 5 % significance level, by comparing the statistic u with the standard normal variate $u_{a/2}$ corresponding to a probability of exceedance $a/_2$.

$$U = \frac{R - \bar{R}}{\sqrt{Var(R)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. (4)$$

3.4.1.2. Tests of homogeneity and stationarity

The Mann- Whitney, (1947) test considers the quantities V and W by testing two samples of size p and q, where p is less than or equal to q are compared. The combined data set of size N = p + q was ranked in increasing order.

$$V = R - \frac{\left(P(P+1)\right)}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .5)$$

$$W = pq - V \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (6)$$

R is the sum of the ranks of the elements of the first sample (size p) in the combined series (size N), V and W are calculated from R, p, and q. V represents the number of times an item in sample 1 follows an item in sample 2 in the ranking. Similarly, W can be computed for sample 2 following sample 1. The M-W statistic U was defined by the smaller of V and W. When N > 20 and p, q > 3, and under the null hypothesis that the two samples came from the same population, U is approximately normally distributed with mean and variance var (U),

$$\bar{U} = \frac{pq}{2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . \dots\dots . (7)$$

$$Var(U) = \frac{pq}{N(N-1)}\left(\frac{N^3 - N}{12} - \sum T\right) \dots\dots\dots . \dots .. (8)$$

$$T = \frac{J^3 - J}{12} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots .. \dots .. \dots\dots\dots . (9)$$

Where T and J is the number of observations tied at a given rank. T is summed over all groups of tied observations in both samples of size p and q. Therefore, in this thesis the statistic u was used to test the hypothesis of homogeneity at 5 % significance level a by comparing it with the standard normal variate for that significance level.

$$u = \frac{U - \bar{U}}{\sqrt{Var(U)}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (10)$$

3.4.1.3.Testing of outliers

Outliers are data points that depart significantly from the tread of the remaining data. The retention or deletion of this outlier can significantly affect the magnitude of statistical parameters computed from the data; especially for small samples procedures for trending outliers require judgment involving both mathematical and hydrological considerations. According to the Jekel et al, (2014) water resources management if the station skew is greater than +0.4 tests for high outliers are considered first; if station skew is less than -0.4, test for low outlier are considered first. Where the station skew is between -0.4 and +0.4, tests for both high and low outlier should be applied before eliminating any outliers from the data set. The following frequency equation can be used to detect high outliers.

$$Y_h = \bar{Y} + K_n S_y \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots (11)$$

Where: -Y_h = High outlier threshold in log units,

K_n = Value read from table for sample size n

S_y= Standard deviation

$$S_y = \sqrt{\frac{\sum(Y_i - \bar{Y})^2}{n-1}} \quad , \quad Q_H = (10)^{Yh}$$

A similar equation can be used to detect low outliers

$$Y_L = \bar{Y} - K_n S_y \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (12)$$

If the logarithms of the values in a sample are greater than Yh in the above equation, then it is considered high outlier. Flood peaks considered high outliers should be compared with historic flood data and flood information at nearby sites. Historic flood data comprise information on unusually extreme events outside of the systematic record. According to the Jekel et al, (2014) water resources management if information is available that indicates a high outlier is the maximum over an extended period of time, the outlier is treated as historic flood data and excluded from analysis. If useful historic information is not available to compare to high outliers, then the outliers should be retained as part of the systematic record.

3.4.2. POT values Selection

An annual flood is defined as the highest momentary peak discharge in a water year. The use of only one flood in each year is the most frequent objection to the use of annual floods. Infrequently, the second highest flood in a given year, which is omitted in the above definition, may outrank many annual floods. The objection noted under annual floods is resolved by listing all floods that are greater than a selected base without regard to number within any given time period. The base is generally selected as equal to the lowest annual flood so that at least one flood in each year is included, however, in a long record, the base is generally raised so that on the average only 3 or 4 floods a year are included. The only other criterion followed in selecting the floods is that each peak be individual; that is, be separated by substantial recession in stage and discharge. An objection to the use of the partial-flood series is that the floods listed may not be fully independent events; closely consecutive flood peaks may actually be one flood. The greater number of floods listed in the partial-duration series might be an advantage, particularly if the record is short. However, most of the additional floods are of low discharge and plot where the curve is well denned; the high-discharge floods are generally identical with those in the annual-flood series. The overall POT values evaluated using WETS Pro. software and this POT values are used as input data to Easy Fit 5.0 software to select the best flood frequency distribution(Division, 2014).

3.4.3. Goodness of fit test

The goodness of fit test where conducted by using Easy Fit 5.0 software. The POT values of flow data supplied to the software through a file or through clipboard using copy/paste commands and then by selecting the well-known probability distribution from the distribution fitting option of the software then after the software automatically fit the distribution based on Kolmogorov Smirnov, Anderson Darling and Chi-square statistical test. The Easy Fit software will rank according to quality level of fitting with data based on goodness of fit statics. Lastly, the distribution graphs and goodness of fit results were used to compare fitted distribution and the software also estimates the parameters by using method of moments. Based on the data the Log-Normal (3P) probability distribution was selected.

3.4.4. Three-Parameter Log-normal (LN (3P)) Probability Distribution

The probability density function of a logarithmic normally distributed variable *x* with three parameters (LN (3)) is given by

$$f(x) = \frac{1}{(x-a)\sigma_y\sqrt{2\pi}} exp\left\{\frac{-\left(\log\,(x-a) - \mu_y\right)^2}{2\sigma^2{}_y}\right\} \ldots \ldots \ldots (13)$$

where μ_y and σ_y^2 are the form and scale parameters, which correspond to the mean and variance of the logarithm of the shifted variable *(x* - a). The standardized variable *u* is obtained as in Eq. 3.4.1.4

$$u = \frac{\log(x-a) - \mu_y}{\sigma_y} \ldots \ldots \ldots \ldots (14)$$

Sangal & Biswas, (1970), suggested a procedure to estimate the parameters of the LN (3) distribution in which only the mean, median and standard deviation of the data are used. The mathematical properties of the LN (3) distribution were discussed by Burges et al. (1975). They also compared two methods of estimation of the third parameter 'a' of the LN (3) distribution.

Kogut & Singh, (1988) used the maximum entropy method to estimate the parameters of the LN (3) distribution. They compared their method to the ML method of parameter estimation. They developed ML estimators of the LN (3P) distribution in which historical data can also be included and demonstrated by using Monte Carlo simulation that inclusion of historical data reduced the bias and variance of extreme flows. Kohler & Krzyżak, (2019) investigated different quantile estimation procedures for the lognormal distribution. They compared the average bias and the root mean square errors associated with these procedures.

3.5. Hydraulic Model (2D-HEC RAS)

The full unsteady flow equations have the capability to simulate the widest range of flow situations and channel characteristics. The basic data requirements for hydraulic routing techniques include: flow data, channel geometry, roughness coefficients, and internal boundary conditions.

Hydraulic modeling is further subdivided into steady flow analysis and unsteady flow analysis. In unsteady flow, time dependent changes in flow rate are analyzed explicitly as a variable, while steady flow analysis models neglect time all together (USACE, 2016). Steady flow analysis can determine a water surface elevation and flow velocity at a given cross section for a given flow using Manning's equation under the assumption of gradually varied flow conditions. Unsteady flow analysis can be used to evaluate the downstream attenuation of the flood wave, providing a more accurate estimate of flood magnitude and velocity at critical locations. HEC-RAS is the most widely used hydraulic model for flood map analyses in the United States and can be utilized for steady and unsteady flow analyses.

3.5.1. Mesh Generation

The accuracy of the HEC RAS result is dependent on the terrain of the study area. Mesh 10*10m of the study area is developed for HEC RAS simulation used for to take geometric data. 2D Mesh of size 10*10m generated for the study area that contain 268887 cells.

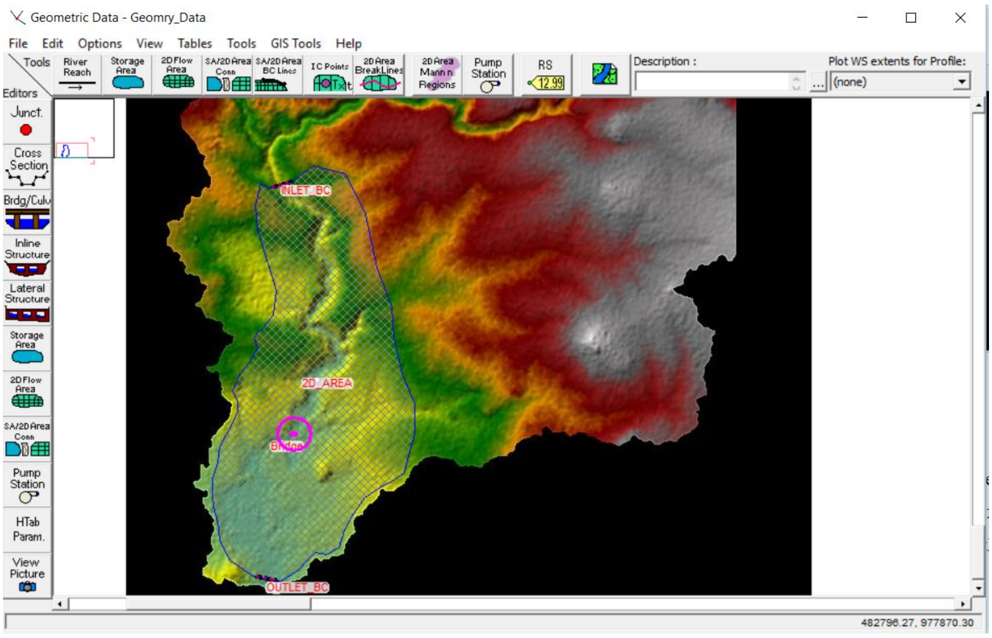


Figure 3.6 : Mesh developed for study area

3.5.2. Manning's roughness coefficient

The manning's roughness coefficient used to reflect the resistance to flow from bed material. The roughness of a surface affects the characteristics of runoff, whether the water is on the surface of the watershed or in the channel. With respect to the hydrologic cycle, the roughness of the surface retards the flow. For overland flow, increased roughness delays the runoff and increase the potential for infiltration. Reduced velocities associated with increased roughness should also decrease the amount of erosion (Gilley et al., 1991).

All hydraulic computations involving flow in open channels require an evaluation of the roughness characteristics of the channel. The ability to evaluate roughness coefficients must be developed through experience. One means of gaining this experience is by examining and becoming familiar with the appearance of some typical channels whose roughness coefficients are known (Bahramifar et al., 2013). Common methods of estimating Manning's roughness coefficients for stream channels, includes use of published *n*- value data, comparison with photographs of channels for which *n* values have been computed, and *n* - value equations (Coon, 1997). A Manning *n* was assigned in accordance with a simple land cover classification that was manually created from parcel outlines and digital orthophotos, using Chow's (1959) tabular *n* values for similar land characteristics (Gallegos et al., 2009). The roughness Manning *n* values for different land uses are provided on Chow's (1959). It could also be selected based on reviewing the site visit, photographs and aerial imagery of channel and flood plain areas (Asnaashari et al., 2014). The Manning's coefficients for the channel and overbank areas have been estimated based on the field investigation (Changzhi et al., 2014).

Chow (1959), determines values of manning's roughness coefficient for different land use as shown in Appendix A. Therefore, the selection of the n values was assigned based on the observation of Akaki river channel and flood plain area and taking them with engineering judgment is as follows.

Table 3.1:Manning's roughness coefficient Values for different land use

Features	n values	Features	n values
Dense Grass	0.05	Row Crop	0.035
Dense Trees	0.15	Scattered Bush	0.05
Developed Area	0.012	Scattered Grass	0.03
Medium Dense Trees	0.07	Scattered Trees	0.05
Natural channel	0.048		

3.5.3. Expansion and contraction coefficient

Contraction or expansion of flow due to changes in the cross-section is a common cause of energy losses within a reach (between two cross-sections). HEC-RAS program takes contraction whenever the velocity head of downstream is greater than the upstream cross-section and it takes expansion whenever the reverse comes true. According USACE (2016), the contraction and expansion coefficient for natural channel which has gradual change in cross-section is estimated to be 0.1 and 0.3 respectively. So Akaki River is a natural channel, it has the same value for contraction and expansion coefficient. Therefore, to form calculation in the channel, 0.1 was used for contraction coefficient whereas 0.3 was used for expansion coefficient.

3.5.4. Entering and editing flow data

The flow data are required in order to perform a water surface profile calculation. After analysis of the flow data recorded for the site found in the Ministry of Water Resources those should be used as an input for the software. Each flow that needs to be simulated is called a profile in HEC-RAS. For carrying out the analysis here, the peak flood having 2, 5,10, 25, 50, and 100 years return period of flows were used.

3.5.5. External 2D Flow Area Boundary conditions

Boundary conditions both at the upstream and downstream ends of study area are needed for the model in flood routing. There are five types of external boundary conditions that can be linked directly to the 2D flow areas. These are Flow Hydrograph, Stage hydrograph, Normal depth, Rating curve and Precipitation boundary condition. The Normal depth and rating curve boundary condition can only be used at locations where flow will leave a 2D flow area. The flow and stage Hydrograph boundary condition can be used for putting flow into or taking flow out of a 2D flow area. The Precipitation boundary condition can be applied directly to any 2D flow area as a time series of rainfall excesses (right now we do not have interception/infiltration capabilities, these will be in future versions) (Brunner, 2010).

