



FLOOD INUNDATION MODELING AND RISK MAPPING OF BIG  
AKAKI RIVER, ADDIS ABABA, ETHIOPIA

MSc THESIS

GIZACHEW MUSIE ALENBO

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

JULY, 2023

FLOOD INUNDATION MODELING AND RISK MAPPING OF BIG  
AKAKI RIVER, ADDIS ABABA, ETHIOPIA

GIZACHEW MUSIE ALENBO

A THESIS SUBMITTED TO THE  
DEPARTMENT OF HYDRAULIC AND WATER RESOURCES  
ENGINEERING,  
HAWASSA INSTITUTE OF TECHNOLOGY, SCHOOL OF  
GRADUATE STUDIES  
HAWASSA UNIVERSITY  
HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE  
REQUIREMENTS FOR THE  
DEGREE OF

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

JULY, 2023

**ADVISORS' APPROVAL SHEET**  
**SCHOOL OF GRADUATE STUDIES**  
**HAWASSA UNIVERSITY ADVISORS' APPROVAL SHEET**

This is to certify that the thesis entitled “FLOOD INUNDATION MODELING AND RISK MAPPING OF GREAT AKAKI RIVER ADDIS ABABA, ETHIOPIA” submitted in partial fulfillment of the requirements for the degree of Master’s with specialization in Hydraulic Engineering the Graduate Program of the Department of HYDRAULIC AND WATER RESOURCES ENGINEERING, and has been carried out by GIZACHEW MUSIE ID. No GPHydr/0005/12 under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Alemu Osore (PhD)

Name major advisor

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

Petros Yohannes (M.Sc.)

Name of co-advisor

\_\_\_\_\_  
Signature

\_\_\_\_\_  
Date

**EXAMINERS' APPROVAL SHEET**  
**SCHOOL OF GRADUATE STUDIES**  
**HAWASSA UNIVERSITY EXAMINERS' APPROVAL SHEET**

We, the undersigned, members of the Board of Examiners of the final open defense by GIZACHEW MUSIE ALENBO have read and evaluated his MSc thesis entitled “FLOOD INUNDATION MODELING AND RISK MAPPING OF GREAT AKAKI RIVER ADDIS ABABA, ETHIOPIA”, and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree.

Alemu Osore (PhD)

Name of Major advisor

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

Moltot Zewdie (Asso. Prof)

Name of Internal Examiner-I

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

Gonse Amalo (MSc)

Name of Internal Examiner-II

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

Fikru Fentaw (PhD)

Name of External Examiner



Signature

12/12/2023

Date

\_\_\_\_\_

SGS Approval

\_\_\_\_\_

Signature

\_\_\_\_\_

Date

## **ACKNOWLEDGMENT**

First and foremost my thanks go to the ‘Almighty God’, for every blessing and entire gift that he enriched me within my entire life. I would like to express my deepest gratitude to my advisors Dr. Alemu Osore and Petros Yohannes, for their devoted criticism, close monitoring, and supervision of the thesis work.

Finally, I would want to express my gratitude to my family for their unwavering love and support over the course of my entire life.

I am so satisfied to my classmates in all our harmonization from start to end of this MSc Program in Hawassa University.

At the last, but not least, I am very proud of my lovely family for their love, support and they are truly a special gift from God for me; and I don’t forget my close friends support and encouragements.

## ACRONYMS

AMS.....	Annual Maximum Series
BC .....	Boundary Condition
DEM.....	Digital Elevation Model
EWS.....	Early Warning Systems
FVI.....	Flood Vulnerability Index
GIS.....	Geographic Information System
HEC-RAS.....	Hydrologic Engineering Center river analysis system
LULC.....	Land Use Land Cover
MoWE.....	Ministry of Water and Energy
PMP.....	Probable Maximum Precipitation
PoT .....	Peaks over Threshold
TIN.....	Triangulated Irregular Network
USD.....	United State Dollar
SUDs.....	Sustainable Drainage Systems
1D.....	One Dimensional
2D.....	Two Dimensional

## TABLE OF CONTENTS

<b>ACKNOWLEDGMENT</b> .....	<b>iv</b>
<b>ACRONYMS</b> .....	<b>v</b>
<b>LIST OF TABELS</b> .....	<b>ix</b>
<b>LIST OF FIGURES</b> .....	<b>ix</b>
<b>DECLARATION</b> .....	<b>x</b>
<b>ABSTRACT</b> .....	<b>xi</b>
<b>1. INTRODUCTION</b> .....	<b>1</b>
1.2. Statement of the Problem .....	3
1.3. Objective .....	5
1.3.1. Main objective.....	5
1.3.2. Specific Objectives .....	5
1.4. Research Questions .....	5
1.5. Scope of the study .....	5
1.6. Significance of the study .....	5
<b>2. LITERATURE REVIEW</b> .....	<b>7</b>
2.1. General overview of floods at global level .....	7
2.2. Floods in Ethiopia and associated effects.....	8
2.3.1. Flash Floods .....	11
2.3.2. River Floods.....	11
2.4. Modeling techniques .....	12
2.3.1. Rainfall Runoff Model.....	12
2.4.2. Sensitivity analysis.....	15
2.5. Model selection criteria .....	16
2.6. Boundary conditions.....	16
2.7. Flood inundation mapping.....	17
2.8. Flood Hazard mapping .....	17
2.9. Flood Vulnerability Analysis .....	17
2.10. Flood risk mapping .....	18
2.11. Flood mitigation measures.....	18
2.12. Gaps on previous studies .....	22
<b>3. MATERIALS AND METHODS</b> .....	<b>24</b>
3.1. Study area description .....	24

3.1.1.	Location .....	24
3.1.2.	Soils.....	25
3.1.3.	Climate .....	25
3.1.4.	Land use land cover .....	26
3.1.5.	Topography .....	27
3.2.	Methods .....	27
3.2.1.	Data collection .....	27
3.2.2.	Hydrologic data.....	27
3.2.3.	Hydraulic Data .....	30
3.3.	Hydrodynamic Modeling technique.....	30
3.3.1.	MIKE Flood model .....	32
3.3.2.	HEC-RAS model.....	32
	Two-dimensional numerical models.....	34
3.3.3.	HECRAS Model development.....	35
3.3.4.	Basic procedures in HEC RAS 2D model .....	35
3.3.5.	Unsteady flow analysis .....	37
3.4.	Flood Hazard Analysis .....	38
3.5.	Flood vulnerability map .....	39
3.5.1.	Selection of flood vulnerability indicators.....	40
3.5.2.	Data arrangements and normalization of indicators .....	41
3.6.	Flood Risk Analysis .....	42
<b>4.</b>	<b>RESULTS AND DISCUSSION .....</b>	<b>43</b>
4.1.	Flood inundation map.....	43
4.2.	Flood depth map.....	44
4.3.	Flood Velocity Maps .....	46
4.4.	Sensitivity Analysis of HECRAS model.....	47
4.5.	Model calibration .....	49
4.6.	Model evaluation.....	49
4.5.	Flood hazard mapping .....	50
4.5.1.	Flood Hazard Classification.....	51
4.6.	Flood Vulnerability Map .....	53
4.7.	Flood Risk Map .....	54
4.8.	Flood risk reduction through Mitigation and Management Options.....	56

4.8.1. Structural Measures of Flood Risk and Vulnerability Reduction .....	56
<b>5. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>58</b>
5.1. Conclusions .....	58
5.2. Recommendations .....	60
<b>6. REFERENCES .....</b>	<b>61</b>
<b>7. APPENDIX.....</b>	<b>68</b>

## LIST OF TABELS

Table 3.1: Goodness of Fit – Summary .....	28
Table 3.2: Fitting Results from easy fit model.....	29
Table 3.3: Flood vulnerability indicators and data sources .....	40
Table 4.1:Flood Depth and Velocity Severity Grid Categories source: FEMA (2018).....	52

## LIST OF FIGURES

Figure 3.1: Location map of the study area .....	24
Figure 3.2: Soil map of the study area .....	25
Figure 3.3: Land use land-cover of Great Akaki catchment.....	26
Figure 3.4: Inflow flood hydrograph for different return period .....	30
Figure 3.5: Geometric editor window .....	36
Figure 3.6: Conceptual 2D model diagrams for floodplain mapping in HEC-RAS .....	38
Figure 4.1: Flood Inundation boundary of Great Akaki river for different return periods ..	44
Figure 4.2: flood depth maps for different return periods.....	45
Figure 4.3: flood velocity maps for different return period .....	47
Figure 4.4 : Flood hazard category .....	51
Figure 4.5: Flood hazard mapping .....	53
Figure 4.6: Flood vulnerability map .....	54
Figure 4.7: Flood risk map of Great Akaki River .....	55
Figure 4.8: Unsafe settlements and proposed levee along unsafe settlements.....	57
Figure 4.9: Sensitivity Analysis of manning’s roughness along Levee structure.....	48
Figure 4.10: Calibrated result of WSE for manning’s roughness N+10%N.....	49
Figure 4.11: Goodness of fit for simulated and observed values of WSE.....	50

## **DECLARATION**

I hereby declare that this MSc thesis is my original work and that has not been presented for a degree in any other university and all sources of material used for this thesis have been duly acknowledged.

Name: Gizachew Musie Alenbo

Signature: \_\_\_\_\_

Date: \_\_\_\_\_

## **ABSTRACT**

*The occurrence of floods as natural disasters has severe consequences worldwide, including loss of life, the spread of diseases, property damage, economic hardships, and social and psychological impacts on affected individuals. This study focused on modeling and analyzing the flood inundation and associated risks of the Akaki River, located in Addis Ababa, the capital city of Ethiopia. The primary objective of this study was to create models and maps that depict the extent of flood inundation and the risks associated with flooding events. To accomplish this, both primary field data and secondary data from various sources was collected. The materials utilized in this study included the HEC-RAS model, GIS software, GPS, and metering tape. The study involved conducting a hydrologic flood frequency analysis for different return periods, which served as input for flood inundation modeling and risk analysis. The HEC-RAS model was employed to develop flood inundation, flood hazard, flood vulnerability, and flood risk maps, which were subsequently mapped using ARC-GIS software. The results of the study revealed that the areas affected by floods varied depending on the return period. For return periods of 10, 25, 50, 100, and 200 years, the areas inundated by floods were measured to be 7.58 km<sup>2</sup>, 9.79 km<sup>2</sup>, 11.2 km<sup>2</sup>, 12.45 km<sup>2</sup>, and 13.83 km<sup>2</sup>, respectively. The study also determined the maximum flood depths and velocities for each return period, with values ranging from 10.21 to 15.02 meters and 3.12 to 5.26 meters per second, respectively. Based on the flood hazard map for the 200-year return period, it was identified that approximately 13.7% of the total flooded area was categorized as an extreme hazard, rendering it unsafe for all individuals, vehicles, and structures vulnerable to flooding. Additionally, 17.6%, 16.7%, 18.9%, and 33.1% of the total area fell under the categories of very high, high, medium, and low hazards, respectively. The flood vulnerability map highlighted five levels of vulnerability, ranging from very low to very high. The very high and high vulnerability classes covered 9.59% (1.21 km<sup>2</sup>) and 15.54% (1.96 km<sup>2</sup>) of the flooded area, respectively. Furthermore, the flood risk was classified into five levels, revealing that 3.6%, 12.6%, 18.5%, 19.8%, and 45.5% of the flooded area were associated with very high, high, moderate, low, and very low risks, respectively. Considering the high risk and danger posed, particularly to residents residing in the flood buffer zone, a proposed solution to protect the area from flood hazards involved the construction of a 5.83 km levee embankment along the settlements on the left side of the river, specifically in areas with high population density. Finally, the performance of the HEC-RAS model was evaluated using model evaluation statistics, resulting in a coefficient of determination (R<sup>2</sup>) value of 0.94 for the water surface elevation, indicating a strong correlation between observed and simulated data. This study provides valuable insights into the flood dynamics, risks, and vulnerabilities associated with the Big Akaki River in Addis Ababa. The findings can inform decision-making processes aimed at mitigating the impacts of floods, protecting vulnerable populations, and enhancing overall flood management strategies in the area.*

**Keywords:** ARC-GIS, HEC-RAS, GPS, Akaki River

# 1. INTRODUCTION

## 1.1. Background

Natural disasters throughout the world are causing the death of people, spreading disease, damaging property, harming economically, and affecting people socially and psychologically. Floods are among the most destructive water-related hazards and are the main ones responsible for the loss of human lives, infrastructure damages, and economic losses (Gebreselassie, M., Belete, G. and Belayneh, 2018). Flooding in Ethiopia is the second major natural hazard next to drought; causes significant damage to the lives, and physical, natural, and economic assets of the country. Flooding is mainly linked to torrential rainfall and the topography of the highland mountains and lowland plains with natural drainage systems formed by the principal river basins (Ndrmc, 2016). However, intensive rainfall in the highlands causes flooding of settlements in the lowland flat parts of the country close to any stretch of river courses.

Ethiopia experiences two categories of floods; river and flash floods. River floods occur due to over flow or bursting river banks and inundate areas along the banks in lowland flood plains. River floods pose a serious threat to millions of people living in river basins worldwide. At the national level, extreme floods may bring back development by some years (Pauw et al., 2010) and threaten national food security (Carlo del Ninno, Paul A. Dorosh, 2003). At the household level, a flood may leave people without shelter (Hernandez-Guerrero et al., 2012), limit possibilities to get involved in economic activities (Linnekamp et al., 2011), and may increase the burden of diseases (Nyakundi et al., 2010; McCann et al., 2011). The severity of flood impacts may further increase in the future due to climate change. In many places, climate change will not only manifest itself as a gradual change in average conditions, but also as a change in the frequency and intensity of extreme events, such as heavy rainfall or drought, or periods of extreme heat or cold (IPCC, 2007).

Flooding in Ethiopia is primarily caused by heavy rainfall and the topography of mountainous highlands and lowland plains, which create a natural drainage system formed by the main river flow. As flooding has become a significant problem affecting society and people's belongings, there has been a growing need to study the causes and effects of flooding. While various solutions have been proposed historically to mitigate the impacts of flooding, there is a lack of

comprehensive knowledge regarding the cause-and-effect relationship. With the advancement of digital computers, there has been a shift towards simulating and modeling flood events and their characteristics. This paper focuses on the development of a reliable flood model to simulate flood events in the Big Akaki catchment area. The main challenge lies in creating a flood model that accurately represents the behavior of flood events in the specific catchment area. This requires understanding the complex interactions between rainfall patterns, topography, and the natural drainage system. By developing a reliable flood model, researchers aim to simulate and study flood events, enabling a better understanding of their characteristics and impacts.

Such a flood model would serve as a valuable tool for assessing flood risks, designing appropriate flood management measures, and evaluating the effectiveness of proposed mitigation strategies. By accurately simulating flood events, policymakers and stakeholders can make informed decisions to minimize the adverse effects of flooding and protect vulnerable communities and infrastructure

With the increasing availability of flood models, both commercially and freely accessible, and the availability of hydrological data and high-resolution Digital Elevation Models (DEMs), the task of predicting flood occurrences has become more feasible for planning purposes. However, it is important to recognize that the accuracy and reliability of flood predictions are highly dependent on the quality and input of data, parameters, and boundary conditions. Various studies have utilized different conditions for flow simulation in flood modeling. These conditions include inputs such as rainfall data, land use information, soil characteristics, river geometries, and boundary conditions such as upstream inflows and downstream outflows. The accuracy and representativeness of these inputs play a crucial role in the reliability of flood model predictions.

For instance, the accuracy of rainfall data used as input can significantly influence the simulation results. Using reliable and high-quality rainfall data can improve the accuracy of flood predictions. Similarly, the resolution and quality of DEMs used to represent the topography of the area can affect the simulation results, as it directly influences the flow paths and inundation patterns. Furthermore, the selection and calibration of model parameters, such as Manning's roughness coefficients or infiltration parameters, can introduce uncertainties and variability in the simulation outcomes. These parameters need to be carefully estimated and calibrated using field measurements or historical flood data to ensure more accurate results. Additionally, the

choice of boundary conditions, including upstream inflows and downstream outflows, can impact the simulation results. Accurate estimation of these boundary conditions is essential to capture the dynamics of flow propagation and accurately represent the flood behavior. It is important to note that different studies may adopt varying approaches and assumptions in selecting data, parameters, and boundary conditions. This can lead to variations in the results and interpretations of flood simulations. Therefore, it is crucial to carefully evaluate and validate the selected conditions to ensure the reliability and accuracy of the flood model predictions.

### **1.2.Statement of the Problem**

Flood is probably the most devastating widespread and frequent natural hazard of the world. This problem is acute in highland area like Ethiopia under strong environmental degradation due to population pressure. Topographically, Ethiopia is both a highland and lowland country. During rainy season, the major perennial rivers as well as their numerous tributaries forming the country's drainage systems carry their peak discharges. It is evident that, the problem of river flooding in Ethiopia is getting more and more due to human intervention in the fragile highland area at an ever-increasing scale. Addis Ababa is the capital city of Ethiopia which is susceptible for flooding due to its topography.

The Big Akaki catchment, which is part of the Awash Basin and includes Addis Ababa and surrounding towns, faces significant challenges related to flooding. The rapid increase in population due to urban-rural migration has led to the expansion of impervious surfaces and illegal settlements without adequate drainage infrastructure. This, combined with the sloping, mountainous topography, the presence of regulated reservoirs, and intense rainfall, has contributed to increase flooding in the area. Since 2015, the vulnerability to flood hazards has particularly affected marginalized groups living in the Akaki floodplain areas. The lack of proper early warning systems and communication channels exacerbates the situation. While formal early warning systems exist, they primarily rely on one-way communication channels such as mass media, sirens, and gunshots, with communities seen as passive recipients of information. However, communities have developed their own informal communication channels, such as door-to-door visits, phone calls, text messages, and local signaling networks, to disseminate warnings.

The main issue is that the warning information lacks specific details regarding the timing and magnitude of the floods, resulting in frequent losses of crops, livestock, property, and community assets. This problem arises from the lack of mechanisms that integrate the four elements of the formal early warning system with the activities of local people: risk knowledge, monitoring and warning, communication and dissemination, and response capacity. The UNDRR (United Nations Office for Disaster Risk Reduction) reports from 2005 emphasize that engaging communities across these four elements enhances the performance of the early warning system in terms of reliability, accuracy, credibility, and salience. The flooding in the Akaki floodplain originates from the upper Akaki catchment and inundates the lower areas, posing risks to both lives and infrastructure in the flood buffer zone. Factors contributing to the increased flood risk include deforestation, land use changes characterized by the dominance of impervious surfaces, and the lack of sufficient drainage systems in the city.

Despite the frequent occurrence of flooding in the Akaki floodplain, the magnitude and extent of inundation have not been thoroughly investigated. Additionally, a comprehensive flood management strategy to mitigate the risks and protect people and property in the flood zone has not been implemented. Therefore, this study is crucial in developing flood maps that depict the areal coverage of inundation, including depth and velocity, as well as flood hazard and risk maps. These outputs will provide essential information to support flood management efforts and minimize the risks associated with floods.

### **1.3.Objective**

#### **1.3.1. Main objective**

The main objective of this research is to develop flood inundation and risk mapping of Big Akaki River

#### **1.3.2. Specific Objectives**

The specific objectives are:

- ✓ To develop flood inundation map for a different return periods.
- ✓ To develop flood Hazard map for 200 years return period.
- ✓ To produce the flood vulnerability and risk maps for 200 years return period.
- ✓ To propose possible flood mitigation measures.

#### **1.4.Research Questions**

- ✓ What are the inundation area, flood depth and velocity of Great Akaki for different return periods?
- ✓ What is the flood hazard level?
- ✓ What are the flood vulnerability and risk map for 200 return periods?
- ✓ What are the possible mitigation measures?

#### **1.5.Scope of the study**

The study focused only on the flooding of Great Akaki river, particularly at flood risk areas in the flood plain. It also encompasses the estimating of the amount of flood and simulates flood inundation mapping, preparing flood vulnerability and risk maps and gives possible mitigation measures.

#### **1.6.Significance of the study**

This Study gives special emphasis on riverine types of floods especially Great Akaki River flooding. It fills the research gaps carried out earlier by reducing flooding risks to urban settlements, infrastructures and cultivated crops in the study area and proposing improved non-structural and structural flood mitigation measurement options. In addition to this, the study will envisage benefiting the following groups of people: urban communities living in flood-prone areas, disaster managers, policymakers, researchers and scholars, and funding agencies. The

findings of this study will expect to be significant for urban habitants, local farmers in providing realistic information about the causes of the flood and its effect on crops and livestock production. Furthermore, the information captured by this research would be important for different institutions and individual scholars such as research institutions and researchers, academic institutions, farmers, decision-makers, and experts.

## 2. LITERATURE REVIEW

### 2.1. General overview of floods at global level

River floods are one of the most common natural hazards, causing devastating impacts worldwide. Previous studies have indicated that increased exposure of people and assets, as a result of population increase and economic growth, has caused more damage due to weather-related natural disasters including flooding (Lal *et al.*, 2012). In addition, climate change may increase the frequency or magnitude of flooding (Arnell and Lloyd-Hughes, 2014). The impact of flooding is especially harmful in developing countries due to low levels of flood protection. For example, 6,648 flood fatalities were recorded in 2013 in India and Nepal, while the Philippines has suffered from recurring flooding that caused more than 100 fatalities every year between 2011 and 2013, and prolonged flooding in Thailand in 2011 caused serious economic losses (Penuel, Statler and Hagen, 2013).

Developed countries have also suffered from flooding: in Europe, the Danube flooded in 2013, as did the Kinu River in Japan in 2015 (Doocy *et al.*, 2013). According to (Hamidifar and Nones, 2021), flooding events that have killed more than 10 people in the 1951-2020 periods have been studied, analyzing the EM-DAT database. The results show that the severity of floods-related deaths is equally distributed worldwide, but present some specific geographical patterns. The floods 5 fatality coefficient, calculated for different countries, identified that Southern, Eastern, and South-Eastern regions of Asia have the deadliest floods in the world. The number of floods events has been increasing since 1951 and peaked in 2007, following a relatively declining trend since then. However, the number of death tolls does not follow a statistically significant trend. An examination of the number of floods events in different decades show that the highest number of events occurred in the 2001- 2010 decade, which corresponds to the largest precipitation anomaly in the world.

The most casualties occurred in the decade from 1991-2000. However, the lethality of floods has decreased over time, from 412 per floods in 1951-1960 to 67 in the 2011-2020 decade, probably as a consequence of a more resilient environment and better risk reduction strategies. In addition, a direct correlation was found between the number of floods events and the number of casualties with the world's population. However, flood loss and damage, especially in terms of numbers of fatalities, are generally less severe in developed versus developing countries due to historical

efforts to mitigate flood impacts. Differences in flood risk among regions reflect the balance between the magnitude of the flood (hazard), the number of people or the value of assets potentially affected by flooding (exposure), and the susceptibility to harm or lack of socioeconomic capacity to cope with flood risk depending on economic, social, demographic, cultural, institutional and governance factors (vulnerability)(Visser, Petersen and Ligtoet, 2014).

