

Flood Inundation Mapping with Integration of GIS and Hydraulic Model (HEC- RAS)
for Early Warning in Dechatu Catchment, Dire Dawa City, Eastern Ethiopia

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Approval of Board of Examiners

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Declaration

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

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List of Acronyms

ASTER	Advanced Space borne Thermal Emission and Reflection Radiometer
CSA	Central Statistics Agency
DEM	Digital Elevation Model
DPPA	Disaster Prevention and Preparedness Agency
ECLAC	Economic Commission for Latin America and Caribbean
ESRI	Environmental System Research Institute
EWS	Early Warning Systems
FDRE	Federal Democratic Republic Of Ethiopia
GEORAS	Geographical river analysis system
GIS	Geographic information system
GPS	Global Positioning System
HEC	Hydrological Engineering Center
IPCC	Inter-Governmental Panel on Climate Change
LULC	Land use land cover
MOWR	Ministry Of Water Resource
NMA	National Metrology Agency
OCHA	Office for the Coordination of Humanitarian Affairs
PMF	Probable Maximum Flood
RAS	River Analysis System
RS	Remote Sensing
SPF	Standard Project Flood
TIN	Triangular Irregular Network
UNEP	United Nations Environment Program
UNISDR	United Nations International Strategy for Disaster Reduction
USGS	United State Geological Survey
USACE	United State Army Corps Engineers
UTM	Universal Traverse Mercator
WGS	World Geodetic System
WMO	World Metrological Organization
WWDSE	Water Works Design and Supervision Enterprise
2D/3D	Two/three Dimensional

List of Abbreviations

QP	Peak Discharge
m ³	Meter cube
s	Second
ha	Hectare
n	Manning's Coefficient
g	Gravitational Acceleration
he	head loss over two cross sections
A	Area
I	Intensity
C	Run off Coefficient
TC	Time of Concentration
V	Speed
X s	Cross section
T	Return Period
Z1, Z2	the elevation of the main channel inverts
Y1, Y2	Depth of water at cross sections
R	Hydraulic radius
S	Water surface slope
α_2, α_1	Velocity weighting coefficients
PF1, PF2, PF3, PF4, PF5	profile for 100, 50, 25, 10, 5 year return periods

Abstract

Nowadays, extraordinary floods are common in many parts of Ethiopia causing a lot of losses to human lives as well as damage to property. Historically, Dire Dawa City has been vulnerable to flash flooding from rainfall, in particular of the Dechatu Catchment. The objective of this study is to constitute flood inundation maps for Dechatu Catchment. In order to achieve the objective, the integrate of spatial technology of GIS and hydraulic model (HEC-RAS) were used as tools. ASTER DEM and Landsat 8 OLI image were used as primary parameter to generate geometric data such as Triangulation Irregular Network (TIN), streamline, river bank, flow paths, manning's n value and cross section cutline. The Fuller empirical method is used for determining the peak flow discharge for return periods of 5, 10, 25, 50 and 100 years and the result is found to be $460.05\text{m}^3/\text{s}$, $890.23\text{ m}^3/\text{s}$, $1450.49\text{m}^3/\text{s}$, $2110.61\text{m}^3/\text{s}$ and $4148.01\text{m}^3/\text{s}$ respectively. In HEC-RAS, river geometry, boundary conditions, manning's n value of different land cover and peak discharge for different return periods were inputted and then steady flow analysis was carried out. The result of Steady flow analysis shows that water surface elevation in the longitudinal profile increase with increasing return period. The flood inundation maps produced clearly indicate that areas with 94.48ha, 123.16ha, 140.13ha, 152.76ha and 172.63ha inundated by 5,10,25,50 and 100 year return period respectively. Also the maximum water level was obtained for the 100 year flood frequency. Generally, high water depth occurred along the main channel and spreads gradually to the floodplains. The current study also suggested that flood prone areas were at the middle and downstream along the banks of the river. Thus, integration of GIS and hydraulic modelling is an important of option for producing flood inundation map. It is concluded that results of this studies can be used for taking precaution measures against life and monetary losses due to floods in urban areas particularly in Dire Dawa City. Moreover, promoting early warning system in the city is important to evacuate people before flood disaster occur.

Key words: Flood, Dechatu River, GIS, HEC- GEORAS, HEC- RAS, Inundation Mapping



1 INTRODUCTION

1.1 Back ground

Flooding is a natural disaster and it causes damages to human that are higher than other natural disasters such as drought and famine and is a major concern in many regions of the world (Green et al., 2008). Flood is defined as a great flow of water, especially, a body of water, rising, swelling and overflowing over land surface. Of all the natural hazards capable of producing a disaster, floods are the most common phenomenon that causes human suffering, inconvenience and widespread damage to buildings, structures, crops and infrastructures (Melsew, 2014). Floods have been observed to disrupt personal, economic and social activities and set back a nations security and development by destroying environment (Haque, 2007).

In the period between 1996 and 2006, floods have had devastating effects on the continents of Africa, Asia, and the Americas (Satterth et al., 2007). It is reported that, during that period, there were 290 flood-disasters in Africa alone, which left 8,183 people dead and 23 million people affected, and which caused economic losses of \$1.9 billion. Similarly, 472 flood-disasters in Asia over the same period killed 42,570 people and affected 1.3 billion people, and were responsible for economic losses estimated at \$129 billion. It is also worth mentioning that floods were the most frequent natural disaster in Africa and the most common in Asia during that time period. According to UNEP (2002) Flood disasters account for about a third of all natural disasters throughout the world and are responsible for more than half of the fatalities. Economically, floods are a leading course of losses from natural events.

The socio economic and ecological impacts of floods are devastating in Africa and other developing countries, because most of them do not have real time forecasting technology or resources for pre-flood and post disasters rehabilitation (Alemayehu, 2007). Flood hazard assessment is based on information on the intensity and frequency of flood events. From reports of various climate prediction centers (IPCC, 2001), it has been indicated that there is a tendency of increased rainfall in the eastern part of Africa while rainfall may decrease in the western and southern Africa. Climate change, as well as growing populations and unplanned urbanization in the developing world, will increase the vulnerability to floods in years to come. The evidence of recent flooding together with the IPCC prediction makes Ethiopia more vulnerable than ever.

Topographically, Ethiopia is both a highland/mountainous and lowland country. It is composed of twelve major river basins, the drainage systems of which originate from the centrally situated highlands and make their way down to the peripheral or outlying lowlands. Awash is one of the basic basin in which study area is located. Especially during the rainy season (June-September) and (March – May) the major perennial rivers as well as their numerous tributaries forming the country's drainage systems carry their peak discharges.

The country experiences two types of floods i.e. flash floods and river floods. Flash floods are the ones formed from excess rain falling on upstream and often result in a considerable toll, and the damage becomes especially pronounced and devastating when they pass across or along human settlements and infrastructure concentration. On the other hand, much of the flood disasters in Ethiopia are attributed to rivers that overflow or burst their banks and inundate downstream plain lands (Kebede, 2012). In most cases floods occur in the country as a result of prolonged heavy rainfall causing rivers to overflow and inundate areas along the river banks in lowland plains. Although an excessive human interference has caused flooding in many places that previously was not flood. In addition to excessive rainfall, some human activities increase the risk of flooding such as the construction in the floodplain of the river that reduces the natural capacity of the river.

Even though flooding cannot be wholly prevented, its impacts can be reduced through appropriate planning and management. There have been immense uses of technology to mitigate measures of flood disaster i.e. structurally and non-structurally. Structural measures are very expensive and time consuming which involves physical work like construction of dams, reservoirs, bridges, channel improvement, river diversion and other embankments to keep floods away from people. Whereas non-structural measures is concerned with planning like flood forecasting and warning, flood plain zoning, relief and rehabilitation for reducing the risk of flood damage to keep people away from floods affected area. In recent times, non-structural flood control methods have been observed to be effective and economical in reducing flood effects. It is therefore very important to delineate flood-inundation areas well in advance to be able to take preventive measures to minimize any damage the flood may cause. So the management of flood plains will be very important. First step to the management of floods and flood plains is preparation of flood plain zoning maps.

U.S. Army Corps of Engineers River Analysis System (HEC-RAS) developed by Hydrologic Engineering Center which models flood inundation scenarios and HEC- GeoRAS which is a set of ArcGIS tool which models development and analysis of the flooded area using GIS have been used in different flood inundation analysis studies. And have provided information for floodplain managers and emergency management personnel which they use to protect against the loss of life and property damage.

The basic aim of current study was to prepare flood inundation mapping of Dechatu Catchment that can be used in planning of land occupation expansion, study of economic development projects, flood forecasting and warning, rescue operations and flood insurance, urban drainage master plans, especially in municipalities under pressure due to the process of population growth and urbanization, as in the case of Dire Dawa City. For this aim, numerical models have been developed to calculate flood discharge due to precipitation of a given return period. Hence combination of HEC-RAS hydraulic model and Arc View GIS software using HEC-GeoRAS extension are used for simulating the hydraulic parameters of Dechatu River for flood inundation mapping.

1.2 Statement of the Problem

Flood is probably the most devastating, widespread and frequent natural hazard of the world that producing many socioeconomic and environmental consequences within the affected floodplains. Flooding, as a natural phenomenon is not new to Ethiopia but it makes news. It has been occurring at different places and times with varying magnitude. 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. Historically, Dire Dawa Administration already has seen stricken severe flood for different times in 1945, 1977, 1981, 1997, 2001, 2004, 2005, 2006 ,2010 and 2016 (CORDAID, 2011 and OCHA, 2016). In Dire Dawa, flood in August 1981 which killed about 80 people was previously considered the worst in the town's history. However, the unprecedented August 6, 2006 flooding was worst of all cases (Daniel, 2007). Altogether 256 people have died and 244 have been missed in Dire Dawa, thousands have lost their property and means of livelihood. This events also takes place in 2010 and about 86,551 peoples were affected and displaced by flood on March and May month in a total of six region including Dire Dawa City (OCHA, 2010). Since April 2016, heavy spring/*belg* rains have caused 100 deaths and Up to 120,000 people have been displaced in the total of six region including Pocket area of

Dire Dawa Administrative Council (OCHA, 2016). Recurrence of flood hazard in Dire Dawa is increasing (Billi *et al.*, 2015). The ever growing magnitude of flood hazards in the Dire Dawa Administration has become a major threat to the survival of the City. Such hazards not only pull back the hardly earned development in the City, but also pose formidable threat on the people's readiness to re-invest their resources and time on future development activities especially during the rain the Dechatu River as well as their numerous tributaries forming the Dire Dawa City's drainage systems.

In the past, flood studies for Dechatu Flood plain have been done by different organizations and researchers before and after the most severe flood event occurred on 2006. Some researchers have tried to estimate the flood inundation area using different methods. Among them the recent study was conducted by Daniel Alemayehu in 2007 focuses only on land use change of Dechatu catchment, identify flood prone wadis in the event of a flash flood and map areas in Dire Dawa city in terms of Flood risk and Flood hazard using multi-criteria evaluation in GIS environment. Eleni in her research in 2011 only focuses on coping strategies of the 2006 flood-displaced victims of Dire-Dawa. On the other hand, Melsew Zenebe on his study in 2014 tried to cover the issue of the socioeconomic impacts of seasonal flooding and its coping mechanisms in the Dire Dawa administration. Yonas Tadesse in 2015 also tried to focus on the socioeconomic impacts of flooding in Dire Dawa. As the investigator knowledge he tried to assess the socioeconomic impacts, by using Economic Commission for Latin America and Caribbean (ECLAC) method.

According to previous studies, mentioned above the combination of GIS and hydraulic models to simulate flooding in residential areas in the Dire Dawa City was low, and using these models to manage downstream is not considered. Even though investigations were made in the past in the area related to this topic that they are qualitative research. Due to considerable progress and invention of new approach including application software the flood inundation mapping has been taken on scientific base quantitatively using GIS-based hydraulic modeling in this thesis. Basic aim of this effort is to identify the area chronically suffering from flooding and create a flood inundation map and flood depth maps based on DEM, meteorological, and Landsat image data. In general the, use of GIS and hydraulic models to process simulation and flood inundation map of Dechatu River was therefore, very important to identify flood prone areas of the catchment for 5, 10, 25, 50, and 100 years return period. The need to conduct this research was therefore,

due to the (limitation) of previous studies with GIS and hydraulic model applications for flood inundation mapping. Therefore, knowing the amount of flood inundation area (its extent) & depth using hydraulic model & GIS, and morphology of the river have a paramount importance to arrive at feasible engineering solution.

1.3 Research Question

What are the hydraulic and basin parameters that will be taken as input and how these will be derived for the models?

How to determine the frequency of flood magnitude for various return periods?

How hydraulic simulation can be carried out?

How inundation area can be measured for each frequency of flood?

1.4 Objective of the Study

1.4.1 General Objective

The general objective of this research is to map flood inundation areas with Integration of GIS and Hydraulic Model (HEC- RAS) for Early Warning application in Dechatu Catchment, Dire Dawa City, Eastern Ethiopia.

1.4.2 Specific Objective

To attain the general objectives, completions of the following specific objective:

- ✚ To generate river stream centerline, bank lines, flow path centerlines, and XS cut lines using GIS and HEC-GeoRAS in the study area.
- ✚ To calculate Rainfall Runoff (discharge) using emperical equation.
- ✚ To run the simulation models in HEC-RAS for different discharges.
- ✚ To Map flood inundation area for various scenarios with ArcGIS and HEC-GeoRAS.
- ✚ To map flood depth for different return period with ArcGIS and HEC-GeoRAS.

1.5 Significance of the Study

This study is to predict flood inundation area for early warning application by developing different simulation model that help to minimize the loss of life, environmental degradation and economic loss in the study area. After getting flood inundated area then by superimpose it on satellite image (Google earth) to see the hazard zone so that an early warning system can easily

be located. It helps to reduce time and money from the government and society for emergency, preparedness, and response/recovery. To inform (concerned body) planning to rehabilitate people from flood prone area to rehabilitation center. Apart from this, it can be used as a source of information for those who intend to investigate further study on the issue.

1.6 Scope of the Study

Although Dire Dawa has been affected by massive seasonal flooding, the scope of this study delimited to geographical and thematic scope. Based on these facts, geographically the study is limited to Dechatu catchment due to time constraints and resource limitations and the work has been concentrated on extracting geometric data, calculate peak discharge, simulating, measuring water surface profiles, analyzing the flood inundation zone with the help of hydraulic model (HEC-RAS) integrated with in GIS environment.

1.7 Limitation of the Study

Difficulties had occurred to get organized, well developed and evident data on the issues. Geometric data's are extracted from Landsat image which have low spatial resolution. Since high resolution Digital Elevation Model (DEM) is not available in our country Digital Elevation Model with a resolution of only 30x30m grid has been be used to prepare geometric data which represents elevations on the study area with some error.

1.8 Organization of the Thesis

This thesis is organized into five chapters. The first chapter contains introduction, where the background, statement of the problem, objectives of the study, research questions and significance of the study discussed. The second chapter focuses on review of related literatures. The third chapter is on the details of the study area in terms of location, topography, climate, soil and Land-use/land-cover. This section also elaborates the source of the data and software used and methodologies applied to achieve the desired objectives with details of the data sources and conceptual models. In the fourth chapter results and discussion are provided and finally the last chapter provides conclusion and recommendations based on results and discussions presented.

2. LITERATURE REVIEW

2.1 Historical Development of Flood

Flooding is a broad term which means that an area under water. The general public often refers to a flood as a high flow and water levels that may cause some damage to property and sometimes injuries and death. The United State Geological survey (2007) define a flood as relatively high water that overflows the natural or artificial banks of a stream or coastal area that submerges land not narrow below water. Flooding occurs when channels are filled beyond their capacity and results in excess water spilling out of the channel onto the adjacent floodplain. Flooding can be the result of any of the following processes: excess precipitation, rapid, increased runoff, steep slopes, tsunami, dam failure, improper drainage system and urban development. The vast majority of stream floods are linked to precipitation (rainfall). When rain falls, some of the water infiltrates, or sinks into the ground. It may then percolate through soil and rock at greater depths. Some evaporates directly into the atmosphere. The rest of the water becomes surface runoff, flowing downhill over the surface under the influence of gravity into the stream. In general $\text{Runoff} = \text{Precipitation} - \text{Infiltration} - \text{Interception} - \text{Evaporation}$.

Flood is a natural phenomenon that occurs when the volume of water flowing in a system exceeds its total water holding capacity. Depending upon the size of the basin and on the intensity and duration a flood may last from a few minutes, to hours, days, weeks, and sometimes even months. In general, a flood is a geophysical phenomenon that has a relatively quick onset and short duration. According to Alagmand et.al (2010), there is a direct relationship between urbanization and hydrological characteristics; decreased infiltration, increase in runoff, increase in frequency and flood height. In addition to population growth and the ongoing accumulation of value assets, both the frequency and magnitude of floods due to climate change are expected to increase in the future, therefore aggravating the existing flood hazard in urban areas. This scenario implies that urban areas in particular suffer from a comparatively high flood risk due to their high population number and density, multiple economic activities and many infrastructure and property values that in turn interferes with the natural infiltration processes. The rainfall runoff process, however, is highly complex, non-linear and temporally and spatially varying because of the variability of the terrain and climate attributes.

During recent years, records of loss of life and damage caused by floods worldwide show a steady rising trend. While being beneficial to the flood plains and their productivity, floods do have great damage potential and affect ever-increasing number of people. On a global scale, there is evidence that the number of people affected and economic damages resulting from flooding are on the rise. The estimated water-related economic losses globally show an increasing trend. The trend had a trough during the period 2001 to 2003, and then increased sharply until 2006 (WMO &GWP, 2005; Adikari and Yoshitani, 2009). Large-scale flood disasters have significant humanitarian, social, security, political, and economic implications. Disasters leave large numbers of people ill, disabled, widowed, orphaned, displaced, or suffering from post-traumatic stress disorder (ADB, 2004).

According to World Bank (2003), in most developing countries flood disasters still claim tens of thousands of lives each year and destroy livelihoods in an instant. Several factors could be mentioned as causes of flooding by different writers. Deforestation can impact hydrological processes, leading to localized declines in rainfall, and more rapid runoff of precipitation, causing flooding and soil erosion, a common phenomenon in most parts of Ethiopia (Dagnachew et al., 2003). On the other hand, the high infiltration rates under natural forests serve to reduce surface runoff and flood response. Certain types of plantation forests may also serve to increase infiltration rates through providing preferential flow pathways down both live and dead root channels. From the theoretical considerations it would be expected that interception of rainfall by forests would reduce floods by removing the proportion of the storm rainfall and by allowing the build-up of the soil moisture deficits (Calder, 1999). According to Dagnachew et al. (2003), Land-use change due to the expansion of urban areas also affects the ground infiltration rate which in turn gives the way flooding to occur. Low level vegetative cover could also affect infiltration and could lead to reduced groundwater levels and the base flow of streams. It is obvious that land-cover can affect both the degree of infiltration and increases runoff following rainfall events

2.2 Floods in Ethiopia

In Ethiopia, the issue of flood continues to be of significant concern to people residing in lowlands, near lakes and river areas, as well as City's located at the foot hills and mountains (as in case of Dire Dawa City). Flood disasters are happening more frequently, and having an ever more dramatic impact on Ethiopia in terms of both the human and economic costs. As a result of the extended and widespread heavy rainfall as of the beginning of 2006 main rainy season, many areas have already experienced devastating damage.

According to UNISDR (2014), United Nations International Strategy for Disaster Reduction report, next to drought flood is hazardous disaster in Ethiopia (figure 2.1)

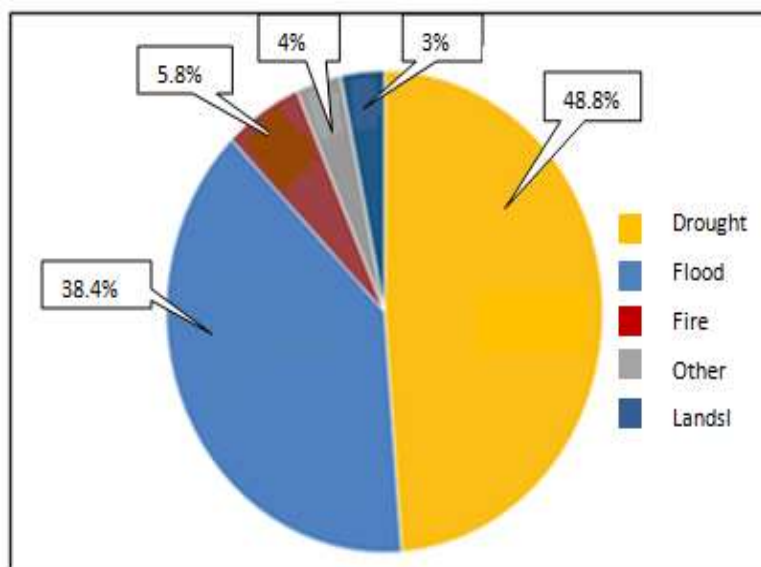


Figure 2. 1 Nationally reported mortality losses in 1990–2014, Ethiopia (UNISDR, 2014).