Boundary conditions are necessary to establish the starting water surface at the ends of the river system upstream and downstream. A starting water surface is necessary in order for the program to begin the calculation. In a subcritical flow regime, Boundary conditions are only necessary at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, Boundary conditions are only necessary at the upstream ends of the river system. If the mixed flow regime calculation is going to be made, then Boundary condition must be entering at all ends of the river system. HEC-RAS allows to set the water surface elevation boundary conditions by four methods. The first one is based on known water surface elevation it is based on the observed (known) water surface elevation for each of the profile to be computed. The second one using critical depth the user not required to enter any further data just the program calculate critical depth for the profile and use that as the boundary condition. The third one is using normal depth is required to enter an energy slope that will be used in calculating normal depth at that location. The energy slope can be approximated by average slope of the channel or by average slope of water surface in the vicinity of the cross-section. The last one by using rating curve it needs elevation determined from an existing stage-discharge relation curve. So that for this thesis normal depth had been selected. The average normal depth should be calculated between upstream and downstream end profile of the study area is 0.002. The upstream boundary condition can be defined by a series of cross-sections cut through or tributaries that inters into the study area. The inflow hydrographs for the upstream boundary will be considered for the flood simulations. Downstream boundary conditions will be established using slope of river (Asnaashari et al., 2014). For this study inflow hydrograph of POT values will be considered as an upstream boundary.

3.6. Unsteady simulation

The unsteady flow computation program in HEC RAS uses the same hydraulic calculation that HEC developed for steady flow; however, the solution of the unsteady flow equation (continuity and momentum equation) are solved (Eichert,1964).

3.6.1. Post Processor

The post processor is used to compute detailed hydraulic information for a set of user specified time lines during the unsteady flow simulation period. The Post processor compute detail output for a maximum stage water surface profile. The computation setting area of the unsteady flow analysis window contain the computation interval, hydrograph output interval, mapping output interval and detailed output interval (Eichert,1964). The computation interval is used in the unsteady flow calculation. This is one of the most important parameters entered into the model and selected with care due to it affects the simulation. Firstly, the interval should be small enough too accurately to describe the rise and fall of the hydrograph being routed. In this study it is taken with 10 seconds. In my study 30 minutes is used as hydrograph output interval. The detailed output interval field allows the user to write out profiles of water surface elevation and flow at a user specified interval during the simulation. One hour is used for detailed output interval. Mapping output interval this field used to enter interval at which user will be able to visualize mapping with in HEC RAS paper. 30 minutes is used for mapping output interval. Practical time step selection- for medium to large rivers, the courant condition may yield time steps that are too restrictive (a larger time step could be used and still maintain accuracy and stability).

The smaller time step is needed when there is lateral weirs/spillways and hydraulic connections between storage areas and the river system. Computational time step stability and accuracy can be achieved by selecting a time step that satisfies the courant condition. Remember that for Hydraulic models, typical time steps are in the range of 1- 60 seconds due to the very fast flood wave velocities (Eichert,1964).

$$C = \frac{V\Delta T}{\Delta X} \leq 2\ (with\ \alpha \max C = 5) Or\ \ \Delta T \leq \frac{2\Delta X}{V}\ \ (with\ C = 2) \dots\dots\dots\dots(15)$$

Where: C=Courant Number; ΔT =Computation time step(s);
V= Flood wave velocity (wave celerity) (m/s); ΔX=Average cell size (ft)

3.6.1.1. 2D energy equation (Mass Conservation)

The continuity equation and momentum equation are the main scientific basis for unsteady flow analysis. The continuity equation is as follow: (Eichert, 1964)

$$\frac{\partial \mathrm{A}}{\partial \mathrm{t}} + \frac{\partial \mathrm{Q}}{\partial \mathrm{s}} - \mathrm{q} = 0\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(16)$$

Where, A = flow area, m2; t = time variable, s;
Q = volume of flow, m3/s; s = spatial distance along the direction of flow, m.
q = the lateral inflow per unit length, m2/s;

3.6.1.2.Diffusion-Wave equation

And one form of the Diffusion-Wave momentum equation is as follow (Eichert, 1964).

$$\frac{\partial \mathrm{A}}{\partial \mathrm{t}} + \frac{\partial \mathrm{QV}}{\partial s} + \mathrm{gA}(\frac{\partial \mathrm{z}}{\partial s} + \mathrm{sf}) = 0\ \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(17)$$

Where, V = flow velocity, m/s; g = gravitational acceleration, m/s2;

z = elevation of water surface, m; Sf = friction slope.

$$\mathrm{sf} = \frac{\mathrm{Q}^2\mathrm{n}^2}{\mathrm{R}^{\frac{4}{3}} * \mathrm{A}^2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots(18)$$

Where, n = manning's roughness coefficient; R = hydraulic radius, m

3.7. Flood Risk Analysis

According to Zimmermann, 2005) the conventional expression of risk is

Risk=Hazard * Vulnerability

where, Vulnerability = Exposure * Susceptibility - Resilience

Flood Hazard is Flooding that has the potential to result in harm; the description of flood hazard may include the physical characteristics of a flood at a given point; including depth and velocity (Samuels & Gouldby, 2009).

Exposure is express an area's predisposition to disruption by a flooding event due to its location in the same area of influence.

Susceptibility is defined as the elements exposed within the system (e.g. people, property, infrastructure etc.) which influence the probabilities of being harmed at times of hazardous floods.

Resilience is the capacity of a system to endure a hazard/disaster event such as a flood, maintaining significant levels of organization in its social, economic, environmental and physical components (Bertilsson & Wiklund, 2012).For this study the value of resilience was taken as zero to prepare maps of maximum risk value.

Based on the above definitions flood hazard indicators were flood depth, duration and velocity of flood flow, exposure indicator was flood inundation area and susceptibility indicators were people, property and infrastructure.

3.7.1. Computation of Flood Hazard Index (FHI) and Vulnerability Index (FVI)

The vulnerability of a system to flood events can be expressed with the following general equation (Balica, 2007, p 37). This equation is used in the present study to compute Flood Vulnerability Index (FVI).

FVI = Exposure Index* Susceptibility Index- Resilience Index

Any flood vulnerability analysis requires information regarding indicators, which can be specified in terms of exposure indicators (X_i), Susceptibility indicators (X_i) and Resilience Index. The collected data were arranged in increasing order that representing indicators in order to obtain Vulnerability Index values. Depending on their functional relationship the exposure and susceptibility index(I) were obtained using the following formula:

$$I = \frac{X_i - Min(X_i)}{Max(X_i) - Min(X_i)} \dots \dots \dots \dots \dots \dots \dots \dots (19)$$

It is obvious that the scaled values of index lie between 0 and 1. The value 1 corresponds to that flooded area with maximum value and 0 corresponds to the flooded area with minimum value.

3.8.Flood Inundation Mapping

Flood Inundation mapping was done on Ras Mapper on the HEC RAS environment to identify the potential risk, safe settlement areas and alignment of preliminary protection works (dike). Water surface profile at location of interest that is at settlement areas were drawn on Ras Mapper. The outputs of the model were exported to GIS environment for further analysis and reporting purpose.

Overall Schematic Representation of River Flood Modelling

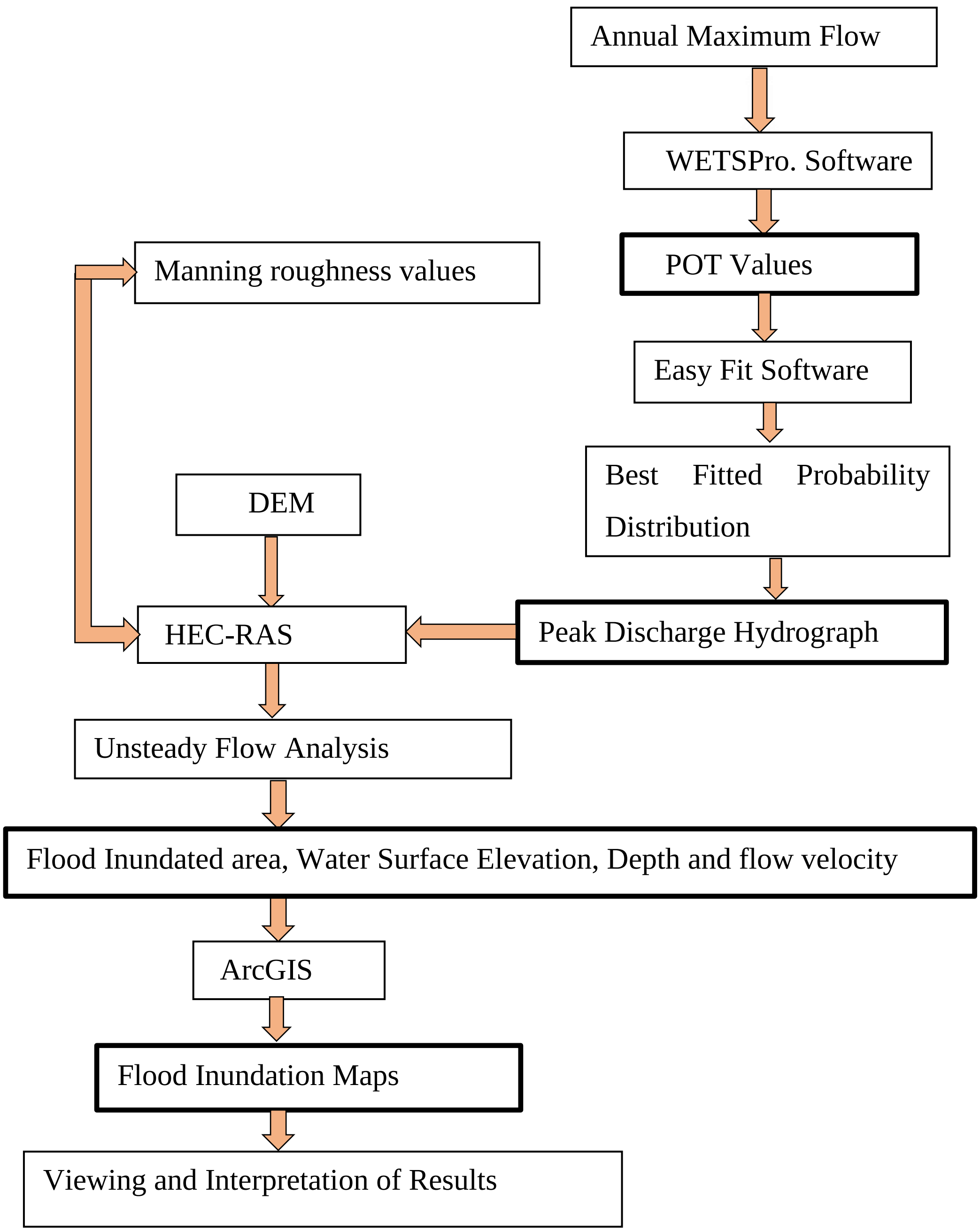


Figure 3.7**:** Over all view of methodology

4. RESULTS AND DISCUSSION

4.1. Test results on hydrologic data

Before conducting flood frequency analysis, test on the hydrological data must be done in order to know the quality of the data that used for quantile estimation. This includes homogeneity and stationary, stationary and independency and outlier test.

4.1.1. Homogeneity and Stationary (M-W) test result

The results of the Homogeneity and Stationary (M-W) test indicated that the test value u = 0.0733 is less than the critical value at 5% significance level, $u_{0.025}$ = 1.96. Thus, we can accept the hypothesis of homogeneity and stationary of Great Akaki River flow data at 5% significance level.

4.1.2. Stationary and independence (W-W) test result

The results of the stationary and W-W tests indicated that the test value u = 0.2489 is less than the critical value at 5% significance level, $u_{0.025}$ =1.96. Hence, we can accept the hypothesis of independence and stationarity of Great Akaki River flow data at 5% significance level.

4.1.3. Outlier test result

The higher and lower threshold value is 693.102 m3/s and 36.554 m3/s respectively. The value of coefficient of skewness was 0.172 that found between-0.4 and +0.4. The maximum and the minimum annual maximum flow data are also 693.102 m3/s and 36.554 m3/s respectively. So that there are no high and low outliers at 10% significant level in the annual maximum flow data from 1986 to 2004 of Great Akaki at Akaki stream flow gauging station.

4.2. POT values

Sixty-six (66) POT values were found is shown in Appendix B that from 19 years' annual maximum peak flow values. Three or four peak flow values were extracted from each year. This is very important to show normal trend of river system. These 66 POT values were used to select best fitted probability distributions using Easy fit 5.0 software.