## **2.2.Floods in Ethiopia and associated effects**

Dire Dawa, which was established in 1910 and located at the foot hills of eastern *Harerge* highlands, has been repeatedly hit by powerful flood disasters. Floods at different time have destroyed homes, public institutions, market places with their properties, infrastructures, crops in the field, livestock. In Dire Dawa, flood in August 1981 which killed about 80 people was previously considered as the worst in the town's history. However, the unprecedented August 6, 2006 flooding was worst of all cases; it surpassed all flood disasters that occurred in the past in loss of human life, and property damages.

Dagnachew and Wubet (2009), cited by Sinafikish (2013), in their study on flood hazard and risk assessment in Fogera Woreda investigated that, the major flooding causative factors particularly in Fogera Woreda are slope condition of the area, soil type, elevation, land use type, drainage density, and rainfall. Similarly, a study taken by Daniel (2006), in his research assessment of flood risk in Dire Dawa Town depicted the same causative factors which identified by Dagnachew and Wubet (2009) that are drainage density, slope, elevation, land use type and road density. Likewise, a study conducted by Yonas (2009), on the socioeconomic impacts of flooding in Dire Dawa, showed that high rainfall intensity accompanied by severe forest degradation has caused increased flood damage in the study area.

Moreover, the result of flood inundation showed that residential areas and business centers experienced the worst socio-economic damages among the different sectors in the city. Similarly, it has also an enormous impact on the economic foundation of the city due to expenditure for rehabilitation and reconstruction of the damaged infrastructures and houses. Absence of early warning system and land-use policy highly contributed to the increment of the flood impact. The same study have been conducted by Yonas and Girma (2010), on flood triggering factors and the efforts to mitigate flood disaster in Dire Dawa, Ethiopia, revealed that, the primary cause of

flooding in Dechatu River is unusually high rainfall and other man induced causes, such as land degradation, deforestation, increased population density along riverbanks, poor land-use planning and zoning and a progressive loss of flood risk perception due to the periodic occurrence of flash floods, play a significant role as well. In addition, analysis of the rainfall data for the Dechatu catchment indicates an uneven distribution of precipitation and though the area is undergoing a general decreasing trend for both rainfall amount and rainy days exceeding 24 mm, peaks of rainfall surprisingly higher than usual may still occur and generate destructive flash floods.

Samson (2008), as cited by Sinafikish (2013), made an assessment of the effects of floods specifically on health in Gambella, Ethiopia in relation to the strength and weakness of coping strategy. The study reported that the main impacts of flooding on human health in Gambella region were deaths, injuries, and diseases such as malaria and diarrhea. Another notable consequence of flooding was crop destruction and subsequent malnutrition. Land use and land cover dynamics are widespread, accelerating, and significant processes driven by human actions but also producing changes that impact humans.

The study conducted by Shiferaw (2011) in Borena Woreda, central Ethiopia, highlights the main causes of land use and land cover changes in the area. These causes can be categorized into two main factors: population growth and natural/human factors.

**Population Growth:** The study identifies population growth as a significant driver of land use and land cover changes in Borena Woreda. The increasing population leads to a higher demand for land for cultivation and settlement purposes. As more land is required to accommodate the growing population, forests and other natural areas may be cleared for agricultural activities and construction. The need for land for cultivation to meet food demands and settlement for housing contributes to changes in land use and land cover patterns.

**Natural and Human Factors:** The study also highlights several natural and human factors that contribute to land use and land cover changes in the area.

a) **Climate Change:** Natural factors such as climate change can influence land use and land cover changes. Changes in temperature and rainfall patterns can impact agricultural practices and vegetation growth, leading to alterations in land use and land cover.

b) Human Factors: Various human factors play a role in land use and land cover changes. Over intensification of land use, where land is continuously cultivated without proper land management practices, can lead to soil degradation and decreased agricultural productivity. Farm size and land tenure status also influence land use changes, as smaller farm sizes may lead to more fragmented land use patterns. Additionally, land use policies and regulations can shape land use decisions and practices.

According to Shiferaw (2011), flooding is the main implications of land use land cover change in Borena Woreda. Similarly, Yonas and Girma (2010) investigated that, the upland catchment of Eastern Harerge has experienced great pressure of population settlement and land-use change. A comparison between the 1985 and 2006 land use maps showed that a remarkable change occurred in the area, namely urbanized area + 44%, bare land +3%, cultivated land +16 %, shrub land -78% and open woodland -38%. In general, expansion of agricultural land and the reduction of shrub land and open wood land have a direct correlation with surface runoff generation potential that increased the flood frequency and the resultant damage in Dire Dawa. All the reviewed empirical literatures in Ethiopia and elsewhere indicate that the researchers have made a detail investigation on the different causes and consequences of flooding in various areas.

The study conducted by Alemayehu (2022) focused on analyzing flood hazards and modeling the flood of the Big Akaki River. According to the findings of the study, flood inundation areas along the Big Akaki River were mapped based on the highest flows using the HEC-RAS model, GIS (Geographic Information System), and HEC-GeoRAS for interfacing between HEC-RAS and GIS. The mapped flood inundation areas are as follows: 273 hectares for the 5-year return period, 308 hectares for the 25-year return period, 313 hectares for the 50-year return period, and 322 hectares for the 100-year return period, and 332 hectares for the 200-year return period.

These figures represent the estimated areas that are susceptible to flooding along the Big Akaki River during specific return periods. The study utilized modeling techniques and geospatial analysis to generate these results, providing valuable information for flood risk assessment and management in the area. It's important to note that the figures provided are specific to the study conducted by Alemayehu (2022) and may not capture the entirety of flood-prone areas in the Big Akaki River catchment. Local authorities and stakeholders should consider these findings

alongside other relevant data and conduct further studies for a comprehensive understanding of flood hazards and risk management in the area.

## **2.3.Types of floods**

### **2.3.1. Flash Floods**

Flash floods are defined as those flood events where the rise in water is either during or within a few hours of the rainfall that produces the rise. Therefore, flash floods occur within small catchments, where the response time of the drainage basin is short. Many hydrological factors have relevance to the occurrence of a flash flood: terrain gradients, soil type, vegetative cover, human habitation, antecedent rainfall, and so on. In steep, rocky terrain or within heavily urbanized regions, even a relatively small amount of rainfall can trigger flash flooding. These hydrological factors determine the response of the catchment to the precipitation event. Thus, a flash flood is clearly the result of the concatenation of both meteorological and hydrological circumstances(Legese and Gumi, 2020).

Most flash floods associated with rainfall are produced by thunderstorms; that is, deep, moist convection. A characteristic of flash floods is the localized nature of the heaviest rainfall. The most intense rainfall is typically confined to a relatively small area. When large amounts of this localized precipitation fall within a small drainage basin, flash floods can occur. Sometimes, the location where flash flood damage occurs may actually receive little or no rainfall. That is, the rainfall that causes the problem can occur upstream of threatened areas. This separation between the rainfall and the flood can cause confusion because it may not even be raining in an area for which flash flood warnings are issued. Another factor in the impact of flash floods is that the precipitation causing the event often falls during the night, when it can be difficult to get warnings to sleeping residents(Legese and Gumi, 2020).

### **2.3.2. River Floods**

River floods, in contrast to flash floods, typically unfold over days, or even months. This is because they occur in large basins involving ‘main stem’ rivers like the Missouri, or the Nile, and are usually the result of many individual rainfall episodes spread out over many days. In fact, within a river flood event, several flash flood events can occur. Again, hydrological factors often contribute to a river flood, but river floods are not as sensitive to them as are flash floods.

Whereas individual thunderstorm systems can cause flash floods, river floods are usually the result of a stagnant synoptic-scale weather pattern(Fikadu and Michael, 2012).

Localized heavy rainfall events occur many times during a period of days or even months, each contributing its share of rainfall to the tributaries, which then discharge into the main stem of a river. The river rises gradually in response to all the input rainfall. The river flood potential of a situation can be increased by concurrent snow melt and other factors besides rainfall. Owing to the long time scale of the rising waters, river floods pose a lower risk of fatalities; people have more time to take proper actions. Of course, some casualties result from waiting until it has become too late to respond to the threat(Iii, 2003).

Levee and dam failures, as well as intentional rapid release of impounded waters to prevent the catastrophic failure of the flood control structures, can produce rapidly rising water situations embedded within a river flood, and these also can contribute to loss of life. Because of the large scale of river floods, the damage figures may be enormous; easily into the billions of dollars. Crop losses are a major factor in the costs of river floods, whenever large tracts of prime agricultural land along floodplains are inundated. Levees are often used to protect populated areas, so the failure of those levees can generate major property losses(Iii, 2003).

## **2.4.Modeling techniques**

There are 2 separate ways to compute the design flood: the first one is a rainfall–runoff model (or a deterministic model). In the rainfall runoff model, the entire analysis is depending on the probable maximum precipitation (PMP) and the second one is a statistical analysis (or an extreme value analysis). This approach depend on either rainfall or floods having specified probabilities or return periods (Micovic et al., 2015).

### **2.3.1. Rainfall Runoff Model**

This kind of models are categorized depend on input of the model and its parameters and the level of physical values functional in the model (Devia et al., 2015a). It may also categorized as distributed and lumped model depend on the parameters of the model as a function of time and space and stochastic and deterministic models depend on the other conditions (Pechlivanidis *et al.*, 2011). In deterministic model, the same result may be produced for an individual input value.

However, in stochastic models, for an individual input, it may produce dissimilar values of result.

(Ganasri, 2015) stated that Lumped models treat the entire watershed as a single unit without considering the spatial variability within the watershed. In these models, spatial changes are ignored, and the focus is on the overall response of the watershed as a whole. This approach can be useful for obtaining general predictions or understanding the average behavior of the watershed. However, it may not capture the spatial processes and variability that exist within the watershed, which can be important for detailed analysis and localized predictions.

On the other hand, distributed models divide the watershed into smaller units, such as square cells or triangular irregular networks (TIN), in order to consider the spatial variability of inputs, parameters, and outputs. By representing the watershed at a finer resolution, distributed models can account for spatial processes and capture the heterogeneity present in the watershed. This enables more realistic simulations and predictions, especially when dealing with localized phenomena or studying the effects of spatially varying factors.

Additionally, the classification of models can also take into account the consideration of time. Static models do not account for time in their analysis, meaning they provide a snapshot of the system without considering temporal variations. On the other hand, dynamic models explicitly incorporate time into their simulations, allowing for the representation of time-dependent processes and the study of system behavior over time (Devia et al., 2015b),.

#### **2.4.1.1. Statistical Method**

The estimation of design floods, also known as flood frequency analysis (FFA), typically involves the use of statistical methods. This approach utilizes historical data of annual peak discharges, which can be estimated using appropriate techniques or directly observed at the site. The goal is to estimate the flood magnitude associated with a specific probability of exceedance Lindeboom (2011). On the other hand, Flood frequency analysis can be based on the historical record of annual peak discharges or the record of annual rainfall events in the area. Regardless of the data source, the focus is on extreme values. The analysis involves investigating the extremes of either the maximum annual series or the peak over threshold (PoT) series. According to Via

and Atallah (2002), we may get the design flood that agrees to a selected probability of exceedance by correlate a distribution to these peaks,.

Accordingly, the flood estimation may be rely on using of the above 2 types of flood peak series, that is Peaks over Threshold (PoT) and Annual Maximum (AM) series, Lindeboom (2011). The estimation in flood frequency analysis is based on whether to use AM series or PoT series. Tanaka (2002) stated that the POT technique is better than the AMS when there are short records. The difficult thing is, yet, the critical decision of how to select a base value in the analysis of POT.

#### ***2.4.1.1.1. Annual maximum series model***

According to Mkhandi et al., (2004), In AMS model, the flow series for each year can be substituted with its highest flood. The flood series of  $Q_1, Q_2, Q_3, \dots, Q_j$ , where  $Q_j$  is the extreme flood happening in the  $j^{\text{th}}$  year, is the accidental sample from some original population. The flood magnitudes distribution,  $Q_j$ , can be estimated by Gumbel statistically. He stated that annual maximum series originate from the extreme value distributions family mentioned as Generalized Extreme Value (GEV) distributions.

#### ***2.4.1.1.2. Peaks over threshold series model***

The AMS procedure has been conventionally used so far. According to Tanaka (2002), in some river basins, the biggest flood took place before the Second World War and flood records are missing during the War. Also, there are a number of rivers that have paleo-flood records before modern systematic hydrological observation. As to data series of such rivers, instead of AMS procedure, the POT procedure or the partial duration series (PDS) procedure becomes useful. It has been revealed that the POT procedure is more beneficial than the AMS one in the case of minimum data. The peak over threshold model substitutes the unceasing flow hydrograph by a series of randomly move apart points on the time axis, Mkhandi et al., (2004). If  $\Delta t$  is the average time between peaks, then,  $1/\Delta t = \lambda$ , is the average number of peaks per unit of time.

The peaks are should be independent statistically. Choice of the peaks from the time series can be carried out using different approaches. In my investigation, the technique proposed by, Mkhandi et al.,(2004) is used where 2 in line peaks are taken to be independent if:

- (i) The time between the 2 peaks is higher than the recession constant of the fast runoff components for the given catchment.
- (ii) The low discharge between the 2 peaks is slighter than 37% of the maximum discharge. In order to omit that minimum peak heights are designated a minimum base value is determined.

#### **2.4.1.2. Easy fit model**

Fitting of data plays a significant role in various engineering, natural science, and other disciplines. The important idea is to evaluate unidentified parameters in a mathematical model that defines a real-life condition, by lowering the distance of some known experimental data from function values of theoretical model, Schittkowski (2002). Easy Fit assists to select and use the distribution that best fits to a given data, confirming that one makes right engineering decisions, and protecting one from time and money loss.

Easy Fit makes one to fit a huge number of distributions to ones data and choose the best distribution in few minutes. Someone may use it as a stand-alone application or with Microsoft Excel, allowing one to solve extensive variety of business problems with only an elementary technique of statistics. According to Beshore (2017), the advantages of easy Fit are:

- Time saving: decrease times of analysis by 70-95% over manual approaches
- money saving: avoid errors during analysis and allow us to made improved business decisions
- confirm the high-class projects
- It may get start quickly: easy Fit is awfully easy to use and learn.

#### **2.4.2. 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. (Shayannejad *et al.*, 2018) investigated the uncertainty of Manning coefficient of roughness and 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).

### **2.5.Model selection criteria**

Choosing the best and proper model is a vital part in any research task. There are several principles for selecting the most appropriate model. According to Cunderlik and Simonovic (2010), the selection based primarily on the necessity and requirements of the research under interest. (Cunderlik and Simonovic, 2010) put the following as criteria:

- a) Required output of the model
- b) Availability of input data
- c) Prices and availability of the model
- d) The model structures

There are different flood modeling tools which have their own distinct model structure and solution procedures. Most widely used 2D flood modeling tools are; HEC-RAS, FLDWAV, ISIS, FLUCOMP, and MIKE11 (Shiferaw 2011). Gilles and Moore (2010) found that FLDWAV has a capacity to simulate complex dam breaches, but is not as “easy” as HEC-RAS, which has a higher ability of pre- and post-processing, demonstrations of flood animation, and simple to make modifications of an input.

HEC-RAS has a capacity to do steady state and unsteady state, 1-D and 2-D dam breach modeling. HEC-RAS figure out velocities of flood, extreme flood wave levels, flood profiles and likely inundated areas when discharge flow, geometry of channel, and geometry of structures was available, Husain (2017).

### **2.6.Boundary conditions**

Both boundary conditions at the upstream and downstream ends of the model are required in flood routing. Their choice is reliant on the dam breach study’s purpose, their locations relative to the area(s) of interest, and level of sensitivity dependent on the degree of confidence required, FERC (2014). The consideration concerning boundary conditions are also serious for dam breach analysis as they could straightly disturb spread of downstream flood flow, Pradesh et al. (2018). It should be necessary to consider: the inflow hydrographs for the upstream boundary, initial flows and internal locations, downstream boundary conditions were recognized at a large

body of water relative to the impoundment water volume behind the study dam. HEC-RAS used level pool routing during breach of the dam, Goodell and Wahlin (2009)

### **2.7.Flood inundation mapping**

Dam breach inundation map is a map representing an area of the downstream from a dam that would practically be likely to be flooded in the occasion of dam failure. The maps benefit extensive range of end-users for planning and as a response tool to determine the effects of dam failure in downstream areas. These include:

- ❖ Assessing and finding the hazard potential classification for a dam
- ❖ Estimating the probable loss of life
- ❖ Developing emergency action plans

Routing of outflow hydrograph from the dam breached is a vital phase in a hazard evaluation or development of flood inundation mapping

### **2.8.Flood Hazard mapping**

Flood Hazard Mapping is flood map illustrating the flood hazard, i.e. the intensity of flood situations and their associated exceedance probability. Usually, flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth and distribution of flow velocity(Bucha and Selvara, 2019).

The hazard aspect of the flood risk is related to the hydraulic and the hydrological parameters. Hazard level may be defined by the parameters like flood depth and flood velocity and flood duration. For this the weighted coexistence model facilitates the analysis by ranking the hazard level(Fikadu and Michael, 2012).

### **2.9.Flood Vulnerability Analysis**

Flood hazard map alone cannot completely fulfill the information requirement to develop flood risk analysis. There is a need to combine flood hazard with flood vulnerability, to develop more useful information. Vulnerability generally refers to that characteristic of society which specifies the potential for the damage to occur as a result of different types of hazards. Vulnerability can be defined as the degree to which people, property, environment, social and economical activities are subjected to harm or being exposed to any destructive

factors or cause. Flood vulnerability describes the damage or exposure to damage due to flood. The flood vulnerability is affected by the land use characteristics of the areas under the influence of flood i.e., a flood of same exceedance probability will have different levels of vulnerability according to the land use characteristics and potential for damage. The vulnerability analysis, therefore, consists of identifying the land use areas under the potential influence of a flood of particular return period(De Risi *et al.*, 2020).

#### **2.10. Flood risk mapping**

Flood risk maps are valuable tools for visualizing and communicating the potential risks and impacts associated with flooding in specific areas. These maps provide an overview of the flood-prone areas and can assist in planning, emergency response, and risk management strategies. However, it's important to note that flood risk maps have certain characteristics and limitations:

Flood risk maps are typically static, meaning they represent a snapshot of the flood risk at a specific point in time. In the case you mentioned, the maps are based on existing data and risk assessment information from December 2019. It's important to recognize that flood risks can change over time due to various factors such as climate change, land use changes, and infrastructure development. Therefore, it's advisable to update flood risk maps periodically to account for these changes. Flood risk maps rely on existing data sources, such as historical flood records, river gauges, topographic information, and flood modeling results. The accuracy and availability of data can vary, and limitations in data quality can impact the reliability of the flood risk assessments. It's important to use the most up-to-date and reliable data sources to ensure the accuracy of the maps(Baky, Islam and Paul, 2020).

#### **2.11. Flood mitigation measures**

Around the world, the diverse nature of floods encountered in any one year poses considerable challenges for flood risk management. Continued efforts to evaluate the performance and interaction of flood prevention, protection and mitigation strategies as we encounter increasingly complex and evolving flood risk from shifts in climate, increased urbanization and other factors are needed. This is indeed paramount in order to design and implement optimal flood management strategies to improve resiliency and mitigate the most adverse impacts of floods on people and the environment(Binns, 2020).

It is important to understand the effectiveness of individual measures in terms of flood mitigation impact when considering structural solutions for flood mitigation. Depending on locality and the nature of the flooding, a number of structural and non-structural mitigation measures may be available. However, flood mitigation measures may only lessen the impact of flooding. No amount of intervention can stop heavy rain or high tides

Structural flood mitigation is where physical structures are constructed or modified to reduce the impact of flooding on individual properties or whole catchments. Sustainable Drainage Systems are best management practices that incorporate various drainage components such as swales, wetlands, detention basin, retention basin and green roofs, permeable pavements, infiltration trenches or infiltration areas. It is imperative to utilize such structures in cities with complex infrastructures and which are vulnerable to flooding and pollution. The portion of urban areas which has high population density, high drainage and road network density is fall in very high to moderate flood risk zones. Therefore, it is imperative to identify these places that have interventions in order to carryout proper evacuation of debris and redesign of some of them for safe discharge of floodwaters. This is achieved by constructing reservoirs at the upstream of an urban settlement to cut down the flood into downstream reach and to reduce the intensity of flood risk disasters. Flood diversion and storage areas should also be established to change the spatial distribution of flood and reduce the risk of flooding to highly populated areas. When considering structural solutions, it is important to understand the effectiveness of individual measures in terms of flood mitigation impact. For example, some works may reduce flooding to a large area by centimeters which provides minimal benefit to a large number of homeowners that are least affected by flooding and almost no benefit to those homeowners that are worst affected(Ramos *et al.*, 2017).

Ongoing maintenance to existing creeks and storm water drainage systems is vital to maintain the hydraulic performance of drains. Developing and reviewing a regular maintenance schedule for flood prone areas can provide significant benefit during seasonal rains. While targeted clearing of creek systems does not always help reduce the impact of large flood events, it does help reduce the impact of smaller, more frequent floods. Where the inundation of flood water is relatively low (nominally less than 700mm), it may be possible to keep flood waters out of homes by installing solid fences, raising windows, sealing doors with 'stop boards' and limiting

sewage contamination through reflux or backflow valves. Improving the flood resilience of roads provides a benefit to flood-affected residents by allowing residents to escape floods and allowing emergency service access. Key routes to essential services such as hospitals and emergency shelters should have at least Q100 flood immunity(Adugna *et al.*, 2019).

The non-structural measures are designed to keep the infrastructures, agricultural land and other structures away from waterways. This measure allows individuals or a community to cope with flood risk disaster more effectively (Khunwishit *et al.*, 2018). The environmental impact of non-70 structural measures of flood control is relatively less and their implementation is easy compared to the structural measures (Mishra & Sinha, 2020; Kang *et al.*, 2009). This gives it more importance in socio-economic and institutional perspectives. There should be a collective effort and cooperation between local communities and government authorities for these measures to be effective (Mishra & Sinha, 2020). Based on this study, the following non-structural measures are suggested. Detailed surveys of flood affected residences can increase the accuracy of flood modeling so that homeowners, insurers and buyers can understand the actual impact of flooding on each property. Strategic land use planning will identify the extent of flood impacted land to limit the construction of urban and rural residential, commercial and industrial land. The Planning Scheme requires all new developments to undertake land suitability investigations to determine the extent of constrained land(Binns, 2020).

Existing building controls require new homes or substantial renovations to construct habitable floor levels 300mm above Q100 year flood levels, to provide some level of protection from flooding. Maintaining up-to-date flood models of developing catchments assists the Development Consent Authority to understand the impact of new development on existing residents in the catchment. New land developments are required to manage the rate at which storm water leaves the development to maintain the pre-development rate of flow(Adugna *et al.*, 2019).