According to DPPA (2006) altogether 635 people have died (364 in South Omo, 256 in Dire Dawa and 19 in various other parts of the country). Increasingly, there is a need for supporting environmental planning choices with simulation and prediction models, due to the development of regulatory and planning tools, such as the river basin master plan, which involve a direct link between the description of physical phenomena (such as floods) and the attribution of land planning constraints.

The overall conceptual approach of flood management in Ethiopia may be framed around two concepts (Semu, 2007). First by minimizing the damage of flood water through maximizing the benefits of flood for food security and poverty reduction. Secondly by using efficient, cost effective and sustainable flood management System that is institutionally manageable and technologically advanced and flexible. The first framework will form part of a continuous study, research and development to convert the ill effects of floods through deriving the benefit from flood water. In most cases, this involves building structural measures such as reservoirs, diversion structures and directing the flood water to dry areas for the purpose of beneficial use. The second concept focuses on institutionalized flood detection, prediction and issuing early warning to potential flooding area. The focus of this study lies on the second alternative of flood damage reduction which entirely depends more on software aspect than physical control structure. Therefore, a technical and technological measure of reducing flood hazards in Ethiopia has plenty of options for flood management and mitigation

measures. These measures can be classified broadly into structural and non-structural measures. Many considerations have to be sought to select suitable flood mitigation measures. Some of the factors such as the type and characteristics of the flood (magnitude, return period, peak, damage, etc.), cost implications and opportunity to maximize the benefit from the flood water must be considered in selecting feasible solution. The structural measures (Engineering or Technical solution) are designed and constructed to modify the characteristics of floods before arriving to the flood damage area through various physical constructions such as reservoirs, diversions, levees, dykes, or channel modifications and river retaining works. Structural measures may be suitable to prevent the ravages of flash floods but the enormity of the financial, economical and ethical requirement undermines the importance of the flood prevention measures. Alternatively, instead of damming the flash flood Rivers, it may be possible to identify most flood generating sub-watersheds and implement series of check dams and detention dams reduce cost. These methods are usually capital intensive and in some instances drain the national economy.

Whereas non-structural measures are designed to modify the damage potential of the flood without interfering to the characteristics of the flood (magnitude, peak, duration, etc.). Such methods focus on software and hardware technological aspects, such as flood proofing, flood warning system, land use control, etc. For instance through flood inundation mapping and early flood warning mechanism, the potential of flood damage to properties and human lives can be reduced. Early warning system can be implemented to evacuation the population and property at risk before the flood wave reaches to the flood prone area. However, flood warning systems requires efficient communication network to relay information and message from observation stations to Forecasting center and from forecasting to response agencies (like DPPA) and to potential flood affected area.

According to Zhang (2002) the integrated use of geographical information system (GIS) and remote sensing (RS) has been performing a very important role in monitoring, controlling, relieving and assessing natural disasters, especially flood disasters by locating inundation area. GIS have extensive possibility for improving disaster management as they offer more efficiency and speed in the input, management, manipulation, analysis and output of data/information. The key benefit of using GIS for flood analyses is that it not only generates a visualization of flooding, but also creates potential to further analyze these events to estimate probable damage due to floods (Hashemyan et.al 2015). Mostly, studies have applied hydraulic model for simulating flood runoff and runoff in low-lying flood-prone

areas, in order to provide flood occurrence, magnitude of the event, location and depth of the inundation for flood management (Booij, 2005). Implementing similar approaches for flood management and monitoring system can possibly help in mitigating flood-induced hazards. Today state-of-the-art flood forecasting and early warning systems have made a significant impact to reduce the losses. By using these advance technologies we can better design for flood mitigation measures, forecast earlier and issue possible warnings to the peoples living in low lying areas which will be affected. Thus, the application hydraulic (HEC RAS) model in GIS environment is almost compulsory tool in hazard zonation.

2.3 Flood Characteristics

Flood disasters are occurring more frequently, and having an ever more dramatic impact on Ethiopia in terms of the costs on lives, livelihoods and environmental resources. Due to global climate change and local environmental pressures, the occurrence and frequency of flood hazards and the magnitude of destruction from floods are increasing through time. Human activities like urbanization, mass migration, development along the flood plains, industrialization and fragmentation/consolidation of agriculture land are the major driving force in altering the land use pattern and significantly affect the hydrologic processes. The effect of this land transformation is to increase the flood flows. Hence, land use change is a major force altering the hydrological processes over a range of temporal and spatial scales. Land use change can affect the runoff generation and concentration by altering hydrological factors such as interception, infiltration and evaporation. Thus, it causes changes in the frequency and intensity of flooding and produces runoff for shorter return periods and increase the susceptibility to damage. In order to understand the urban impacts on flooding, the total runoff must be quantified. This runoff is used to compute flow profiles and flood depths. Flood damages occur as a result of the particular flood event. The factors that influence the damage are land use pattern, frequency of flooding, characteristics of flood including depth and duration. Flood studies are important because of its effect on health, living conditions and economy of the society and it should consider the anthropogenic factor, which increases the vulnerability to floods.

2.4 Image Classification

Remote sensing data are huge sources of data for studying spatial and temporal variability of the environmental parameters. Among the main application of remotely sensed data is to create a classification map of features or classes of land cover types in a scene.

There are two methods of image classification: supervised and unsupervised. With supervised classification, the user develops the spectral signatures of known categories and then the software assigns each pixel in the image to the cover type to which its signature is most similar. With unsupervised classification, the software groups pixels into categories of like signatures, and then the user identifies what cover types those categories represent. During supervised classification, there are operations that must be followed, which are defining of the training Sites, extraction of signatures and classification of the Image (Gao *et al.*, 2007). This kind of classification is important as the analyst can have clues in editing and creating the signatures or training areas. This is a merit used to segregate features with nearby reflectance values (Campbell and Wynne, 2011).

2.5 Description of the Model

2.5.1. HEC-RAS Model Description

The Hydrologic Engineering Center-River Analysis System (HEC-RAS) was developed by the Hydraulic Engineering Centre, a part of the Institute for Water Resources, U.S. Army Corps of Engineers (USACE, 2012b). HEC-RAS is an integrated system of software that is able to simulate the water flow in rivers and channels using a numerical model. The model is used for determination of water surface profiles for different flow scenarios. HEC-RAS, combined with HEC-GeoRAS, offers engineers a powerful tool in the process of hydraulic modeling and analysis. Hydraulic modeling of natural rivers could be successfully analyzed with four equations: continuity, energy, momentum, and Manning. The Manning equation is considered to be empirical and is used to estimate friction loss while the energy equation is considered semi-empirical (Dyhouse *et al.*, 2003). In hydraulic modeling, flow in the channel is simulated by solving the complete set of Saint Venant equations. This type of model is based on continuity equation (conservation of mass) and momentum equation (conservation of momentum). These equations are solved numerically by either explicit or implicit methods (Bedient *et al.*, 1988). The explicit method solves the velocity and depth in a particular point in the river using the previously known data only. The implicit method solves the equations simultaneously at each time step and over all calculation points that cover the entire river. The HEC-RAS system includes four river analysis components. They include the steady flow water surface profile computations, unsteady flow simulation, sediment transport computations and water quality analysis. In addition to these components, the model contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. HEC-RAS applications include floodplain management studies, bridge and culvert

analysis and design, and channel modification studies (HEC, 2010b). The most important component of HEC-RAS is the steady flow water surface profile. It is used to compute the water surface profiles of flash flood events to simulate and create flood inundation maps. The water surface profile calculation is based on the one dimensional energy equation.

According to energy equation the Gradually varied water surface profiles are based on the principle of the conservation of energy, which states that the sum of the kinetic energy and potential energy at a particular cross section is equal to the sum of the potential and kinetic energy at any other cross section plus or minus energy loss or gains between the sections (Figure 2.2). Water surface is calculated from one cross section to the next by solving the energy equation written in following equation 1

$$Y_2 + Z_2 + \frac{\alpha_2 V_2^2}{2g} = Y_1 + Z_1 + \frac{\alpha_1 V_1^2}{2g} + h_e \quad \text{Eqn 1}$$

Where Z_1, Z_2 = represents the elevation of the main channel invert

Y_1, Y_2 = depth of water at cross sections

$\frac{V^2}{2g}$ = represents the velocity head at a point

g = gravitational acceleration

h_e = represents the head loss over two cross sections

α_2, α_1 = velocity weighting coefficients (dimensionless)

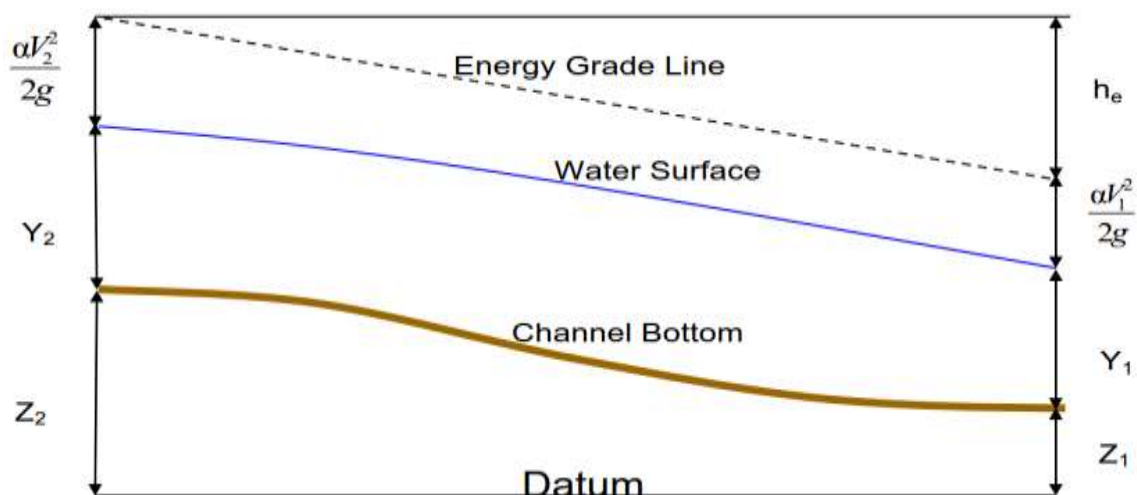


Figure 2. 2 Representation of terms in the energy equation (after USACE, 2002)

Based on the energy equation, the energy head loss is the sum of friction losses and expansion, or contraction of coefficient.

$$h_e = L\bar{S}_f + C \left| \frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 V_1^2}{2g} \right| \quad \text{Eqn2}$$

Where, L = Discharge weighted reach length, S_f = Representative friction slope between two sections, C = expansion or contraction loss coefficient, the distance weighted length L is calculated as:

$$L = \frac{L_{lob}\bar{Q}_{lob} + L_{ch}\bar{Q}_{ch} + L_{rob}\bar{Q}_{rob}}{\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}} \quad \text{Eqn3}$$

where: L_{lob} , L_{ch} , L_{rob} = Cross section reach lengths specified for flow in the left over bank, main channel, and right over bank, respectively, " $\bar{Q}_{lob} + \bar{Q}_{ch} + \bar{Q}_{rob}$ " = Arithmetic average of the flows between sections for the left overbank, main channel, and right over bank, respectively.

2.5.2 HEC-Geo RAS Extension

HEC-GeoRAS is an ArcView GIS extension, cooperatively developed by the HEC and the Environmental System Research Institute, Inc. (ESRI), specifically designed to process geospatial data for use with HEC-RAS (HEC, 2010). The HEC-GeoRAS is a GIS extension with a set of procedures, tools, and utilities for the preparation of river geometry GIS data to import into HECRAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC-GeoRAS model are Triangular Irregular Network (TIN), DEM, and land use. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping, such as in Europe (Dragan et.al , 2009; Gkiokas et.al , 2013) in the USA (Brunner, 2013; kamal , 2011; Liu et. al , 2008) in Africa (Botes and Smith , 2010) and in Asia (Hasanpour et . al ,2013 ; karim and Suleiman ,2009). HEC-GeoRAS is a data management interface between ArcGIS and HEC-RAS. The river stream centerline, bank lines, flow path centerlines, and XS cut lines should be digitized from a previous river file, aerial photographs, Landsat image or topographical datasets using HEC-GeoRAS interface. The river geometry file, manning n' value and stream flow data with boundary condition are the main input files for HEC-RAS to generate the water surface level along the River.

2.5.3 Integration of GIS in HEC-RAS Model

HEC-GeoRAS is the geospatial tool used in this study, which serves as the interface between GIS and the simulation model HEC-RAS. HEC-GeoRAS allows engineers to concentrate on hydraulic model development and analysis rather than GIS mechanics. The user environment provides engineers an opportunity to view real-world systems of interest, which in turn assists them to rectify errors and make informed decisions in the model development (*Ackerman et al, 1999*). The Connection between the two programs is provided by the HEC-GEORAS extension dedicated to run on Arc GIS. The whole (Figure 2.3) constitutes therefore a coherent computing tool that allows primarily to prepare the geometric Data (preprocessing) then, to make the necessary calculations (simulation) and finally, to exploit the results (post-processing).

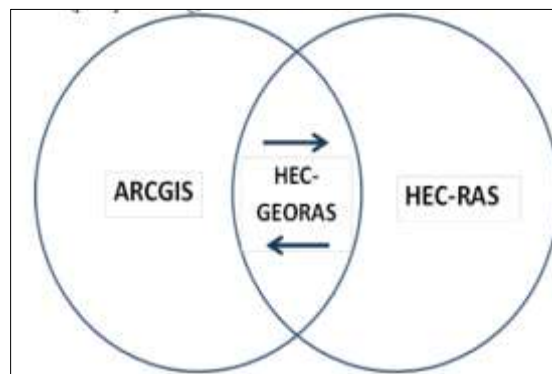


Figure 2. 3 Schematic representation of the used computer device.

The interface extracts the geometric data in an .xml format that is imported into HEC-RAS. The results of the HEC-RAS model simulation will be entered into a GIS environment and further analyses will be performed using HEC-GeoRAS tool. The GIS data exchanged between HEC-RAS and ArcGIS are in sdf file format. The HEC-GeoRAS assists the ArcGIS in providing pre-processing, direct support, and post-processing functionality before and after the hydraulic analysis. For pre-processing, both HEC-GeoRAS and ArcGIS packages should preprocess data, but HEC-GeoRAS provides the extra capability to capture the geometric data according to the HEC-RAS format required for the hydraulic modeling. The HEC-GeoRAS exports and imports the spatial data to different formats between ArcGIS and HEC-RAS by using a data exchange format called a RAS GIS File.

2.6 Inflow Design Flood

Design floods are the hypothetical floods, which are adopted as the basis for the design of engineering structures on or along the streams or rivers (WWDSE, 2007). From the

hydrologic analysis point of view, the design floods could be classified into two groups (WWDSE, 2007). In the first one, the design flood is conceptualized on hydrologic considerations such as the “Probable Maximum Flood” (PMF) and “Standard Project Flood” (SPF). The PMF is based on the concept, that there exists some kind of upper limits on flood producing factors like storm rainfall and/or snow melt, catchment type and wetness. Such floods are analyzed by detailed analysis of hydrological and hydro meteorological factors, using physics based methods of analysis. The concept of SPF is not as definite, but is based usually on maximum experienced values of the causative factors. In the second group, the statistically derived floods are included with the associated Return Periods (exceedance probability). A year return period flood, by definition is that flood magnitude (peak, volume or any other element of flood), which will be equalized or exceeded on an average once in T years. Unfortunately, there is no information about the Dechatu River discharge since only flow level data are available from March 2003 to September 2010 and no rating curve has ever been constructed.

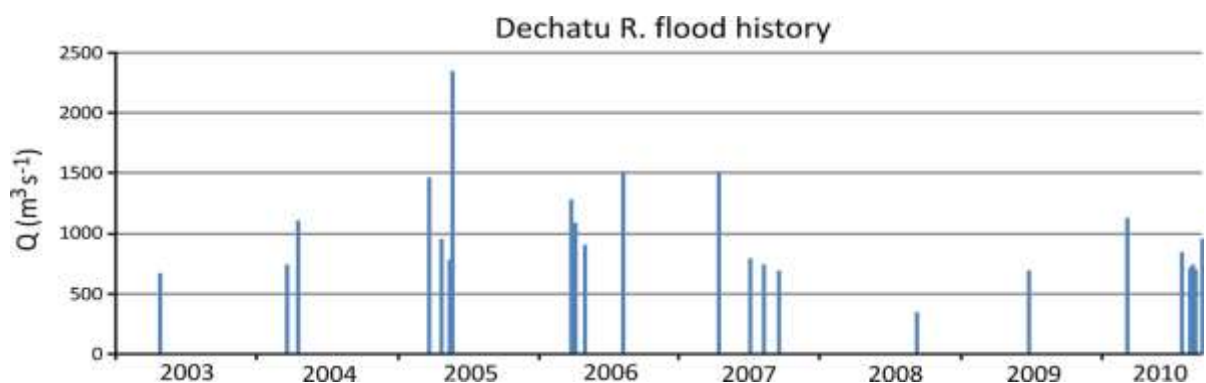


Figure 2.4 Occurrence of floods with a discharge higher than $300\text{m}^3/\text{s}$ observed after 2003

Source: Yonas Tadesse, 2015

From the figure 2.4, the largest flood had a peak discharge of about $2,338\text{ m}^3\text{ s}^{-1}$ and occurred on May 20, 2005. Other six large floods, with peak discharge (Q_p) higher than $1,000\text{ m}^3\text{ s}^{-1}$ occurred on April 14, 2004 ($Q_p = 1,095\text{ m}^3\text{ s}^{-1}$), March 20, 2005 ($Q_p = 1,456\text{ m}^3\text{ s}^{-1}$), March 25, 2006 ($Q_p = 1,269\text{ m}^3\text{ s}^{-1}$), April 6, 2006 ($Q_p = 1,080\text{ m}^3\text{ s}^{-1}$), April 12, 2007 ($Q_p = 1,508\text{ m}^3\text{ s}^{-1}$), and March 8, 2010 ($Q_p = 1,118\text{ m}^3\text{ s}^{-1}$) (Yonas et.al ,2015) . To estimate the magnitude of a flood peak the three alternative methods are available academically. These are rational method, Empirical methods and Slope area methods. The use of particular method depends upon desired objective, available data and size of the catchments. Rational method is found to be suitable for peak flow prediction in small

catchments up to 50Km² in area. It is applicable in urban drainage design and in the design of small culverts. The equation of rational method is given by

$$QP = 0.278 C \cdot I \cdot A \quad \text{Eqn4}$$

Where QP = Peak discharge (m³/sec) C = Coefficient of run off A = Drainage area in Km², I = mean intensity of precipitation (mm/hr.) for duration equal and an exceedance probability. The use of this method to compute QP requires three parameters; tc, (I) and C. Rational method is not convenient for the determination of peak flood for river like Dechatu. Because estimation of I, tc, p requires some other regional constants based on catchment size difference. According to Slope Area Method, based on the parameters the peak discharge were estimated and compared to observed discharge that obtained from literature. The equation of slope area method is given by

$$Q = V \cdot A \quad \text{Eqn5}$$

$$V = \frac{1}{11} * R^{2/3} * S^{1/2} \quad \text{Eqn6}$$

Where Q = Discharge in m³/s, V = Velocity in m/s, A = Area in m², R = Hydraulic radius, S = Slope. To estimate the maximum flood discharge at different return periods Fuller empirical formula have been applied using the following equations 7

$$Q_{\max} = Q_{PT} (1 + 2.66A^{-0.3})$$

$$Q_{PT} = CA^{0.8} (1 + 0.3474 \ln T) \quad \text{Eqn 7}$$

Where T is flood return period (years), C is a constant coefficient that amount of which depends on the slope and basin land cover that is between 15 to 100, A is area (km²) and Q_{max} is maximum flood discharge (m³/s). Though the Fuller method is empirical and developed for small catchments in the mid-western USA, it was found to be particularly suited for streams with negligible base flow, i.e., rivers for which the ratio of direct runoff to total runoff is close to one, as it is commonly observed in ephemeral streams of arid and semiarid regions (Ponce and Hawkins 1996). This is also the case of the Dechatu that is dry for most of the time and has some water flowing only in response to individual, intense rainstorms. Therefore, it is not surprising that the hydraulic and hydrologic approaches used, though conceptually different, produced a very similar result.

2.7 Flood Early Warning System

An Early Warning System (EWS) can be defined as a set of capacities needed to generate and disseminate timely and meaningful warning information of the possible extreme events or disasters (e.g. floods, drought, fire, earthquake and tsunamis) that threatens people's lives. The purpose of this information is to enable individuals, communities and organizations threatened to prepare and act appropriately and in sufficient time to reduce the possibility of harm, or loss.