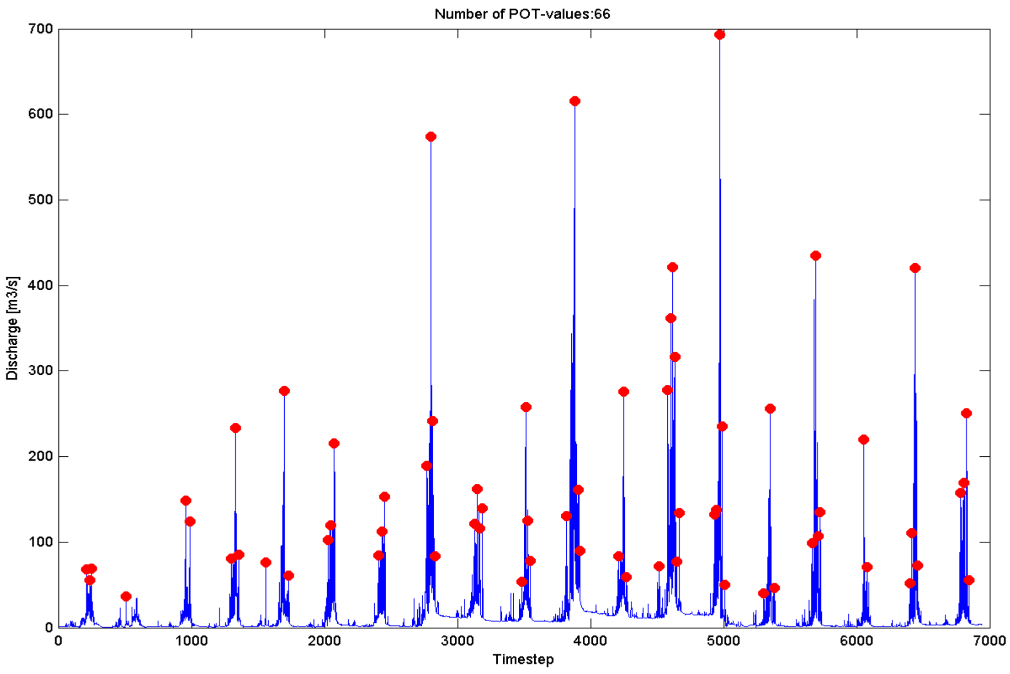


Figure 4.1: POT Values of WETS Pro. software

4.3. Goodness of Fit Test Results

Based on 66 POT values the result of parameters of probability distribution were found is shown in Appendix C1 for the selected well-known distribution. Log-normal (3p) probability distribution was chosen as best fitted probability distribution shown in the Table 4.1.

Table 4.1: Ranks of probability distribution

Goodness of Fit - Summary

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	Exponential	0.2453	8	2.1945	6	16.047	7
2	Exponential (2P)	0.30237	9	5.9772	9	28.875	8
3	Gamma	0.19537	4	1.381	3	10.01	6
4	Gamma (3P)	0.22776	7	5.6531	8	N/A	
5	Gumbel Max	0.20081	5	2.0518	5	3.4892	2
6	Log-Pearson 3	0.17427	2	1.3642	2	5.8603	3
7	Lognormal	0.18264	3	1.4438	4	7.0489	4
8	Lognormal (3P)	0.15078	1	0.8486	1	3.4033	1
9	Normal	0.22299	6	2.9033	7	7.2266	5

4.4. Log-normal (3p) Probability Distribution

The quantile estimation (X_{tr}) in Log-normal (3p) distribution which corresponds to different return periods and coefficient of skewness was summarized in the table 4.2.

Table 4.2.: Quantile estimates for different return periods using Log-normal (3p) distribution

Return Periods	X_{tr} for 1 day	X_{tr} for 3 days	X_{tr} for 5 days	X_{tr} for 7 days	X_{tr} for 9 days	X_{tr} for 11 days	X_{tr} for 13 days	X_{tr} for 15 days
2	210.29	181.14	160.26	145.05	130.53	115.66	103.09	92.90
5	333.04	302.76	247.16	211.92	185.52	162.06	146.09	132.77
10	453.16	413.64	322.59	274.75	241.19	214.40	193.88	176.09
25	626.19	579.81	453.62	392.75	340.07	302.75	272.40	247.77
50	769.75	722.21	588.01	515.52	463.33	426.40	389.06	357.98
100	925.41	880.41	728.68	634.97	578.84	536.46	496.13	461.67

4.5. Composite Hydrograph

Based on the LN (3P) distribution results, flood frequency distributions were derived for the rainfall-runoff discharges in a range of aggregation-levels which varies from 1 day to 15 days. They were summarized in the form of 'composite hydro-graphs'. These composite hydrographs are synthetigfc hydrographs constructed in such a way that the average discharge equals a specific return period for all durations that are considered centrally in the hydrograph. Figure 4.2 shows the composite hydrographs for various return periods. When the composite hydrographs are constructed, they are considered as the upstream boundary conditions. The use of composite hydrographs can thus be considered as an accurate and easy method to simulate specific safety levels along the river, on the basis of the two-dimensional flood modelling approach.

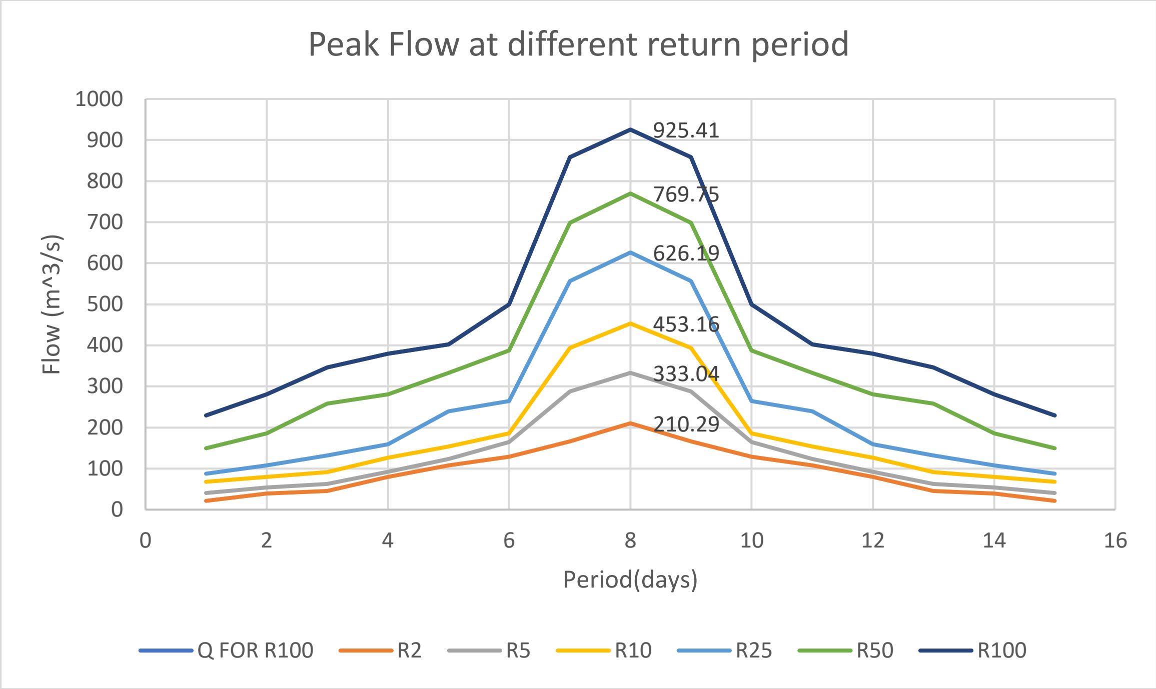


Figure 4.2: Composite hydrographs for Great Akaki River Catchment for return periods of 2, 5, 10,25, 50 and 100 years.

The recorded maximum peak flow which 693.102 m^3/s (Figure 4.1) is found between the peak flow value of 25 and 50 years return periods. So, this predict as recorded maximum peak flow will happen between 25 to 50 years from previous recorded period.

4.6. Flood Inundation Maps

4.6.1. Flood Inundation Boundary Map

The flood inundation map boundary provides a description of the areal extent of flooding which would be produced by the river flooding at different return periods. For this study flood inundation boundary map of the flood prone area was prepared by exporting inundation boundary result from the RAS Mapper to ARC-GIS as shape file. The total areal coverage of the flood was found 350 hectares which calculated in ArcGIS. Figure 4.3 presents flood inundation boundary map of the area for 100 years return periods.

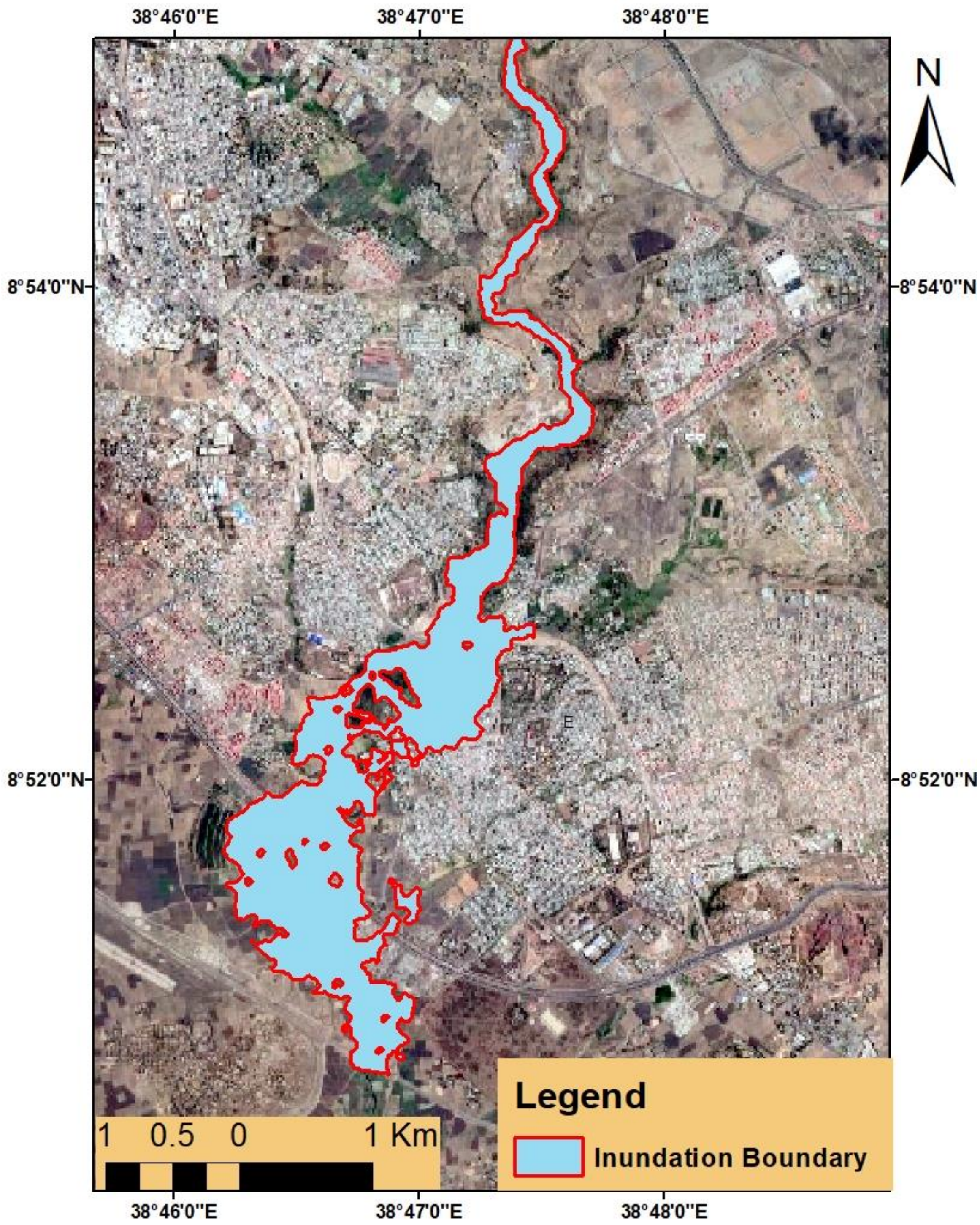
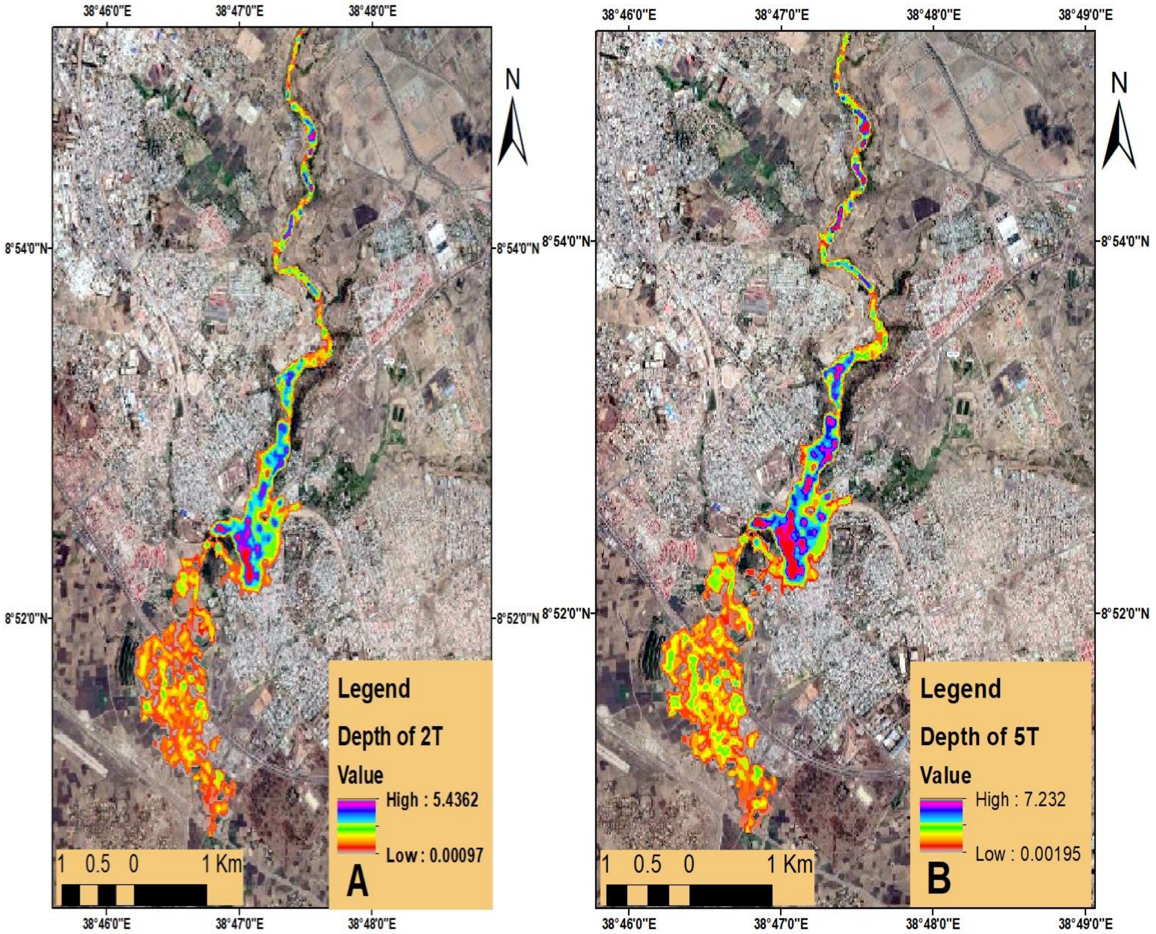