As many floods occur at night, early warning systems are extremely important in flash flooding events to provide residents with the ability to respond to impending flood waters. This may include relocating of parked vehicles, collecting pets and valuables and implementing personal emergency plans. In conjunction with a household emergency kit, a household emergency plan is

essential for all Territories. Regardless of any mitigation measures, every household must be prepared for extreme weather, including flooding. Knowing your local flood history and developing an understanding of how floods behave in your area provides you with the ability to respond in time to an impending flood. Monitoring tide and rainfall forecasts can alert residents when the conditions that may result in flooding could occur. Floods usually damages large number of lives and economic losses due to submergence of vast area of agricultural lands and collapse of buildings and other government infrastructures especially in low lying areas. It is highly suggested that architectural approaches of flood control measures such as structure elevation (building structures above the flood level), prevention of exterior walls of building by using watertight emulsion and establishing flood resilient building codes with regards to occupancy and the use of buildings in areas with low lying elevations and high flood risk areas could be implemented to reduce the flood risk of these locations(Bucha and Selvara, 2019).

Land use planning when coupled with land use restriction policies provide an effective measure of risk reduction in a particular area (Mishra & Sinha, 2020). Land use planning defines how land should be used in a given area. Land use planning should be implemented in the study allocating various land uses to specific areas that suit such land uses such as agricultural land, industrial areas, business spots, and residential areas. Financial risk of living in floodplain for individual or societies to flood risk is reduced through flood insurance particularly in areas of high flood risk and vulnerability due to high population density and low economic status. Flood insurance is considered a mitigation technique because it doesn't reduce damage but compensate the affected individual or societies for their losses (Mishra & Sinha, 2020; Kang et al., 2009). In areas with high to very high flood risk and vulnerability, the government should implement flood insurance system for the inhabitants living in these regions that cover life and economic damages due to floods.

Capacity building for flood resilience is a measure used reduces the physical vulnerability of people to floods (Mishra & Sinha, 2020; Khunwishit et al., 2018). This could be achieved through sensitization workshops and training of the residence of the local communities on flood risk reduction. The communities with high to very high vulnerability in the study area has low literacy rate and need to be educated on the techniques of flood risk reduction and mitigation. - Hazard forecasting, Early Warning System and Emergency Plans Weather forecasts of the

severity and intensity of rainstorm and accurate prediction of flood levels in rivers helps government and the public in making decision of evacuating valuable properties from flood hazard zones. Early warning systems and proper dissemination of information on flood occurrence and intensity reduce life and property losses (Shale et al., 2020). Furthermore, timely mitigation and preparedness measures should be implemented in high to very high risk areas of the study area in order to reduce the aftermath of the flooding.

### **2.12. Gaps on previous studies**

On previous studies conducted on flood mapping and hazard analysis in the Akaki River region, several gaps that can be addressed in future research. In the study by Birhanu (2019), flood mapping using the HEC-RAS model revealed that approximately 350 hectares of land were inundated during a 100-year return period flood. However, the study lacked a comprehensive assessment of flood vulnerability and did not adequately address the dominant indicator required for accurate vulnerability mapping. Future research could focus on improving flood vulnerability assessments by considering additional indicators and giving proper attention to the dominant indicator.

Similarly, Alemayehu (2022) analyzed flood hazards and modeled the flood of the Big Akaki River using the HEC-RAS model, GIS, and HEC-GeoRAS. The study mapped the flood inundated areas for various return periods. However, the assumption of a 1-D model for flood hazard simulation, which assumes constant velocity and a horizontal water surface, limited the applicability of the model in situations with complex river geometries. The study did not consider the spread of overbank flows resulting from bank overtopping, which violates the principle of 1-D flow. Additionally, the study did not specify the risk level of the locations of interest, which is crucial information for land use planners and emergency evacuation procedures.

In Wondimu study (2019), hydrologic and hydraulic models were developed to analyze the effects of rainfall on surface runoff and peak discharges in the downstream floodplain areas of the Great Akaki River. The study considered the discharge released from Lega Dadi and Dire dams and found that the maximum channel flood depths reached 15.5 meters during 200-year return periods. The flooding had a significant impact on the large floodplain downstream during

high flood levels. However, the study did not investigate the risk level of the people and properties vulnerable to floods or propose effective countermeasures.

To address these gaps, future research could focus on improving flood vulnerability assessments by considering a comprehensive range of indicators and addressing the dominant indicator as required. Additionally, the application of advanced modeling approaches, such as 2-D or 3-D models, should be explored to accurately simulate flood hazards in areas with complex river geometries. The assessment of risk levels for vulnerable areas and populations, along with the development of effective flood risk mitigation strategies, would provide valuable information for land use planners and emergency evacuation procedures

### 3. MATERIALS AND METHODS

#### 3.1. Study area description

##### 3.1.1. Location

The study was conducted on Akaki River, which is one of the tributaries of the Bulbula River in Ethiopia. The Akaki catchment is located in central Ethiopia, specifically along the western margin of the Main Ethiopian Rift. The Akaki catchment is geographically bounded between 8°46′–9°14′N latitude and 38°34′– 39°04′E longitude. The catchment covers an area of approximately 1500 km<sup>2</sup>. It includes a range of elevations, with altitudes ranging from 2048 meters to 2600 meters above sea level. The catchment is surrounded by several prominent geographic features. To the north, it is bounded by the Intoto ridge system. The western boundaries are formed by Mount Menagesha and the Wechecha volcanic range. Mount Furi marks the southwestern boundary, while Mount Bilbilo and Guji define the southern boundary. The Gara Bushu hills are situated to the southeast, and the eastern boundary is marked by the Mount Yerer volcanic center (Demlie and Wohnlich, 2006).

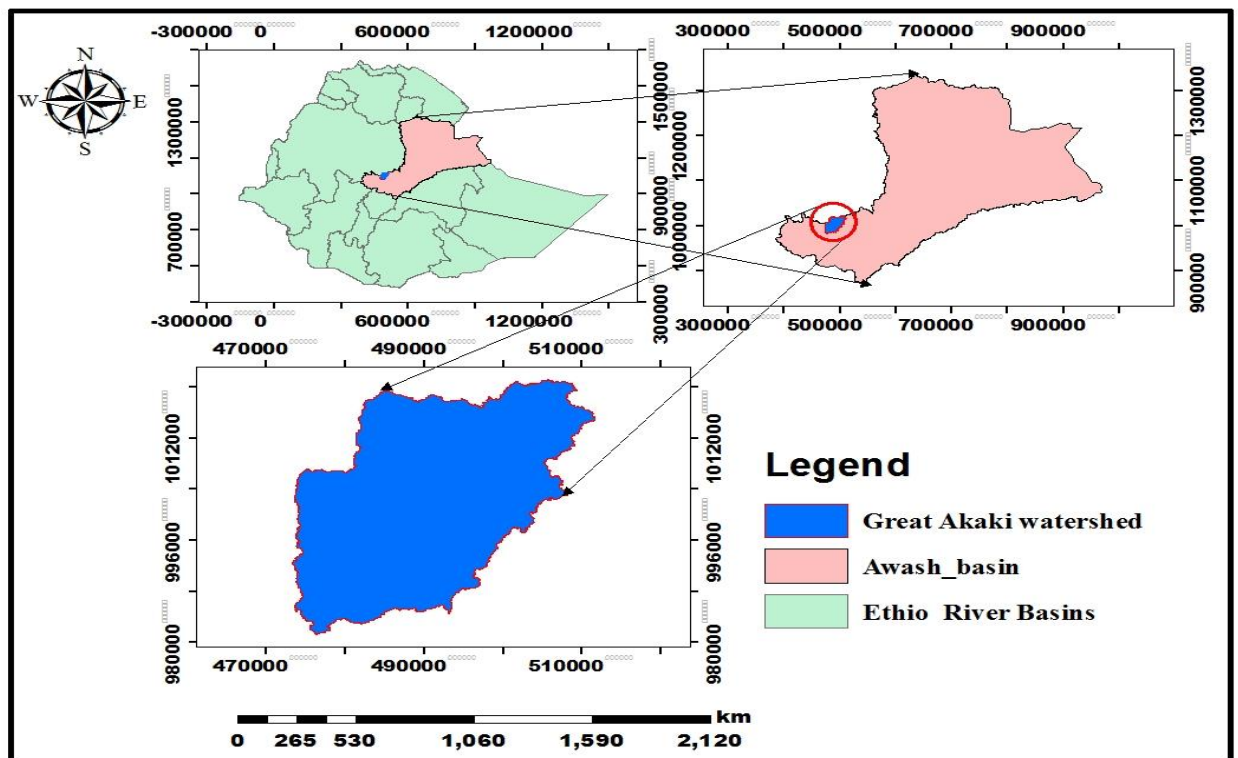


Figure 3.1: Location map of the study area

### 3.1.2. Soils

The major soil types of the catchment are Chromic Luvisols, Eutric Nitisols, Pellic vertisols, and Vertic Cambisols. From these Pellic vertisols is the most dominant one in the area.

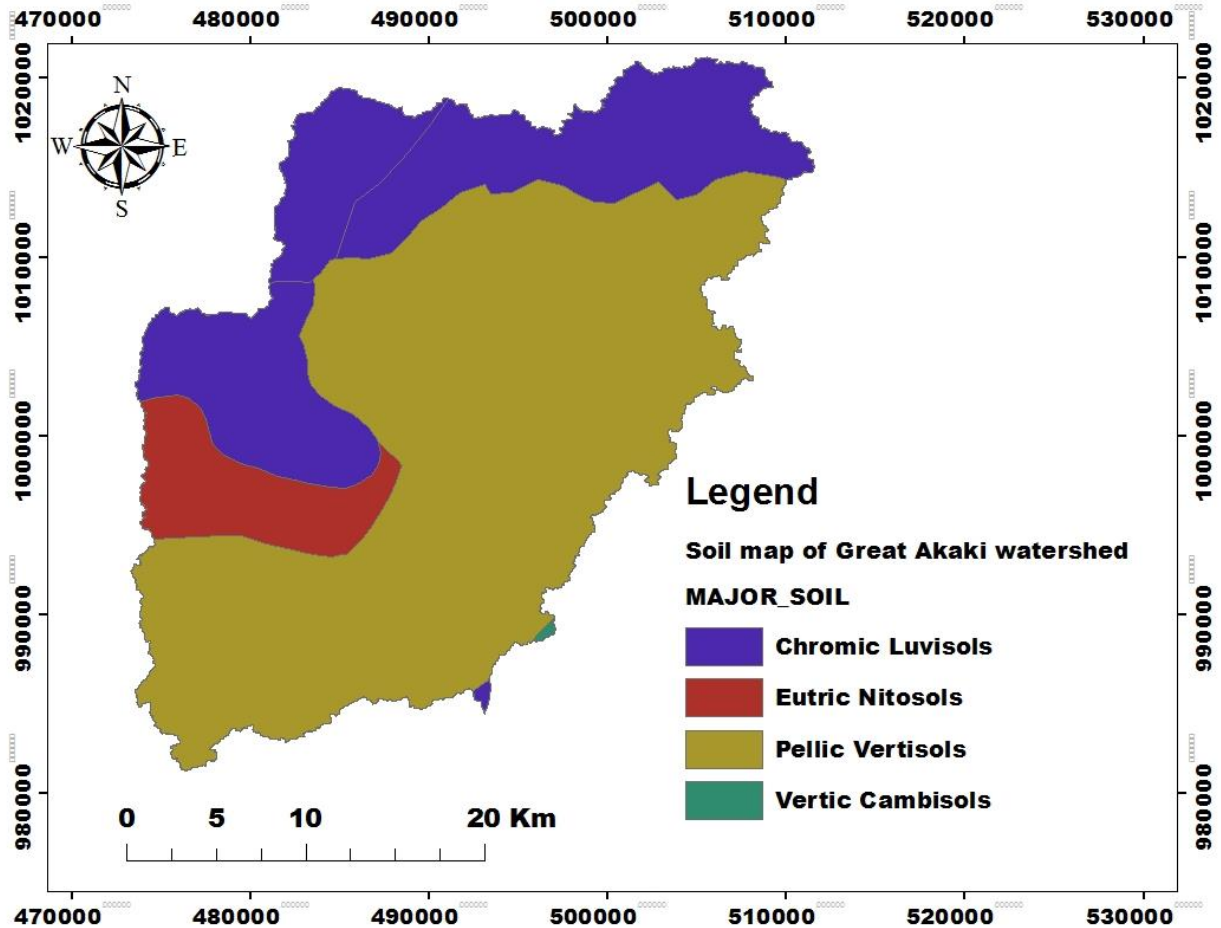


Figure 3.2: Soil map of the study area

### 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

### 3.1.4. Land use land cover

The Akaki catchment was mainly covered by annual crop land, settlements, open shrub land and little dense and sparse forests. Pattern in the city holds residential areas, market quarters, industrial zones, agricultural areas, forest and quarries. The rapid urbanization requires wide areas for various purposes and hence the size of the city is increasing at high rate. Presently industrial 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).

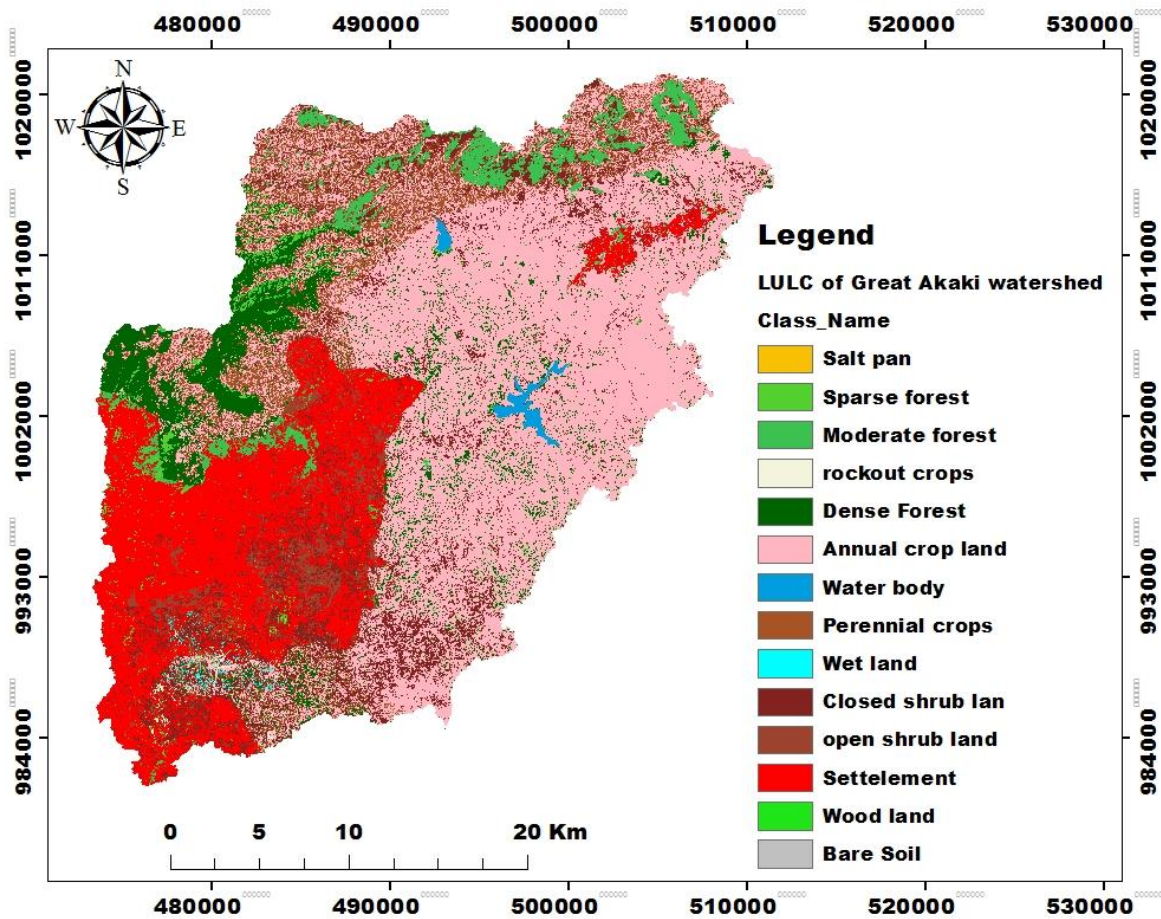


Figure 3.3: Land use land-cover of Great Akaki catchment

### **3.1.5. 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 vertisols clay soils (Backhaus et al., n.d.).

## **3.2.Methods**

### **3.2.1. Data collection**

Different data were collected from different sources to achieve the objectives of the study. These data are, DEM, stream flow data and land use/land cover data. The stream flow data was collected from Ministry of Water Resources, Ethiopia. The Manning's roughness coefficient were collected from field survey and verify it from relevant literature Chow (1959).

Digital Elevation Model (DEM) of 20-meter resolution taken from MoWR is imported to HEC RAS software. Now, from Tools menu in RAS-Mapper, create terrain from selected Digital Elevation Model (DEM) which is then used in RAS-Mapper to work on the hydrodynamic properties and building up the geometry of 2-D flow region of study area. Moreover, cell size of 20 m × 20 m was provided, which are created along the selected 2-D flow area of the River of the study area. The geometric pre-processing tools in Ras-Mapper were used for creation of hydraulic properties of each cell of the reach. Manning's roughness coefficient is allocated for the 2D area, considered for the research area in RAS-Mapper. For unsteady flow simulation in RAS-Mapper, upstream and downstream boundary conditions of the area are very essential. For upstream, Flood hydrograph for different return periods is used for simulation, and in the downstream normal depth of channel slope (0.0012) is used as boundary condition.

### **3.2.2. Hydrologic data**

In order to analyze the flood hazard and risk analysis, the inflow design flood for different return period was used. Observed stream flow data were collected over a period of 1985-2004 available from MoWE was used. The flow data were available for one station; the name of the station is Akaki. The station had data ranging in time from 1985 to 2004, though it had data no missing gaps during the period. Design flood may be estimated by executing frequency analysis of observed maximum flood over a number of years at the site of interest. The core objective of flood frequency analysis is thus to create a relationship between flood magnitude (Q) and

recurrence interval. Two types of flood peak series are used to estimate flood magnitudes namely: Annual Maximum (AM) series and Peaks over Threshold (PoT). In this study, Annual Maximum (AM) series was selected.

### 3.2.2.1. Goodness of fit test

It has been an issue of interest for so long period in order to select best distribution which is used in flood frequency analysis. The AM series values of flow data were entered into Easy Fit 5.0 software for selecting the well-known probability distribution from the distribution fitting option of the software. Chi-Squared test and Kolmogorov-Smirnov test have been specifically used to find the distributions of stream flow for flood frequency analysis. For the goodness of fit tests, the Anderson-Darling (AD), Kolmogorov-Smirnov (KS), and Chi-Squared ( $\chi^2$ ) tests are used. The goodness of fit tests was performed using Easy-Fit software. All test values and statistics were produced from this program. Based on the goodness of fit summary Table 3.1, Gen. Extreme value probability distribution was the best fitted probability distribution.

Table 3.1: Goodness of Fit – Summary

#### Goodness of Fit - Summary

#	<u>Distribution</u>	Kolmogorov Smirnov		Anderson Darling		Chi Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	<u>Gen. Extreme Value</u>	0.14956	1	0.30584	1	5.9959	3
2	<u>Gen. Pareto</u>	0.1501	2	4.2174	6	N/A	
3	<u>Lognormal</u>	0.22676	7	1.8229	3	8.1415	4
4	<u>Lognormal (3P)</u>	0.15409	3	0.3192	2	5.8216	2
5	<u>Triangular</u>	0.17151	4	2.8194	5	1.5	1
6	<u>Uniform</u>	0.21321	6	7.8587	7	N/A	
7	<u>Weibull</u>	0.21236	5	1.8697	4	9.5022	5
8	Weibull (3P)	N/A		N/A		N/A	

Table 3.2: Fitting Results from easy fit model

Fitting Results		
#	Distribution	Parameters
1	Gen. Extreme Value	$k=-0.00649$ $\sigma=154.13$ $\mu=197.85$
2	Gen. Pareto	$k=-0.43124$ $\sigma=369.54$ $\mu=27.641$
3	Lognormal	$\sigma=1.3182$ $\mu=5.243$
4	Lognormal (3P)	$\sigma=0.32877$ $\mu=6.2692$ $\gamma=-271.24$
5	Triangular	$m=162.99$ $a=1.1304$ $b=693.1$
6	Uniform	$a=-40.217$ $b=611.89$
7	Weibull	$\alpha=0.70226$ $\beta=371.51$
8	Weibull (3P)	$\alpha=0.71828$ $\beta=1.3174E-5$ $\gamma=1.3$

Composite hydrograph can be used as input for HEC-RAS model, for instance on the basis of flood probability calculations. Based on the results of long-term simulations with hydrological models (e.g. lumped conceptual models) for the different sub catchments of the river basin, flood frequency distributions can be derived for a range of aggregation-levels. These distributions can be summarized in the form of "discharge/duration/frequency (QDF) relationships" and, more advanced, in the form of "composite hydrographs". This type of synthetic hydrographs is constructed in such a way that the average discharge equals a specific return period for all durations that are considered centrally in the hydrograph.

Composite hydrographs have the important feature that river states with the same safety level at all locations along the river can be derived by one single short-term simulation. This is explained by the fact that rivers are often "uni-modal" systems. When the composite hydrographs are simulated in the river model, they are considered as the upstream boundary conditions. The use of composite hydrographs can be considered as an accurate and easy method to simulate specific safety levels along the river, and thus can be used on the basis of flood probability and flood risk studies. Figure 3.4 shows the composite hydrograph for different return periods.