There are some basic steps to be followed before and after flood occurrence for the development of an efficient flood warning system. The steps before the flood occurrence are: generation of flood inundation maps for various flood stages, quantification of thresholds in maps, and identification of flood hazard areas for different flood scenarios. Similarly, the steps after the flood occurrence are: to inform concerned officials/authorities, issue warnings to the people of possible inundation areas, evacuate people from probable inundation areas, and conduct rescue operations. Providing response on the basis of early warning and disaster assessment information enables resources allocated for response to be properly utilized for the intended purposes and, in the event of a disaster, to save lives and livelihoods by providing timely and appropriate response by properly identifying areas and people in need of emergency relief assistance (FDRE, 2013).

The purpose of a flood early warning system is to 'empower individuals and communities to respond to floods appropriately in order to reduce the risk of death, injury, property loss. According to Rajendra (2013), there are four elements in natural hazard early warning systems.

- Risk Knowledge: Risk assessment provides essential information to set priorities for mitigation and prevention strategies and designing early warning systems.
- Monitoring and Predicting: Systems with monitoring and predicting capabilities provide timely estimates of the potential risk faced by communities, economies and the environment
- Disseminating Information: Communication systems are needed for delivering warning messages to the potentially affected locations to alert local and regional governmental agencies. The messages need to be reliable, synthetic and simple to be understood by authorities and the public

-
- Response: Coordination, good governance and appropriate action plans are key points in effective early warning. Likewise, public awareness and education are critical aspects of disaster mitigation.

The basic idea behind early warning is that the earlier and more accurately we are able to predict short- and long term potential risks associated with natural and human induced hazards, i.e. flood the more likely we will be able to manage and mitigate a disaster's impact on society, economies, And environment.

2.8 Review of Previous Studies

Several studies have focused on the topic of flood inundation mapping. Floodplain modelling could be improved by having a better understanding of the actual hydraulic behavior of the river system. These models are essential tools where development of flood inundation maps can raise the awareness of decision-makers and people living in flood-prone areas. Because complete protection from the risk of flooding is not possible (more *et al.*, 2008), living in the flood of new policies regarding land use management and development of river areas in order to reduce its harmful effects is essential.

Although, flood is normally expected in Ethiopia studies are conducting on flood Inundation Area Mapping in some parts of the country using GIS and RS to facilitate the administrators and planners for flood hazard mitigation measure but thus studies not integrate GIS and hydraulic models. In the past, flood studies for Dechatu Flood plain have been done by different organizations and researchers before and after the most severe flood event occurred on 2006. Even though investigations were made in the past in the area related to this topic, due to considerable progress and invention of new approach including application soft wares flood studies still will continue in many aspects.

Some researchers have tried to estimate the flood inundation area using different methods. Among them the recent study was conducted by Daniel Alemayehu in 2007 focuses only on land use change of Dechatu basin, identify flood prone wadis in the event of a flash flood and map areas in Dire Dawa city in terms of Flood risk and Flood hazard using multi-criteria evaluation in GIS environment and it is not hydraulic based. Eleni in her research in 2011 only focuses on coping strategies of the 2006 flood-displaced victims of Dire-Dawa. On the other hand Melsew Zenebe on his study in 2014 tried to cover the issue of the socioeconomic impacts of seasonal flooding and its coping mechanisms in the Dire Dawa administration. Yonas Tadesse in 2015 also tried to focus on the socioeconomic impacts of flooding in Dire

Dawa. As the investigator knowledge he tried to assess the socioeconomic impacts, by using Economic Commission for Latin America and Caribbean (ECLAC) method.

According to studies, the combination of GIS and hydraulic models to simulate flooding in residential areas in the Dire Dawa City was low, and using these models to manage downstream is not considered. In this study, GIS and hydraulic models (HEC RAS) has been used to process simulation and flood inundation map Of Dechatu River. This study was, therefore, very important to identify flood prone areas of the catchment for 5, 10, 25, 50, and 100 years return period.

3. MATERIALS AND METHODS

3.1 General Description of Study Area

3.1.1 Location

Dire Dawa City is one of the two chartered cities in Ethiopia (the other being the capital, Addis Ababa). The administrative council consists of the city of Dire Dawa and the surrounding rural areas. The city lies on the trucking route from the main port of Djibouti to Addis Ababa, and is also an important trail way transit City. The city has created an opportunity for the recreation and hotel industries, and as a commercial center it has recently attracted many migrants in search of work and for a better life (DDAEP, 2011). In line with this the recent trends shows that the city attracts different peoples from different parts of the regions of Ethiopia and from its surrounding regions.

The city is located in the eastern part of Ethiopia between $9^{\circ}27'N$ and $9^{\circ}49'N$ latitude and $41^{\circ}38'E$ and $42^{\circ}19'E$ longitude. East Hararge Administrative zone of Oromiya Regional State borders it in the south and southeast and Shinele zone of Somalia Regional State in the north, east and west. Dire Dawa City is accessible by air, railway and road, and is about 515 kms road distance to the east of Addis Ababa and 311kms to the west of Djibouti port. Specifically Dechatu watershed is one of the watersheds of Dire Dawa Administrative Council in eastern Ethiopia which passes in the middle of the City. This Watershed is situated in the north - west part of Dire Dawa Administrative Council at the margin of eastern part of Ethiopian Rift Valley in the Awash basin (Fig 3.1). It is located between $09^{\circ} 32'54.06'$ to $09^{\circ} 38'32.81'$ North and $41^{\circ} 50'48.67'$ to $41^{\circ} 54'7.86'$ East in the UTM zone 37 with altitude between 1073 to 1509 m above mean sea level. The study watershed covers an area of about 3176.27ha.

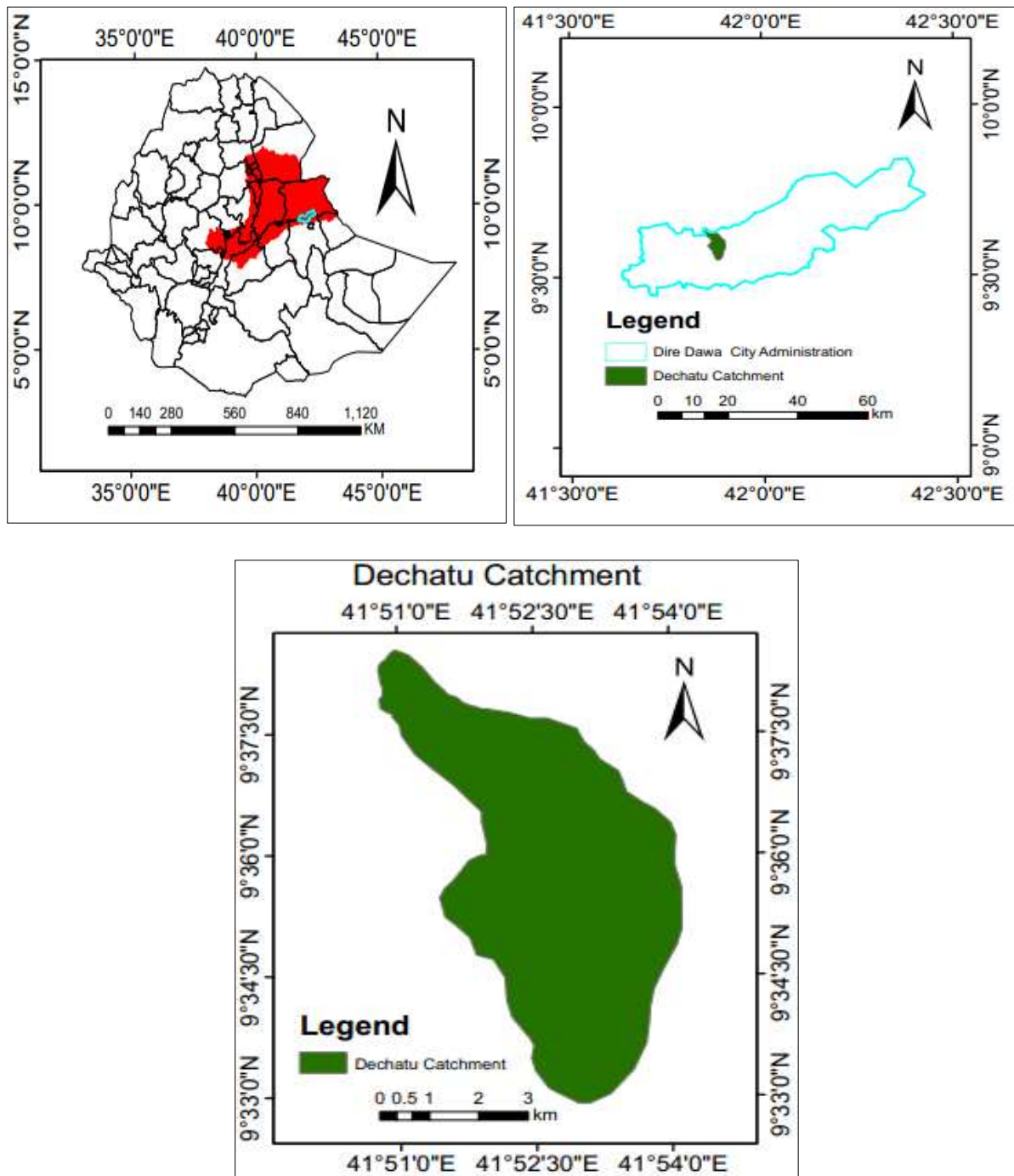


Figure 3. 1 Location map of study area

3.1.2. Climate and Topography

Dire Dawa administrative council is situated in kola agro-climatic region; because of its tropical location Dire Dawa is experiencing high temperature throughout the year with minor seasonal variations. Temperature progressively increases northward from somewhat temperate type along the mountain side of the city in its southern most point (Amente and Tesega, 2014). The mean annual temperature of Dire Dawa is about 25.4°C. The average

maximum temperature is 31.4°C, while its average minimum temperature is about 18.2°C (Fazzini et al., 2015). The elevation of study area ranges from 1073 to 1509 m above mean sea level as shown on figure 3.2 below.

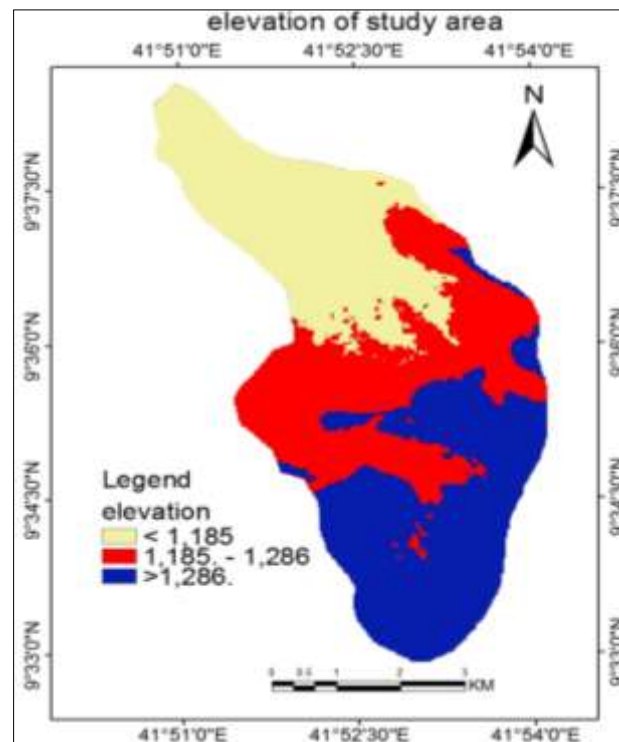


Figure 3. 2 Elevation map of study area.

3.1.3 Population

Based on the 2007 census conducted by the Central Statistical Agency of Ethiopia (CSA), Dire Dawa has a population of 341,834, of whom 171,461 are men and 170,461 women; 233,224 or 68.23% of the population are urban inhabitants. For all of Dire Dawa 76,815 households were counted living in 72,937 housing units, which results in an average of 4.5 persons to a household, with urban households having on average 4.2 and rural households 4.9 people.

3.1.4 Soil

The major soil types of Dire Dawa exhibit a general relationship with altitude, climate and vegetation. Shallow and infertile soil is being the characteristics of the mountains. This is due to the fact that the mountains experienced serious forest degradation and resulting soil erosion. While fertile soils are the major properties of river terraces and flat plains of the study area generally, the soils of the valley are developed on recent alluvial sediments derived from the adjacent mountain ranges. According to soil taxonomy the study area soils are Cambids (23%) and Trompepts (77%). Texturally dominating soils are clay loam and

sandy loam soils (MoWR Ethiopia, 2006). The soil types in an area are important as they control the amount of water that can infiltrate into the soil, and hence the amount of water which becomes runoff. The soil in the Dechatu Catchment has low infiltration capacity and has high runoff potential. Soil erosion in the Dechatu Catchment is a major problem that the top soil is experienced severe degradation. There is severe degradation of forestland mainly due to expansion of farmlands in the upland area of Dechatu Catchment; the magnitude of soil erosion is very serious in the area. According to MoWR, 2006, the Soil Conservation Research Project that has been carried out at national level estimated an average soil loss of 42t/ha/yr in cultivated fields and the maximum of 300-400 t/ha/year in highly erodible and intensively cultivated fields like Eastern Hararge high lands, where the study area is located.

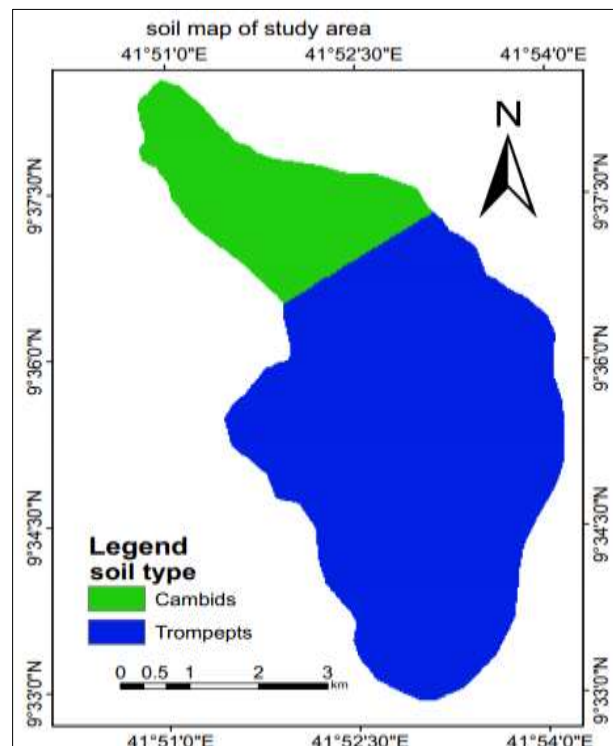


Figure 3.3 Soil Map of Dechatu Catchment

3.1.5 Drainage Density

The Dire Dawa Administration (DDA) is not blessed by large rivers, which flow throughout the year as that of other regions of the country. Only few intermittent and perennial streams pre dominate the natural water flow system of the region. According to the study made by the agricultural development office of the DDA in the year 2000, the region has over 130 springs with different water discharging capacity and over 44 perennial and intermittent streams. The most important intermittent and perennial streams that drain the Dire Dawa City are Dechatu, Butiji, Lega Hare, Dube, Goro and Elbah (WWDSE, 2004). All the rivers originate from the

southern highland catchments of Langey, Dengego, Kersa and Haramaya. The City is bounded by Lega Hare in the eastern and by Goro Rivers in the west. Dechatu River pass through the middle of the City. Among the main intermittent streams in the Dire Dawa, Dechatu is the major one where most of the precipitation as run-off from the south (escarpment zone) drains into it. Although this stream is dry for the most part of the year, it carries very large flow in the rainy season which sometimes causes flash flooding that result in some damage in the City, mainly because it passes through the middle of the City. Most of the runoff from Dechatu and the other streams spread in the low lying and flat topographic areas north of the City contributing a lot to the ground water (WWDSE, 2004).

The City of Dire Dawa has both enclosed and open storm water drainage systems. The central parts of the city and most of the main roads are embedded with drainage channels. However, the overall drainage services of the city are in adequate in terms of both quality and coverage. For instance, there are no drainage facilities in places where there are no roads. Besides, some of the existing drainage channels are not functioning well due to inadequate maintenance (Yalemtsega, 2007).

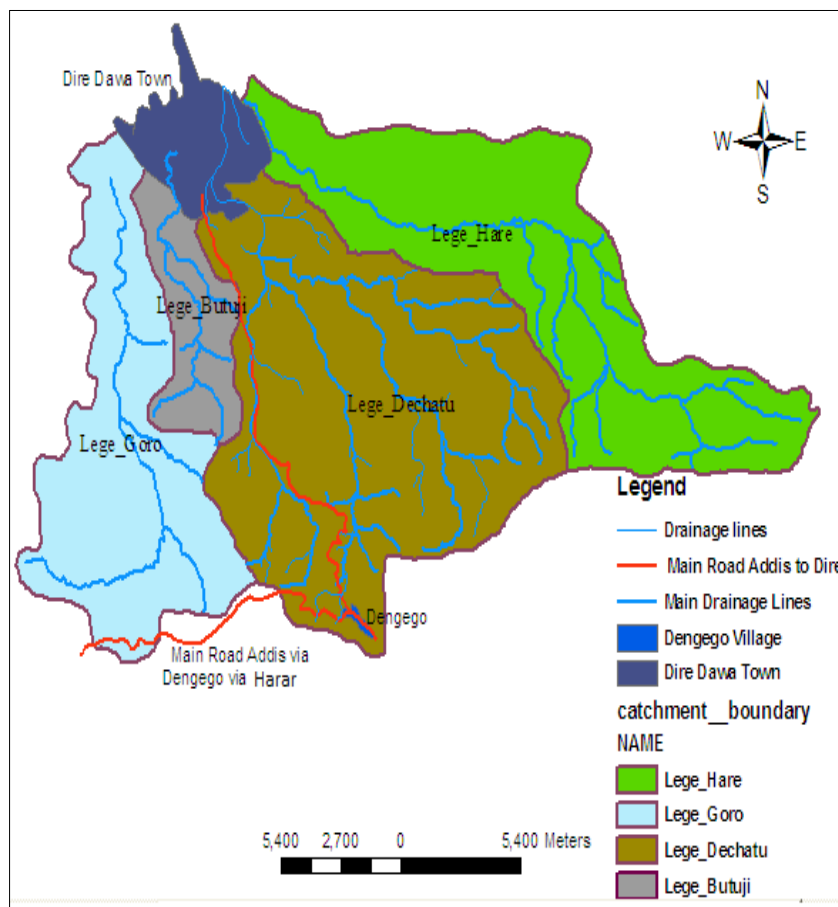


Figure 3. 4 Dire Dawa and its Basins Boundary and Stream lines.

Source: Dire Dawa Agriculture, Water, Mines and Energy Bureau, 2008.

3.1.6. Land Uses/ Land Cover

Land use for certain area influenced by several numbers of factors Such as geographic position, topography, elevation and available infrastructure. Human activities have significance influence on land use, particularly in urban area. The land use land cover of dechatu catchments are shrub land, sand deposited, built up and bare land as shown in figure 3.5

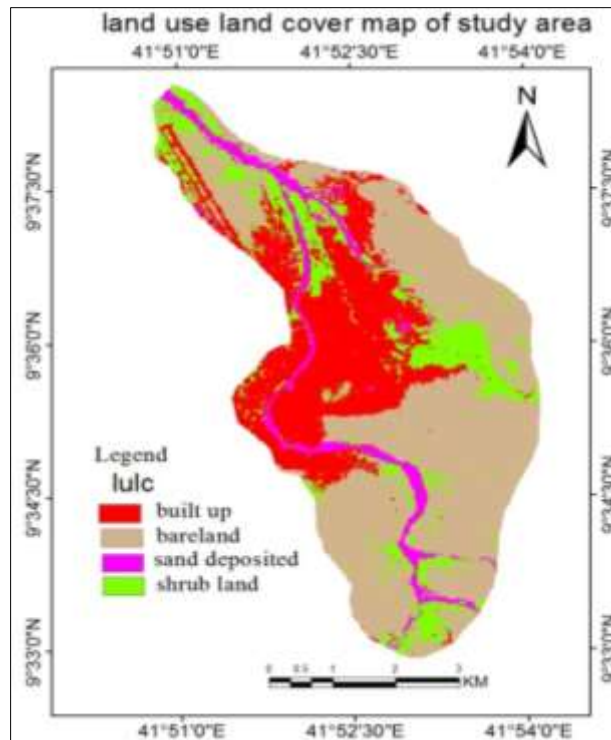


Figure 3. 5 land use land cover map of Dechatu Catchment

3.1.7 Ground Water

The main source of water supply for Dire Dawa City is ground water, but its problems are ground water resource depletion, high pollution from domestic and industrial origins due to rapid infiltration conditions of the unsaturated zone of the sandy formation of the area and shallow ground water conditions and pathways created from poor design and construction (MoWR, 2006).