Figure 4.3: Flood inundation boundary map

4.6.2. Flood Inundation Depth Maps

Flood inundation depth is described as distance between water level and bed level. In flood inundation mapping accurate prediction of inundation levels at the places where there is infrastructure and population at risk is important task. For this study flood inundation depth map was prepared by exporting inundation depth Geo-tiff file (raster) from RAS Mapper to ArcGIS and overlie it to satellite image of study area. Figure 4.4 Shows flood inundation depth variation at different part of the flood plain area. The maximum flood inundation depth for 2, 5, 10, 25, 50, and 100 years return periods are 5.436m, 7.232m, 8.41m, 9.82m, 11.21m, and 13.98m respectively. This flood depth can cause severe damage to infrastructures, the peoples settled in the area and the irrigation command area at downstream of the Akaki Kaliti Sub-city.



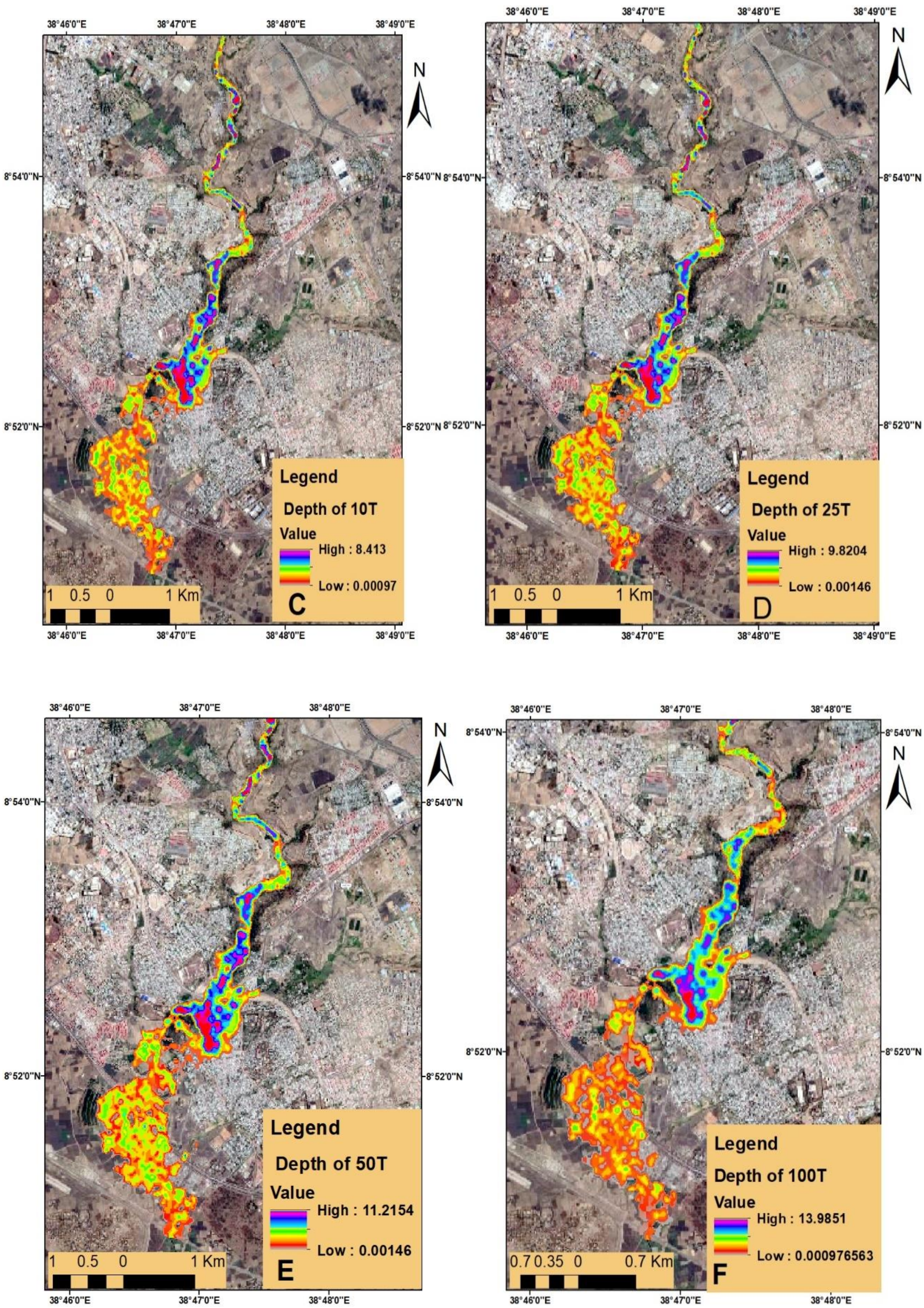
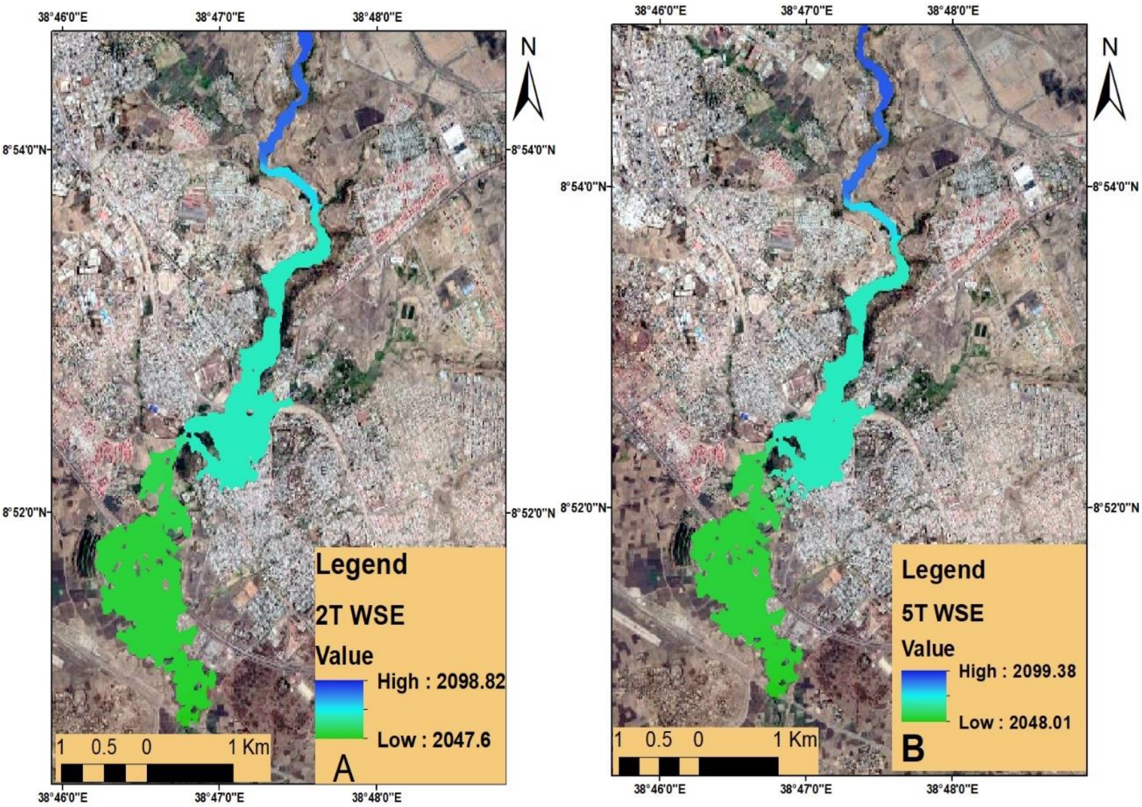


Figure 4.4: Flood inundation depth maps of A,B,C,D,E and F are for 2,5,10,25,50 and 100 years return periods respectively

4.6.3. Water Surface Elevation Maps

In unsteady flow analysis computed water surface profile can be exported from RAS Mapper to ArcGIS, and overlie on satellite image of study area. Figure 4.5 shows the water surface elevation of the flood plain area. The maximum and minimum water surface elevation were found figure below. Figure 4.5 presents water surface elevation of the flood plain area over lied on satellite image of study area. From the study it was also found that water surface elevation at the downstream, middle and upstream part of the flood plain area ranges from 2048.94 to2065.58m, 2065.58 to 282.86m and 2082.86 to 2102.66m a.m.s.l. respectively. The downstream and the middle one covers more than 90% of the flood inundated area. At these areas the water surface elevation was found nearly uniform. This is due to uniform topographic elevation of the flood plain area. The downstream one covers command area and the middle covers population settlement area.