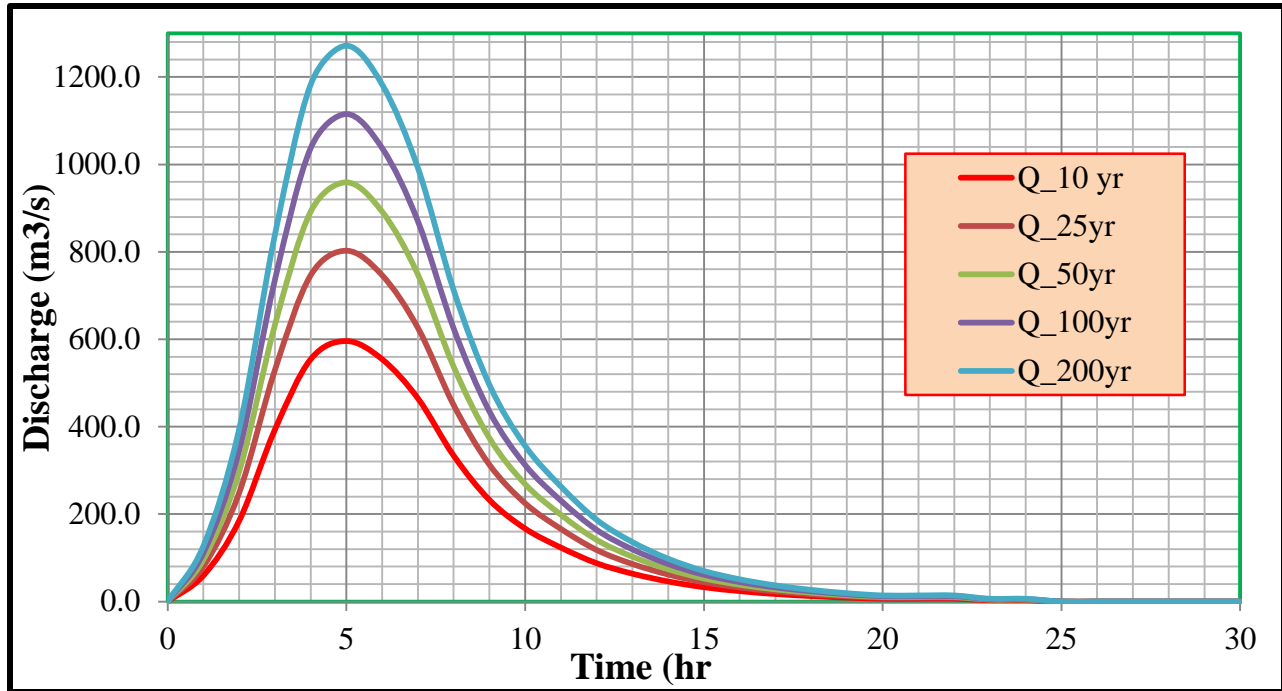


Figure 3.4: Inflow flood hydrograph for different return period

### 3.2.3. Hydraulic Data

#### 3.2.3.1. Manning's Roughness Coefficients

Manning's  $n$  values were used in the model to define roughness for the different land covers in the 2D area. The  $n$ -values were assigned by first defining land-use characteristics for common areas. This was done on high resolution image produced on ARC-GIS. Each land-use characteristic was given an  $n$ -value based on published values for similar conditions (Chow, 1959; Barnes, 1967), and photographic comparisons. The roughness values associated with each land use within the model area was then linked through land use terrain association in the geometric data editor on HEC-RAS 6.1.0.

### 3.3. Hydrodynamic Modeling technique

Hydrodynamic modeling is central in most modeling tasks in the marine area. Apart from being important in itself, it also forms the basis for a number of other tasks, such as sediment transport simulations, different kinds of spreading and dispersion studies and studies of water quality or ecological systems. Defining boundary conditions and bathymetries can pose important challenges for the modeler (Bucha and Selvara, 2019).

Regarding MIKE 11 HD, it is specific hydrodynamic modeling software developed by DHI Group. MIKE 11 HD is primarily used for flood forecasting, dispatching measures, canal/irrigation system design, and storm surge research. The software solves one-dimensional unsteady flow equations known as Saint-Venant equations based on vertical integration. It calculates hydrological factors such as river water level and discharge for each river section.

$$\frac{1}{B} \frac{\partial Q}{\partial x} + \frac{\partial H}{\partial t} = qL \dots \dots \dots (3.1)$$

$$\frac{\partial u}{\partial t} + g \frac{\partial H}{\partial x} + g \frac{u |u|}{C^2 R} = 0 \dots \dots \dots (3.2)$$

where H is the water level of the channel section, Q is discharge, u is average velocity, B is the width of the river cross-section, qL is lateral flow, R is hydraulic radius, C is the Chezy coefficient, and x and t are position and time coordinates.

MIKE 21 hydrodynamic model MIKE 21 HD is mainly used to simulate two-dimensional free surface flow. This module can simulate changes in water level and discharge due to the impact of various forces in lakes, river mouths, and coastal areas. When the user provides terrain data, Manning coefficients, wind fields, and hydrodynamic boundary conditions, the model can simulate changes in water level and discharge in each grid. The model uses the finite difference method of alternating-difference implicit (ADI) second-term accuracy to solve the mass equation and momentum equation of dynamic flow. This model can describe various hydraulic phenomena, such as tidal exchange, tidal flow, storm surge, whirlpools, surface undulation, dam bursts, and tsunamis. The equations take into account many factors, such as Coriolis force ( $\square$ ), wind force (V), and atmospheric pressure (Pa). The variables  $\zeta$ , d, h, p, and q represent water level, water depth, elevation, and discharge in the x- and y-directions respectively.

$$\frac{\partial \zeta}{\partial t} + \frac{\partial p}{\partial x} + \frac{\partial q}{\partial y} = \frac{\partial d}{\partial t} \dots \dots \dots (3.3)$$

$$\frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial y} \left( \frac{pq}{h} \right) = gh \frac{\partial \zeta}{\partial x} + \frac{gp\sqrt{p^2+q^2}}{C^2 h^2} - \frac{1}{\rho\omega} \left[ \frac{\partial}{\partial x} (h\tau_{xx}) + \frac{\partial}{\partial y} (h\tau_{yy}) \right] - \Omega_q - fvv_x + \frac{h}{\rho_x} \frac{\partial}{\partial y} (p_a) = 0 \dots \dots \dots (3.4)$$

$$\frac{\partial q}{\partial x} + \frac{\partial}{\partial y} \left( \frac{p^2}{h} \right) + \frac{\partial}{\partial x} \left( \frac{pq}{h} \right) = gh \frac{\partial \zeta}{\partial y} + \frac{gq\sqrt{p^2+q^2}}{C^2 h^2} - \frac{1}{\rho\omega} \left[ \frac{\partial}{\partial y} (h\tau_{yy}) + \frac{\partial}{\partial x} (h\tau_{xx}) \right] + \Omega_q - fvv_y + \frac{h}{\rho_x} \frac{\partial}{\partial xy} (p_a) = 0 \dots \dots \dots (3.5)$$

**3.3.1. MIKE Flood model**

The MIKE Flood model dynamically couples the one dimensional (MIKE 11 HD) and two-dimensional (MIKE 21 HD) models. The coupled model can take advantage of the benefits of both models, and can solve problems of spatial resolution and computation that often occur when the two models are used separately. In this study, the MIKE Flood model was used to simulate the two-dimensional flood evolution path, submerged area, and duration in urban areas as well as one-dimensional river flood overtopping and levee bursts. MIKE Flood provides two different approaches to link one-dimensional and two-dimensional models, namely standard and lateral links, which are fitted for different occasions. An important part of MIKE Flood model application is link selection and creation.

**BENEFITS**

- ❖ MIKE FLOOD builds on well-proven technology and simulation engines, which are applied successfully in numerous important engineering projects all over the world.
- ❖ With the parallel 2D engines, it provides a unique framework for coupling 1D and 2D models using graphics processing units (GPU) for fast simulation execution.
- ❖ Especially for environmental flood impact assessments, MIKE FLOOD provides unique features for dynamically coupled pollution transport and water quality processes.
- ❖ It offers the highest flexibility in options for coupling 1D and 2D engines
- ❖ Integrated flood modeling comprising dynamic coastal, urban, river and floodplains interactions
- ❖ Access to flood modeling expertise in more than 30 countries around the world

**3.3.2. HEC-RAS model**

HEC-RAS is open-source software that models the hydraulics of water flow through natural rivers and other channels, developed by the U.S. Army Corps of Engineers (USACE). This software allows the user to perform one-dimensional steady and unsteady

flow modeling, 2-D unsteady flow modeling, as well as combined 1-D and 2-D unsteady flow routing, sediment transport/mobile bed computations, and water temperature/water quality modeling (Brunner, 2016a). The HEC-RAS 2-D unsteady flow equation solver uses an implicit finite volume algorithm. The implicit solution algorithm enables a larger computational time step than the explicit method. The program was designed for the application of unstructured computational mesh, but can also handle structured mesh.

HEC-RAS 2-D presents two types of computational approaches in order to compute the flow field in the defined 2-D mesh: Full Momentum (Saint-Venant) equations and the Diffusion Wave model. The 2-D Full Momentum equations solver takes into account the turbulence and Coriolis effects in the flow field and thus needs greater computational power and more time to perform the simulations. Furthermore, a very fine mesh is required to overcome rapid changes in the direction of flow within the 2-D flow field. The numerical mesh prepared for the simulation in this study was at the mesh sizes of 1, 2 and 5 cm, and composed of 92,403, 23,014 and 3,641 computational cells, respectively.

The Diffusion Wave model requires less time and promises higher model stability but at the expense of the precision of the results (Quiroga et al., 2016). Artichowicz & Gąsiorowski (2019) presented a study that deals with increasing the computational efficiency in modeling floodplain inundation by using a two-dimensional Diffusion Wave equation. In the present study, both model options (the Full Momentum equations and the Diffusion Wave) were considered for HEC-RAS 2-D. The solved 2-D Saint Venant equations in their non-conservative forms are as follows:

$$\frac{\partial H}{\partial t} + \frac{\partial(hu)}{\partial x} + \frac{\partial(hv)}{\partial y} + q = 0 \dots\dots\dots (3.6)$$

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -g \frac{\partial H}{\partial x} + v_t \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) - c_f u + f_v \dots\dots\dots (3.7)$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -g \frac{\partial H}{\partial y} + v_t \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) - c_f v + f_u \dots\dots\dots (3.8)$$

Where t is time, u and v are considered as the velocity horizontal components in x and y direction, respectively, and q is a source/sink flux term. H is water surface elevation, h

is water depth,  $g$  is gravitational acceleration,  $\nu_t$  is the coefficient of horizontal eddy viscosity,  $cf$  is the coefficient of bottom friction, and  $f$  is the Coriolis parameter. A full explanation of the equations can be found in the HEC-RAS version 5.0 hydraulic reference manual (Brunner, 2016b).

**One-dimensional numerical models**

The one dimensional method to dam breach modeling only considers the flood flow in the direction of  $x$  axis (the downstream direction), Zhang and Bao (2012). The simulation of the downstream river circumstances in the occasion of a dam failure by one dimensional hydraulic models needs the knowledge of the lateral and longitudinal geometry of the river and its frictional resistance, Soleymani et al. (2015). This governs the way the maximum flood wave is reduced as it attenuates downstream, the arrival time of the maximum flood discharge between points of interest, the highest water level at points of interest, and the change in shape of the hydrograph as it moves downstream. The most extensively used method to model 1D flow is Saint- Venant Equations based on conservation equations of mass and momentum, Gilles and Moore (2010).

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \dots\dots\dots (3.9)$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}(uQ) + gA \left( \frac{\partial h}{\partial x} - S_o \right) + gAS_f = 0 \dots\dots\dots (3.10)$$

Where  $Q$  is flow discharge,  $A$  is cross-sectional area,  $u$  is flow velocity,  $h$  is flow depth,  $so$  is bed slope, and  $S_f$  is friction slope.

**Two-dimensional numerical models**

In the two-dimensional method, cross-sections are not used, as with one dimensional flow modeling. As a substitute, the riverbed is well-defined by series of mesh such that, the shape can be square or polygonal thus, each single grid has an allied elevation, Tayefi et al. (2007). Within the two-dimensional flow model, water spreads by a grid to grid evaluation basis. The Manning coefficient is so variable and applied at every grid location, Dottori and Todini (2010). The exchange of impulses between cells is possible, and hence, the momentum exchange between the main channel and the flood area is possible. Occurrence of Complex interaction of channel and floodplain flow fields make 2D simulation codes more necessary than 1D codes in many

modeling conditions, Gilles and Moore (2010). Most widely used for modeling 2D flood flow is Navier-Stokes equations, regularly called the Saint-Venant equation described below, Gilles and Moore (2010) and Klieppe (2017).

$$\frac{\partial h}{\partial t} + \frac{\partial(hU)}{\partial x} + \frac{\partial(hV)}{\partial y} = 0 \dots\dots\dots (3.11)$$

$$\frac{\partial(hU)}{\partial t} + \frac{\partial(hUU)}{\partial x} + \frac{\partial(VU)}{\partial y} = \frac{\partial(hT_{xx})}{\partial x} + \frac{\partial(hT_{xy})}{\partial y} - gh \frac{\partial z}{\partial x} - \frac{\tau_{bx}}{\rho} \dots\dots\dots (3.12)$$

$$\frac{\partial(hV)}{\partial t} + \frac{\partial(hUV)}{\partial x} + \frac{\partial(VV)}{\partial y} = \frac{\partial(hT_{xy})}{\partial x} + \frac{\partial(hT_{yy})}{\partial y} - gh \frac{\tau_{by}}{\rho} \dots\dots\dots (3.13)$$

Where h is flow depth, U and V are velocities in the x and y directions, T<sub>xx</sub>, T<sub>xy</sub>, and T<sub>yy</sub> are depth-averaged turbulent stresses, z is the water surface elevation, and τ<sub>bx</sub>, τ<sub>by</sub> are bed shear stresses. 2D models reject many of the assumptions needed by 1D models and, hence, offer a more accurate illustration of complex hydraulic situations come across in the real world, FHWA (2019)

**3.3.3. HECRAS Model development**

Different computer models are currently available on hand to model flooding. HEC-RAS is one of the most powerful software which is intensively used in hydraulic modeling. The newer version of HEC-RAS is capable of modeling 2D flow which is more appropriate to use in flood modeling. It incorporates satellite images for cross section extraction and also reduces the instability problems which were observed in previous versions. For the case of Great Akaki River, the analysis was carried out using HEC-RAS 6.1.0 software which is capable of modeling 2D flows. The output of flooding on critical locations were processed in ARC GIS so as to provide better flood risk Maps.

**3.3.4. Basic procedures in HEC RAS 2D model**

The first thing to do in HEC-RAS is to insert the tiff elevation file in the RAS Mapper with the appropriate projection. Once tiff file imported, then land use land cover data imported so as to create Manning's roughness coefficient (n). Manning's values will be inserted in a table based on the land cover type and ID. Once this step is completed it is possible to go to geometric editor window. RAS Mapper is also the section of the software where all the output results will be displayed with background satellite maps. In the geometric editor window all necessary data for

flood area will be inserted. Figure 3.5 shows the geometric data window, where two-dimensional flow area has been defined over a digital terrain model.

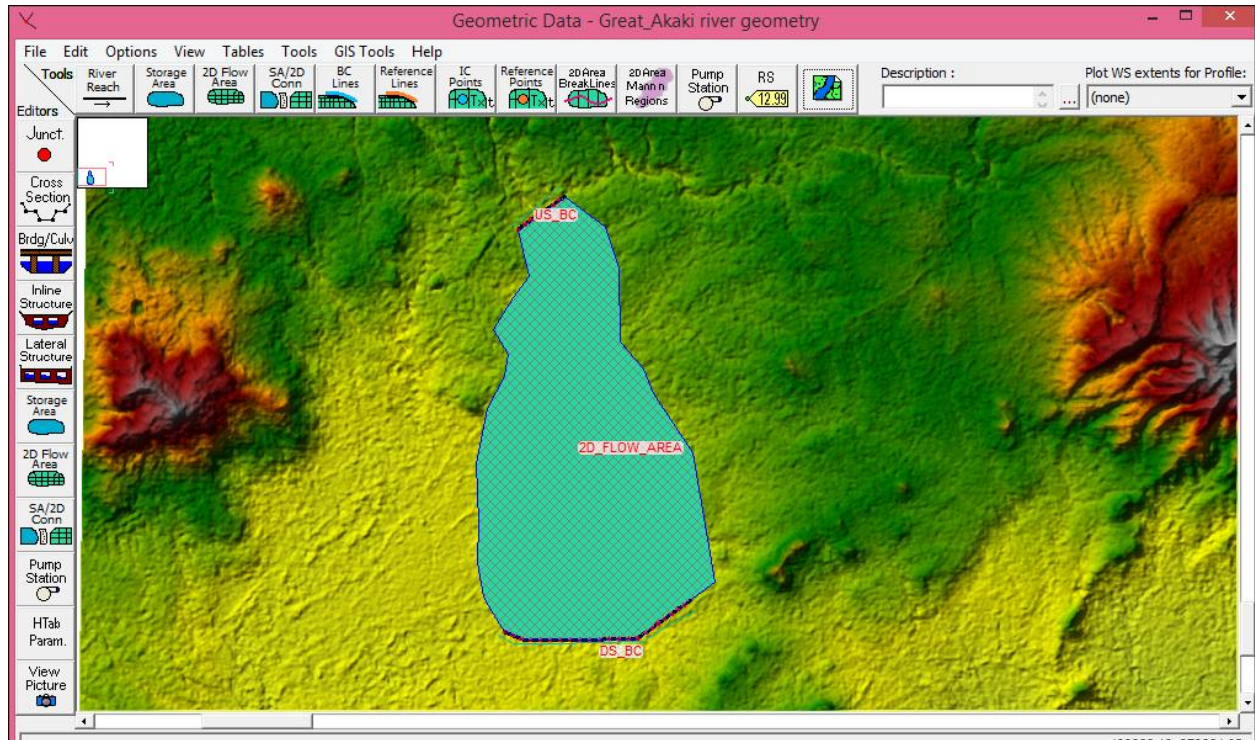


Figure 3.5: Geometric editor window

And finally, the flood area will be marked using 2D flow area editor tool. Using these tool downstream locations where flooding is expected will be marked. The area within the mark will be gridded into small cells where every cell represents a unique elevation. Once 2D flow area is created, HEC-RAS will generate cross sectional data at any given location for hydraulic computation. The Manning n value is also incorporated for every cell. Since HEC-RAS requires boundary condition for hydraulic computations, both upstream and downstream boundary conditions will be inserted using SA/2D Area BC line tool.

Once all the required data is inserted in the geometric data editor window then the final input data will be inflow data, boundary condition and initial conditions. For upstream boundary condition, the inflow hydrograph for different return periods are used where as for the downstream boundary condition, normal depth or slopes at the outlet of the flow were used. After these, the model was run for the all return period scenarios and the outputs were displayed in Ras Mapper and exported to GIS in order to produce inundation maps and risk map.

### **3.3.5. Unsteady flow analysis**

Flood is a typical example of unsteady flow since the stage of the flow changes instantaneously as the flood wave pass. In this study HEC-RAS was used to simulate unsteady flow throughout the downstream of Great Akaki River. Once all of the geometric data are entered in to HEC-RAS, required unsteady flow data was entered to undertake the unsteady flood simulation. Unsteady flow data includes boundary conditions at all of the external boundaries of the system, as well as any desired internal locations, and set the initial flow and storage area condition at the beginning of the simulation.

Generally unsteady flow data required are boundary condition and initial condition. There are different types of boundary conditions some of them are Flow Hydrograph, Stage Hydrograph, Stage and Flow hydrograph, Rating Curve, Normal Depth, Lateral Inflow hydrograph etc. Unsteady flow data used as a boundary condition in this study are: 10yr inflow hydrograph, 25yr inflow hydrograph, 50yr inflow hydrograph, 100yr inflow hydrograph, 200yr inflow hydrograph and Normal depth. Normal depth is used as a downstream boundary condition.

Normal depth can only be used as a downstream boundary condition for an open-ended. To use normal depth, it is required to enter a friction slope for the reach in the vicinity of the boundary condition. The slope of the water surface is often a good estimate of the friction slope. In addition to the boundary condition, initial condition should be established at the beginning of the unsteady flow simulation. Initial condition consists of flow and stage information at each of the cross sections, as well as elevations for any storage areas defined in the system. Once all the geometric and unsteady flow data have been entered, unsteady flow calculations can be performed.

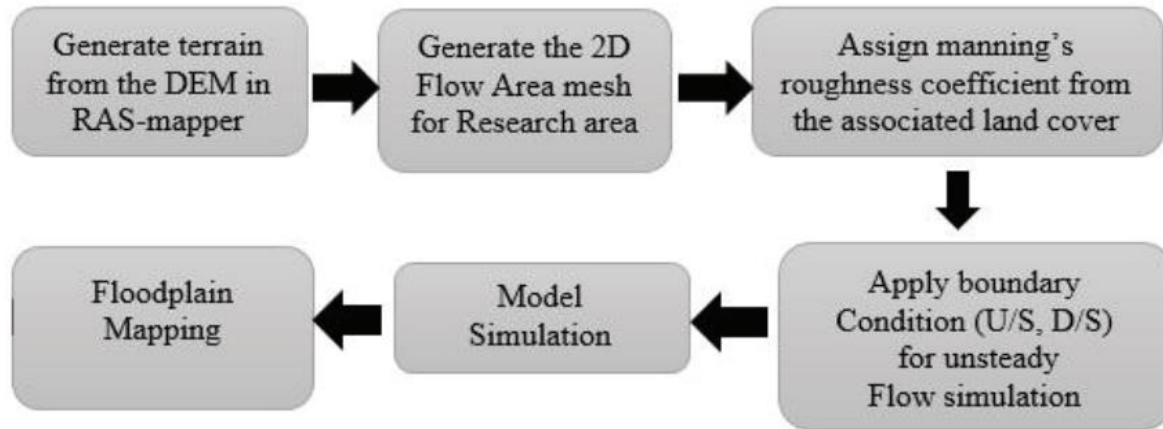


Figure 3.6: Conceptual 2D model diagrams for floodplain mapping in HEC-RAS

### 3.4.Flood Hazard Analysis

To identify the potential danger or hazard associated with the flood, flood hazard maps were derived taking into account the depth and velocity of the floodwaters. Flood hazard assessment and mapping is used to identify areas at risk of flooding, and consequently to improve flood risk management and disaster preparedness. Flood hazard assessments and maps typically look at the expected extent and depth of flooding in a given location, based on various scenarios (e.g. 100-year events, 50-year events, etc.). Measures to improve preparedness can include changes in land-use planning, implementation of specific flood-proofing measures, creation of emergency response plans, etc. Flood hazard assessments can be further expanded to assess specific risks, which take into consideration the socioeconomic characteristics (e.g. industrial activities, population density, and land use) of the exposed areas.

Flood Hazard Mapping 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 identification of areas at risk of flooding and also helps priorities mitigation and response efforts (Bapulu & Sinha, 2005). Flood hazard maps are designed to increase awareness of the likelihood of flooding among the public, local authorities and other organizations. They also encourage people living and working in flood-prone areas to find out more about the local flood risk and to take appropriate action (Environment Agency, 2010).

It is important to note here, that climate change must be carefully considered when implementing flood hazard mapping. Flood hazard mapping typically provides a ‘snapshot’ of flood risk at a

given point in time. When considering the effects of climate change however, it is important to consider the dynamic nature of flood risks. The creation of flood maps usually combines topographic data with historic or modeled information on extreme sea levels and wave heights. This allows determination of the water level at the coast under extreme conditions and shows how this water could flood inland. This is likely to involve the deployment of storm surge and wave models. Key components of flood hazard assessment and mapping include data for Digital Elevation Models (thus the topography characteristics of the area) and hydrological models to simulate various flood events and their impacts. The data can be further supplemented by land cover data, soil data, and other datasets. For creation of maps and visualization tools, additional software (e.g. ArcGIS) may be required. The combined effect of depth and velocity of flooding is used as Flood hazard and mapped using GIS software.

### **3.5.Flood vulnerability map**

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).

$$\text{FVI} = \text{Exposure Index} * \text{Susceptibility Index} - \text{Resilience Index}$$

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: Generally, flood vulnerability studies are based on the extent of potential harm that is inflicted under a certain physical and socio-economic susceptibility and capacity measures in a particular area at a particular time period. In this study, the socio-economic indicators are considered based on the data availability. This study adopted and modified the socio-economic indicators selected by Mishra & Sinha, (2020) to suit the conditions of the study area.