3.2 Data Source, Description and Software's

3.2.1 Data Source and Description

To achieve the designed objective, data were collected and organized from primary and secondary Sources. Landsat image, ASTER DEM and Global Positioning System (GPS) data are among the primary data sources. Rainfall data is secondary data source. Published and

unpublished documents area also among the secondary data sources. Vector and raster data were collected from different governmental organizations as shown in Table 3.1. The detail of the datasets and utilities are discussed below

Table 3. 1 Description of GIS data layers used in the study.

S.NO	Data type	Description	Data Source
1	Raster	Land-use/land-cover classification(30*30m) resolution	Landsat8OLI (glovis.usgs.gov)
2	Raster	ASTER DEM (30*30m) spatial resolution	USGS.com (glovis.usgs.gov)
3	Vector (point)	GPS point data of different Land-use/land-cover types for verification	GPSsurvey(hand held)
4	Vector (point)	Rainfall data	National Metrology agency from 1990-2015 monthly, annual precipitation.

3.2.1.1 Landsat Image

It is used to generate a classified LULC map having spatial resolution 30m*30m which is captured On June, 2017 .The process of classification is discussed in methodology part. The prepared LULC map is used to determine the roughness coefficient for bank side LULC along the different Cross section and to generate geometric data with the help of HEC-GeoRAS extension. The Landsat image of study area was shown in the figure 3.6a.

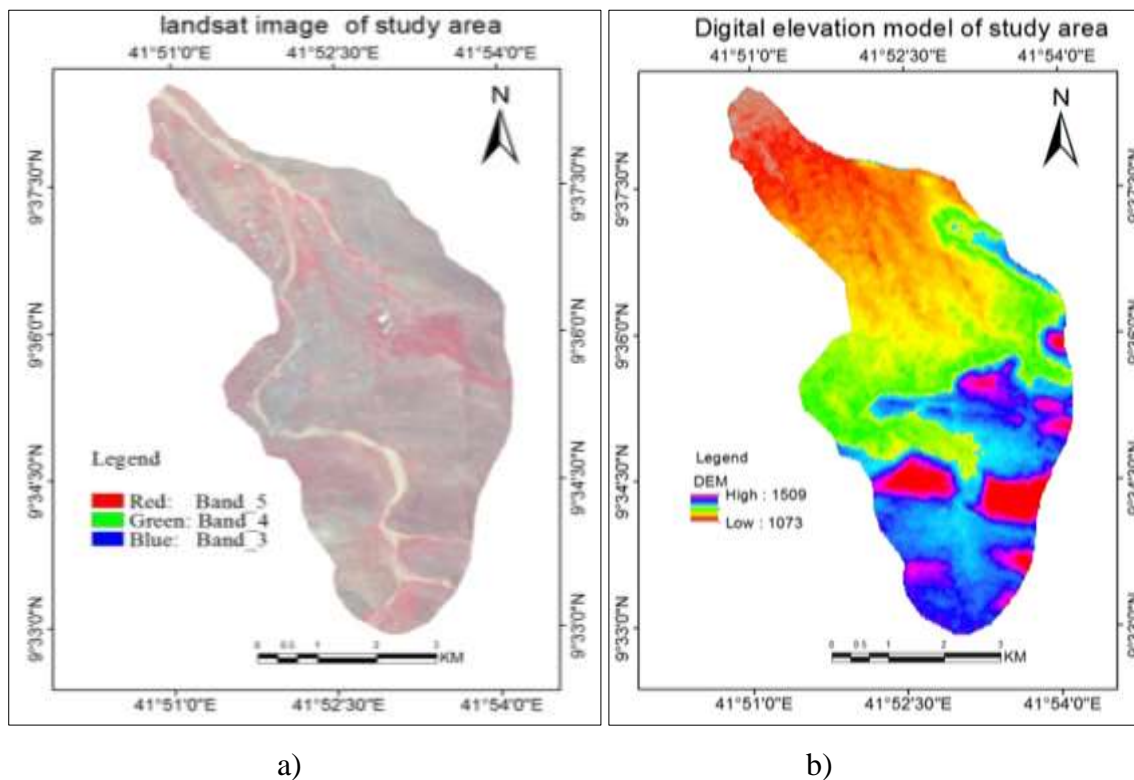


Figure 3. 6 (a) Landsat image map of study area and (b) ASTER DEM map of study area

3.2.1.2 Digital Elevation Model

Nowadays Digital elevation model (DEM) is being used for determining elevations at any point, slope and aspect and for finding features on the terrain, such as drainage basins and watershed, drainage networks and channels, peaks and pits and other landforms .The ASTER DEM, supplied by USGS, is used here to generate TIN. Digital Elevation Model have various spatial resolutions, in this study 30m grid size of DEM has been used. Digital Elevation Model for the study area was shown in figure-3.6b

3.2.1.3 Rainfall Data

The region (DDAC) has two rain seasons; that is, a small rain season from March to April, and a big rain season that extends from August to September. According to Fazzini et al. (2015), the aggregate average annual rainfall that the region gets from these two seasons is about 629 mm. The continuous monthly precipitation, mean monthly temperature data (1990 –2015) has been used for this study see appendix F. The figure 3.7 shows annual rainfall data of Dechatu station.

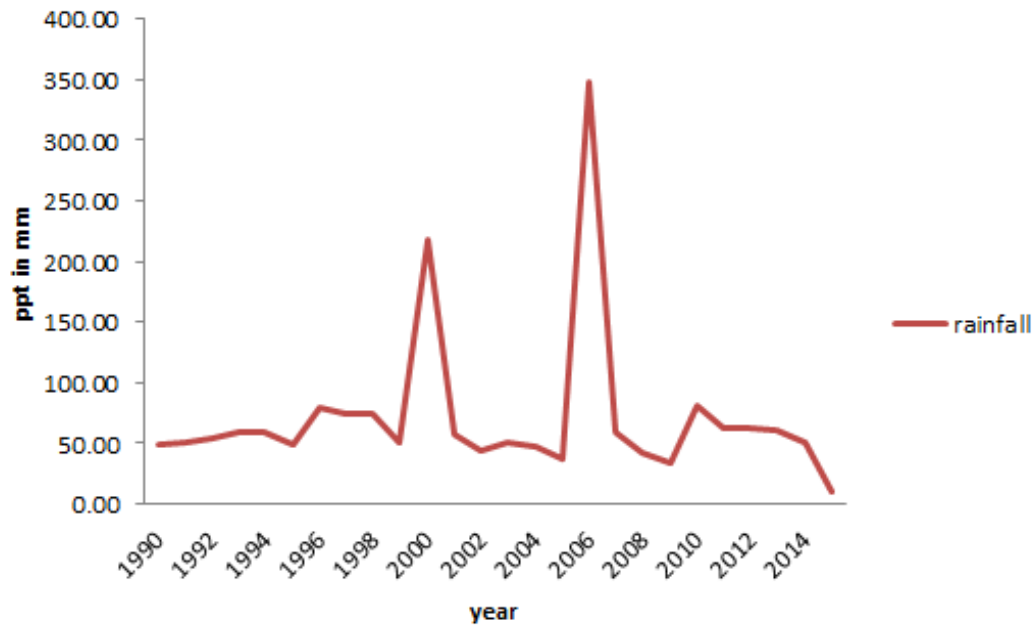


Figure 3.7 Rainfall data from 1990-2015 of Dechatu station. Source: NMA

3.2.2 Software

Software used in this study was selected based on the capability to work on the existing problems in achieving the predetermined objectives. This research utilized three different software packages, ArcMap 10.2 software package with HEC-GeoRAS tool extension, ERDAS Imagine 2014 and HEC-RAS 5.0.3 software Package. Utilizing these software packages offers the best opportunity to perform flood inundation mapping and analysis (Alagmand, et al 2010). ArcMap 10.2 was used for watershed delineation mapping and analysis. It was also used together with HEC-GeoRAS extension for pre-processing and post-processing for flood inundation mapping. HEC-RAS 5.0.3 software package was used in simulating flood modeling. The flexibility of Graphical User Interface of the ArcGIS software package allow users to incorporate additional capabilities and tools (extensions) that are not originally available in the software environment (Alagmand, et al 2010), these reasons permit this research to utilize the software successfully for a desired end result in flood inundation mapping and analysis. HEC-GeoRAS tools and utilities are ArcGIS extension that uses a Graphical User Interface (GUI) for processing of hydraulic and hydrological models of geospatial data. “The interface allows the preparation of geometric data for import into HEC-RAS and the process simulated results exported from HEC-RAS” (Hydrologic Engineering Center 2013). The Earth Resources Data Analysis System (ERDAS) imagine software has been used for image processing like file format transformation of the datasets, reprojection and LULC map creation by classification techniques.

3.3 Methods

The methodology adopted in this study follows literature review, data collection, organization and analysis of data as per the requirement of the model in use. Figure 3-8 shows summary of the methodology.

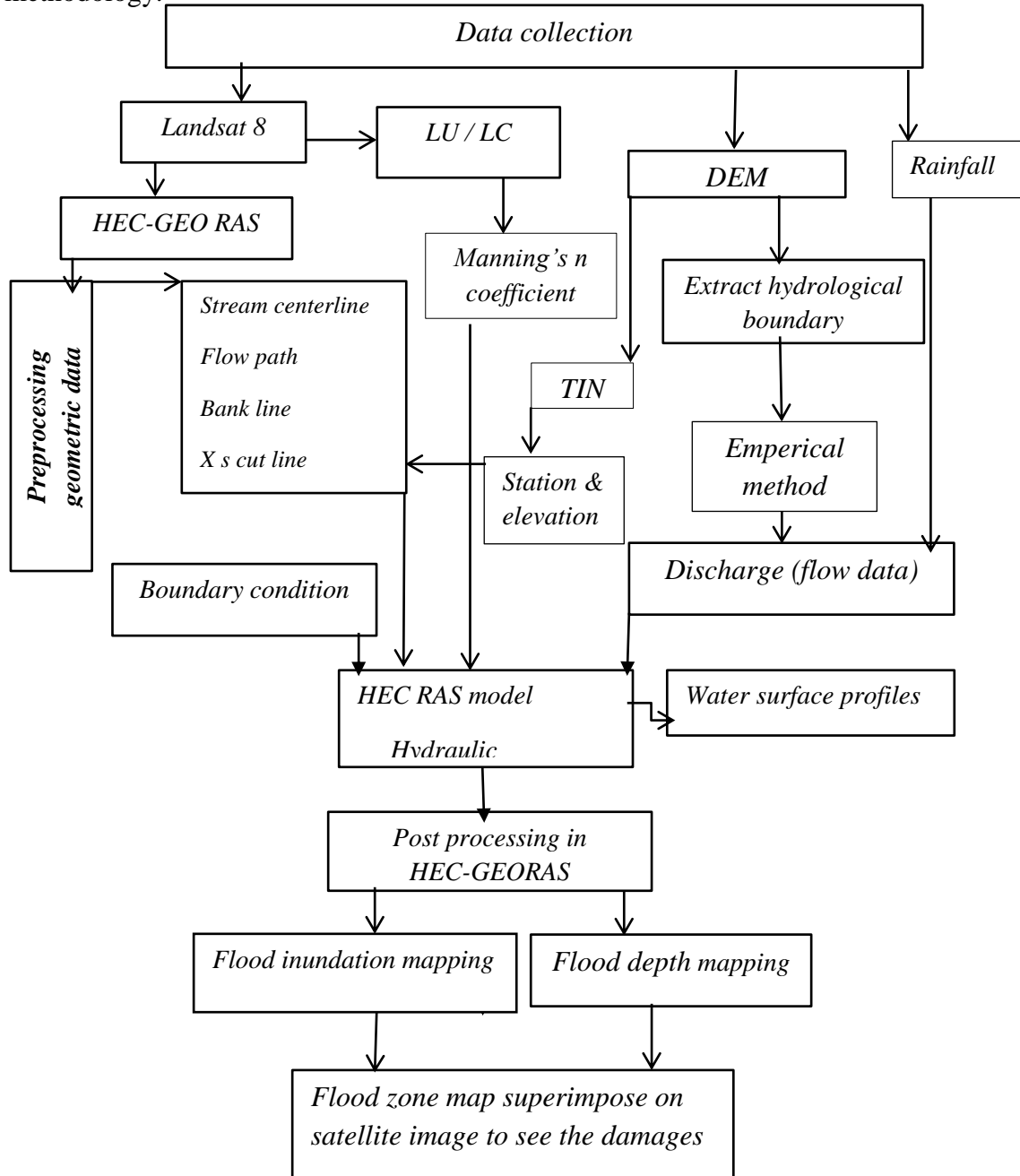


Figure3. 8 Flow charts of the GIS based hydraulic (HEC-RAS) modeling approach

The development of the present flood model integrates GIS with the HEC-RAS river hydraulic model. Numerous past studies have shown these models to provide accurate and useful results in flood related studies (Ahrens and Maidment, 1999; Anderson et al., 2002).

In this study to prepare flood inundation map for different return periods, the following methodology with three phases was adopted.

- (I) HEC- GeoRAS preprocessing;
- (II) HEC- RAS model run (simulation)
- (III) HEC- GeoRAS post processing (Inundation Mapping)

Before starting the preprocessing part Land Use/ land cover Classification of the Study area has been done by using GIS and ERDAS imagine softwares.

3.3.1 Land Use/ land cover Classification

Before image classification was done, actual field observation was held and a total of *four* classes were selected which include, sand deposited, bare lands, shrub land and Built-up. Landsat 8 OLI imagery (path 166 and row 53) of the period June 2017 was used to classify the current land cover of the study area. The land cover classification was done in Arc GIS 10.2 and ERDAS 2014 software's. In Pre-processing of image classification reprojecting has been done to the data to make it accessible for further analysis. During re projection process, WGS_ UTM _ Zone_37N spatial reference system was followed for raster data as well as vector data in the research to maintain uniformity. This research used supervised image classification to classify the dominant land cover types in the study area using reference sources imagery (Google earth) and field notes. Different stages were carried out to classify the land cover types as training sites selection and sampling intersect were performed, Signature analyses of each land cover types were done, Supervised classifications of data set were performed based on maximum likelihood classifier. Maximum likelihood classifier is the most widely adopted parametric classification algorithm for land cover information, and finally land cover types in the study are classified and mapped.

3.3.1.2 Accuracy assessment

Accuracy assessment was done after the image has been classified in to different land use classes based on their pixel value or brightness value, after the classified image has been produced its quality was assessed using ground truth. 100 ground truth points were collected from the field. Each point was marked by using hand held GPS apparatus which was later integrated with the image. Half of this data was used as input for supervised image classification and the remaining was used for accuracy assessment to quantitatively determine how effectively pixels were grouped into the correct feature classes.

3.3.2 HEC-GeoRAS Pre-Processing

HEC- GeoRAS is an ArcView GIS extension, developed by Hydrologic Engineering Center and ESRI in order to process the geospatial data for use with the HEC- RAS model. HEC-GeoRAS was used to create the HEC- RAS geometric data. A Digital Terrain Model (DTM) in the form of Triangular Irregular Network (TIN) was created using ASTER DEM of 30 m x 30 m resolution using 3D Spatial Analyst Tool in ArcGIS software. TIN was used for extracting the station-elevation data along the cross sections. It was also helpful in visualizing the terrain. The elevation data extracted from the terrain was used to locate the flood plain.

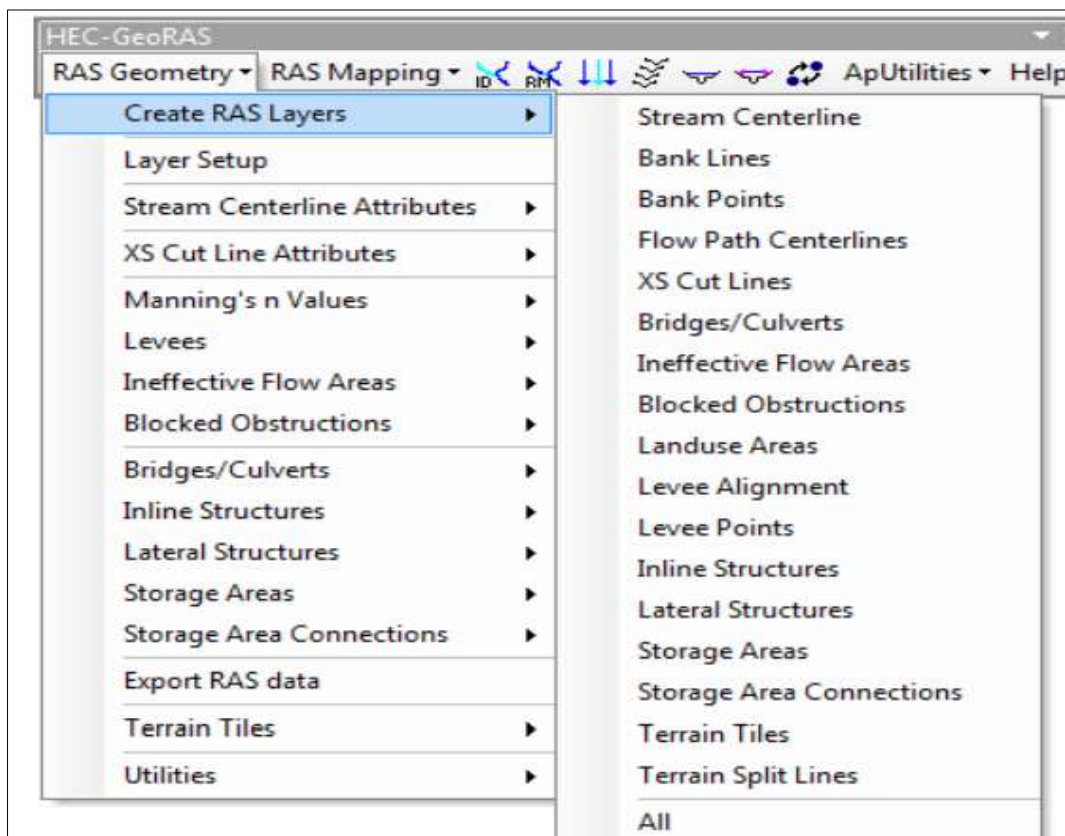
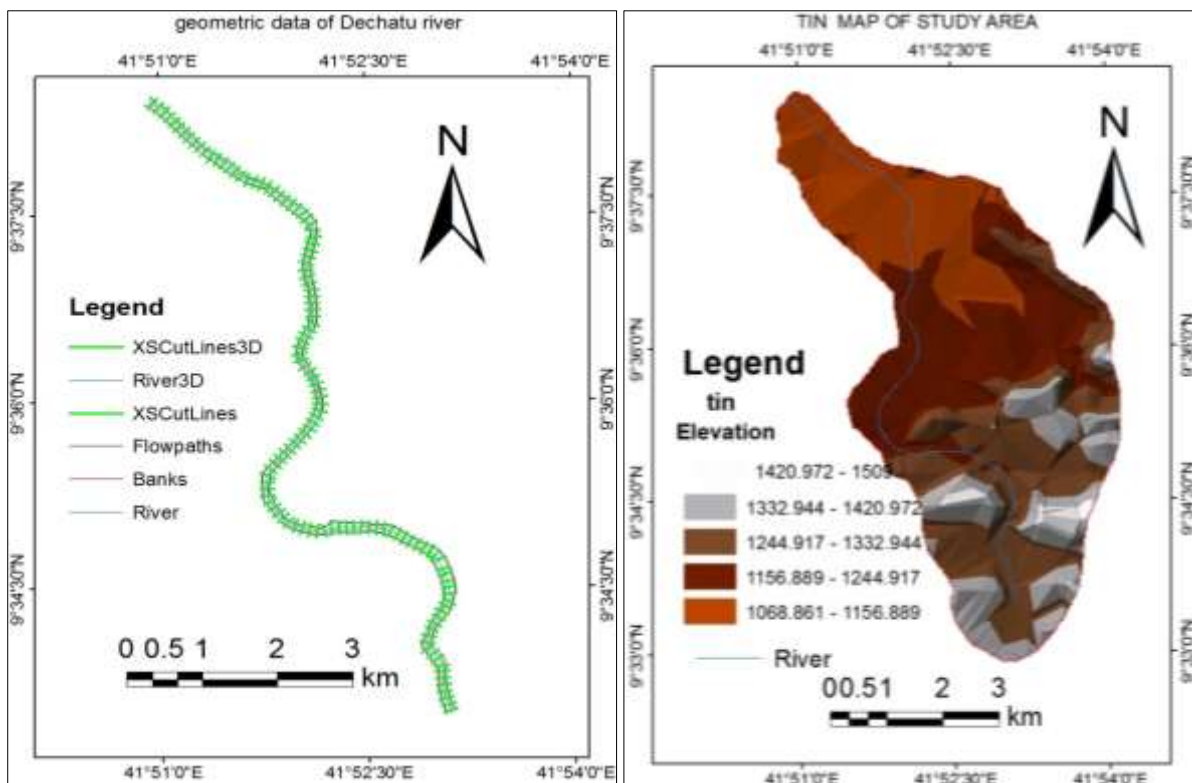


Figure 3.9 The HEC GeoRAS tool bar.