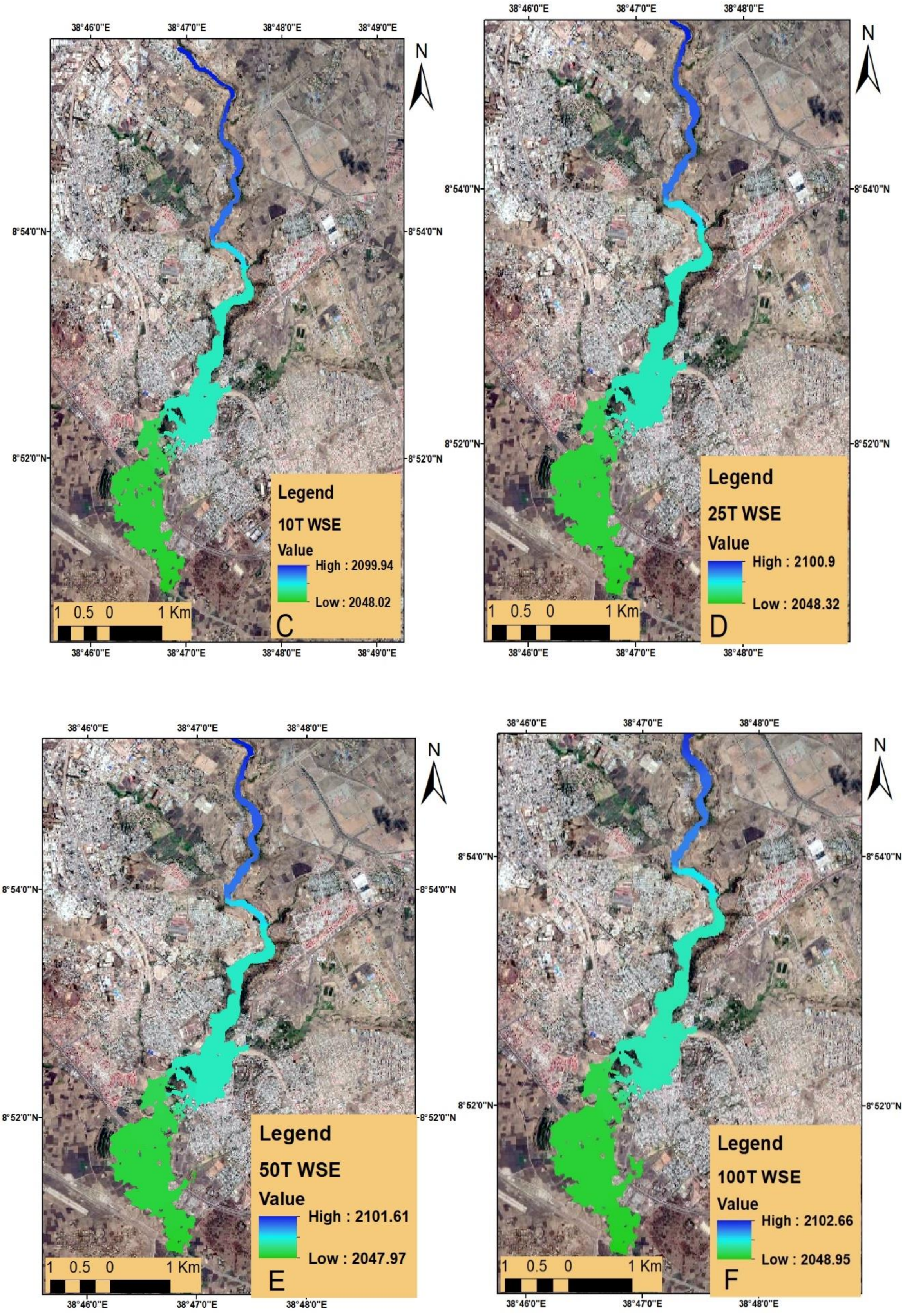
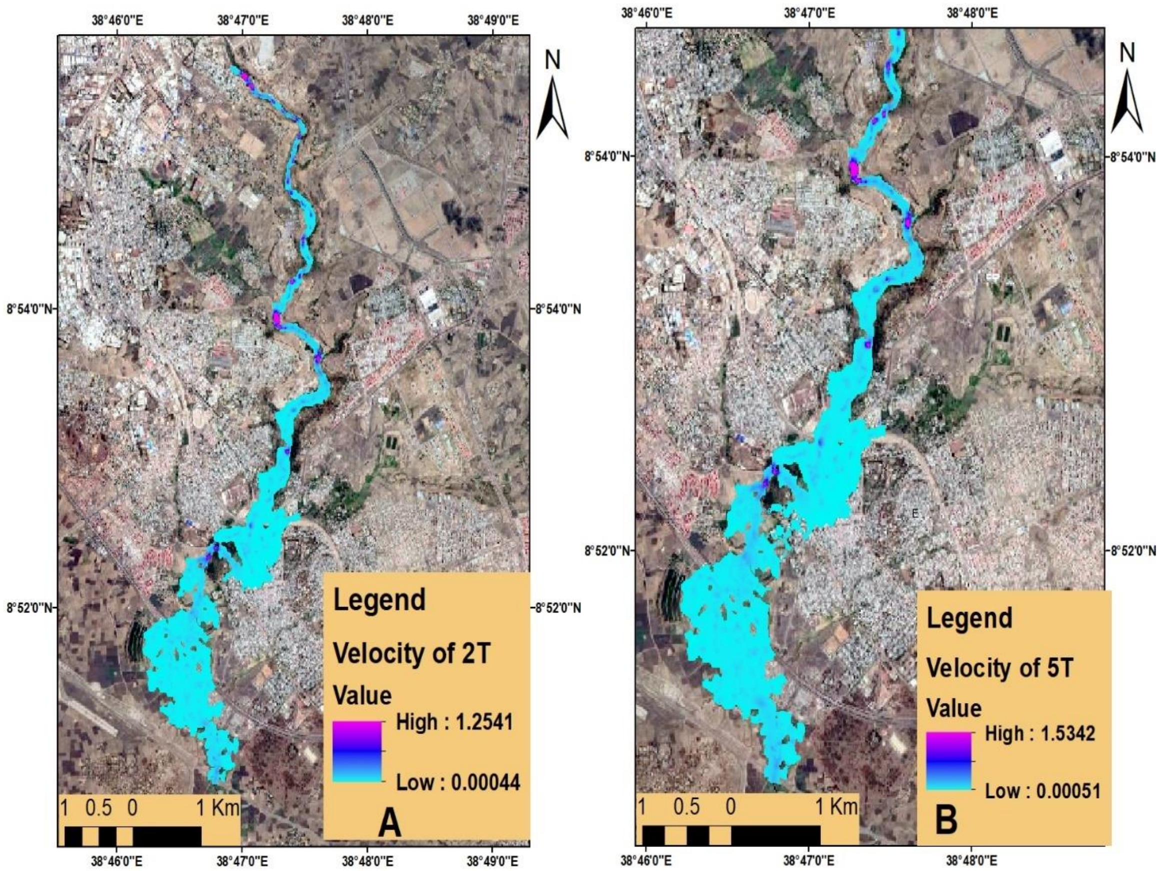


Figure 4.5: Flood inundation Water surface elevation maps A,B,C,D,E and F are for 2,5,10,25,50 and 100 years return periods respectively

4.6.4. Flood Flow Velocity Maps

In flood modeling velocity mapping is necessary to assess the damage caused by the flood. According to Kreibich et al. (2009) flow velocity is significant parameter in flood damage modeling. A flow velocity greater than 1m/s can cause structural damage of road infrastructure and residential buildings. For this study the maximum flood velocity of different return periods ranges from 1.25 to 4.54 m/s, and becomes zero at the final boundary of the flood plain area. Figure 4.6 presents velocity (m/s) map of the flood plain area. The maximum flood velocity for of 2,5,10,25,50 and 100 years return periods are 1.25,1.53,2.25, 2.86,3.72 and 4.54 m/s respectively. This maximum velocity found across river channel and minimum velocity found out of river channel.



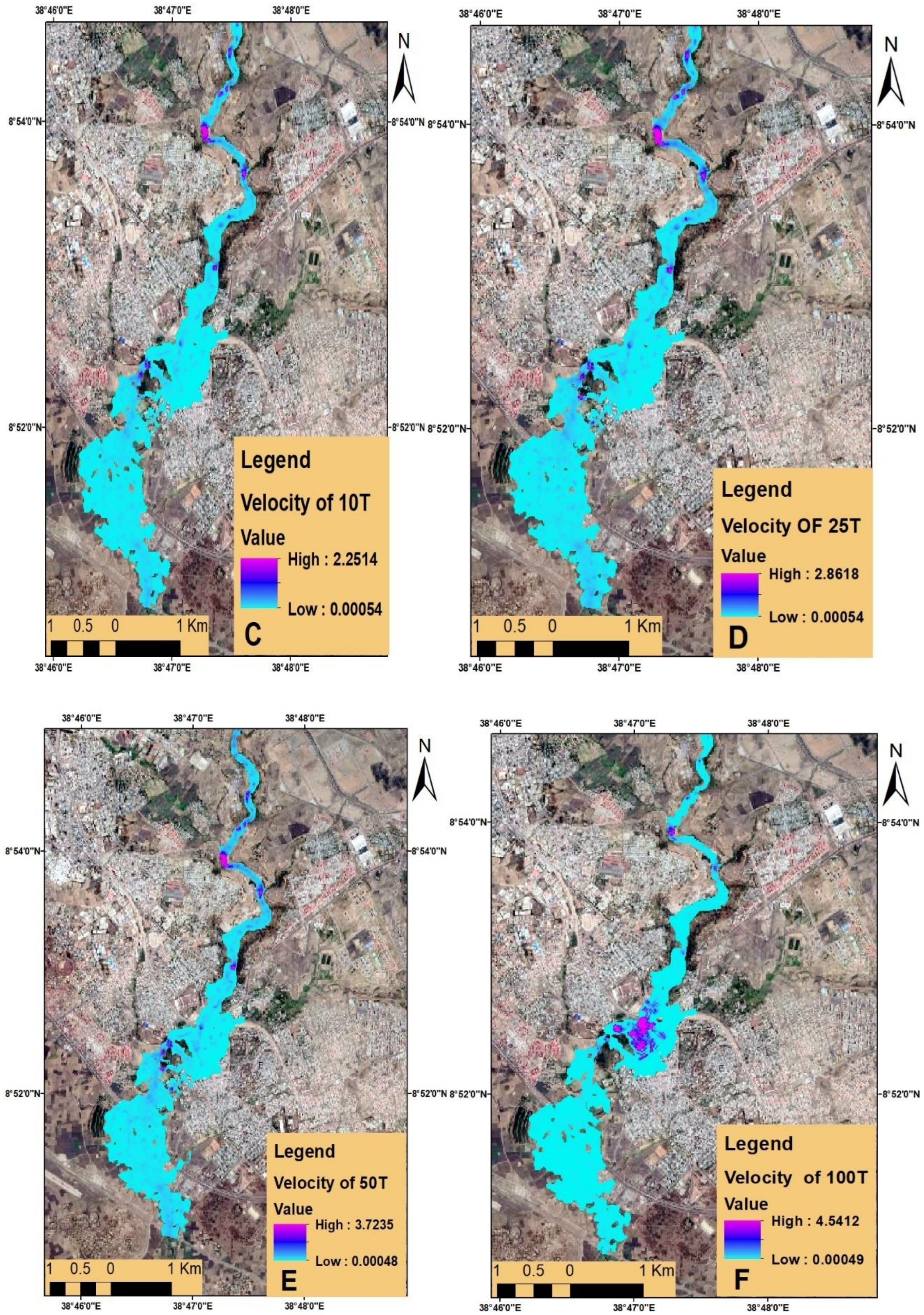


Figure 4.6: Flood inundation velocity maps in (m/s) A,B,C,D,E and F are for 2,5,10,25,50 and 100 years return periods respectively

4.7. Recent Flood Inundation Map of Great Akaki River

The recent floods on Aug 23,2018 and also Aug 15,2019 out of Great Akaki river in Akaki Kality sub-city affected the community settled around Great Akaki river. Flood inundation Map of this flood was developed using interviews of affected community, video recorded during flooding, debris hanged in trees, and the survey data collected by hand GPS. Then compare and contrast hand GPS point data with google satellite if there is point error, correct it using photo taken from the area and Google satellite. After correcting point data in google Earth, then change point data to polygon of inundated area. Comparing this polygon with the above flood inundation area maps of different return periods, the polygon fitted with flood inundation area of 5 years return periods. The height of flood was 7m from bottom river channel. During this flooding inundation area was 123 ha and 471 houses with 1413 people was vulnerable and 4 cattle were died.

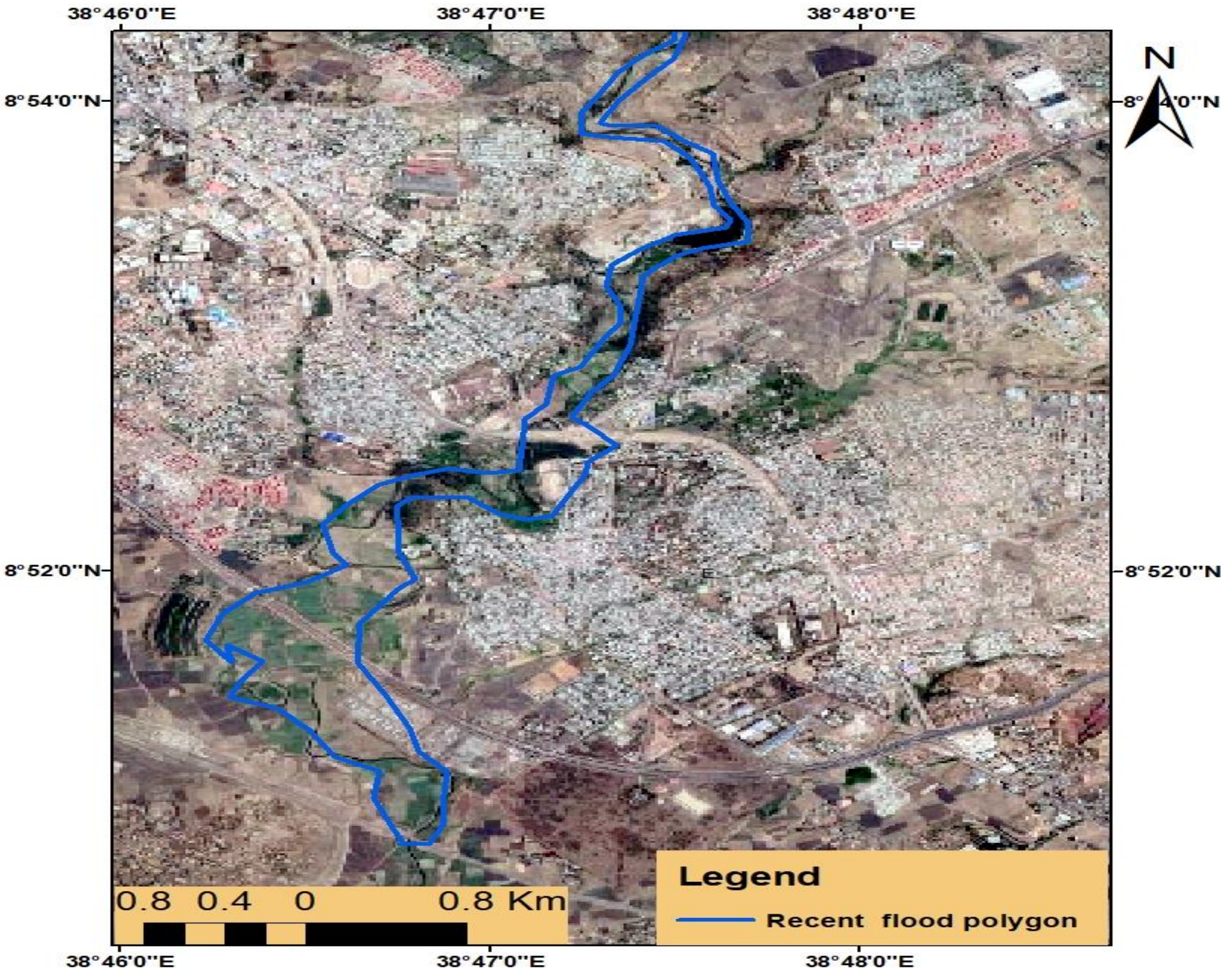


Figure 4.7: Map showing areal extent of recent flood

Figure 4.8: Photo showing the height of recent flood

The debris hanged on trees shows as 2.5m high above ground surface and the height of water recorded from bottom of the channel to ground surface is 4.5m. So, the total height of flood depth was 7m from the bottom of river channel.