The various indicators that are selected for socio-economic flood vulnerability analysis are based on the data availability, extensive literature review and rigorous group discussion with the population, policy makers residing in the community and their influence and

relationship with flood vulnerability. Based on the literatures reviewed, field visit and focused group discussion (FGD) with key informants in the study area, the socio-economic indicators such as population density, Flood depth, Flood velocity, flood duration, slope and land-use, are selected in this study as they so much influence the vulnerable nature of the study area.

The population density, flood depth and flood velocity are considered as the key factors in vulnerability mapping because the population density is the superset of all the vulnerability indicator drivable from population census data whereas flood depth and flood velocity are the next factor. Finally, these dataset are processed in GIS to generate spatial maps which are afterward used for the flood vulnerability analysis. The flood vulnerability map is produced by integrating these maps to a single whole using GIS analysis.

### 3.5.1. Selection of flood vulnerability indicators

The indicator-based food vulnerability assessment has been acknowledged as the most appropriate for evaluating population groups at all levels. However, the real conditions that determine food vulnerability is site-specific localized and hazard dependent. As a result, the numbers of widely accepted indicator are very limited. To practically assess vulnerability of specific study area, identification of variables that made a specific people vulnerable to food hazard and how these variables make an effect is a primary activity of this study. Therefore, the selection of food vulnerability indicators of Akaki city was governed by availability of data, personal observation and results of previous research works. Accordingly, 6 indicators for which data were available and which best fits to the local vulnerability conditions were combined into the composite vulnerability index (Table 3.3).

Table 3.3: Flood vulnerability indicators and data sources

No	Indicator	Data Sources	Abbreviation
1	Flood depth	HEC-RAS	FD
2	Flood velocity	HEC-RAS	FV
3	Flood duration	HEC-RAS	FD
4	Population density	Survey	PD
5	Slope	DEM	S
6	Land use Land cover	USGS	LULC

The FVI were computed based on unequal method of FVI weighting method developed by Iyengar and Sudarshan (1982). Finally, an accurate village level food vulnerability maps were created using ArcGIS software.

### **3.5.2. Data arrangements and normalization of indicators**

The data collected from various sources were arranged and mapped in GIS. Each indicator is in different units and scale of measurements. The UNDP's Human Development Index (HDI) method of normalization was adopted to obtain the indicators free of units and scales (UNDP 2006). Furthermore, normalization was adopted to standardize the value of each indicator so that they all lie between 1 and 5. Finally, the index of normalized score was constructed by using unequal weights to all indicators. Before normalization, the indicators were arranged in relation to functional relationship with vulnerability. Indicators can have two type of functional relationship with vulnerability. Some have positive relationship and increase the level of vulnerability. The others have negative relationship and decrease the level of the vulnerability.

Many authors agree that vulnerability is a function of exposure, susceptibility and resilience (Cardona 2013; Smit and Wandel 2006; Balica et al. 2012; Balica 2007; IPCC 2001). Therefore, the general formula for computation of FVI demands categorizing the indicators as [exposure (E), susceptibility (S) and resilience (R)]. Exposure represents values that are present at the location where floods can occur. These values can be human being, properties, infrastructure, cultural heritage, agricultural fields and the like. Though there are different working definitions of exposure, the theme concept of exposure is defined as “the predisposition of a system or its elements to be affected by a food due to its location in the same area” (Balica 2007; Fuchs et al. 2011; Veenstra 2013).

Susceptibility is described as the potential of a system to be harmed by a hazardous event such as flooding, caused due to fragility, relative social or economic weaknesses or disadvantageous conditions (Cardona 2013; Balica 2007; Veenstra 2013). Resilience is the ability of a system to adjust to changes or threats, to avoid, mitigate or absorb potential damage, to cope with the consequences without loss or to even take advantage of opportunities (IPCC 2001; Pelling 2012; Veenstra 2013). Both exposure and susceptibility have a positive influence on vulnerability, and resilience has a negative influence on vulnerability.

### **3.6.Flood Risk Analysis**

After flood hazard and flood vulnerability has been developed, flood risk were developed by overlaying flood hazard map and food vulnerability map. High-risk flood areas can be identified, allowing planners to improve preparedness and design interventions. Flood hazard assessments and related maps can also be adopted by land use and development planners as part of an integrative approach to improve flood preparedness that can improve future land developments and raise community awareness. According to Zimmermann, 2005) the conventional expression of risk is,  $Risk=Hazard * Vulnerability$ .

## 4. RESULTS AND DISCUSSION

### 4.1. Flood inundation map

Hydraulic models help to predict where flooding might occur, how severe it might be, and the impact that different mitigation measures might have on flood risk in different situations. A flood map provides information on depth of flooding, extent of inundation, and most importantly the direction of flow paths as the flood water travels. A flood inundation map is a set of maps that show the spatial extent and depth of flooding at specific water-level (stream stage) intervals along an individual stream section. The flood map can be overlaid with other varieties of maps and aerial photographs so that anyone can easily read and understand the map. This allows the residents to find out whether their farm/ property/ community are likely to be flooded in a specific situation.

For this study, the flood inundation boundary of the flood prone area was prepared for all return periods and is exported from the RAS Mapper to ARC-GIS for detail mapping. The areas inundated by floods are 7.58Km<sup>2</sup>, 9.79Km<sup>2</sup>, 11.2Km<sup>2</sup>, 12.45Km<sup>2</sup>, 13.83Km<sup>2</sup> for 10, 25, 50, 100, 200 years return periods respectively. As it has been known that major settlements, farm lands and buildings are located along the flat flood plain at the lower part, and scattered settlements are at upper flood plain. All these are likely to be affected due to inundated flood.

Figure 4.1 shows the inundation area of Akaki city due to Great Akaki river flood inundation. The inundation map and failure scenarios give direction for emergency action plan to see the perspective through which mitigation measure undertaken to reduce the risk of flood or take appropriate remedial measure

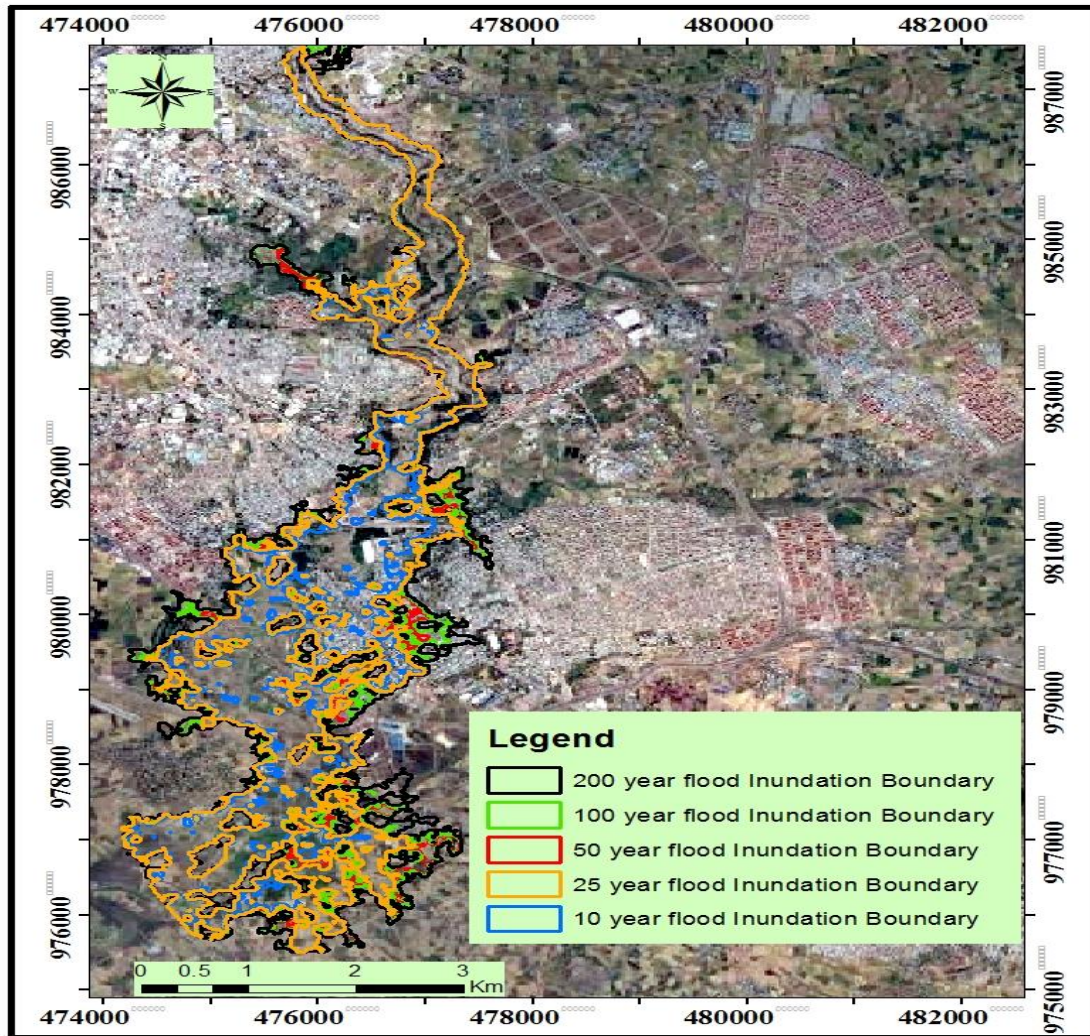


Figure 4.1: Flood Inundation boundary of Great Akaki river for different return periods

#### 4.2. Flood depth map

Flood depth maps show the water level at the given flood frequency. Flood depth maps used for producing flood vulnerability and risk maps, which further helps to estimate possible consequences (social, cultural, economic, and environmental) of flooding. Emergency responders are primarily interested in the extent and depth of inundation rather than the elevation of flooding. The results shows the maximum flood depth of 10.21, 11.59, 14.25, 15.02m for return periods of 10, 25, 50, 100, 200 years respectively ( Figure 4.2). In general, high water depth occurred along the main channel and spreads gradually to the floodplains. Also, the river flows in between slightly hilly terrain and, as such, rain water uphill flows rapidly into the river channel.

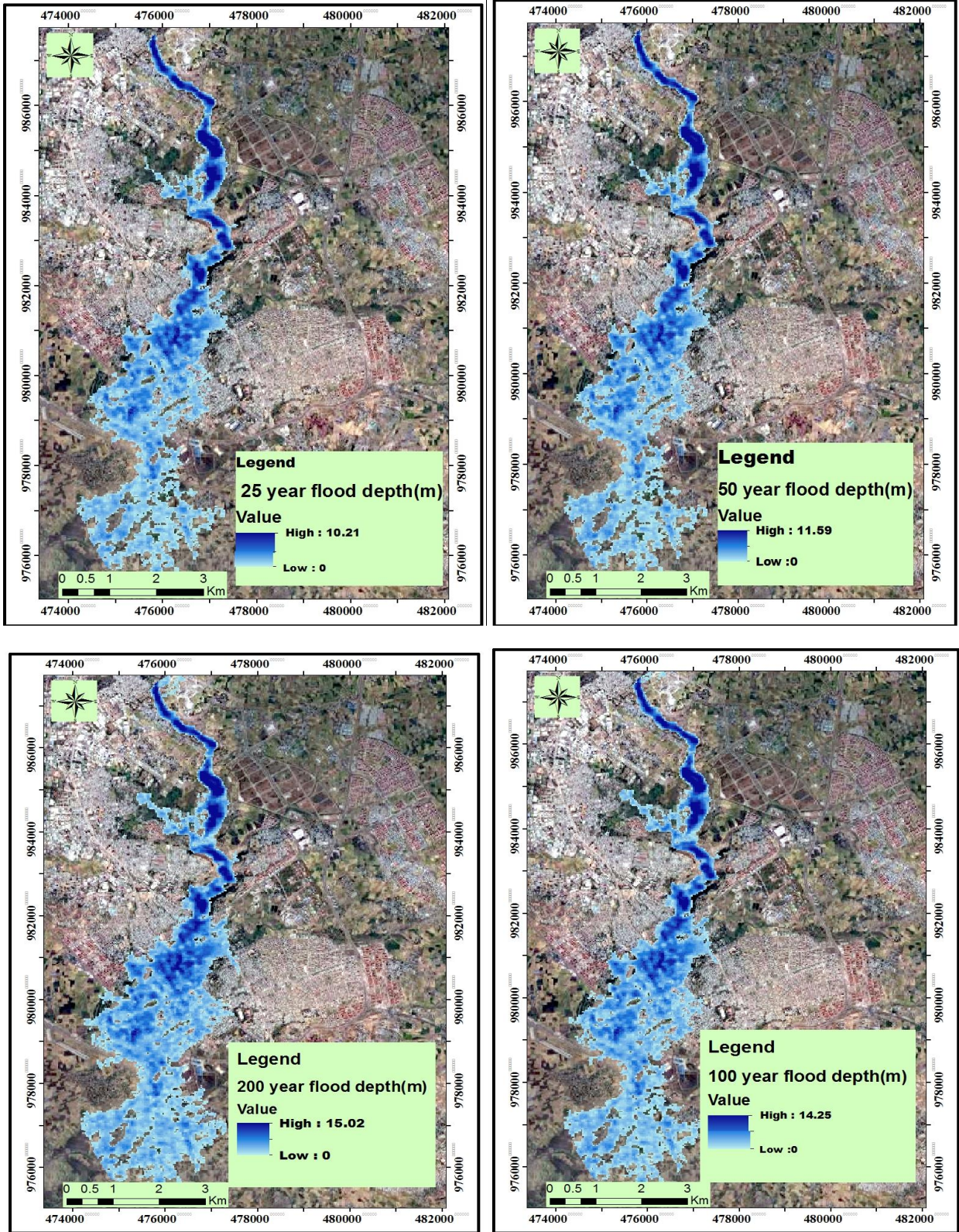
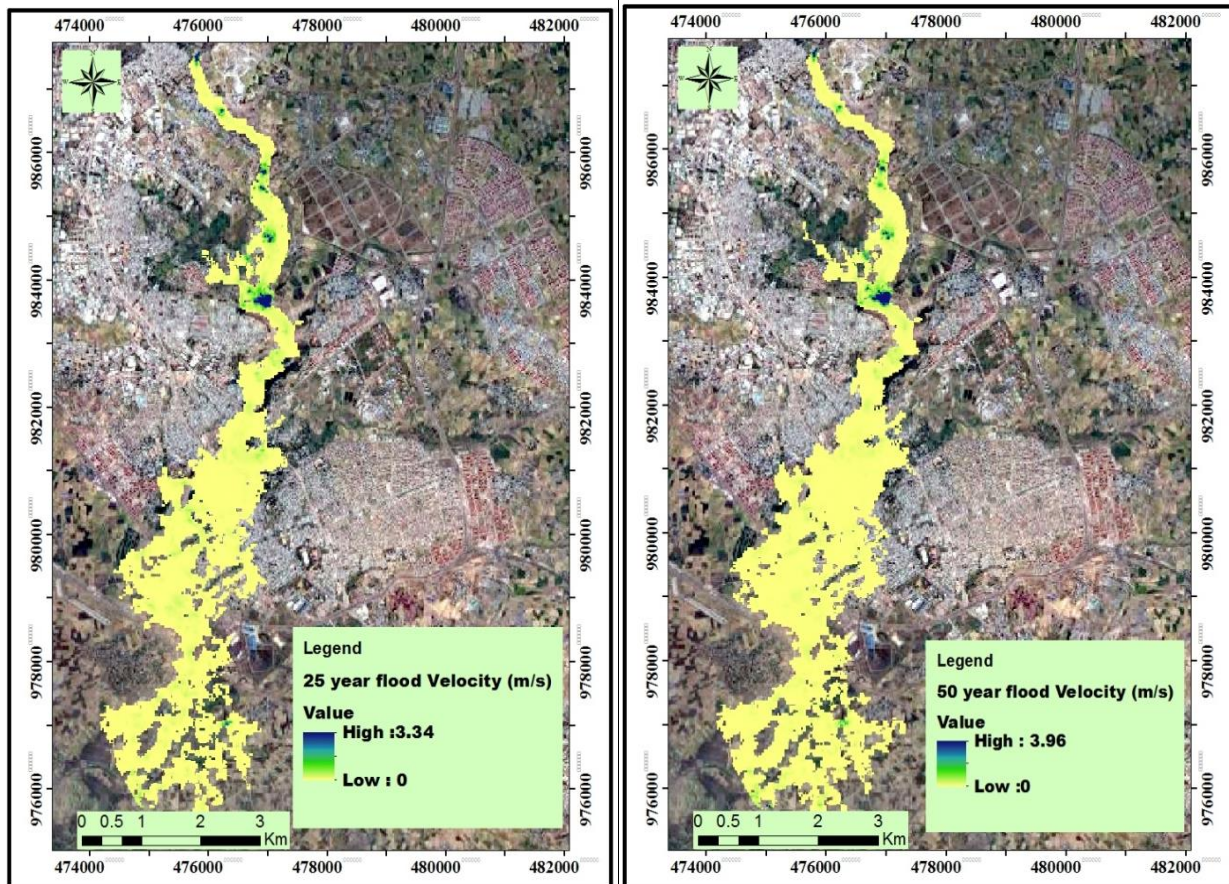


Figure 4.2: flood depth maps for different return periods

### 4.3.Flood Velocity Maps

Velocity maps are particularly important for emergency and engineering tasks. Emergency workers use the latter to determine how fast the water flows in areas where rescue operations take place. In constructing flood defense structures, velocity of water is also needed to be known. Figure 4.3 shows velocity (m/s) map of the flood plain area. The maximum flood velocities for 10, 25, 50, 100, 200 years return periods are, 3.12, 3.34, 3.96, 4.78, 5.26 m/s respectively. This map combines with flood depth map in order to make hazard mapping. The maximum velocity found across river channel and minimum velocity is found in the flat flood plain. Most part of flood inundation is with flat topography such that the velocity of the flood in major part is low as indicated on the figure 4.3 below. In such areas, floodwaters tend to spread out across the landscape, resulting in extensive inundation. Flat topography allows floodwaters to spread over a large area, covering vast expanses of land. As a result, the flood inundation may extend over a considerable distance, affecting a significant portion of the landscape.



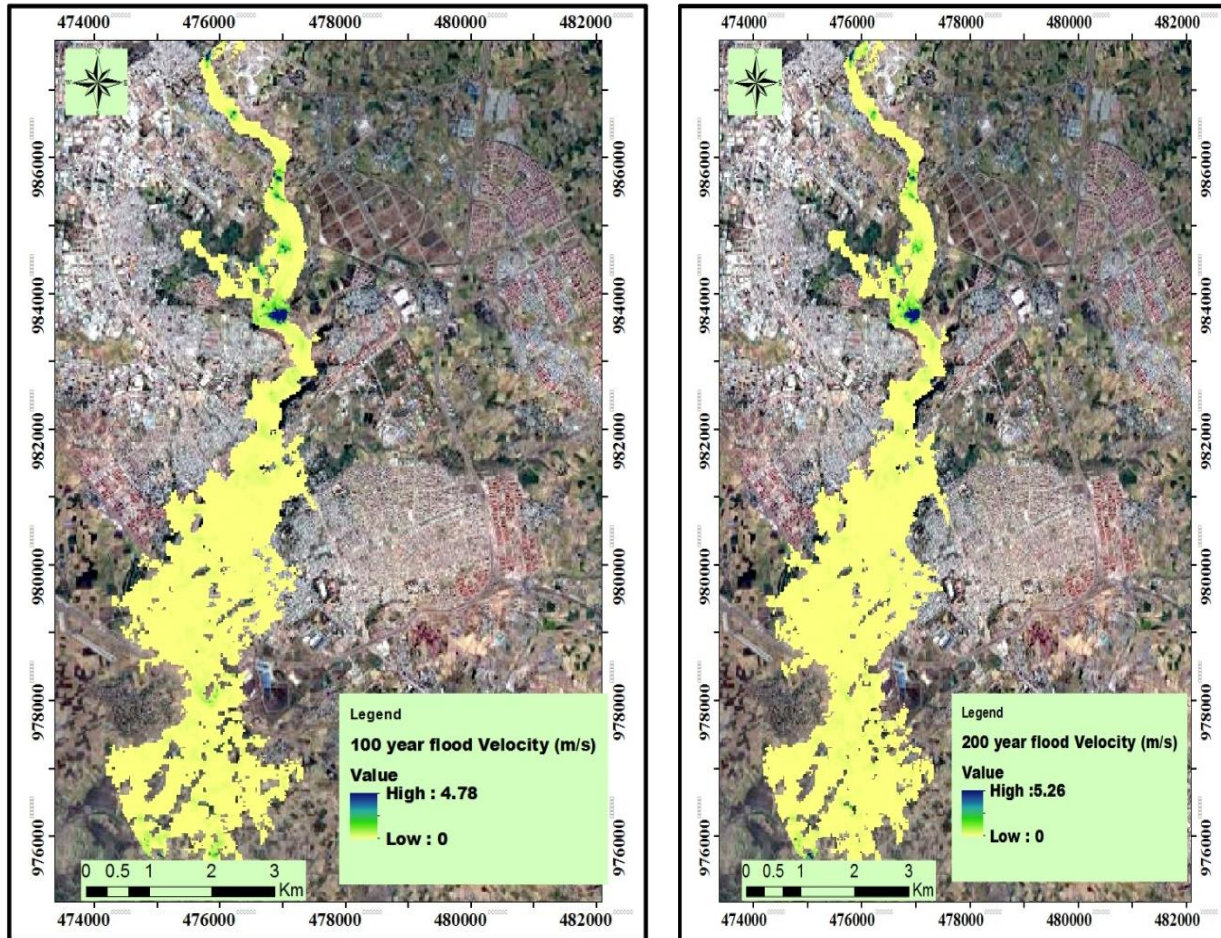


Figure 4.3: flood velocity maps for different return period

#### 4.4.Sensitivity Analysis of HECRAS model

In order to fit the simulated value of water surface elevations with the measured one, five simulation scenarios were carried out during sensitivity analysis. Manning's roughness is one of input parameter to simulate un-steady flow in HEC-RAS. The selection of an appropriate value for Manning's  $n$  is quite significant for the accuracy of the computed water surface profiles. The value of Manning's  $n$  is highly variable and depends on several factors, including the type of river bed, flood plain characteristics, type of vegetation, channel irregularities, channel alignment, obstructions, size and shape of the channel, suspended material, and bed load. The value of this parameter is affecting the depth of the flow, velocity of water in the river and water surface profile. Manning's  $n$  influences the flow resistance, with higher values indicating rougher surfaces and increased resistance. A higher  $n$  value results in greater flow resistance, leading to higher water depths for a given discharge. Manning's  $n$  affects the flow resistance, and

consequently, the velocity of water in the channel. Higher  $n$  values correspond to lower velocities, as more energy is required to overcome the increased resistance. Manning's  $n$  plays a significant role in establishing the water surface profile. The roughness characteristics represented by  $n$  influence the flow resistance, and accurate selection is vital for accurately predicting water surface elevations along the channel. Choosing an appropriate Manning's  $n$  value requires careful consideration of field observations, available data, and expert knowledge. Calibration and validation against observed data are crucial to ensure accurate representation of flow characteristics and water surface profiles in HEC-RAS simulations.