HEC-GeoRAS preprocessing involved creation of several River Analysis System themes like stream center line, bank line, flow path center line, cross sectional cut lines, land use area (manning's n value) connections in GIS format. These themes were used together with TIN to develop the geometric data. These geometric parameters were then exported into HEC-RAS Model. Themes used for data extraction are listed in Table 3.2. The Landsat image of the Dechatu Catchment was used as the base map for digitizing the RAS themes.

Table3. 2 Summary of RAS themes used for HEC-RAS input

RAS layers	Description
Stream Centerline	Used to identify the connectivity of the river network and assign river stations to computation points.
Cross-Sectional Cut Lines	Used to extract elevation transects from the DEM at specified locations and other cross-sectional properties.
Bank Lines	Used in conjunction with the cut lines to identify the main channel from overbank areas.
Flow Path Centerlines	Used to identify the center of mass of flow in the main channel and overbanks to compute the downstream reach lengths between cross sections.
Land Use	Used to assign flow roughness factors (Manning's n values) to the cross sections.



a)

b)

Figure 3.10 a) Geometric data and b) TIN map of study area

3.3.3 Hydraulic modeling with HEC-RAS

There are two main ways for specifying the inputs to build a model in HEC-RAS. One is to do a physical survey of the study site, and collect data manually regarding the river geometry. The other way is to use geospatial datasets like Digital Elevation Models (DEM) and Landsat image to develop the geometric data in GIS.. The main inputs to the model are River geometric data (stream center line, flow path, bank line cross section outline) from Landsat image, Manning ‘n’ value for the land use type covering the river from land use land cover, Boundary conditions (slope, critical depth, normal depth, known water surface elevation) and Stream discharge values calculated by empirical formula. To estimate the maximum flood discharge at different return periods Fuller empirical formula have been applied using the following equations

$$Q_{\max} = Q_{PT}(1 + 2.66A^{-0.3})$$

$$Q_{PT} = CA^{0.8}(1 + 0.3474\ln T)$$

Eqn 7

Where T is flood return period (years), C is a constant coefficient that amount of which depends on the slope and basin land cover that is between 15 to 100, A is area (km²) and Q_{max} is maximum flood discharge (m³/s). The outputs from the model include Water surface elevations , Rating curves, Hydraulic properties i.e. energy grade line slope and elevation, flow area, velocity Visualization of stream flow, which shows the extent of flooding . Steps in creating a hydraulic model with HEC-RAS: Starting a new project, Entering geometric data, Entering flow data and boundary conditions, performing the hydraulic calculations, and viewing and printing results. Before importing the GIS data into HEC-RAS a new project was started and saved under a user-given name as shown below in figure 3.11

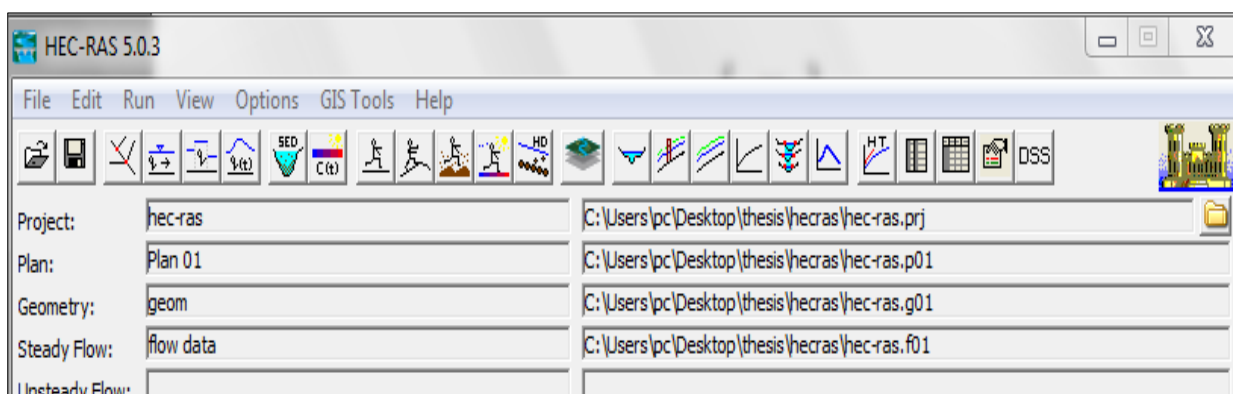


Figure 3. 11 The main HEC RAS window with title and file name

3.3.3.1 Importing and Editing Geometric Data

Once the Geometric Data editor was opened the import geometry data/GIS Format option was chosen from the File menu of the editor window. From the Import Options window, SI (metric) units tab were selected and save in geometric data window.

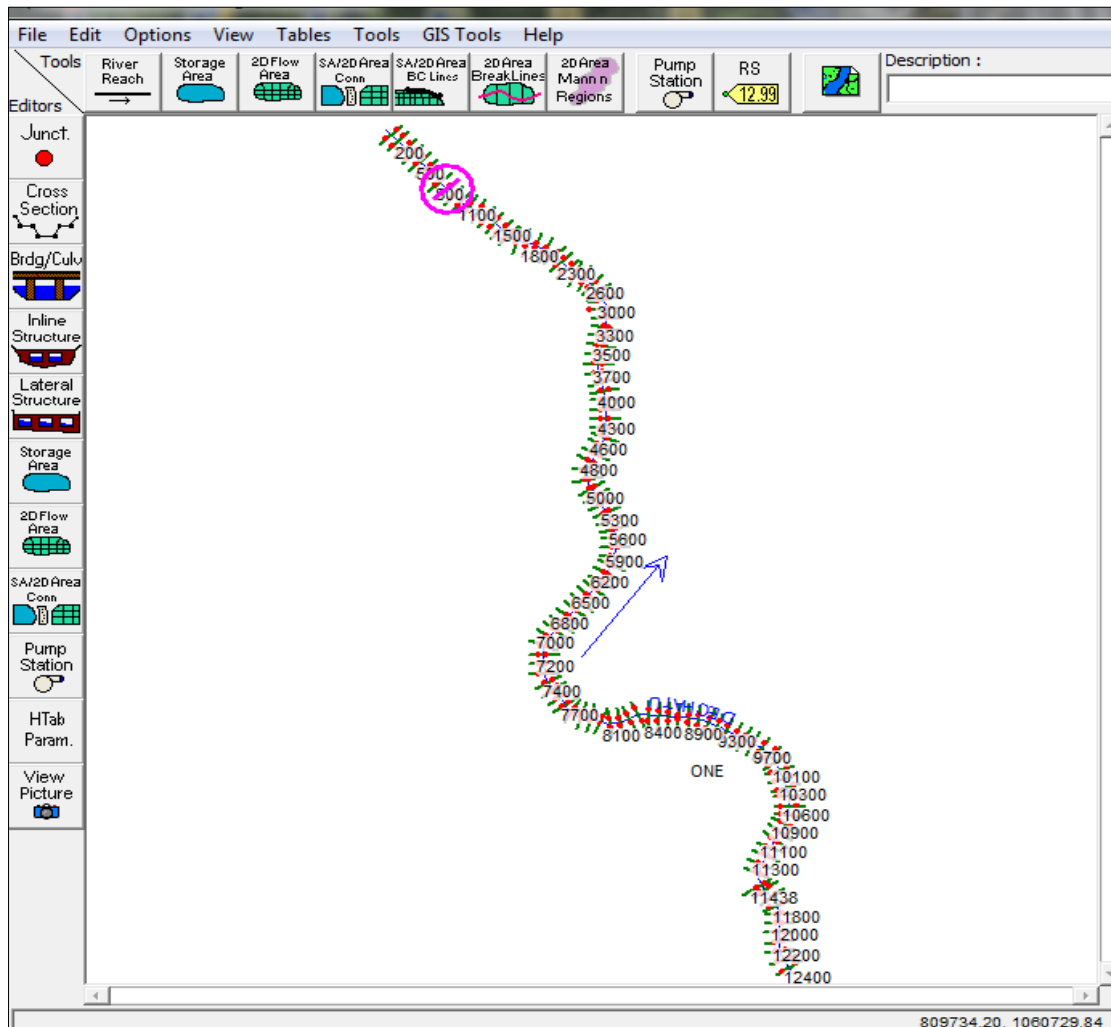


Figure 3. 12 Geometric data window

After importing the Geometric data, Geometric window is used to perform a quality check of the data to make sure the information imported from GIS is correct; information that contains some errors can be edited and corrected (Hydrological Engineering Center, 2002). In this research several information such river bank station and manning's n information were edited from geometric window. In HEC-RAS, the river geometry is represented by a sequence of cross-sections called river stations. The numbering of the river stations increases from downstream to the upstream side. The distance between adjacent cross-sections is termed the reach length. Each cross-section is defined by a series of lateral and elevation coordinates, which are typically obtained from geospatial datasets.

3.3.3.2 Flow Data and Boundary Conditions

HEC-RAS can solve for both steady flow and unsteady flow. Steady flow solutions are selected in analysis for flood plain modeling. In order to perform a steady water surface calculation, steady flow data such as flow regime, boundary conditions and peak discharge were entered. Haestad et al. (2003) indicated that both subcritical and supercritical flow can be experienced during floods; therefore, a mixed flow regime was selected for the simulation. The mixed flow regime computes both a subcritical and supercritical water profile and then reports the higher water surface elevation.

Boundary conditions were important inputs in hydraulic model for establish a starting water surface elevation and influence of external system to model domain through a connecting node. There are four different boundary condition types i.e., Known water surface, Critical depth, Normal depth and rating curve. The type selected depends largely upon the available data. Since no observed flow data (Known Water Surface) is available, it was very important to choose appropriate steady flow boundary conditions. Usually, if there is no observed data, the normal depth is used (*Merwade.v et al., 2006*). Normal depth requires the energy slope or when this is not available the slope of the channel bottom. The slope of the channel bottom was obtained from DEM generated profile.

Discharge information was other boundary condition that required at each cross section in order to compute the water surface profile. Discharge data were calculated using empirical equation and entered from upstream to downstream for all reach.

3.3.3.3 Steady Flow Analysis (Simulation)

Once all data (geometric data, manning's n value, boundary condition and flow data) are entered, it could be possible to calculate steady water surface profiles. This was done using HEC-RAS main window and by selecting Steady Flow Analysis from the Run menu. Then the compute button was pressed to start the simulation. Now water surface profiles are computed for the flow data. After successful simulation HEC RAS results are exported to ArcGIS to view the inundation extent.

3.3.3.4 Exporting HEC-RAS Output

After steady flow analysis in HEC-RAS where water surface elevation at locations from upstream boundary to downstream boundary are obtained, the results were exported to ArcGIS using Export GIS Data button and imported to GIS and by using HEC-GeoRAS and Xtools extensions, flood zones and its areas was extracted. HEC-GeoRAS was used to extract water surface profile data from HEC-RAS and incorporate it into a floodplain map in GIS.

3.3.4 Post-processing of Hydraulic Results and Floodplain Mapping

The result from HEC RAS analysis was further post-processing using HEC GeoRAS to prepare flood inundation maps for different flow conditions. In this step, the water surface elevation data exported from HEC- RAS simulations were processed in HEC- GeoRAS for GIS analysis. HEC- GeoRAS facilitates the generation of flood plain maps by reading the Spatial Data Format (SDF) file from HEC- RAS. During the post processing of HEC- RAS results, GIS layers for inundation depth and flood plain boundary were created. The GIS layers developed were based on the HEC- RAS export file and the terrain (TIN) data.

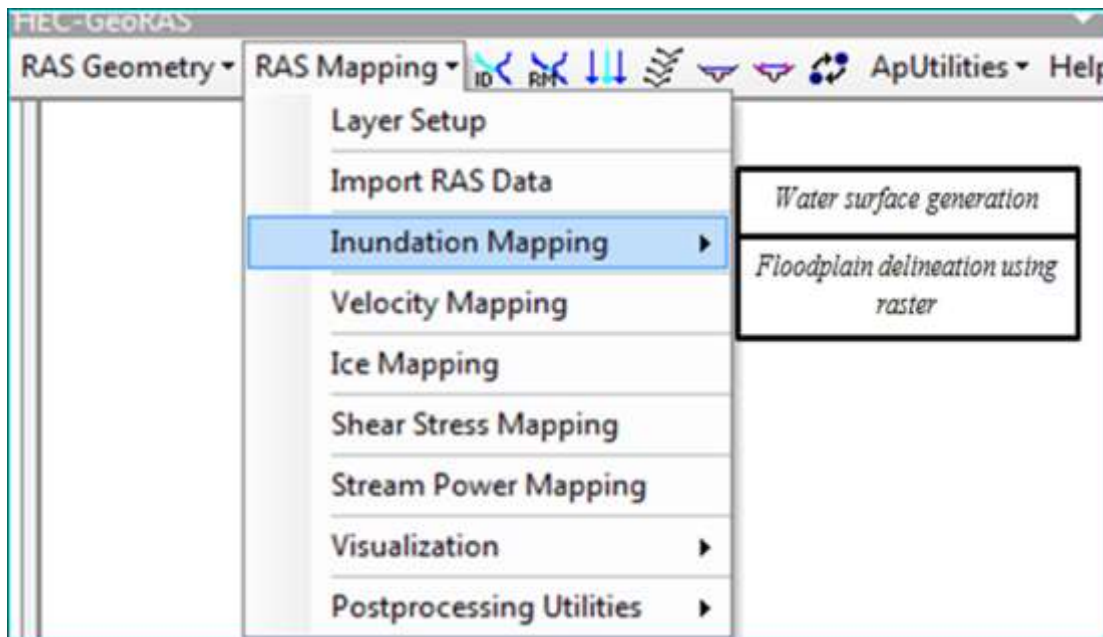


Figure 3. 13 HEC-GeoRAS post processing Functionalities

3.3.5 Flood Inundation Mapping

After steady flow analysis in HEC-RAS where water surface elevations at locations from upstream boundary to downstream boundary are obtained, the next step is to use these water surface elevations for flood mapping. Floodplain mapping is accomplished in the GIS using HEC-GeoRAS. HEC-GeoRAS is a set of ArcGIS tool which is specially designed to serve as a bridge between HEC-RAS and ArcGIS. It prepares geometric files on ArcGIS and also it export and import geometric files from and to HEC-RAS and ArcGIS.

To prepare the map in ArcGIS GIS information is exported from HEC-RAS and read into the GIS with GeoRAS. The cross sections are imported and water surface elevations attached to the cross sections are used to create a continuous water surface. Using Inundation Mapping

(Floodplain Delineation) button water surface TIN is first converted to a GRID, and then DTM grid is subtracted from the water surface grid. The area with positive results (meaning water surface is higher than the terrain) is flood area, and the area with negative results is dry. All the cells in water surface grid that result in positive values after subtraction are converted to a polygon, and the final flood inundation polygon area with respect to each return period were calculated. HEC-GeoRAS produces inundation maps for flood extent and depth.

4 RESULTS AND DISCUSSIONS

4.1 General

Based on the methodology and input requirement of the model selected, all the necessary steps are undertaken and the flood inundation Analysis is simulated. So in this part all the necessary results has been shown and discussed towards the objective of the research.

4.2 Land use Land Covers Classification

The land cover classification map for 2017 from land sat 8 images generated after running a maximum likelihood supervised classification algorithm is presented in Figure 4.1. The figure showed that Shrub land 468.607 ha (14.75%), Built up, 945 ha (30%), Sand deposited, 207.248 ha (6.52%), bare land, 1554.75 ha (48.95%). The results of classification accuracy assessment are showed an overall accuracy of 88.40% from the accuracy assessment report table.

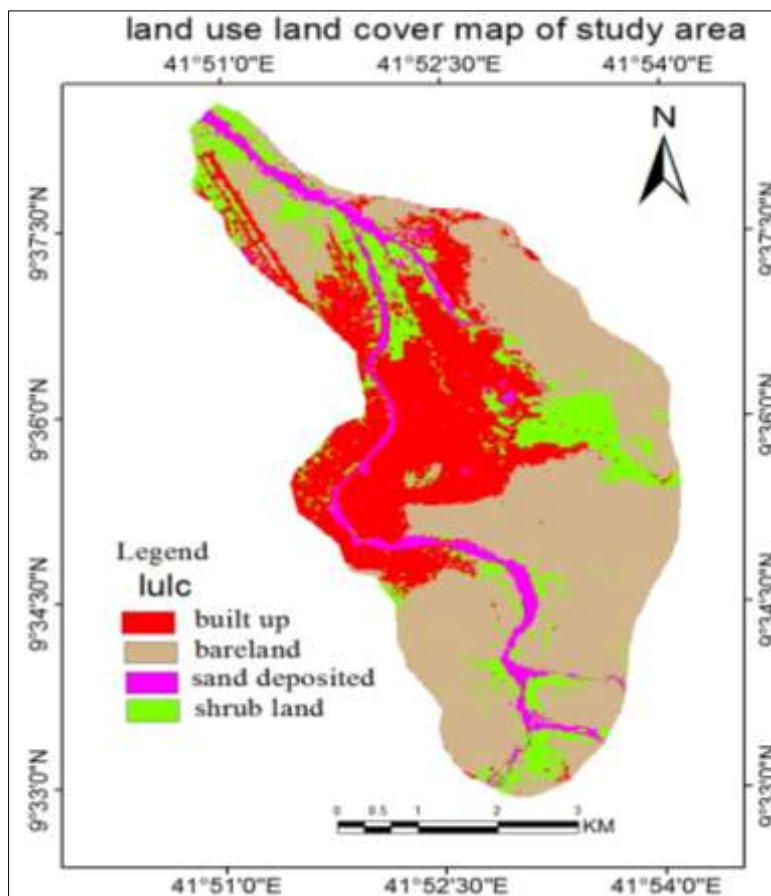


Figure 4. 2 Land use land cover map of Dechatu Catchment

Table 4. 1 distribution of Land use land covers by area and percent

LU/LC	Sand deposited	Built up	Bare land	Shrub land	total
Area (ha)	207.248	945	1554.75	468.607	3176.27ha
Percentage %	6.52	29.78	48.95	14.75	100%

4.3 Discharge Estimation for Different Return Period

The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. To estimate the magnitude of a flood peak the three alternative methods are employed and the one which fit the thesis objective is selected. The use of particular method depends upon desired objective, available data and size of the catchments.

The empirical formula has been used for the estimation of peak flood and it is essentially regional formula based on statistical correlation of the observed peak and important catchment properties. To simplify the form of the equation, only a few of the many parameters affecting the flood peak are used. For example almost all formula use the catchment area as a parameter affecting the flood peak and most of them neglect the flood frequency as a parameter. While the objective of research is to accounts the flood frequency as a parameter.

Therefore, in this study to estimate the maximum flood discharge at different return periods Fuller empirical formula have been applied using equations 7 as discussed under section 2 of this thesis and the result is found to be presented in table 4.2.

Table 4.2 Discharge in m^3s^{-1} of the Dechatu River for floods with different return time.

Return period (year)	5	10	25	50	100
Discharge Value (m^3/s)	460.05	890.23	1450.49	2110.61	4148.01

From the result of table 4.2 the minimum peak flow for the Dechatu River is occurred for 5 year return period for 24 hour duration and the maximum obtained with 100 year frequency for the same duration. The value being $460.05 m^3/s$ and $4148.01m^3/s$ for 5 year and 100 year

frequency respectively. It shows that the value of flow data increase as return period increase. The statistical relationship can be shown in the figure 4.2

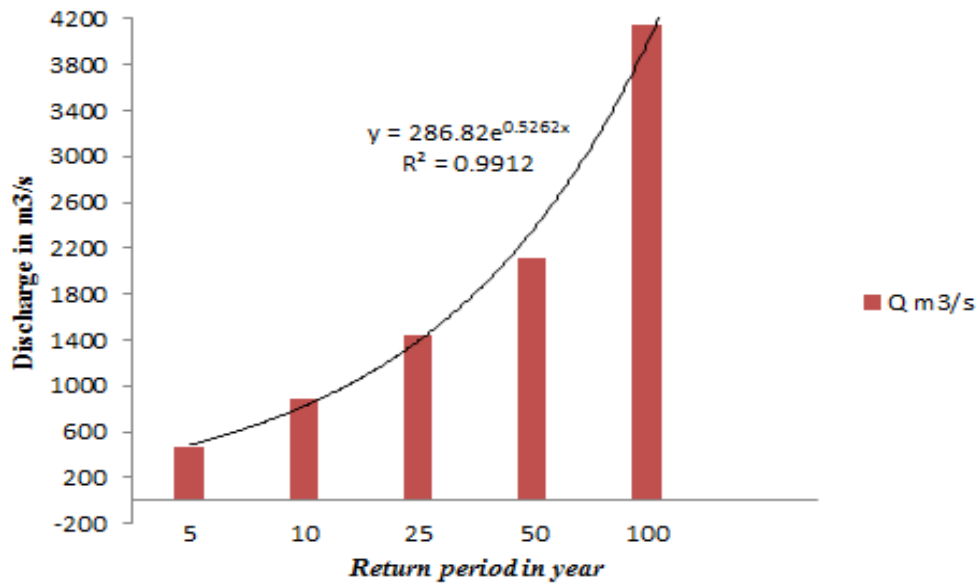


Figure 4. 3 Discharge value computed by Fuller empirical method for different return period.