4.8. Sensitivity analysis of manning roughness

Roughness is an important hydraulic parameter in the simulation of water surface. The simulated water depth is lower than the actual if the chosen roughness is higher than the actual value, On the contrary, it will be lower than the actual. The measured values of maximum water depth and inundated area were 7m and 123 ha respectively., and calculated values of maximum water depth and inundated area were 7.014m and 123ha respectively for 5 years return period with n-5%*n. The comparison of measured and calculated values shows that the errors between the measured results and the numerical values is less than 1%. It indicated that a good agreement with the model parameters for the entire course of the numerical calculation.

Table 4.3:Different manning roughness values for sensitivity analysis

Features	n values	n-5%*n	n-10%*n	n+5%*n	n+10%*n
Dense Grass	0.05	0.0475	0.045	0.0525	0.055
Dense Trees	0.15	0.1425	0.135	0.1575	0.165
Developed Area	0.012	0.0114	0.0108	0.0126	0.0132
Medium Dense Trees	0.07	0.0665	0.063	0.0735	0.077
Natural channel	0.048	0.0456	0.0432	0.0504	0.0528
Row Crop	0.035	0.03325	0.0315	0.03675	0.0385
Scattered Bush	0.05	0.0475	0.045	0.0525	0.055
Scattered Grass	0.03	0.0285	0.027	0.0315	0.033
Scattered Trees	0.05	0.0475	0.045	0.0525	0.055

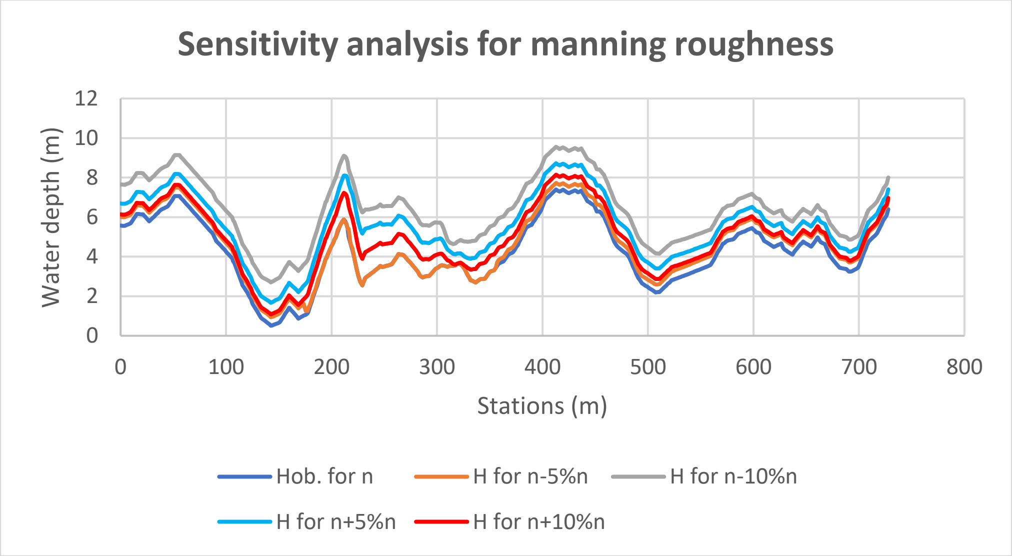


Figure 4.9:Sensitivity analysis for manning roughness.

Sensitivity analysis for manning roughness was done by fixing other parameters of HEC RAS 2D modeling which are computation interval, u/s and d/s boundary condition, and varying roughness. The manning roughness values of n-5%*n is the best fitted values for simulation of unsteady analysis.

4.9. Flood Risk Analysis

Flood Risk analysis is one of the vital tools for understanding and identifying the potential the risks in research area. Indeed, it can help to manage the risks and good decision making how to mitigate the risks. The flood risk takes into account the probability associated to flood event with their areal coverage and the vulnerability consider to the flood prone area characteristics related to the potential damage. Flood risk map for the study area is developed based on LULC, flood hazard and population density. As shown in the figure 4.10, the most risk vulnerable areas are found near river channel. In fact, these areas are found within the urban land cover and have more population density. Among the LULC, built up and cultivated lands lie with the most risk areas. For this study total inundated area was found to be 350 hectares as stated from section 4.6.1. From total area the inundated area coverage for irrigation command area, population settlement area and swamp area were found 78,34 and 238 hectares respectively. From the total areal coverage of the flood the population settlement area coverage accounts 27.68 % the remaining 18.38 % and 53.94 % accounts for irrigation command area and swamp area respectively. Figure 4.9 reveals the amount of buildings and inhabitants in hazard area for different return periods.

The flood inundation map of 100 years return period was overlie on high resolution rectified image as shown on Figure 4.9 so that the number of vulnerable houses already at risk could easily be counted. Hence, of the total number of vulnerable houses on the left bank looking in the direction of flow were 1340 whom totally with in the perimeter of the flood zone. However, vulnerable houses on the right bank only 121 houses were found at risk. Interview was taken from One hundred houses that affected by flood to know a number of people per house. According to interview a number of vulnerable people per house was three. According to Statistical report on the 2012 urban employment unemployment survey a number of people per house in Addis Ababa was four(CSA, 2008).For this study a number of vulnerable people per house was three because of Akaki Kality is sparsely populated area compared to overall Addis Ababa city.

Farm land area, Swamp area, Population settlement area in hectares, No. vulnerable houses and No. of vulnerable population for different return periods are presented in table 4.3.

Table 4.4: Elements at risk and its magnitudes.

Return Periods(years)	2	5	10	25	50	100
Peak Flow(m^3/s)	210.29	333.04	453.16	626.19	769.75	925.41
Flood inundation depth (m)	5.436	7.232	8.41	9.82	11.21	13.98
Inundated area(ha)	86	123	156	228	285	350
Farm land area (ha)	23	33	43	65	71	78
Swamp area (ha)	56	80	100	145	187	238
Population settled area (ha)	7	10	13	18	27	34
No. vulnerable houses	329	471	597	873	1090	1340
No. of vulnerable population (3 per house)	987	1413	1791	2619	3270	4020

Figure 4.10: Comparing number of vulnerable houses and population in hazard area for different return periods.

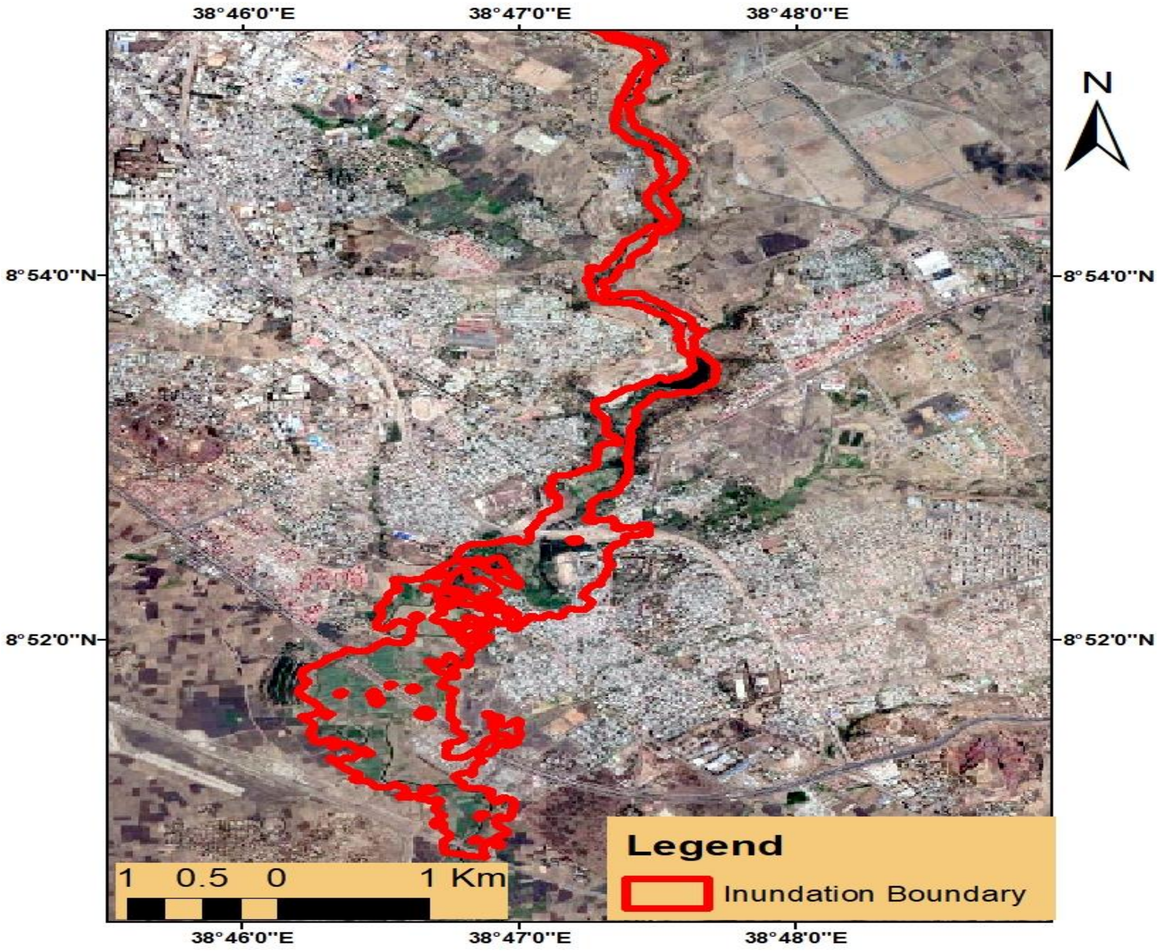


Figure 4.11: Flood inundation boundary Map of 100 years overlaid on high resolution satellite image

4.10. Flood Risk Mapping

Flood risk map is prepared from flood hazard map and flood vulnerability analysis as flood risk comprises hazard and vulnerability. By importing flood hazard map with its magnitudes in ArcGIS and result of vulnerability index in attribute table, the flood risk map was prepared.