To see the fluctuation of the simulation results, the WSE values obtained were plotted along the levee for different roughness as shown in figure below. These results show that with increase in roughness coefficient, WSE profile is no longer uniform and appears as a gradual variable flow, thus the WSE profile changed.

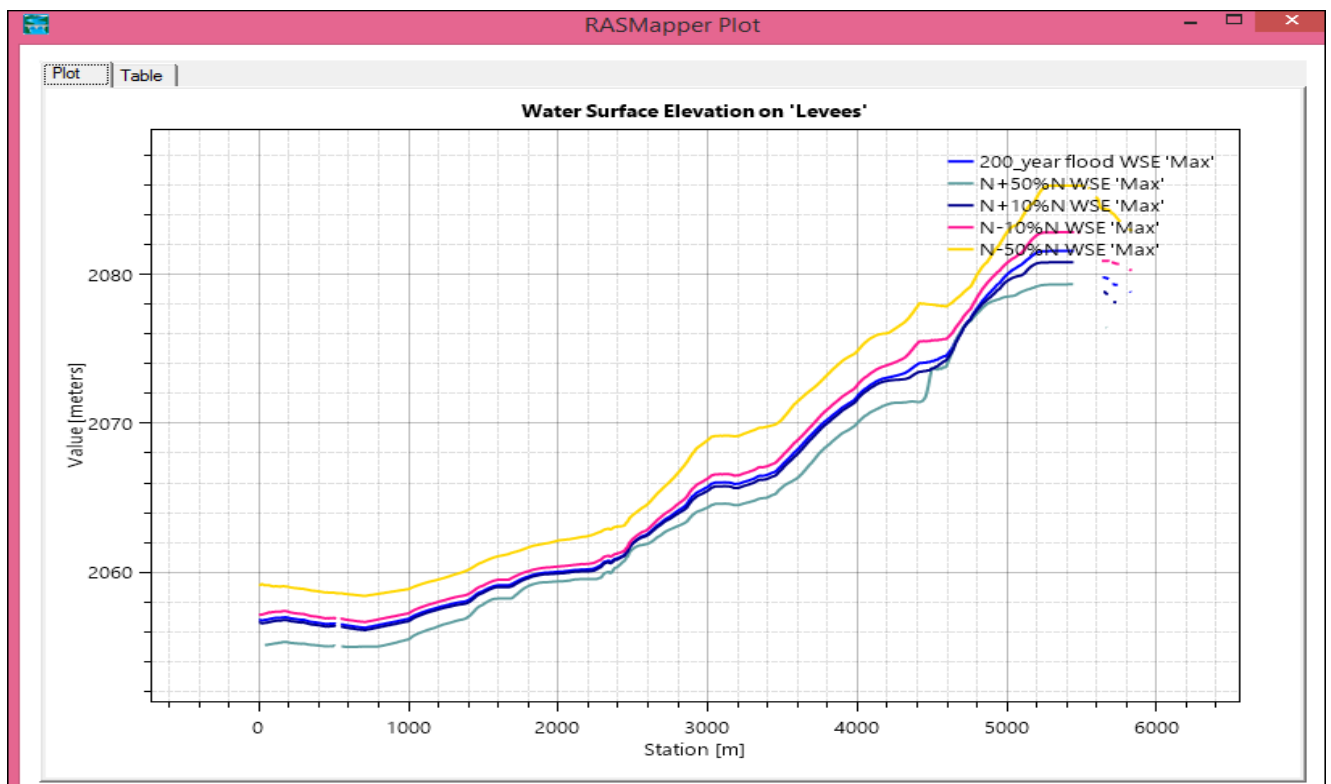


Figure 4.4: Sensitivity Analysis of manning's roughness along Levee structure

#### 4.5. Model calibration

During calibration, the Manning's coefficient "n", were changed iteratively until the differences between simulated and observed values of WSE were within the allowable criteria range. The calibration procedure gave the actual Manning's of the river channel. Figure 4.5 below shows the result of simulated WSE that were obtained after conducting sensitivity analysis of manning's roughness for Great Akaki River flood plain. At N+10%N, the simulated water surface elevation values fitted well to the measured values

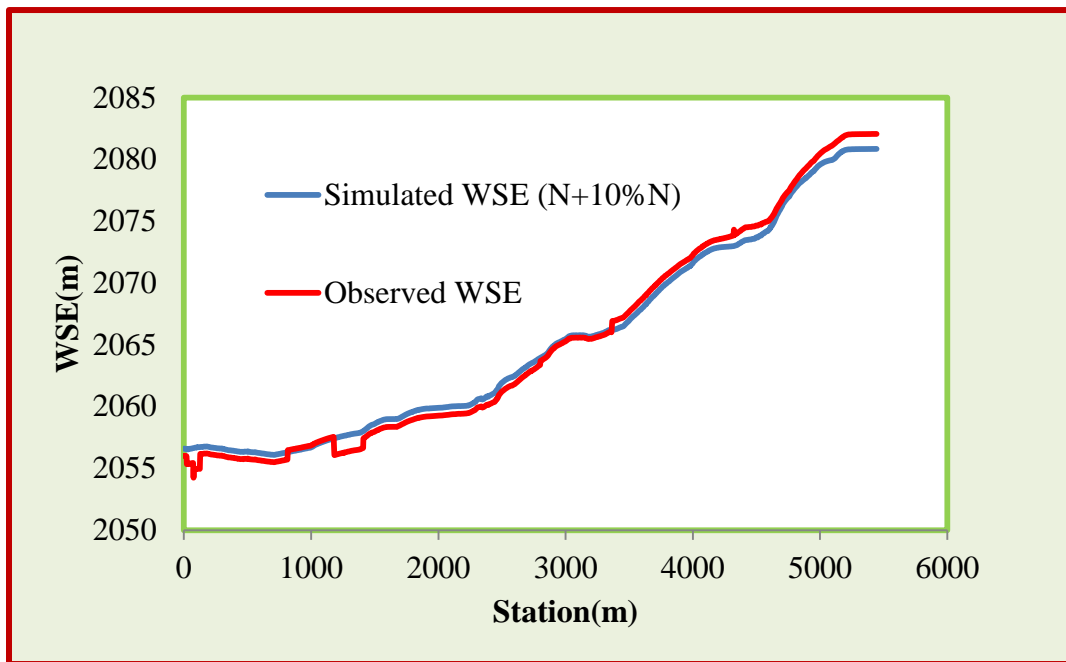


Figure 4.5: Calibrated result of WSE for manning's roughness N+10%N

#### 4.6. Model evaluation

Model evaluations aims to estimate the generalization accuracy of the model on future data and assess goodness of fit between observed and simulated parameters. The coefficients of determination ( $R^2$ ) represent the collinear relationship between simulated output and observed values. The values of  $R^2$  lie between 0 to 1 showing the proportion of variance in measured data. The value close to greater than 0.5 is considered acceptable, whereas the value close to one indicates the perfect model. The result on figure 4.6 show that the coefficients of determination ( $R^2$ ) of 0.94. These show that the model performed very well. Higher values of  $R^2$  indicate less error variance and typically values greater than 0.50 are considered acceptable.

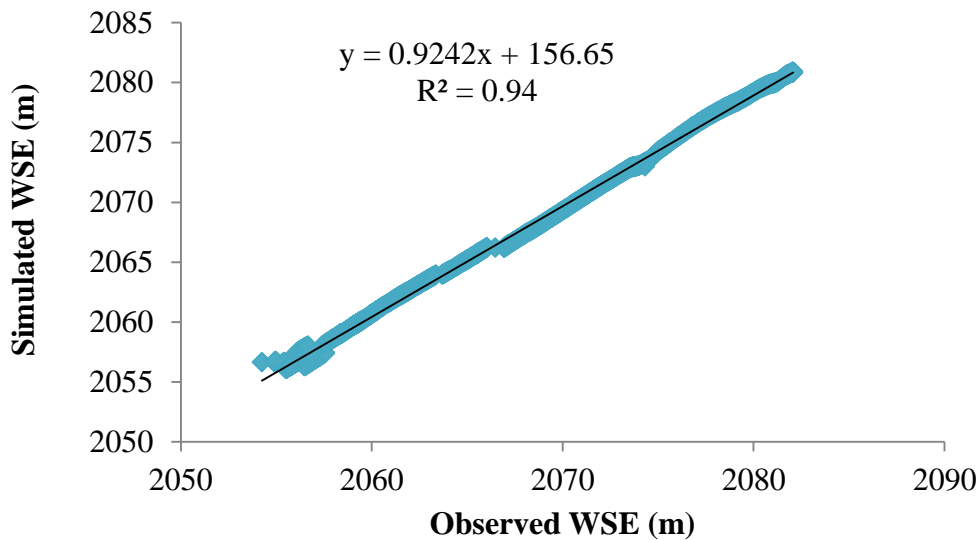


Figure 4.6: Goodness of fit for simulated and observed values of WSE

#### 4.5.Flood hazard mapping

A flood hazard is the occurrence of the expected source of danger because flooding. It alters with flood severity and place of occurrence within the floodplain for the similar flood event. This variation with both flood behavior and the interaction of the flood with the topography. The most important factors affecting human stability in flood waters are firstly depth and secondly velocity. Depth dictates what type of failure is to occur, either sliding (friction) or tumbling (moment) failure. As the depth of water increases, the damage increases. Nevertheless, even small depth water moving at high velocity may knowingly damage a structure or damage its foundation. Faster the velocity of flood water, higher the chance of loss of life.

Persons incapable to evacuate may become trapped in a home or business center that is being destroyed by high-velocity water or rising floodwaters. High depths increase buoyancy and reduce friction under foot. Low depth-high velocity flows may cause instability but the chances of drowning are less than in the more dangerous deep-water situations. At velocities in excess of 2 m/s, the stability of foundations and poles can get affected by scouring. As grass and earth surfaces begin to erode, scour holes may develop. At depths in excess of 2 m, lightly framed buildings may be damaged by water pressure, floatation and debris impact, even at low velocities. Therefore, there is a need for a combined set of hazard vulnerability, which can be used as a general classification of flood hazard on a floodplain.

### 4.5.1. Flood Hazard Classification

Different studies and guidelines have different flood hazard classification limits and justifications. The depth-velocity hazard classification diagram considered in this study is based on FEMA (2018) guide line. Flood severity grid prepared by FEMA (2018) is shown in the Figure 4.7 in order to obtain upper limits of the depth \*velocity product for each category of hazard level.

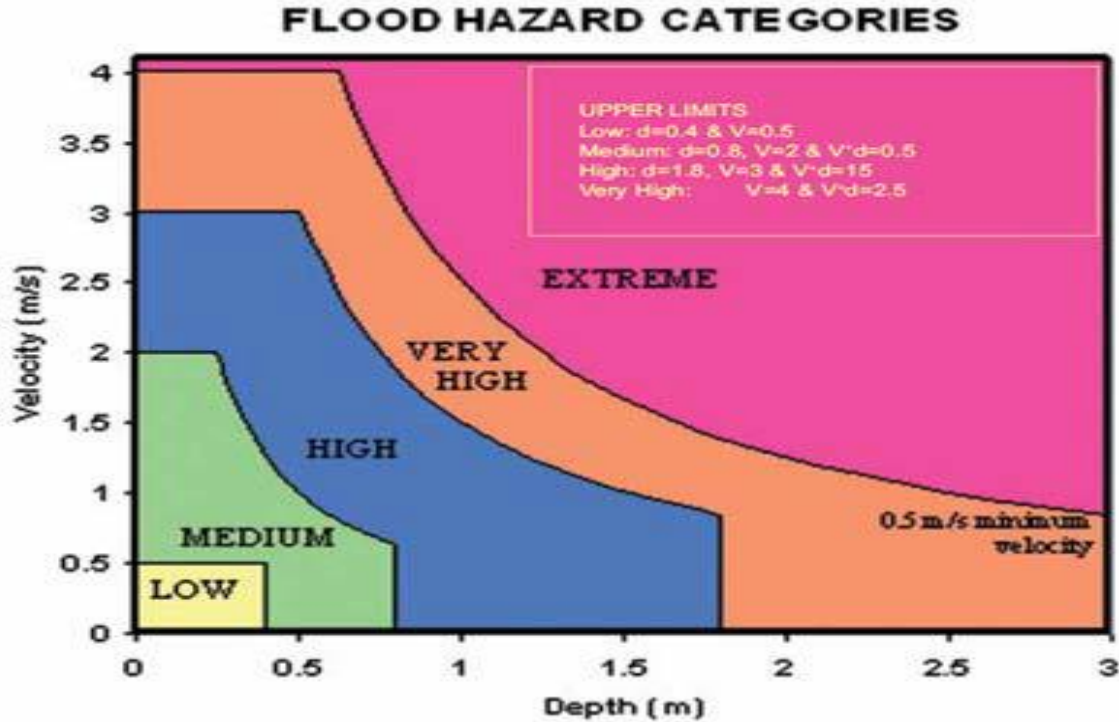


Figure 4.7 : Flood hazard category

The combined effect of depth and velocity has been considered while classifying the hazard at a grid point. These hazard criteria are assigned hazard index on 1 – 5 scale, 1 being low hazard category while 5 being extreme hazard category. The hazard classification scheme is shown in table 4.1.

Table 4.1:Flood Depth and Velocity Severity Grid Categories source: FEMA (2018)

Flood index	Flood severity category	Depth *velocity range (m <sup>2</sup> /sec)	Description
1	Low hazard	≤ 0.2	Generally safe for vehicles, people and buildings.
2	Medium hazard	0.2 - 0.5	Unsafe for small vehicles.
3	High hazard	0.5 - 1.5	Unsafe for vehicles, children and elderly.
4	Very high hazard	1.5 - 2.5	Unsafe for vehicles and peoples
5	Extreme hazard	> 2.5	Unsafe for all vehicles, peoples, and buildings

Using the maps of (Depth \* Velocity) for 200 year return periods and using the hazard classification scheme mentioned in Table 4.1, the hazard map for 200 year return periods has been prepared and is shown in Figures 4.8 below. These maps are the backbone for preparation of emergency action plan in the short term and floodplain regulatory management in the long term. As indicated on Figure 4.8, about 13.7 % of the total flooded area is under an extreme hazard of flooding which means unsafe for all peoples, vehicles and structures vulnerable to flooding and whereas 17.6%, 16.7%,18.9% and 33.1% of total area are under very high, high, medium and low hazard respectively. The extreme, very high and high hazard areas are mostly in the relatively covers small area with high slope gradients and sparse vegetation. The medium and low hazard areas are relatively covering low elevation areas with flat gradients and dense vegetation.

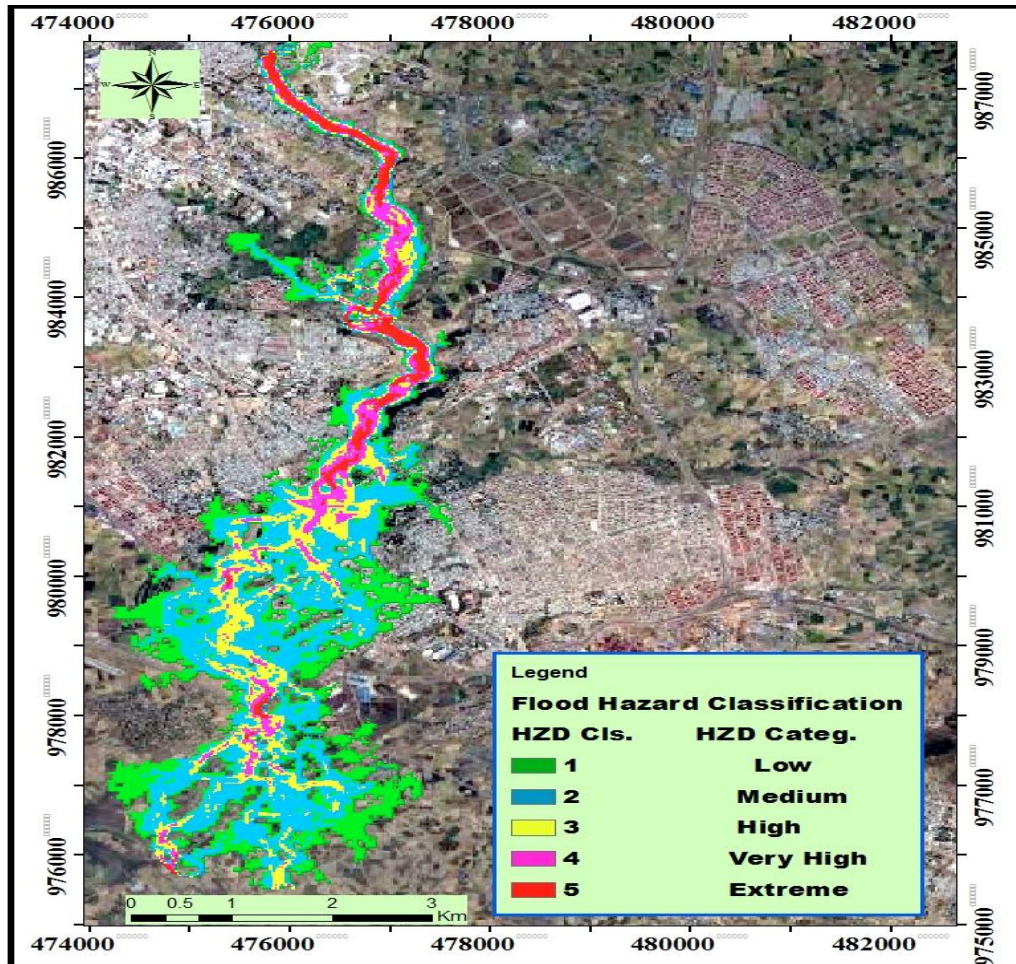


Figure 4.8: Flood hazard mapping

#### 4.6. Flood Vulnerability Map

The flood vulnerability map of the study area is presented in Figure 4.9 which highlights five areas of vulnerability classes ranging from very low, low moderate, high and very high. The very high and high classes cover 9.59 % (1.21 Km<sup>2</sup>) and 15.54 % (1.96 Km<sup>2</sup>) of the flooded area respectively. It is basically areas characterize with urban built up and open classes of land use, high population, steep slope, high flood depth and high flood velocity. The medium vulnerability class covers 24.33 % (3.07 Km<sup>2</sup>). The low and very low vulnerability classes cover 34.17% (4.31 Km<sup>2</sup>) and 16.37% (2.07 Km<sup>2</sup>) of the flooded area respectively. These constitute areas of agricultural lands, vegetation, less population density, flat land slope. In general, high flood vulnerability may lead to high flood risk. The total number of vulnerable houses during the site visit under very high, high, moderate and low risk was 2850, 350, 158, 15 respectively. By taking the average family size of 4 which were done by direct survey during site visit, the total

number of people vulnerable for very high, high, moderate and low risk were 11400, 1400, 632, and 60 respectively.

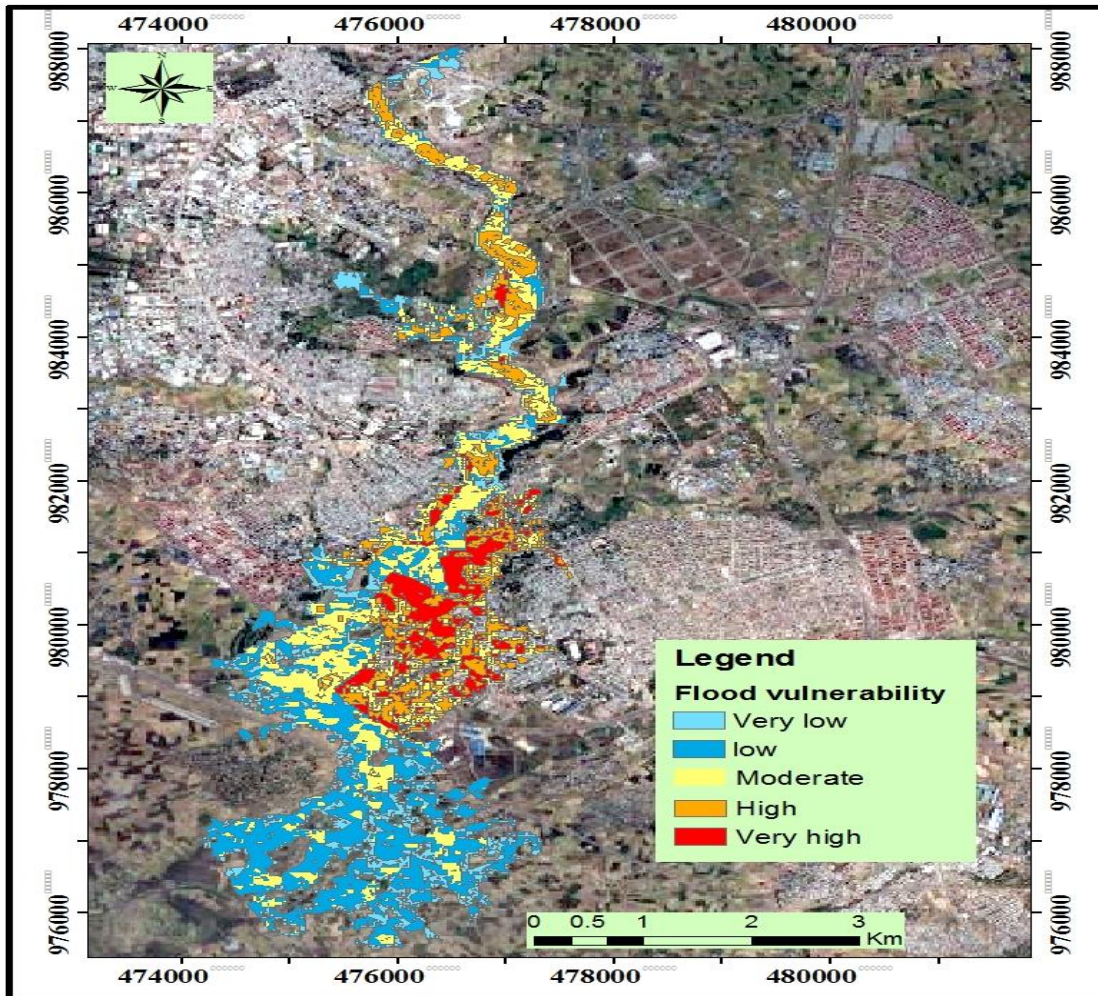


Figure 4.9: Flood vulnerability map

#### 4.7.Flood Risk Map

The flood risk map of the study area is presented in Figure 4.10. The flood risk is divided into five levels of risk ranging from very low to very high risk. The Figure reveals that areas of very high, high, moderate, low and very low risk are 3.6 %, 12.6 %, 18.5 %, 19.8 % and 45.5 % of the flooded area respectively. The high and very high risk zones are characterized by low slopes and elevations; high flood depth and velocity, high population density, urban built up and bared land type of land uses. The overall area covered with high and very high flood risk in the basin constitutes about 16.2 % (2.04 Km<sup>2</sup>) of the entire area. A careful analysis of the risk map reveals

that the urban built up, high flood depth, velocity, duration and low slope and elevation plays a vital role in increasing the risk of flood in these regions. The medium risk class covers about 18.5% (2.34 Km<sup>2</sup>) of the area while the low and very low flood risk zones constitute 65.3% (8.25 Km<sup>2</sup>) of the area. These risk classes are concentrated at the downstream part of the flooded area and the zones are characterized by flat slope and low elevation, permeable soil, vegetation and forest type of land use, very sparse population density and high flood depth and velocity. As indicated on vulnerability map the total numbers of vulnerable houses were 3,373 and the total numbers of vulnerable peoples were 13,492. Out of total vulnerable houses and peoples, 84.5% are highly vulnerable to risk.