4.4 Determination of Manning Roughness Coefficient

The selection of Manning values involves judgment, skill, and subjectivity. Roughness characteristics of natural channels are given by Barnes (1967). Barnes presents photographs and cross sections of typical rivers and their respective n values. Therefore, the roughness value for Dechatu River flood plain was determined by comparing the Barnes standard photos with that of Dechatu River main channel and found to be between 0.03 and 0.05.

Table4. 3 Determination of manning’s coefficient for each section

No of section	Right bank	Main channel	Left bank	Number for each cross section
1	0.05	0.04	0.05	1 to 58
2	0.035	0.03	0.035	59 to 124

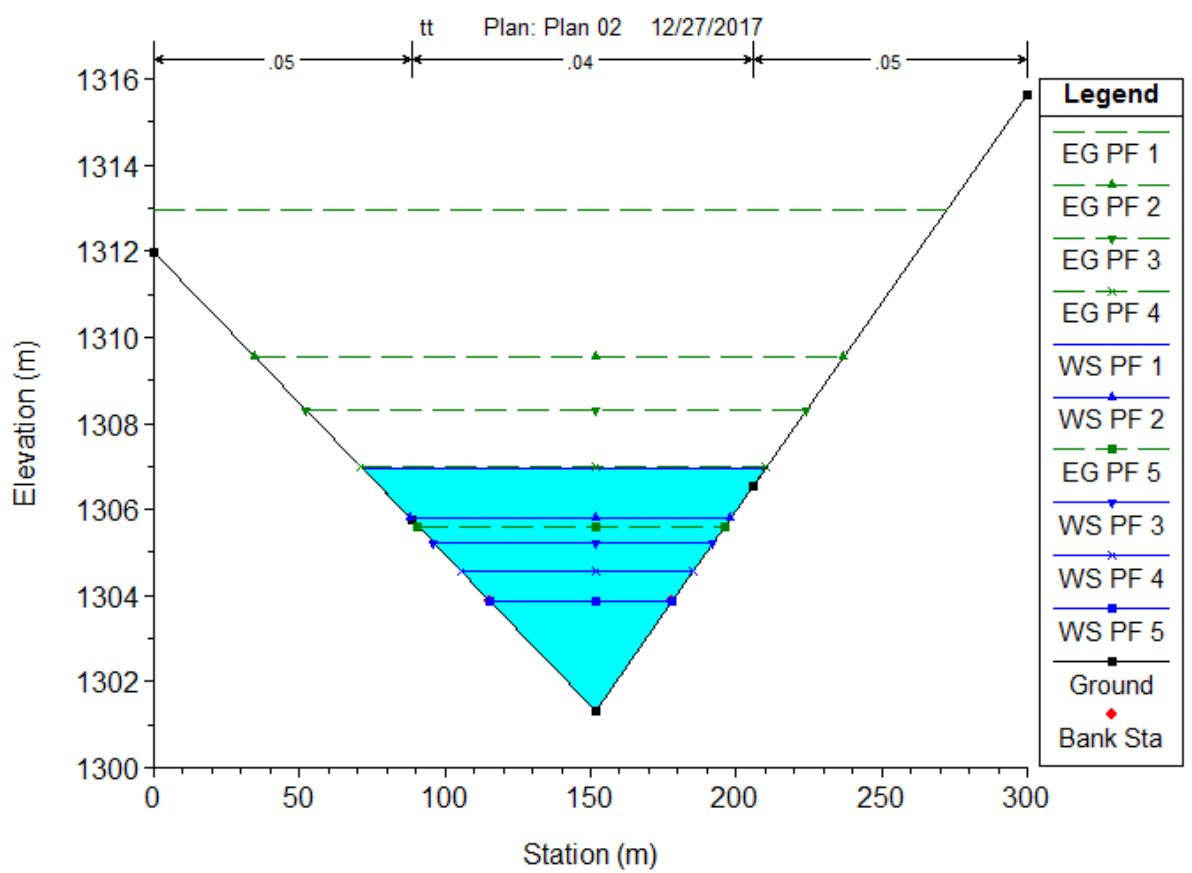
4.5 Hydraulic Model (HEC-RAS) Result

The Model HEC RAS needs geometric data, boundary condition and flow data. Inserting the flow data and importing the geometric data from ArcGIS using the HEC RAS processing, by running the model for the five flow condition profiles to determine the water surface profile of the reach. The simulation is made for steady flow condition. After the computations performed by HEC-RAS software, river flood modeling results are shown in graphical and

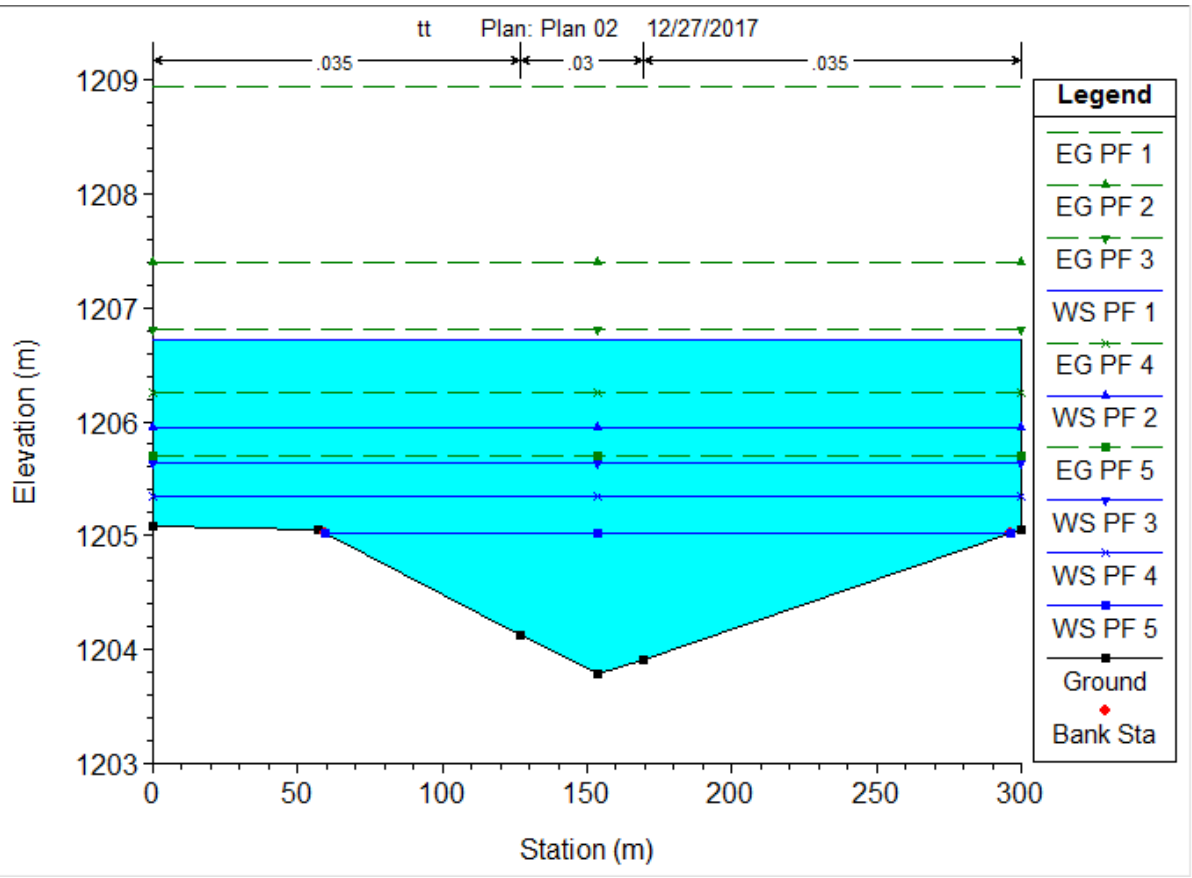
tabular formats. After running the simulation successfully, the result of the simulation analysis can be viewed and analyses in cross section window, profile plot window, rating curve window, general profile plot-velocities, and X, Y, Z perspective plot window. The simulation results are discussed as follows.

4.5.1 Cross Section Results

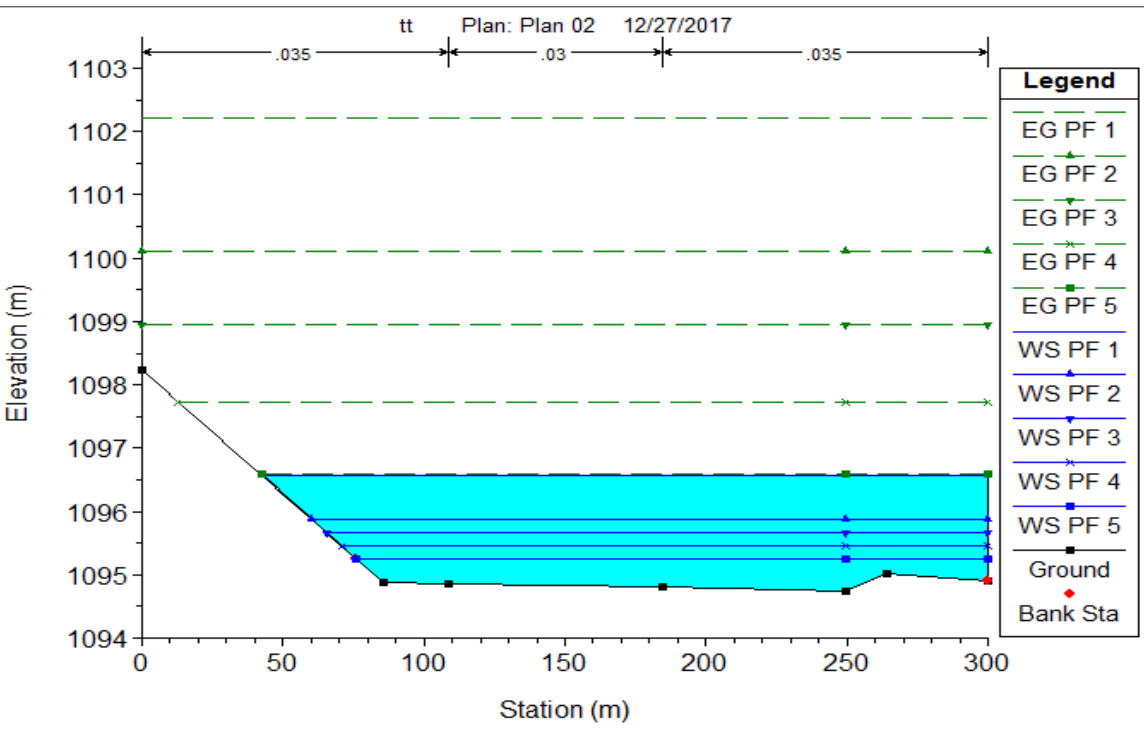
Knowledge of the river stations is essential for understanding the hydraulic modeling results. The stations outline the location of each cross section along the modeled stream according to their distance to the downstream outlet. Figures 4-3 a, b and c are cross sections taken at representative points along the three reaches(stream), that is for the upstream, middle and downstream respectively. The direction of cross sections is towards downstream. The cross sectional view shows Energy grade line profile (EG PF), the water surface label profile (WS PF) for the 5, 10, 25, 50 and 100 years flow condition and it is observed that the cross section is made for length of 300m across the flood plain.



a) Cross section view at River station 12300 for different profile.



b) River cross section view at station 6200 for different profile.



c) Cross section view at 200 stations for different profile

Figure 4.3 Cross section view at River station 12300(a), 6200(b) and 200(c) for different profile.

The cross sectional graph indicates (figure 4.3 a) the capacity of the natural drainage system to pass the volume of water generated by rainfall in different return periods. The X axis show the Cross sectional distance in meter and the Y axis represents the water elevation of 5, 10.25, 50 and 100 years return periods in meter. The result shows that cross sections were narrow and water can out-flow the river Cross section, selected river section as shown in Figure 4.3 b & c and make inundation of the area. Also the Figure 4.3 shows that HEC-RAS can create geometric data for the stream profile. Cross-sectional data is essential for analysis of the channel at 100m intervals. The reliability of the geometric data in turn depends on the reliable estimates of DEM.

4.5.2 Longitudinal Profile Result

The Longitudinal profiles graph figure 4.4 indicates the water elevation in different return periods of Dechatu River. The X axis show the main channel distance in meter and the Y axis represents the water elevation of 5, 10, 25, 50, 100 years return periods in meter. Generally Steady flow analysis result Longitudinal profiles showed that water elevation in the longitudinal profile increased with increasing return period. This finding is in agreement with, (Fekadu et al, 2017), which reported that with increasing return period water elevation in the longitudinal profile will be increased too.

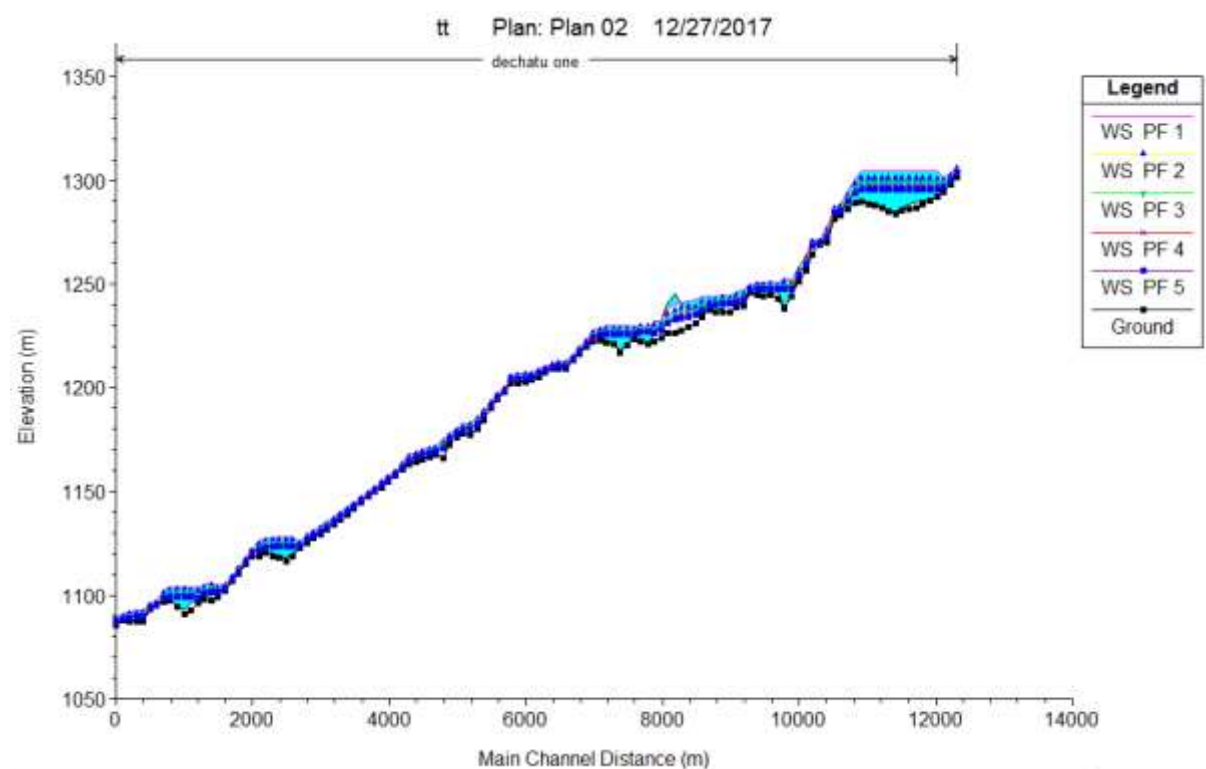


Figure 4.4 Water surface profiles for 5, 10, 25, 50 and 100 year return periods.

The figure 4.4 shows the water surface profile along the reach for the five flow conditions.

The flow conditions are labeled as PF1, PF2, PF3, PF4 and PF5 which represents 100, 50, 25, 10 and 5 years respectively.

4.5.3 Discharge Rating Curve

The other result from HEC RAS model was discharge rating curve. The rating curve graphs given below figure 4.5 indicate the relationship between water surface elevations of flood with design runoff (discharge). The X axis shows the design runoff in meter cube per second of Dechatu River for 5, 10, 25, 50 and 100 years, Y axis represents the water surface elevation in meter at each return period. A stage/discharge rating curve was constructed ($R^2 = 0.95$) and the discharge associated with all the flow level data calculated was plotted.

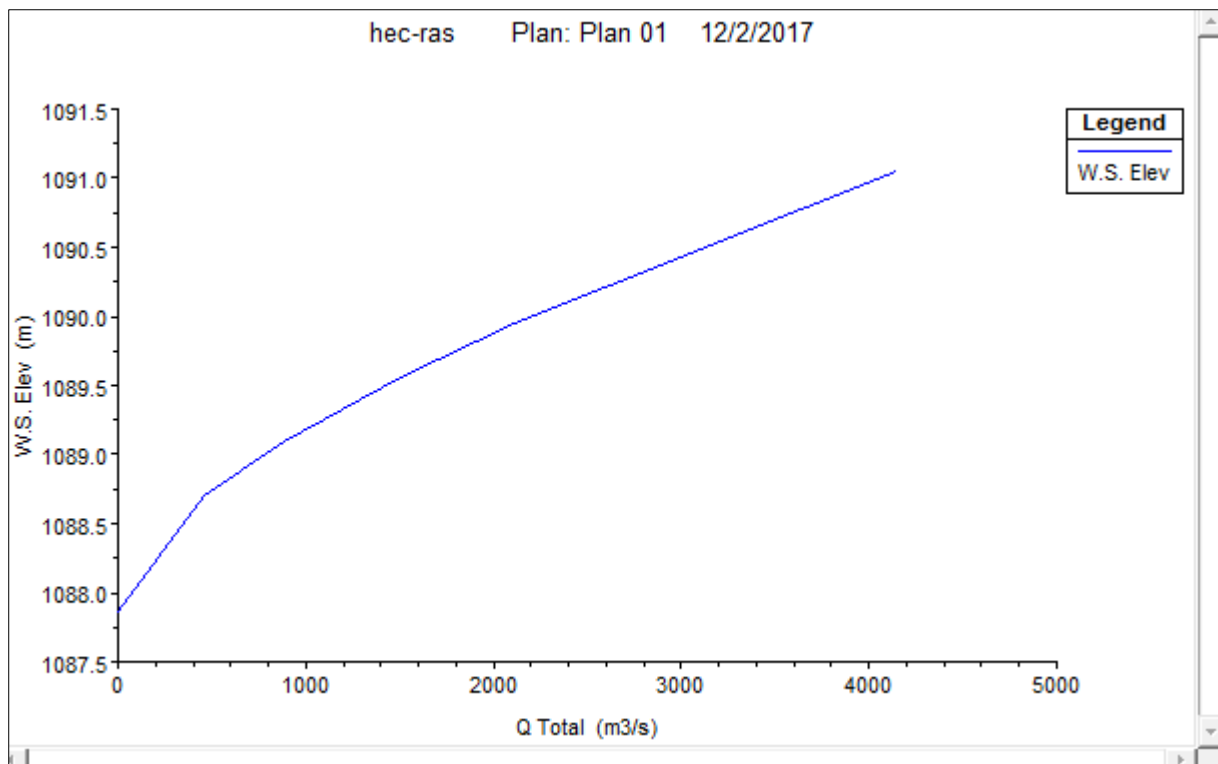


Figure 4.5 Rating curve of study area around downstream at station 100

4.5.4 General Profile Plot

The figure 4.6 shows that channel velocity, right bank velocity and left bank velocity for the five different return period i.e. PF5, PF4, PF3, PF2, PF1 for 5, 10, 25, 50, 100 year respectively. The channel velocity is higher in 100year return period when compared to 5 year return period.