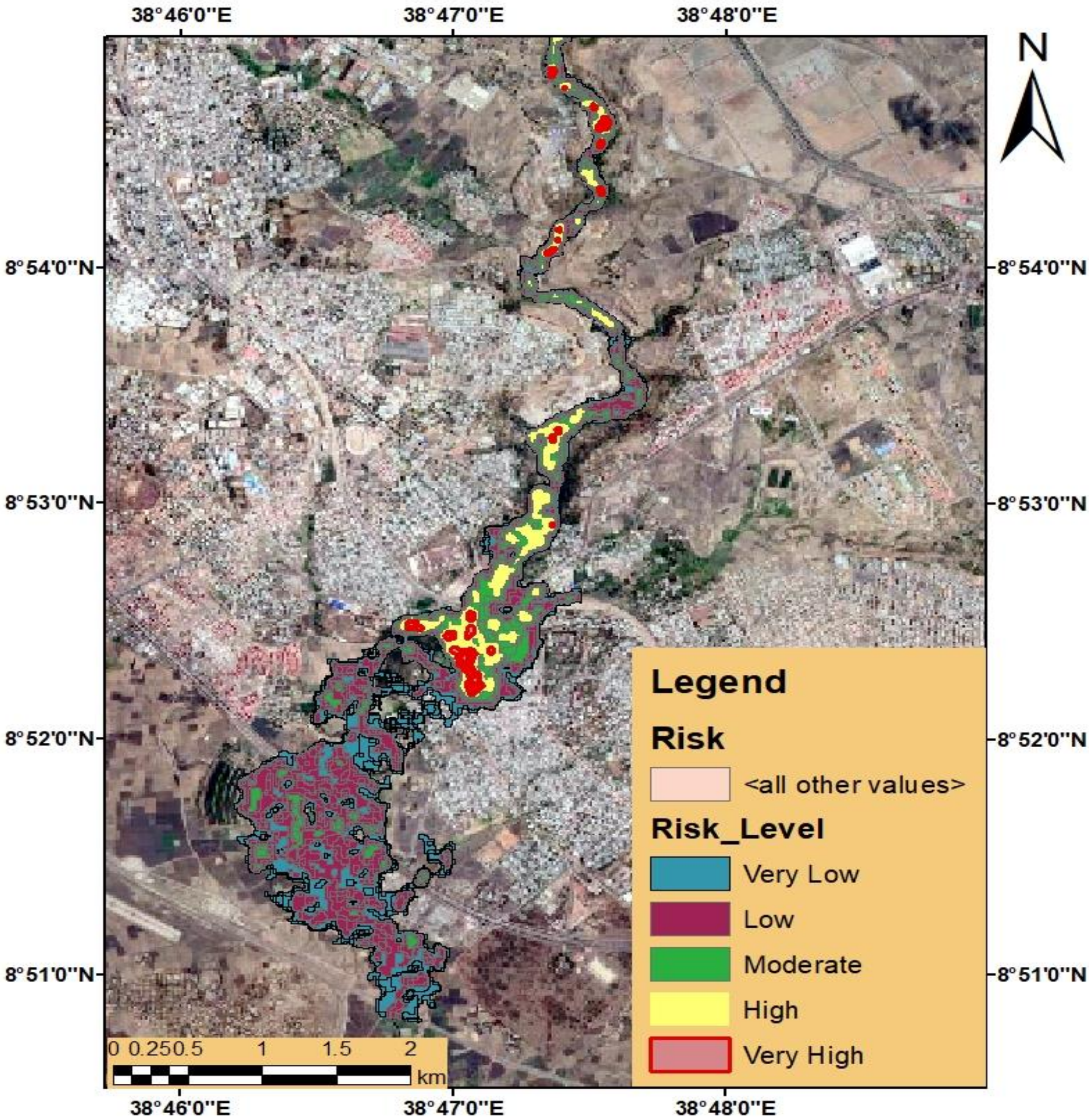


Figure 4.12: Flood Risk map of 100 years return period

The result of the risk map as shown above, the most flooded risky areas are found in near river channel represented by red and yellow colors. These areas also the most victims of flood hazard and characterized by most populations compared to adjacent flooded area. In contrast, the less flooded risky areas are found in downstream of Akaki Kality sub city which are characterized by less population density and irrigation command area. Based on flood hazard and vulnerability indicators the risk levels were identified is shown in Appendix F. Risk level identified as risk values from 0-0.0004 as very low, 0.0004-0.00998 as low, 0.00998-0.09206 as moderate, 0.09206-0.56402 as high and 0.56402-1 as very high.

4.11. Flood Protection Structures

The unsafe settlement areas were identified as shown in figure 4.14 following the perimeter of the mapped flood zone. Fortunately, the numbers of residence on the right bank were minimal compared to the settlers on the left bank. Existing Flood protection structure such us gabion structure constructed at upstream of bridge was with 1.5m height and 800m wide as shown in figure 4.12 to safe flood inundated area. This structure was not enough to resist coming flood. Appropriate flood protection structure should be construct at upstream and downstream of bridge at left side of river to reduce risks. The potential risks could be reduced by devising flood protection works such as dike, as one possible method. The preliminary alignment of the protection work is shown on the Figure 4.13. Along this preliminary alignment the water surface elevation and terrain profile are shown on Figure 4.15. Hence by having detailed design along this preliminary alignment the flood risk could be reduced to 5% or the people already at risk could be relocated to areas outside the perimeter shown in Figure 4.14.

Figure 4.13: Current existing flood protection works (gabion)

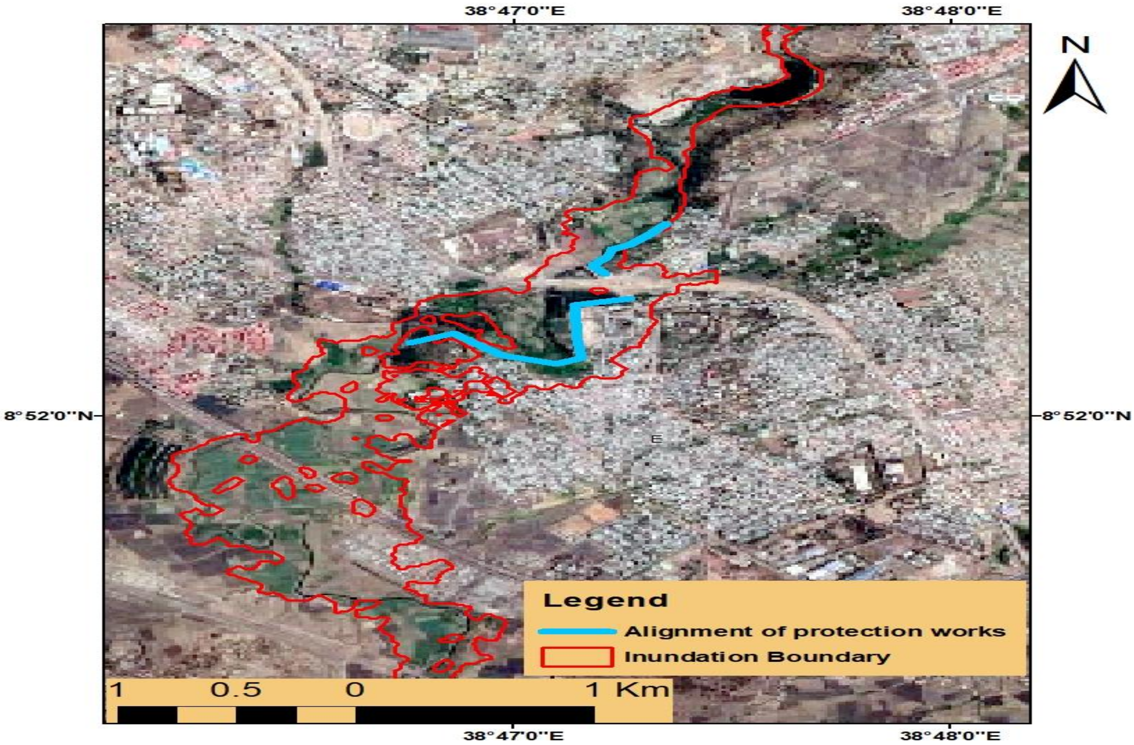


Figure 4.14: Preliminary Alignment of Protection Work.

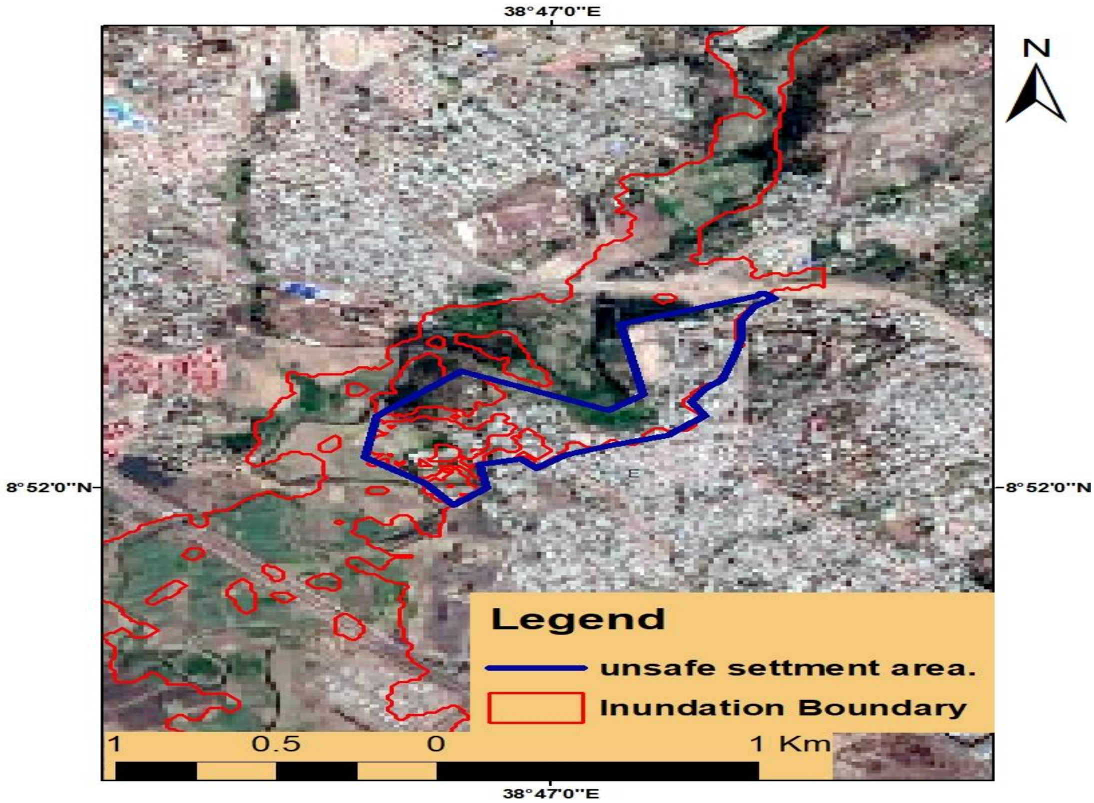


Figure 4.15: Map showing polygon of unsafe settlement area

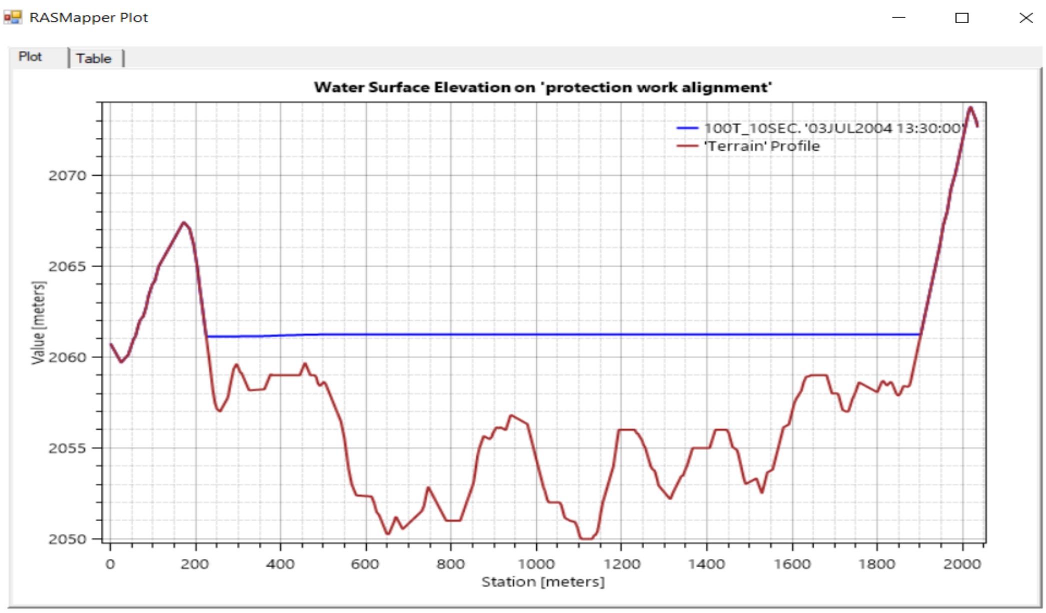


Figure 4.16: Water surface elevation and terrain profile on protection work alignment

This terrain profile shows the opening that flood could flow out of river channel to left bank of river. So, to safe this area, the opening or low level of terrain should close by constructing flood protection structures

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

Generally, the aim of this study was to develop flood inundation maps of Great Akaki river in Addis Ababa Akaki Kality sub city to provide valuable information to Area officials, emergency managers, and local residents for planning an emergency response and to identify flood zones. For the analysis different types of data have been gathered with the current recommended literature and models. The inflow hydrograph resulting from composite hydrograph analysis after the three-parameter lognormal distribution. The peak flow for the computed inflow hydrograph were 210.29, 333.04, 453.16, 626.19, 769.75, and 925.41 m3/s for 2, 5,10,25,50, and 100-years return periods respectively. The river hydraulics model HEC-RAS 5.0.5 two-dimensional modeling have been used to develop flood inundation maps for different return periods.

The areal extent of the flood due to river flooding for 100 years return period was found 350 hectares with maximum flood depth of 13.98 m, and maximum water surface elevation of 2102.66m a.m.s.l. As noticed from the flood inundation map the farm land area in downstream and population settled at left side of river are the most flood vulnerable areas for all return periods. Whereas, the flood has a little impact on population settled in upstream of study area. The prepared flood hazard and risk maps that show the flood extent and risky area for different return periods help the decision makers and local authorities to develop proper early warning system and emergency preparedness for flood plain areas in order counter act the ill effect of flooding.

Finally, structural flood mitigation measures that dike was proposed with its preliminary alignment which would reduce the flood risk and flood areal extent.

5.2. Recommendations

In order to prevent vulnerability of the irrigation command area in downstream and population settled at left side of river every stake holder, specially Area officials and emergency managers should participate. Based on the finding of the study outcomes the following recommendation are drawn

- Governments and key stakeholders should engage the local farmers and local authorities in making them aware of floods early warning systems.
- The flood affected areas should be free of permanent development structures,
- It better to resettle the peoples living flood inundated area by finding another safe settlement area,
- The irrigation command area should be free from permanent cropping,
- Area officials and emergency managers should take mitigation measures by constructing suitable structures across river at left side,
- Researchers also should give special attention to flood mapping analysis and mitigation measures on Great Akaki river and make a detail investigation by using the latest hydraulic software's.