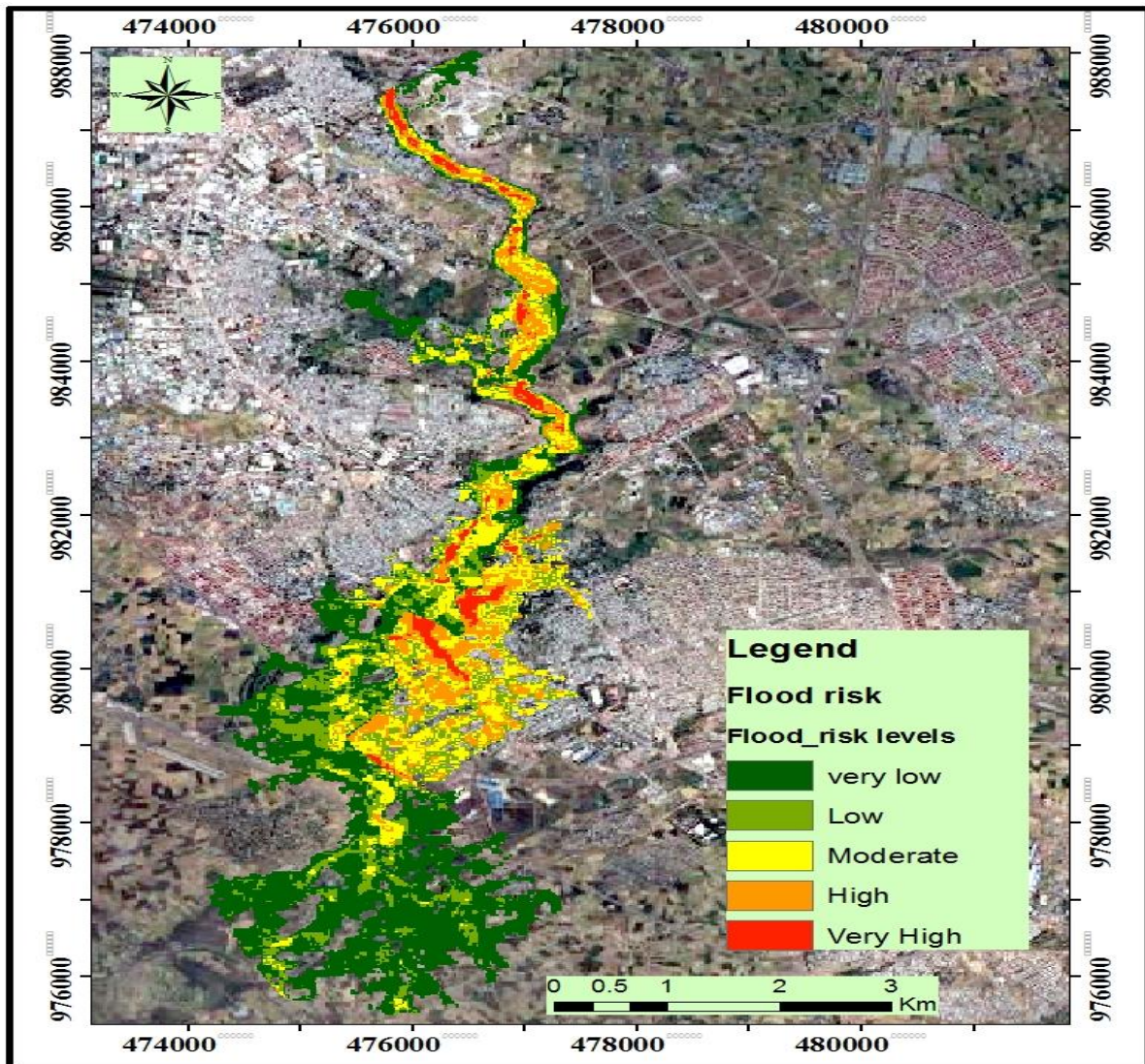


Figure 4.10: Flood risk map of Great Akaki River

#### **4.8. Flood risk reduction through Mitigation and Management Options**

Flood reduction and mitigation can be achieved by employing either structural or non-structural measures which largely depend on available flood information and knowledge of potentially affected areas or areas that are prone to flooding event. This suggests that, the flood risk map of great Akaki River seek for exploring sustainable flood reduction and mitigation measures that will suit the condition of the study area. Based on the literature review, focus group discussion with expert, rigorous field study and analysis of result of the flood hazard, risk and vulnerability of the study area, the structural measure of flood risk reduction was proposed.

##### **4.8.1. Structural Measures of Flood Risk and Vulnerability Reduction**

The structural measures of flood control employ the techniques of storing, diverting and confinement of flood water (Mishra & Sinha, 2020). This measure can be achieved through the installation of facilities that prevent disasters (Kang et al., 2009). They are basically designed to keep water away from infrastructures, residential areas, agricultural lands, and flood plains by constructing permanent structures in order to reduce the damage of risk. The outcome of this research and in depth field observation and the interview with experts suggested Levees and embankments as Flood control structures provide a sound degree of flood protection especially when combine with other alternative means of flood reduction. Great Akaki river embankment is not monitored and evaluated properly and large population of the basin are dwelling close to rivers. This calls for frequent monitoring and evaluation of this structure by government and local residence. This activity should be combined with a comprehensive health monitoring programs particularly in the more vulnerable areas identified in this research in order to derive long lasting protection. The figure below shows an area of unsafe settlements and to protect an area from risk of flood, 5.83 Km levee embankment is proposed along the settlements on the river left side. Therefore, the government and all concerned parties should take this into consideration and work for the people under threat by building proposed flood prevention structures to avoid damage and death from flood disaster.

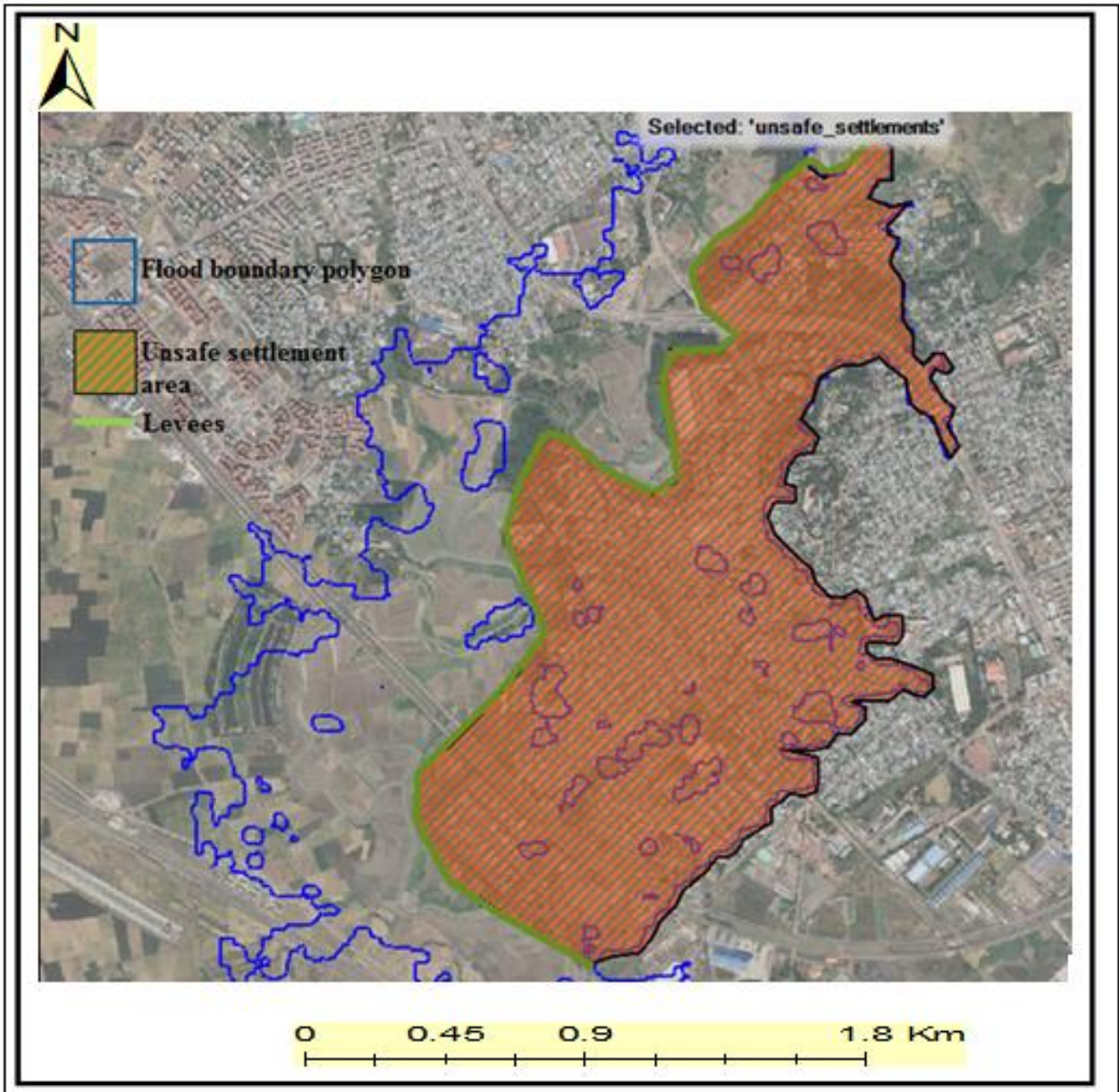


Figure 4.11: Unsafe settlements and proposed levee along unsafe settlements

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1. Conclusions

In general, Flood is probably the most devastating widespread and frequent natural hazard of the world which is the main causes for the death of people, spreading disease, damaging property, harming economy, and affecting people socially and psychologically .In present study, the flood inundation and risk of the Great Akaki River was modeled and analyzed. The study was conducted on Great Akaki River and its one of the tributary of Bulbula River from upstream to down Akaki Kality sub city. The main objective of this study was to model and map the flood inundation and risk associated with the occurrence of flooding. Different data were collected from different sources to achieve the objectives of the study. These data are, DEM, stream flow data and land use/land cover data. The stream flow data was collected from Ministry of Water Resources, Ethiopia. The manning's roughness coefficient where collected from field Digital Elevation Model (DEM) of 20-meter resolution taken from MoWR.

Materials used for study are: HEC-RAS model, GIS software, GPS, Metering tape. In order to analyze the flood hazard and risk analysis, the inflow design flood for different return period was developed. Observed stream flow data were collected over a period of 1985-2004 available from MoWE was used Hydrologic flood frequency analysis. To develop flood inundation, flood hazard, flood vulnerability and flood risk map of an area, HEC-RAS model was used and the result where mapped in ARC-GIS software. As the result indicated that, the areas inundated by floods are 7.58 Km<sup>2</sup>, 9.79 Km<sup>2</sup>, 11.2 Km<sup>2</sup>, 12.45 Km<sup>2</sup>, and 13.83 Km<sup>2</sup> for 10, 25, 50, 100, 200 years return periods respectively. The results of flood depth and velocity shows that, the maximum flood depth of 10.21, 11.59, 14.25, 15.02m and maximum flood velocities 3.12, 3.34, 3.96, 4.78, 5.26 m/s for return periods of 10, 25, 50, 100, 200 years respectively. To identify the potential danger or hazard associated with the flood, flood hazard maps were derived taking into account the depth and velocity of the floodwaters.

Flood hazard map for 200 year return periods has been prepared and the result shows that about 13.7 % of the total flooded area is under an extreme hazard of flooding which means unsafe for all peoples, vehicles and structures vulnerable to flooding and whereas 17.6%, 16.7%, 18.9% and 33.1% of total area are under very high, high, medium and low hazard respectively. This map is

used to identify areas at risk of flooding, and consequently to improve flood risk management and disaster preparedness. The flood vulnerability map of the area was prepared by considering the vulnerability indicators such as flood depth, flood velocity, flood duration, slope, land use land cover, and population density. The flood vulnerability is classified to five areas of vulnerability classes ranging from very low to very high. The very high and high classes cover 9.59 % (1.21 Km<sup>2</sup>) and 15.54 % (1.96 Km<sup>2</sup>) of the flooded area respectively. In general, high flood vulnerability may lead to high flood risk.

The total number of vulnerable houses during the site visit under very high, high, moderate and low risk was 2850, 350, 158, 15 respectively. By taking the average family size of 4 which were done by direct survey during site visit, the total number of people vulnerable for very high, high, moderate and low risk were 11400, 1400, 632, and 60 respectively. The flood risk map of an area was prepared by considering flood hazard and flood vulnerability. The flood risk is divided into five levels of risk ranging from very low to very high risk. The Figure reveals that areas of very high, high, moderate, low and very low risk are 3.6%, 12.6%, 18.5%, 19.8% and 45.5% of the flooded area respectively. A careful analysis of the risk map reveals that the urban built up, high flood depth, velocity, duration and low slope a vital role in increasing the risk of flood in these regions. The medium risk class covers about 18.5% (2.34 Km<sup>2</sup>) of the area while the low and very low flood risk zones constitute 65.3% (8.25 Km<sup>2</sup>) of the area.

These medium risk classes are concentrated at the downstream part of the flooded area which is characterized by flat slope and low elevation, permeable soil, vegetation and forest type of land use, very sparse population density. As indicated on vulnerability map the total numbers of vulnerable houses were 3,373 and the total numbers of vulnerable peoples were 13,492. Out of total vulnerable houses and peoples, 84.5% are highly vulnerable to risk. This shows that, flood risk map of great Akaki River seek for exploring sustainable flood reduction and mitigation measures that will suit the condition of the study area. Based on the literature review, focus group discussion with expert, rigorous field study and analysis of result of the flood hazard, risk and vulnerability of the study area, the structural measure of flood risk reduction, 5.83 Km levee embankment was proposed along the settlements on the left river side at high population density.

Sensitivity analysis for Manning roughness was carried out in order to fit the simulated value of water surface elevations with the measured one. Finally, the performance of the HEC-RAS model was evaluated using model evaluation statistics and the value of the coefficient of determination ( $R^2$ ) for observed and simulated water surface elevation was 0.94.

## **5.2.Recommendations**

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

- ✚ Constructing flood defense structures along the risky areas of flood plain is the mitigating step that local officials and emergency managers should have to implement.
- ✚ Future studies should consider the effect of sedimentation deposited on the river channel on flooding
- ✚ Real time flood forecasting and emergency response centre in Akaki town that has linkage with various governmental, public, nongovernmental and private organizations.
- ✚ Early warning systems and reliable communication systems should be developed (mobile phone network and radio) to facilitate information sharing during the floods.
- ✚ Installation and operation of a real-time reporting network of rainfall and river gauges.
- ✚ Governments and important parties should inform local authorities and farmers about flood early warning systems.
- ✚ Relocating the settlements from flood buffer zone to avoid the disasters associated with floods.

## 6. REFERENCES

- Adugna, D. et al. (2019) 'Evaluating the hydraulic capacity of existing drain systems and the management challenges of stormwater in Addis Ababa, Ethiopia', *Journal of Hydrology: Regional Studies*. Elsevier, 25(October), p. 100626. doi: 10.1016/j.ejrh.2019.100626.
- Arnell, N. W. and Lloyd-Hughes, B. (2014) 'The global-scale impacts of climate change on water resources and flooding under new climate and socio-economic scenarios', *Climatic Change*, 122(1–2), pp. 127–140. doi: 10.1007/s10584-013-0948-4.
- Artichowicz & Gąsiorowski (2019) Artichowicz W, Gąsiorowski D. Computationally efficient solution of a 2D diffusive wave equation used for flood inundation problems, 2019;
- Backhaus, A., Adugna, D., Mhina, G. J., Herslund, L. B., & Fryd, O. (n.d.). *Water Resilient Green Cities in Africa*.
- Baky, M. A. Al, Islam, M. and Paul, S. (2020) 'Flood Hazard, Vulnerability and Risk Assessment for Different Land Use Classes Using a Flow Model', *Earth Systems and Environment*. Springer International Publishing, 4(1), pp. 225–244. doi: 10.1007/s41748-019-00141-w.
- Balica SF (2007) Development and application of food vulnerability indices for various spatial scales (Master theses, Unesco-IHE)
- Balica SF, Wright NG, van der Meulen F (2012) food vulnerability index for coastal cities and its use in assessing climate change impacts. *Nat Hazards* 64(1):73–105
- Bapulu, G.V. and Sinha, R. (2005) *GIS in Flood Hazard Mapping: a case study of Kosi River Basin, India*. Noida: GIS Development.
- Beshore, David G. 2017. "Mathwave Data Analysis and Simulation." (September).
- Binns, A. D. (2020) 'Flood mitigation measures in an era of evolving flood risk', *Journal of Flood Risk Management*, 13(3), pp. 13–15. doi: 10.1111/jfr3.12659.

Birhanu, B. (2019) ‘Flood Mapping On Great Akaki River in Addis Ababa, Akaki Kaliti Sub-City’.

Brunner (2016a) Brunner GW. HEC-RAS river analysis system 2D modeling user’s manual. Davis: US Army Corps of Engineers—Hydrologic Engineering Center; 2016a.

Bucha, N. M. and Selvara, R. (2019) ‘Flood Inundation Mapping in Gelana in Ethiopia’, Global scientific journals, 7(5), pp. 148–158.

Cardona OD (2013) the need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management. In: Bank of G, Frerks G, Hilhorst D (Eds) Mapping vulnerability. Routledge, pp 56–70

Carlo del Ninno, Paul A. Dorosh, and L. C. S. (2003) ‘Public policy, food markets, and household coping strategies in Bangladesh: Lessons from the 1998 floods’, p. 156.

Chow, V.T. Open Channel Hydraulics; McGraw-Hill Book Company, Inc.: New York, NY, USA, 1959; pp. 109–113. [Google Scholar]

Cunderlik, Juraj, and Slobodan P. Simonovic. 2010. “Hydrologic Models for Inverse Climate Change Impact Modeling.” *18th Canadian Hydro-technical Conference* (June): 1–9.

Dagnachew L. and Wubet G. (2009). Flood Hazard and Risk Assessment in Fogera Woreda using GIS & Remote Sensing. Addis Ababa University

Daniel Kassahun, Yonas Tadesse and Sinework Dagnachew (2006). Flood Disaster Impact in Dire Dawa: Some Recommendation for Future Flood Risk. Ethiopian Red Cross Society

De Risi, R. et al. (2020) ‘From flood risk mapping toward reducing vulnerability: the case of Addis Ababa’, *Natural Hazards*. Springer Netherlands, 100(1), pp. 387–415. doi: 10.1007/s11069-019-03817-8

Devia, Gayathri K., B.P. Ganasri, and G.S. Dwarakish. 2015a. “A Review on Hydrological Models.” *Aquatic Procedia* 4(December): 1001–7.

- Doocy S., Daniels A., Murray S. & Kirsch T. D. The human impact of floods: a historical review of events 1980–2009 and systematic literature review. *PLOS Currents Disasters* 2013.
- Dottori & Todini (2013) Dottori F, Todini E. Testing a simple 2D hydraulic model in an urban flood experiment. *Hydrological Processes*. 2013;
- FEMA. 2018. “Guidance for Flood Risk Analysis and Mapping Flood Depth and Analysis Grids.” (February).
- FERC. 2014. “Dam Breach Analysis: Engineering Guidelines Risk-Informed Decision Making
- FHWA. 2019. “Tech Overview of Practices for Adopting 2D Hydraulic Modeling.”
- Fikadu, S. and Michael, Y. (2012) ‘Flood inundation of Gelana river’.
- Fuchs S, Kuhlicke C, and Meyer V (2011) Editorial for the special issue: vulnerability to natural hazards— the challenge of integration. *Nat Hazards* 58(2):609–619
- Ganasri, B P. 2015. “A Review on Hydrological Models ENGINEERING ( ICWRCOE 2015 ) A Review on Hydrological Models.” (December).
- Gilles, Daniel, and Matthew Moore. 2010. “Review of Hydraulic Flood Modeling Software Used in Belgium , The Netherlands , and The United Kingdom.”
- Goodell, Christopher, and Brian Wahlin. 2009. *Dynamic and Level Pool Reservoir Drawdown-A Practical Comparison for Dam Breach Modeling*.
- Granger. J., & Carey, S. K. (2007). The cold regions hydrological model : a platform for basing evidence. *Hydrological Processes*, 2667(October 2006), 2650–2667.
- Hamidifar, H. and Nones, M.: Global to regional overview of floods fatality: the 1951–2020 periods, *Nat. Hazards Earth Syst. Sci. Discuss.*, 2021
- Husain, A. 2017. “Flood Modelling by Using HEC-RAS.” 50(1): 1–7.
- IPCC (2001) Intergovernmental panel on climate change. *Climate change 2001: impacts, adaptation and vulnerability*. Cambridge University Press, Cambridge

Kang, S.-J.; Lee, S.-J.; Lee, K.-H. A Study on the Implementation of Non-Structural Measures to Reduce Urban Flood Damage -Focused on the Survey Results of the Experts-. *J. Asian Arch. Build. Eng.* **2009**, 8, 385–392.

Khunwishit, S.; Choosuk, C.; Webb, G. Flood Resilience Building in Thailand: Assessing Progress and the Effect of Leadership. *Int. J. Disaster Risk Sci.* **2018**, 9, 44–54

Klieppe, Jon. 2017. “Derivation of Fluid Flow Equations.” *Norwegian University of Science and Technology*: 1–6.

Iii, D. (2003) ‘Flooding’, (University of Oklahoma, Norman, OK, USA), p. pp 769-776.

Iyengar NS, Sudarshan P (1982) A method of classifying regions from multivariate data. *Econ Political Wkly* 17:2047–2052

Lal, P. N. et al. (2012) National systems for managing the risks from climate extremes and disasters, *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change.*

Legese, B. and Gumi, B. (2020) ‘Flooding in Ethiopia; Causes, Impact and Coping Mechanisms. A Review’, *International Journal of Research and Analytical Reviews (IJRAR)* [www.ijrar.org](http://www.ijrar.org), 7(3), p. 707. Available at: [www.ijrar.org](http://www.ijrar.org).

Lindeboom, R. 2011. “The Science of Surface and Ground Water Lesson Geomorphology of Rivers.” : 1–25.

Mechal, A., Birk, S., Winkler, G., Wagner, T., & Mogessie, A. (2016). Characterizing regional groundwater flow in the Ethiopian rift: A multimodal approach applied to Gidabo river basin.