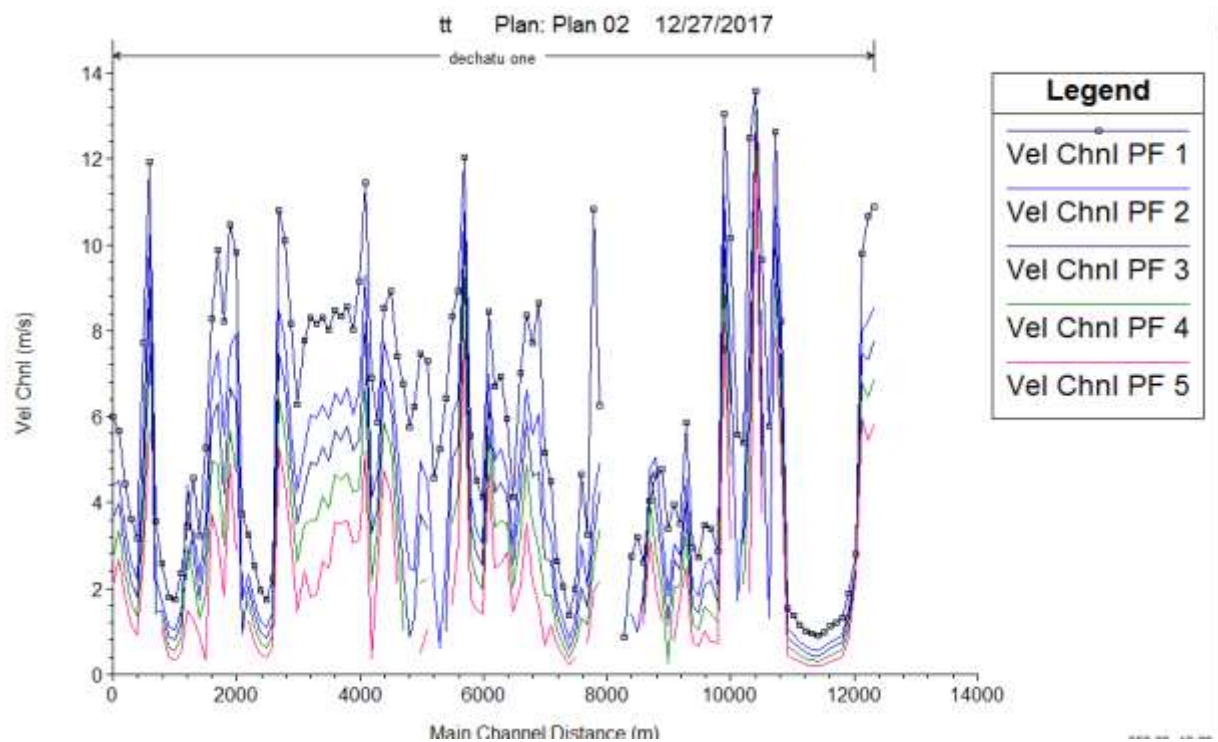


Figure 4.6 General profile plots for velocity map of study area.

4.5.5 3D Perspective View of the Flood Plain

HEC-RAS is providing the 2D river water profile to ArcGIS to display the flood plain in 3D. The flood plain mapping and finally delineated output is the one which uses the RAS output in the form of the river profile.

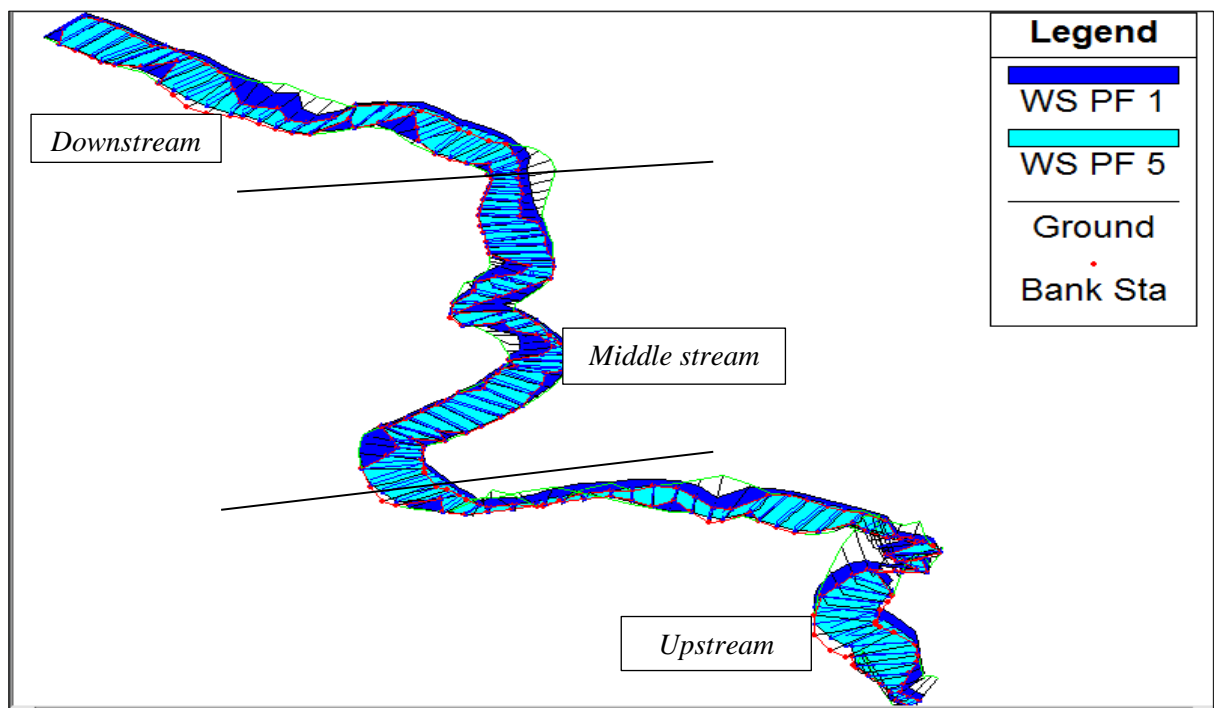


Figure 4.7 3D Perspective View of the Flood Plain for water surface profile for 100 & 5 year

Figure 4-7 shows the 3 D view of the reaches upstream, middle and downstream with their cross sections and their stations. Also it indicates water surface extent of 5 (WS PF 5) and 100 (WS PF 1) year. 100 year return flood is more significant when compared to 5 year; hence communities need to be prepared for such flows through feasible flood management practices.

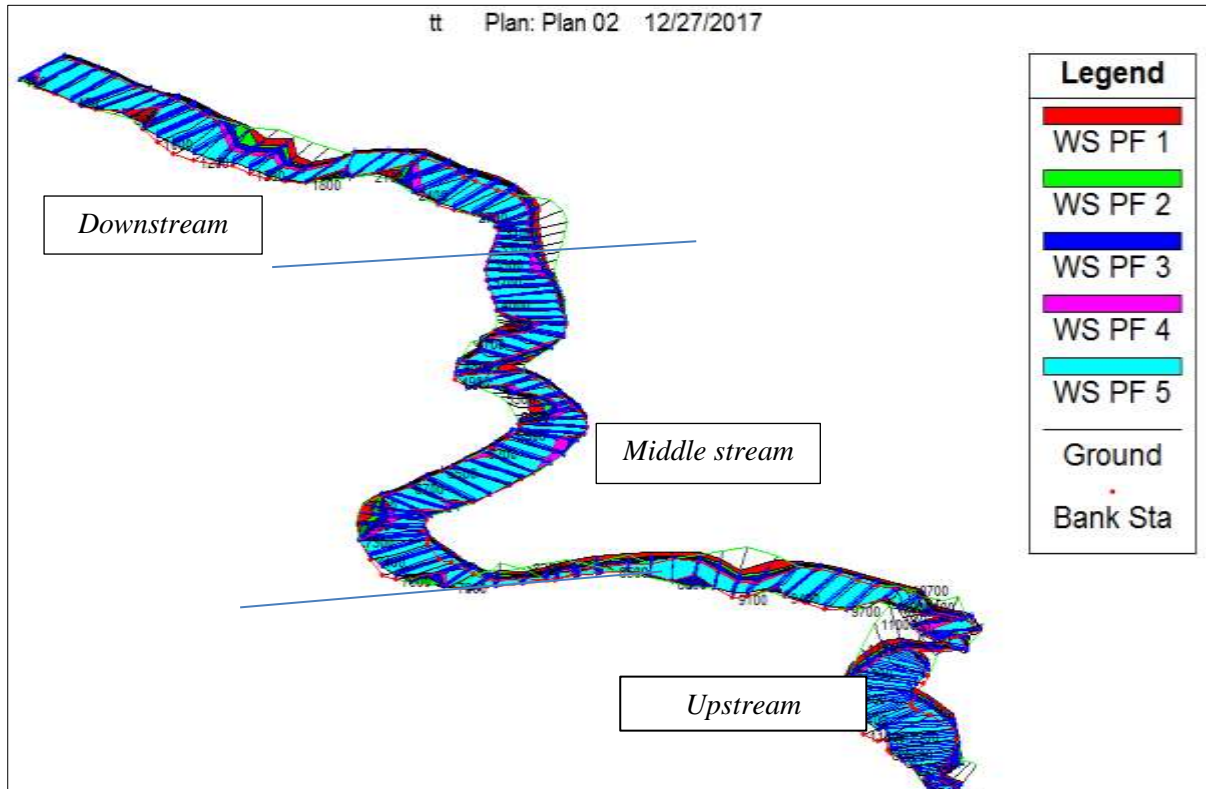


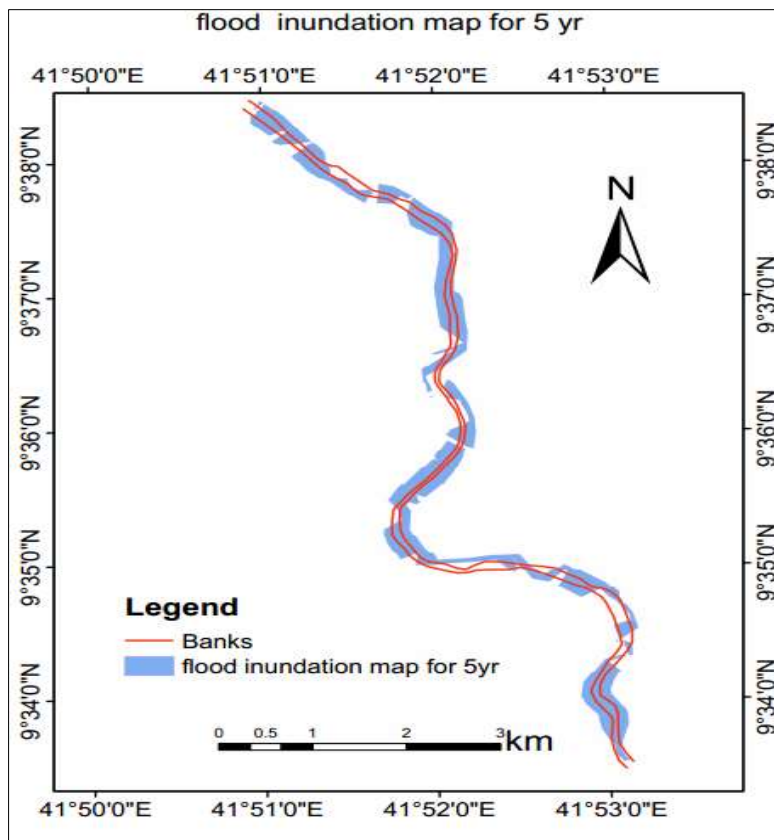
Figure 4.8 3D Perspective View of the Flood Plain for different water surface profile.

The 3 D view of the Figure 4-8 upstream, middle and downstream shows the cross sections and their stations with water surface profile (WS PF1 ,WS PF2,WS PF3,WS PF4,WS PF5) for 100, 50 ,25, 10 and 5) year return period respectively.

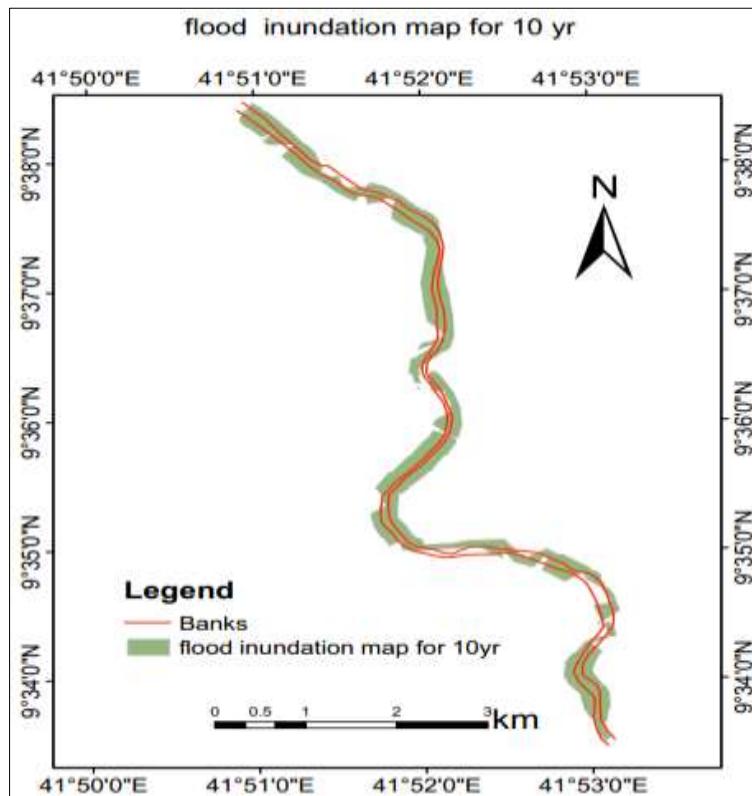
4.6 Flood Inundation Map and Delineation

Using the Hec- GeoRAS post processing exporting the HEC-RAS out puts in .sdf format to ArcGIS the flood plain inundation mapping and delineation was done using the ArcGIS tool bars. In flood inundation mapping and delineation the flooding map shows the area extent that can be delineated as buffer zone. Areas inundated by flooding occur wherever the elevation of the floodwater exceeds that of the land. To delineate these areas, we will create surface models of the floodwater and land surface, and then compare the elevations. HEC-RAS represents the floodplain as a computed water surface elevation at each cross-section. During the data import step, these elevations were brought into ArcGIS, along with the

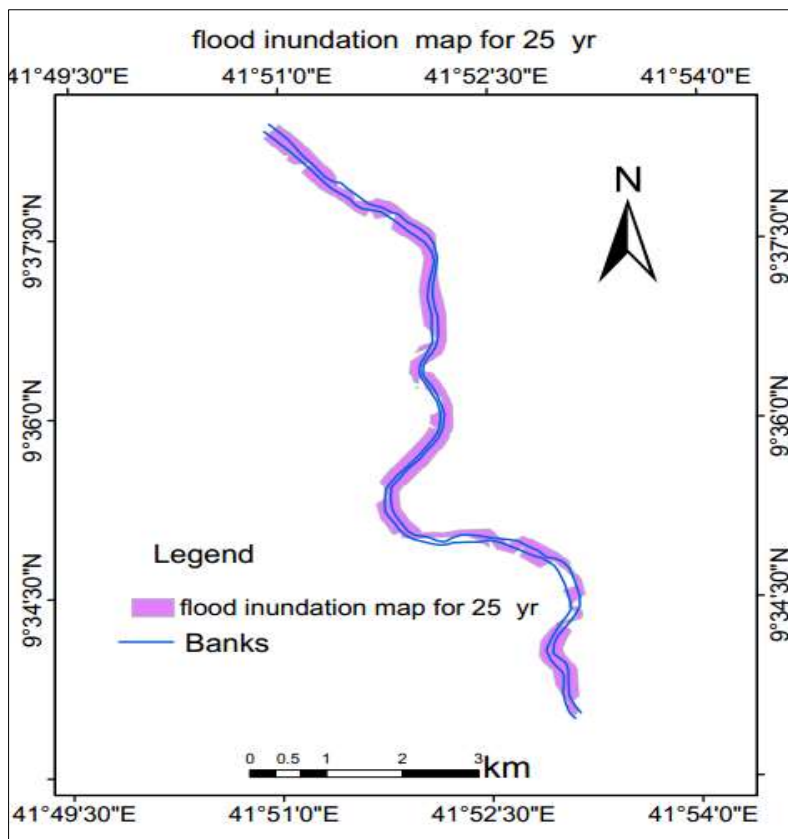
distance from the stream centerline to the left and right floodplain boundaries. The inundation map shows the flood extent at peak flow of 100 year return period. The spatial distribution of the flooded area was located at areas with low relief and covered an area of about 173.66ha. The flooded area was also graphically overlaid on the Google Earth. The outcome of the overlay which has been shown in (Fig. 4.14) clearly identified the affected settlements including both the infrastructure and houses which are located around middle and downstream. The result of flood inundation maps shown in the following figure 4.9 a, b, c, d and e for 5, 25, 50 and 100 year respectively.



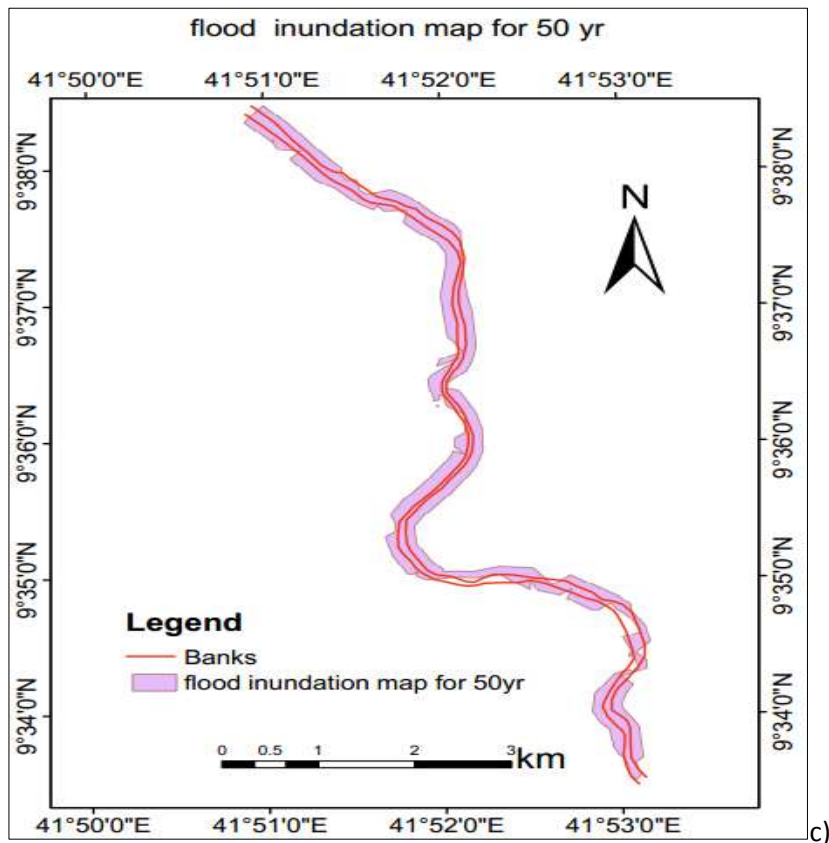
a)



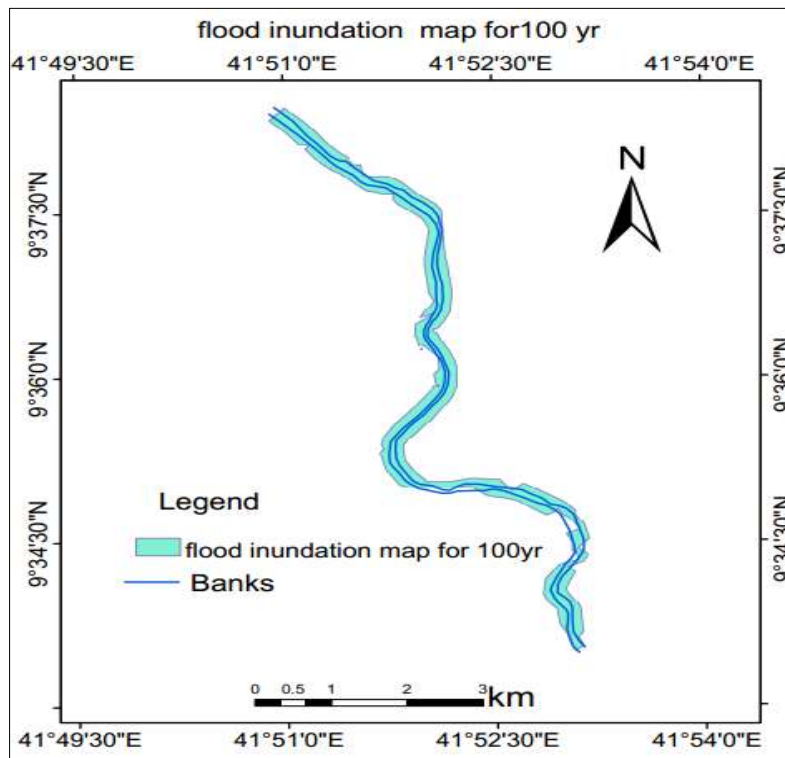
b)



c)



d)



e)

Figure 4.9 flood inundation maps a, b, c, d, e for 5, 10, 25, 50, 100 year respectively.