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APPENDICES

Appendix A: Maximum Monthly Stream Flow Data at Great Akaki River

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An.Max. Flow(m^3/s)
1986	1.4	2.9	5.1	7.9	6.0	11.5	67.8	59.4	68.8	5.6	3.2	0.7	68.8
1987	0.9	2.3	9.8	23.4	36.6	7.9	24.4	35.1	8.7	2.1	1.2	1.2	36.6
1988	7.9	3.2	1.6	7.1	2.7	3.0	20.6	148.4	124.3	7.1	3.1	1.7	148.4
1989	1.1	4.6	4.6	22.8	2.0	10.9	80.5	233.8	133.4	5.0	1.7	2.4	233.8
1990	1.5	10.4	15.0	76.4	3.9	4.6	94.9	277.2	61.2	29.0	2.0	2.0	277.2
1991	1.7	4.4	5.6	9.9	4.4	18.9	102.7	124.3	215.2	5.8	3.5	9.9	215.2
1992	6.0	8.7	2.7	3.2	3.9	5.0	52.1	112.4	153.1	12.8	2.4	2.2	153.1
1993	2.2	10.2	1.7	34.2	21.1	37.3	189.5	403.5	573.6	83.7	15.5	14.1	573.6
1994	13.1	12.6	20.7	24.9	32.9	31.6	121.3	162.6	139.1	11.1	8.9	8.1	162.6
1995	8.1	24.9	15.8	40.2	40.2	33.3	53.8	258.0	124.9	10.2	7.9	7.7	258.0
1996	8.9	7.4	15.8	23.4	31.2	130.5	343.8	615.8	161.5	30.3	19.7	19.1	615.8
1997	26.4	17.5	19.4	22.0	25.2	36.4	83.7	276.3	59.1	30.3	17.8	12.1	276.3
1998	23.4	27.5	16.6	19.1	71.8	45.2	277.8	421.5	316.7	134.3	18.8	16.3	421.5
1999	18.1	15.2	20.4	18.1	16.9	43.1	138.1	693.1	50.4	14.6	7.9	6.8	693.1
2000	6.4	2.3	2.8	18.0	20.2	9.7	51.1	255.8	46.3	13.4	6.0	2.0	255.8
2001	1.9	2.4	9.5	14.9	21.0	32.0	383.7	435.3	135.3	3.1	2.1	1.9	435.3
2002	3.0	2.6	8.1	15.6	4.2	10.4	219.9	105.0	52.6	2.1	1.4	2.6	219.9
2003	2.0	8.2	2.2	5.4	3.3	8.0	110.9	420.1	104.2	8.8	3.7	7.5	420.1
2004	5.6	4.4	10.8	15.2	4.4	10.4	157.2	169.8	250.5	8.8	3.8	3.7	250.5

Appendix B: WETS Pro. Software Results (POT Values)

No.	Time at POT Values	POT Values	Time at previous minimum	sta.dev.	No.	Time at POT Values	POT Values	Time at previous minimum	sta.dev.
1	211	67.82	1	13.89	34	3919	89.70	3911	10.94
2	236	55.83	214	15.50	35	4215	83.73	4142	11.74
3	251	68.78	247	13.76	36	4247	276.32	4218	14.23
4	510	36.55	489	18.10	37	4269	59.10	4263	15.06
5	956	148.35	653	3.03	38	4518	71.81	4468	13.35
6	991	124.28	982	6.27	39	4581	277.76	4532	14.42
7	1299	80.49	1159	12.18	40	4604	361.96	4591	25.78
8	1330	233.77	1316	8.49	41	4620	421.52	4611	33.81
9	1357	85.20	1352	11.54	42	4633	316.73	4621	19.68
10	1558	76.39	1392	12.73	43	4648	77.29	4647	12.61
11	1697	277.22	1639	14.35	44	4666	134.29	4657	4.92
12	1728	61.21	1716	14.78	45	4931	132.38	4855	5.18
13	2030	102.68	1908	9.19	46	4947	138.14	4934	4.40
14	2048	119.48	2042	6.92	47	4972	693.10	4962	70.43
15	2074	215.22	2052	5.99	48	4990	235.38	4986	8.71
16	2408	84.15	2266	11.68	49	5011	50.43	5009	16.23
17	2431	112.42	2430	7.87	50	5302	40.51	5242	17.57
18	2455	153.07	2453	2.39	51	5350	255.78	5304	11.46
19	2767	189.48	2587	2.52	52	5386	46.29	5369	16.79
20	2801	573.57	2780	54.31	53	5665	99.31	5582	9.64
21	2816	241.67	2810	9.56	54	5693	435.34	5668	35.67
22	2831	83.73	2830	11.74	55	5709	107.33	5698	8.56
23	3130	121.28	3024	6.68	56	5724	135.31	5718	4.79
24	3149	162.58	3147	1.11	57	6055	219.87	5890	6.62
25	3165	115.93	3159	7.40	58	6081	71.24	6061	13.43
26	3188	139.12	3184	4.27	59	6401	52.10	6256	16.00
27	3483	53.84	3316	15.77	60	6416	110.95	6402	8.07

28	3517	257.98	3489	11.75	61	6443	420.06	6428	33.61
29	3531	124.92	3529	6.19	62	6460	73.02	6456	13.18
30	3548	77.99	3545	12.51	63	6779	157.18	6638	1.84
31	3819	130.49	3780	5.43	64	6810	169.75	6784	0.14
32	3884	615.76	3837	60.00	65	6824	250.47	6822	10.74
33	3906	161.52	3904	1.25	66	6845	55.80	6843	15.51

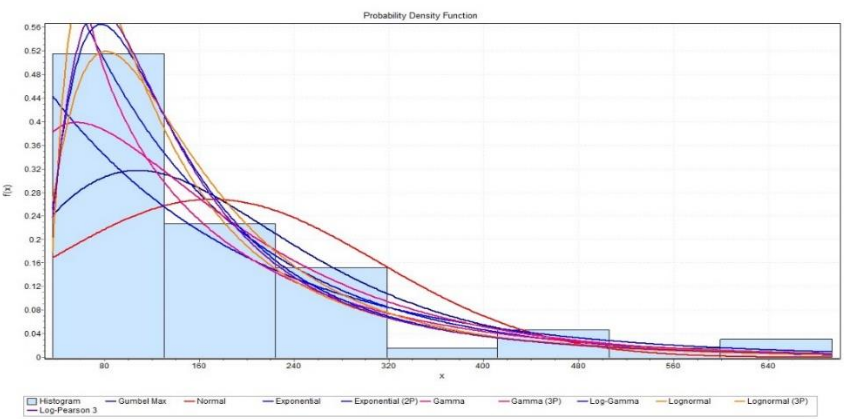
Appendix C: Easy Fit outputs

Table C1: Parameters of the distribution

Fitting Results

#	Distribution	Parameters
1	Exponential	λ=0.00585
2	Exponential (2P)	λ=0.00745 γ=36.554
3	Gamma	α=1.498 β=114.02
4	Gamma (3P)	α=0.73672 β=172.72 γ=36.554
5	Gumbel Max	σ=108.81 μ=107.99
6	Log-Gamma	α=48.8 β=0.10008
7	Log-Pearson 3	α=23.386 β=0.14457 γ=1.503
8	Lognormal	σ=0.69383 μ=4.8841
9	Lognormal (3P)	σ=0.93388 μ=4.5515 γ=27.745
10	Normal	σ=139.55 μ=170.8

Table C2: Graphs of the distributions



Appendix D: Manning's roughness coefficient value (Chow, 1959)

Table A 1: -Recommended design values of manning roughness coefficients

	Manning n Range[b]
I. Unlined open channels[c]	
A. Earth, uniform section	
1. Clean, recently completed	0.016–0.018
2. Clean, after weathering	0.018–0.020
3. With short grass, few weeds	0.022–0.027
4. In graveled soil, uniform section, clean	0.022–0.025
B. Earth, fairly uniform section	
1. No vegetation	0.022–0.025
2. Grass, some weeds	0.025–0.030
3. Dense weeds or aquatic plants in deep channels	0.030–0.035
4. Sides, clean gravel bottom	0.025–0.030
5. Sides, clean, cobble bottom	0.030–0.040
C. Dragline excavated or dredged	
1. No vegetation	0.028–0.033
2. Light brush on banks	0.035–0.050
D. Rock	
1. Based on design section	0.035
2. Based on actual mean section	
a. Smooth and uniform	0.035–0.040
b. Jagged and irregular	0.040–0.045
E. Channels not maintained, weeds and brush uncut	
1. Dense weeds, high as flow depth	0.08–0.12
2. Clean bottom, brush on sides	0.05–0.08
3. Clean bottom, brush on sides, highest stage of flow	0.07–0.11
4. Dense brush, high-stage	0.10–0.14
II. Roadside channels and swales with maintained vegetation[d,e] (values shown are for velocities of 2 and 6 ft/sec):	
A. Depth of flow up to 0.7 ft	
1. Bermuda grass, Kentucky bluegrass, buffalo grass	
a. Mowed to 2 in.	0.07–0.045
b. Length 4 to 6 in.	0.09–0.05
2. Good stand, any grass	
a. Length about 12 in.	0.18–0.09
b. Length about 24 in.	0.30–0.15
3. Fair stand, any grass	
a. Length about 12 in.	0.14–0.08
b. Length about 24 in.	0.25–0.13

	Manning *n* Range[b]
B. Depth of flow 0.7–1.5 ft	
1. Bermuda grass, Kentucky bluegrass, buffalo grass	
a. Mowed to 2 in.	0.05–0.035
b. Length 4 to 6 in.	0.06–0.04
2. Good stand, any grass	
a. Length about 12 in.	0.12–0.07
b. Length about 24 in.	0.20–0.10
3. Fair stand, any grass	
a. Length about 12 in.	0.10–0.06
b. Length about 24 in.	0.17–0.09
III. Natural stream channels[f]	
A. Minor streams[g] (surface width at flood stage less than 100 ft)	
1. Fairly regular section	
a. Some grass and weeds, little or no brush	0.030–0.035
b. Dense growth of weeds, depth of flow materially greater than weed height	0.035–0.05
c. Some weeds, light brush on banks	0.04–0.05
d. Some weeds, heavy brush on banks	0.05–0.07
e. Some weeds, dense willows on banks	0.06–0.08
f. For trees within channel, with branches submerged at high stage, increase all above values by	0.01–0.10
2. Irregular sections, with pools, slight channel meander; increase value in la-e by	0.01–0.02
3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage	
a. Bottom of gravel, cobbles, and few boulders	0.04–0.05
b. Bottom of cobbles, with large boulders	0.05–0.07
B. Floodplains (adjacent to natural streams)	
1. Pasture, no brush	
a. Short grass	0.030–0.035
b. High grass	0.035–0.05
2. Cultivated areas	
a. No crop	0.03–0.04
b. Mature row crops	0.035–0.045
c. Mature field crops	0.04–0.05
3. Heavy weeds, scattered brush	0.05–0.07
4. Light brush and trees[h]	
a. Winter	0.05–0.06
b. Summer	0.06–0.08

Appendix E: Roughness Values determination


Medium dense trees,n=0.07
Scattered trees,n=0.05
Dense grass,n=0.05
Scattered grass,n=0.03
Scattered bush,n=0.05
Scattered bush,n=0.05

Appendix F: Risk Level Analysis

Depth	Pro. Depth	Area	Pro. Area	No. of houses	Vul.1	No. of Pop.	Vul.2	Vulnerability	Risk	Risk Level
0	0.0000	0	0.0000	0	0.0000	0	0.0000	0.0000	0.00000	V. Low
1	0.0667	0	0.0000	0	0.0000	0	0.0000	0.0000	0.00000	V. Low
2	0.1333	15	0.0429	56	0.0418	168	0.0418	0.0017	0.00001	V. Low
3	0.2000	23	0.0657	75	0.0560	225	0.0560	0.0031	0.00004	V. Low
4	0.2667	58	0.1657	150	0.1119	450	0.1119	0.0125	0.00055	Low
5	0.3333	86	0.2457	329	0.2455	987	0.2455	0.0603	0.00494	Low
6	0.4000	102	0.2914	392	0.2925	1176	0.2925	0.0856	0.00998	Low
7	0.4667	123	0.3514	471	0.3515	1413	0.3515	0.1235	0.02026	Medium
8	0.5333	156	0.4457	597	0.4455	1791	0.4455	0.1985	0.04718	Medium
9	0.6000	186	0.5314	720	0.5373	2160	0.5373	0.2887	0.09206	Medium
10	0.6667	228	0.6514	873	0.6515	2619	0.6515	0.4244	0.18433	High
11	0.7333	285	0.8143	1090	0.8134	3270	0.8134	0.6617	0.39511	High
12	0.8000	315	0.9000	1186	0.8851	3558	0.8851	0.7834	0.56402	High
13	0.8667	328	0.9371	1234	0.9209	3702	0.9209	0.8480	0.68878	V. High
14	0.9333	334	0.9543	1275	0.9515	3825	0.9515	0.9053	0.80635	V. High
15	1.0000	350	1.0000	1340	1.0000	4020	1.0000	1.0000	1.00000	V. High

Appendix G: Field Survey photos