Micovic, Zoran, Melvin G. Schaefer, and George H. Taylor. 2015. “Uncertainty Analysis for Probable Maximum Precipitation Estimates.” *Journal of Hydrology* 521(February 2015

Mishra, K.; Sinha, R. Geomorphology Flood risk assessment in the Kosi megafan using multi-criteria decision analysis: A hydro-geomorphic approach. *Geomorphology* 2020

Mkhandi, S, A O Opere, and P Willems. 2004. “Comparison between annual maximum and peaks over threshold models for flood frequency prediction.”

- Moore, D. G. and M. (2010) Review of Hydraulic Flood Modeling Software used in Belgium , The Netherlands , and The United Kingdom, International Perspectives in Water Resource Management.
- Pechlivanidis, I. G., B. M. Jackson, N. R. McIntyre, and H. S. Wheater. 2011. “Catchment Scale Hydrological Modelling: A Review of Model Types, Calibration Approaches and Uncertainty Analysis Methods in the Context of Recent Developments in Technology and Applications.
- Pelling M (2012) The vulnerability of cities: natural disasters and social resilience. *Remote Sens* 49:85–91. <https://doi.org/10.1109/TGRS.2010.2057513>
- Penuel, K., Statler, M. and Hagen, R. (2013) ‘Em-Dat’, Encyclopedia of Crisis Management. doi: 10.4135/9781452275956.n114.
- Pradesh, Andhra, Sanjeet Kumar, and Andhra Pradesh. 2018. “Dam break analysis of kalyani dam using hec-ras.” 9(5): 372–80.
- Quiroga et al. (2016) Quiroga VM, Kurea S, Udoa K, Manoa A. Application of 2D numerical simulation for the analysis of the February 2014 Bolivian Amazonia flood: application of the new HEC-RAS version 5. *Ribagua*. 2016;3(1):25–33. doi: 10.1016/j.riba.2015.12.001.
- Ramos, H. M. et al. (2017) ‘Urban floods adaptation and sustainable drainage measures’, *Fluids*, 2(4), pp. 1–18. doi: 10.3390/fluids2040061.
- .Samson Abaya (2008). Floods and Health in Gambella Region, Ethiopia: An Assessment of the Strength and Weakness of the Coping Mechanism. LUMES – Lund University International Master Programm in Environmental Studies and Sustainability Science
- Schittkowski, K. 2002. “EASY-FIT: A Software System for Data Fitting in Dynamical Systems.” *Structural and Multidisciplinary Optimization* 23(2): 153–69.
- Shayannejad, M. et al. (2018) ‘Analyzing of Flow in Open Channels Networks Using HEC RAS’, *Natural resources journal*, 2, pp. 1–7. doi: 10.23880/JENR-16000136.

Shiferaw, M. 2011. “2D Hydrodynamic modeling of rib river: Addis Ababa University, Ethiopia.”

Shiferaw, A (2011). Evaluating the Land Use and Land Cover Dynamics in Borena Woreda of South Wollo Highlands, Ethiopia. *Journal of Sustainable Development in Africa* (Volume 13, No.1, 2011). Clarion University of Pennsylvania

Shumba, E. M. (2001). *Forestry Outlook Studies in Africa*. (December).

Sinafikish Gezahegn (2013). Causes and Consequences of Flooding in Dire Dawa City, Eastern Ethiopia

Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. *Glob Environ Change* 16(3):282–292

Soleymani, Somaye, Hamidreza Golkar, Hamzee Yazd, and Mojtaba Tavousi. 2015. “Numerical Modeling of Dam Failure Phenomenon Using Software and Finite Difference Method.” *Journal of Materials and Environmental Science* 6(11): 3143–58.

Tanaka, Shigenobu. 2002. “A Study on Threshold Selection in POT Analysis of Extreme Floods.” (2): 299–304.

Tayefi, V, Stuart Lane, R Hardy, and Dapeng Yu. 2007. “A Comparison of One- and Two-Dimensional Approaches to Modeling Flood Inundation Over Complex Upland Floodplains.” *Hydrological Processes* 21.

Wondimu, Z. (2019) ‘Hydrologic And Hydraulic Modelling Using Hec-Hms And Hec-Ras Models (Case Study On Big Akaki River Basin)’, *Ms.C Thesis*.

UNDP (2006) Human development report, United Nations Development Program. <http://hdr.undp.org/hdr2006/statistics>.

Veenstra J (2013) Flood vulnerability assessment on a community level in Vietnam. Unpublished Bachelor thesis, VNU University of Science in Hanoi, Vietnam

Via, The Charles E, and Tony A Atallah. 2002. “Report A REVIEW ON DAMS AND BREACH

Prepared by : Dr . Muhammad Hajj ( Co Chair ).” (January).

Visser H., Petersen A. C. & Ligtoet W. On the relation between weather-related disaster impacts, vulnerability and climate change (2014).

Yonas Tadesse (2009).Socio-Economic Impacts of Flooding in Dire Dawa, Ethiopia. International Center for Water Hazard and Risk Management (ICHARM), PWRI, Japan

Yonas Tadesse and Girma Moges (2010). Flood Triggering Factors and the Efforts to Mitigate Flood Disaster in Dire Dawa, Ethiopia. Dire Dawa University, Ethiopia

Zhang, Xiao Qin, and Wei Min Bao. 2012. “Modified Saint-Venant Equations for Flow Simulation in Tidal Rivers.” *Water Science and Engineering* 5(1): 34–45.

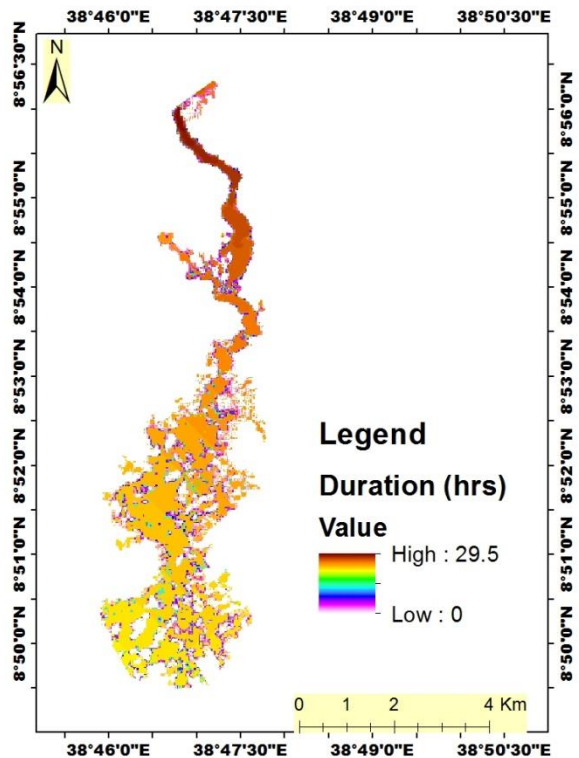
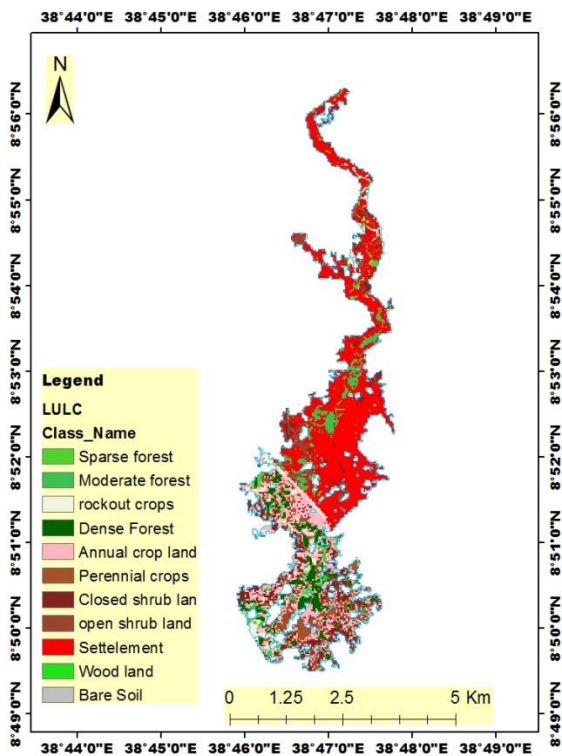
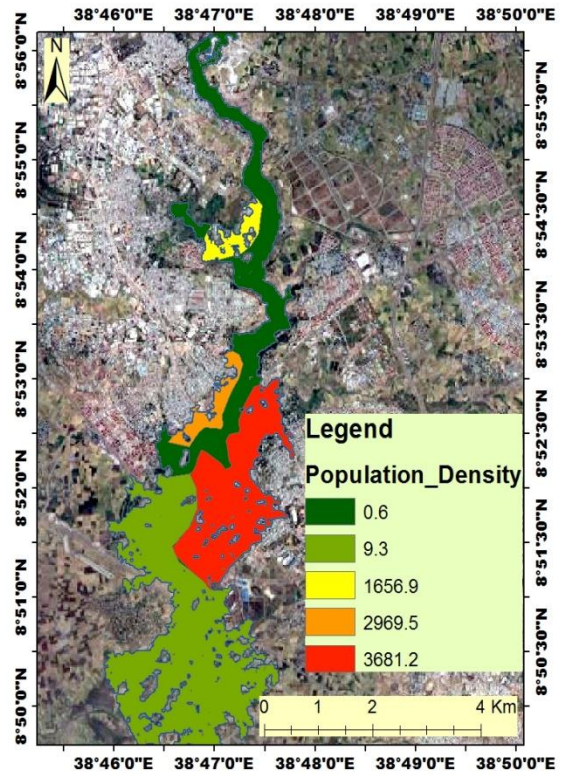
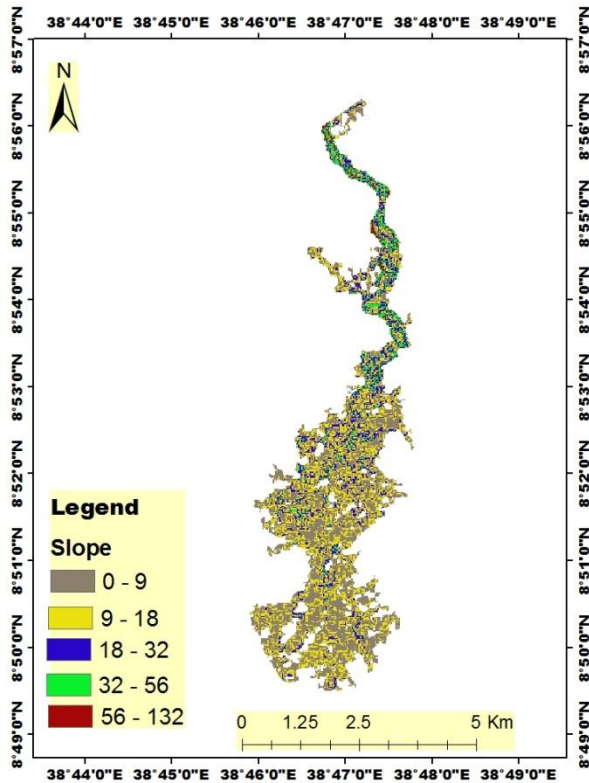
Zimmermann, M. N., 2005. *The Risk Concept*. Kobe, World Conference on Disaster Reduction (WCDR

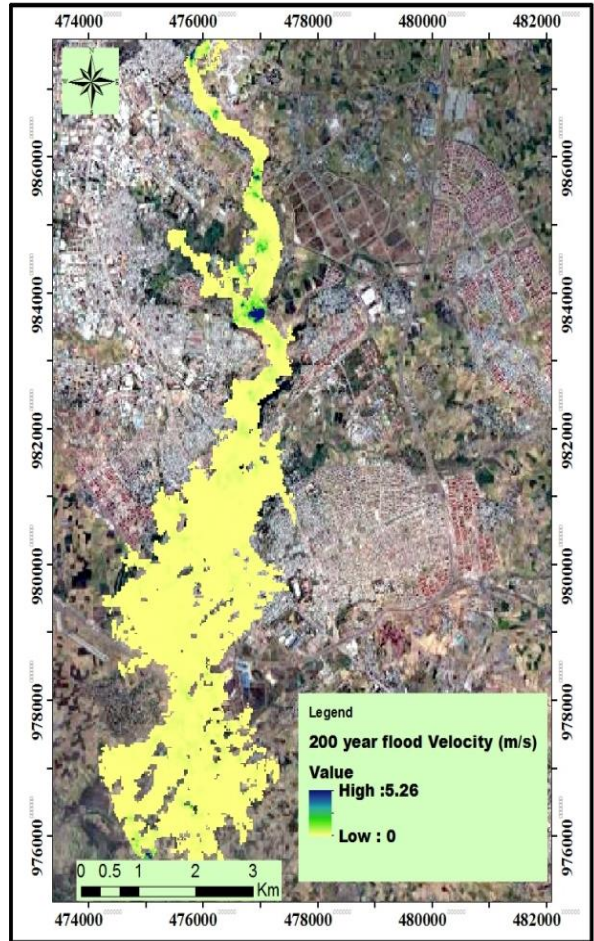
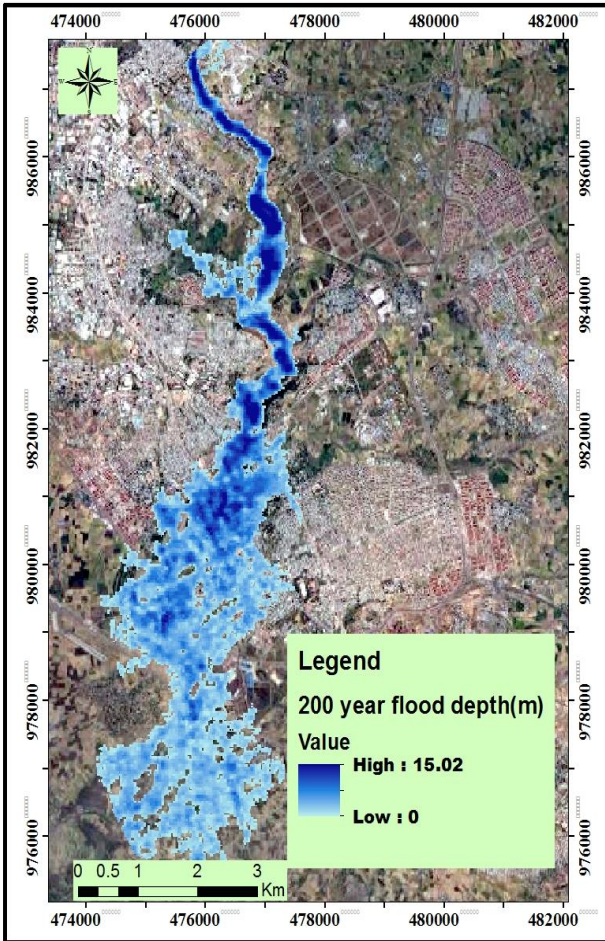
## 7. APPENDIX

### Appendix A: Maximum annual Stream Flow Data of Great Akaki River

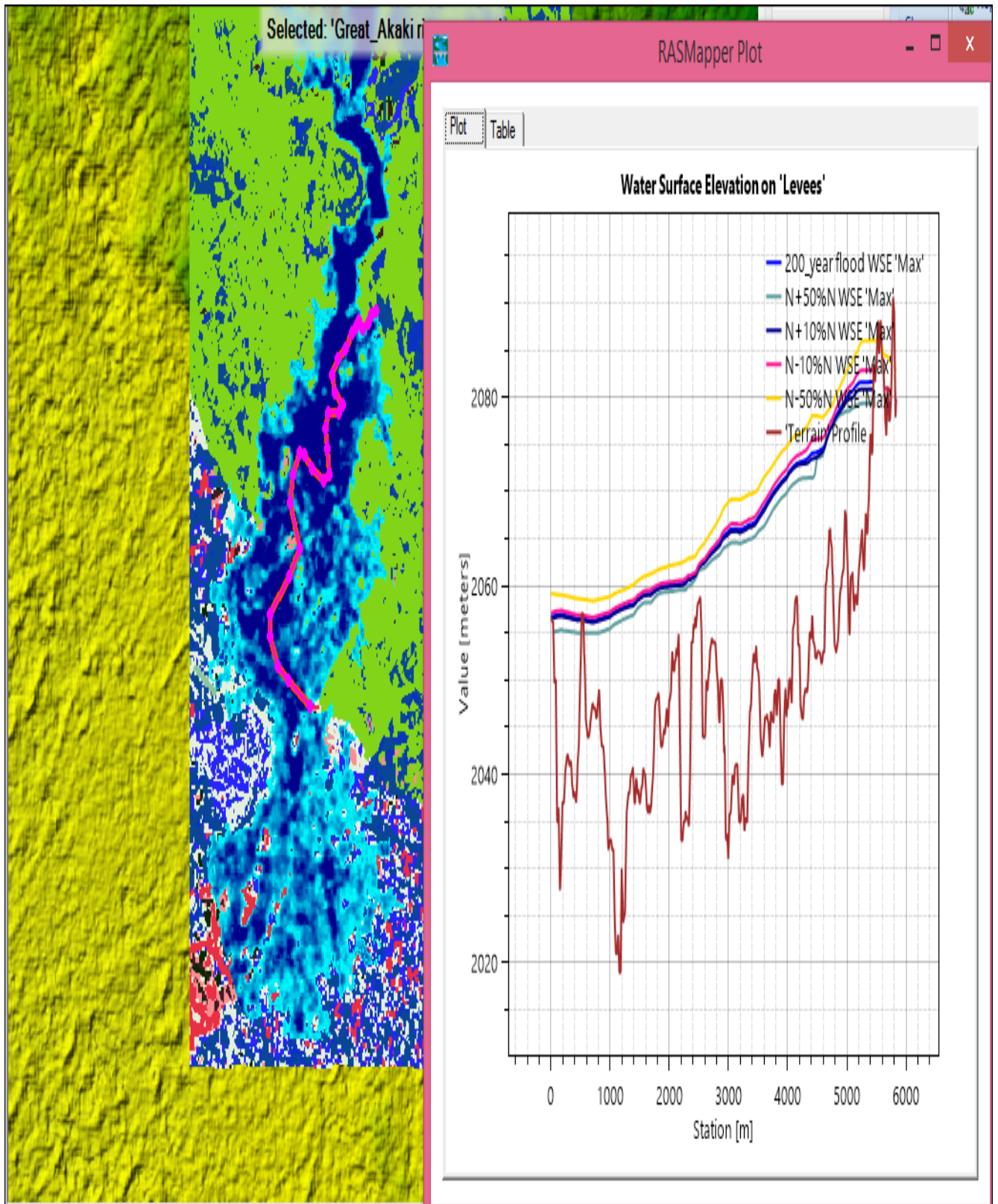
S/N	Year	Max annual stream flow
1	1985	1.413
2	1986	68.777
3	1987	36.554
4	1988	148.353
5	1989	233.769
6	1990	277.219
7	1991	215.224
8	1992	153.074
9	1993	573.569
10	1994	162.58
11	1995	257.976
12	1996	615.761
13	1997	276.323
14	1998	421.518
15	1999	693.102
16	2000	255.776
17	2001	435.338
18	2002	219.869
19	2003	420.059
20	2004	250.468

Appendix B: Maps required for Flood vulnerability preparation

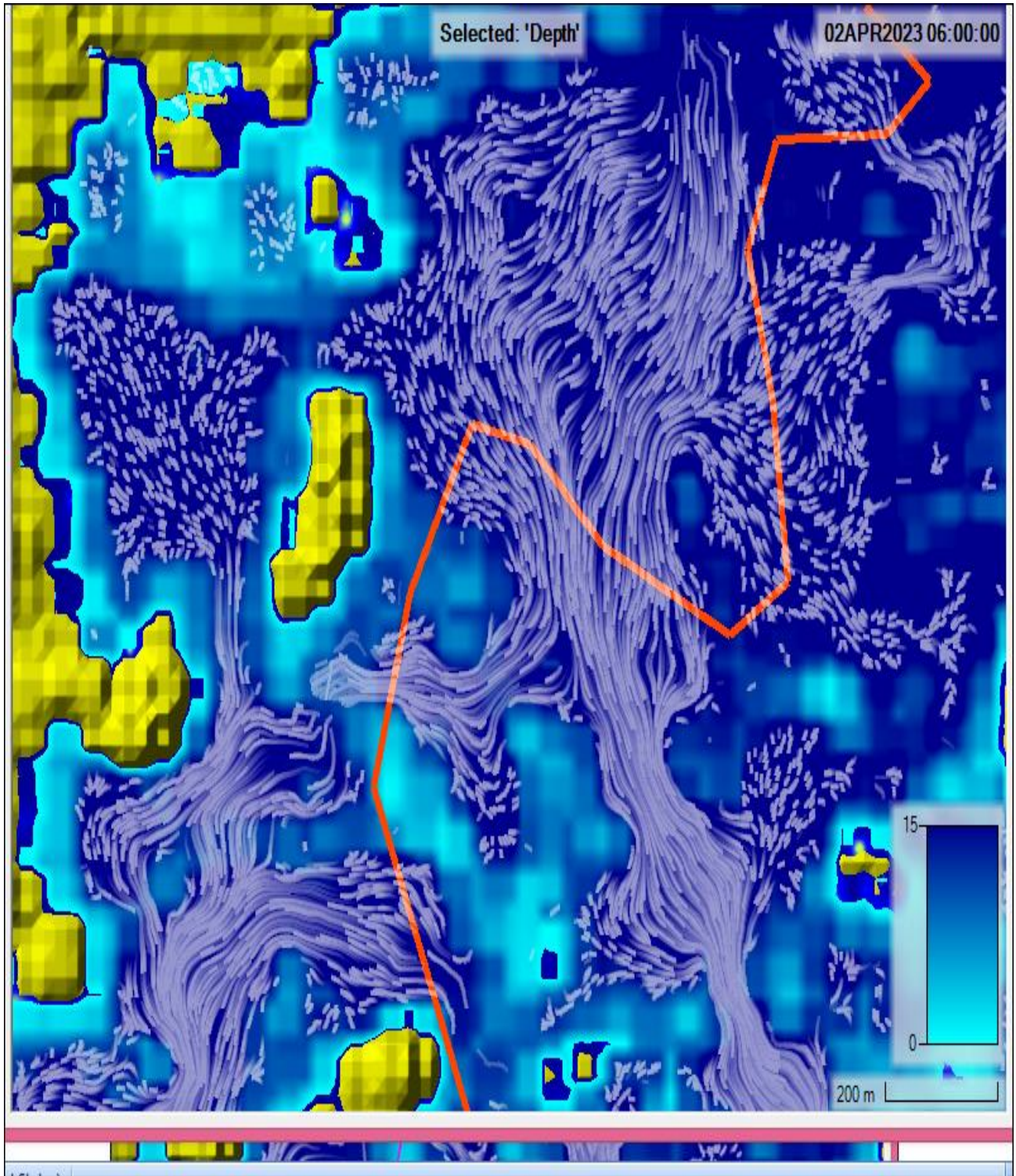




Appendix C: Water surface profiles over Levees



Appendix D: particle tracking of 200 years flood over Levees structure



Appendix E: Photos during field survey