The flood inundation and stream flow value of the Dechatu Catchment quantified as (94.48ha, 460.05m³/s), (123.16ha, 890.23m³/s), (140.13ha, 1450.49m³/s), (152.76ha, 2110.61m³/s) and (173.66ha, 4148.01m³/s) respectively for 5, 10, 25, 50 and 100 years return period. Due to the increased stream flow in the 100 year return period, the inundated area was high relative to other return periods. The relationship between Return Periods and Area Inundation were presented in Figure 4.10. The figure shows that area inundation increase with increasing return period. The statistical relationship can be shown on figure 4.9 and constructed for ($R^2=0.981$).

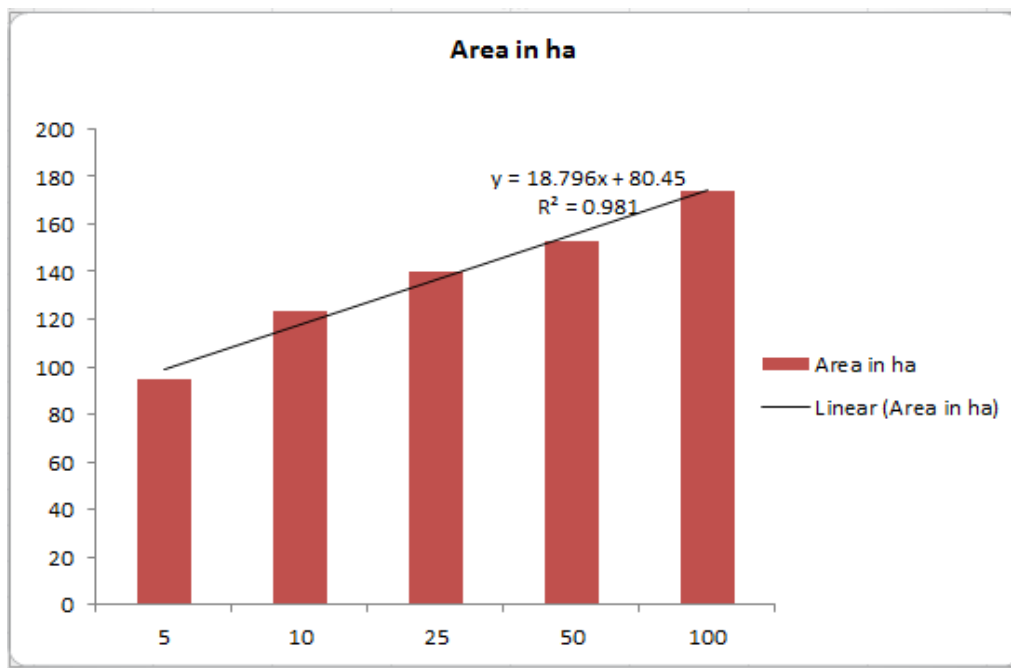


Figure 4.10 Relationship between return periods and area inundation

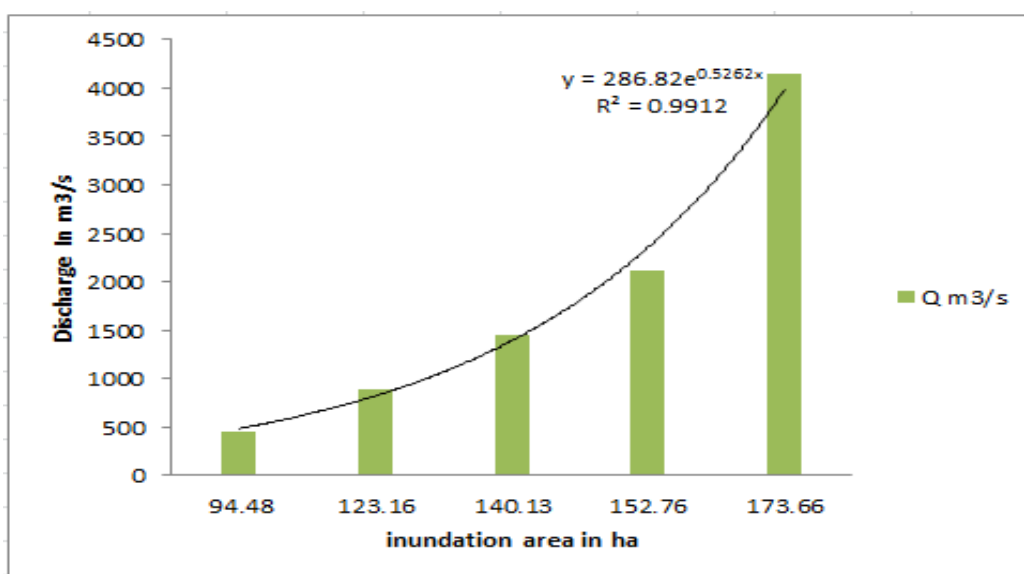
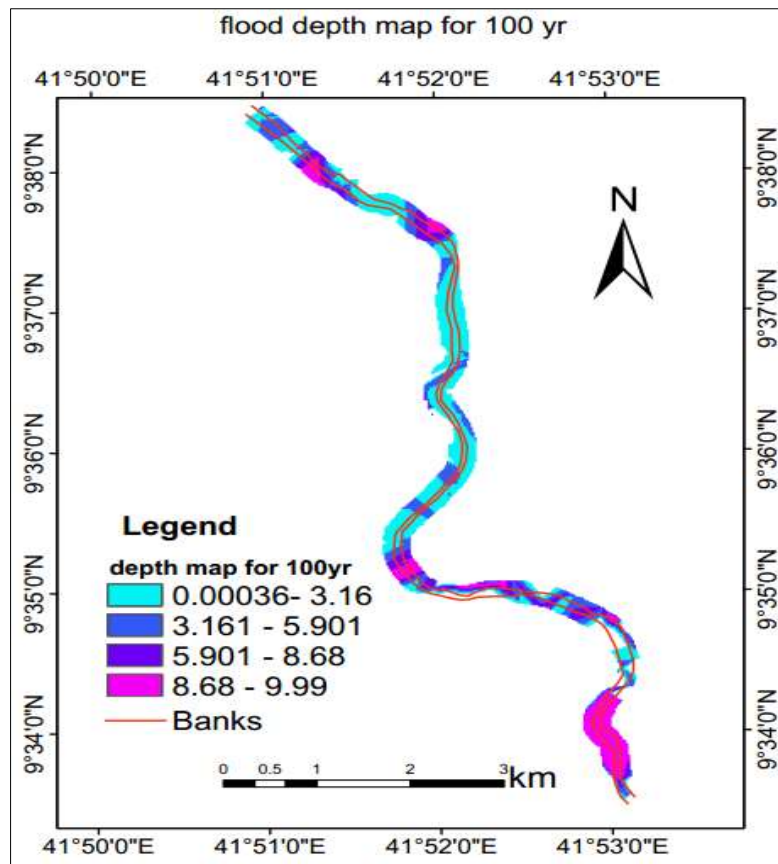


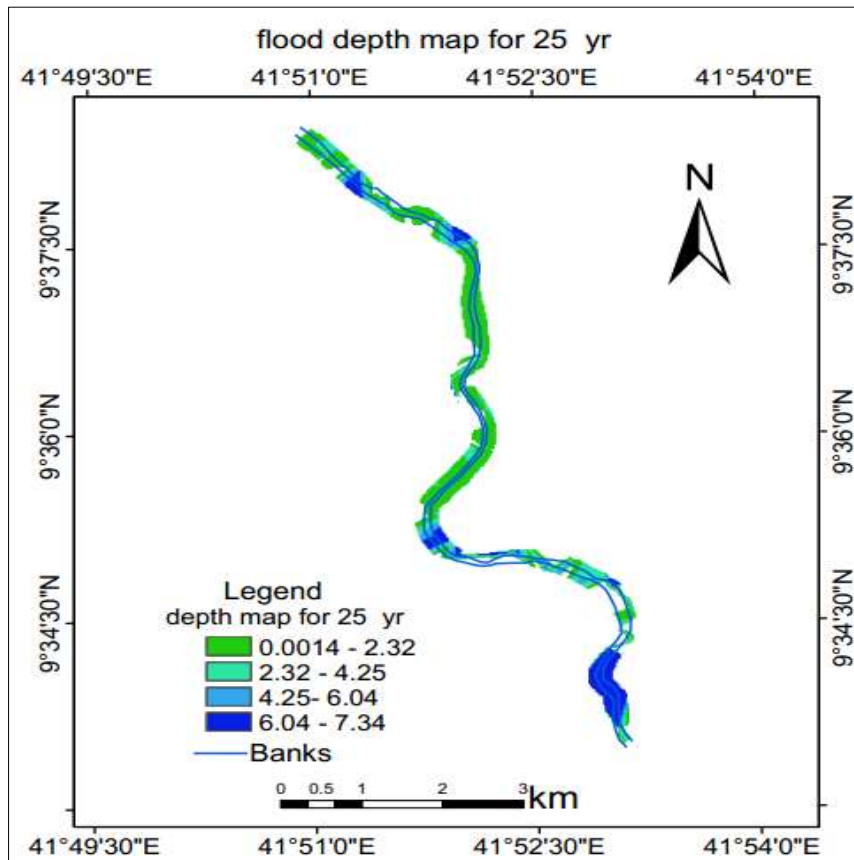
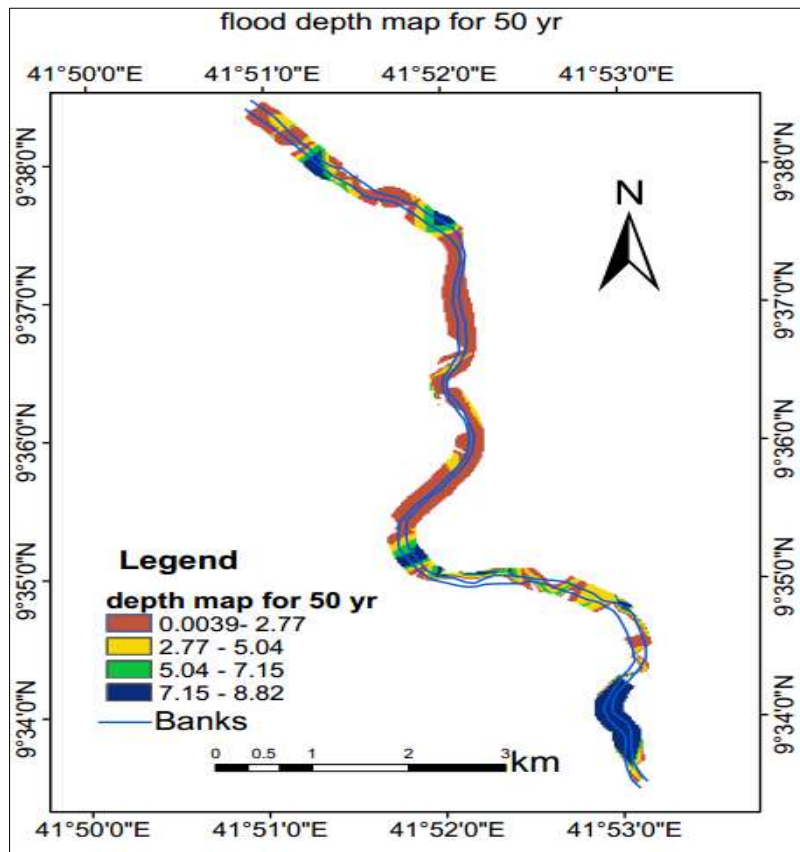
Figure 4.11 Relationship between design runoff and inundation area.

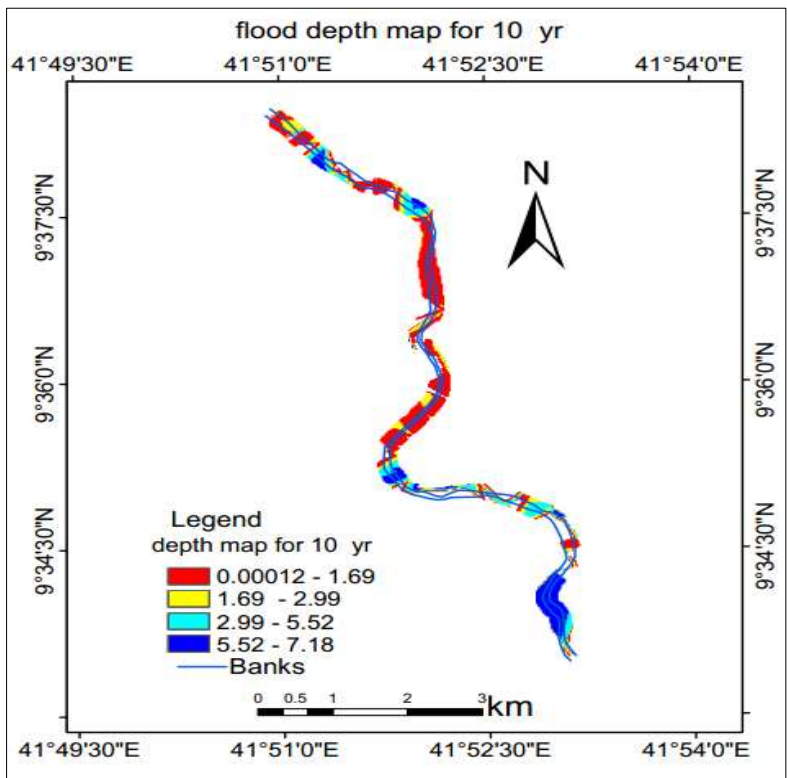
The statistical relationship between flow (discharge) data and inundation were constructed for $R^2=0.9912$.

Flood depth map is an important output of the model showing the vulnerability of the area by indicating the water depths (levels). Generally, water depth is higher along the main channel and lower at the floodplains. The depth of water can be calculated by subtracting grid maps of water surface and terrain. The result of flood depth maps are shown in the following figure 4.12 a, b, c, d and e for 100, 50, 25, 10 and 5 year respectively.

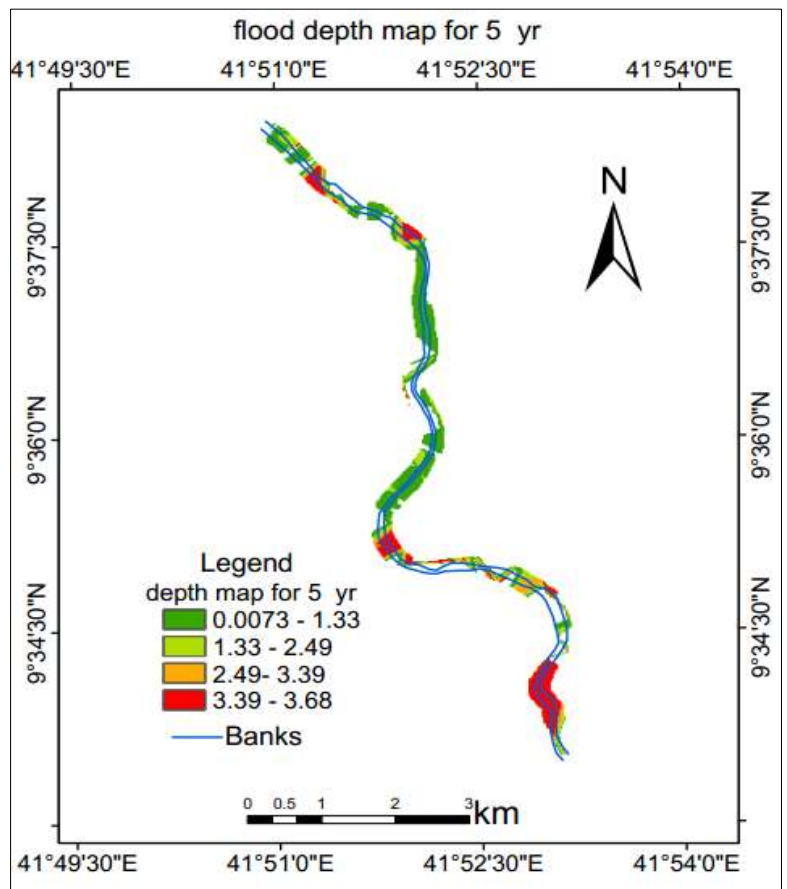


a)





d)



e)

Figure 4.12 flood depth map for 100, 50, 25, 10, 5 years (a, b, c, d and e) respectively.

The flooded area and depth were also graphically overlaid on the Google Earth. The outcome of the overlay which has been shown in (Fig. 4.13) clearly identified the affected settlements including both the infrastructure and houses.

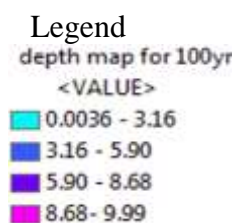
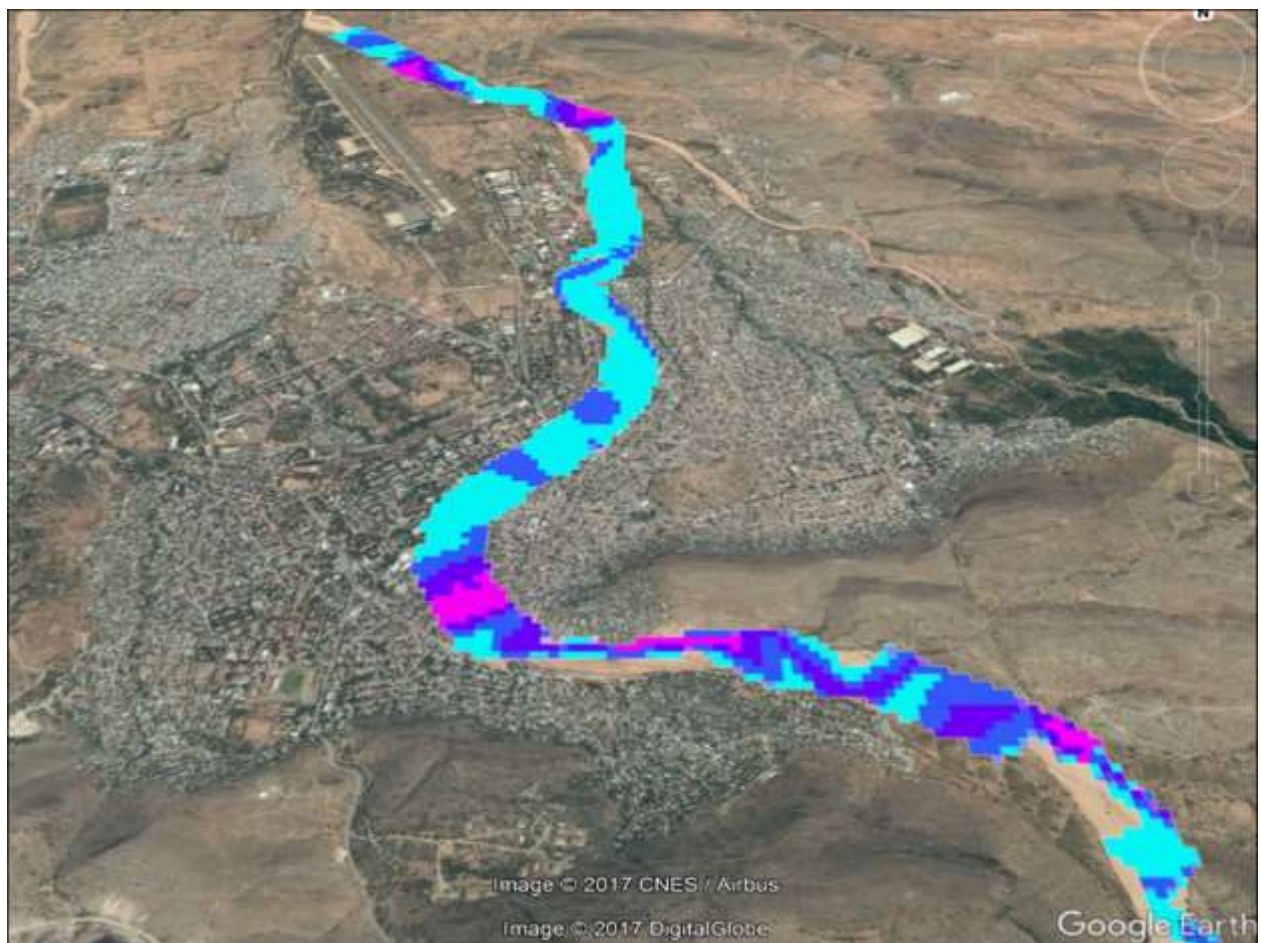


Figure 4.13 flood depth map for 100 year superimpose on satellite image (Google Earth). Since all of the houses in the inundated area are one story houses, this depth of inundation was big enough to cause several casualties and property damage. Due to increase in flooding frequency, population residing near the river banks and other valuable infrastructure like roads and bridges are found at high risk of flood inundation. Thus, hydraulic modeling using GIS technique proved useful in simulating flood water depth and inundation areas for various return periods.



Figure 4.14 Flood Inundation map superimpose on Google earth for 5 year (red) and 100 year (green) return period.

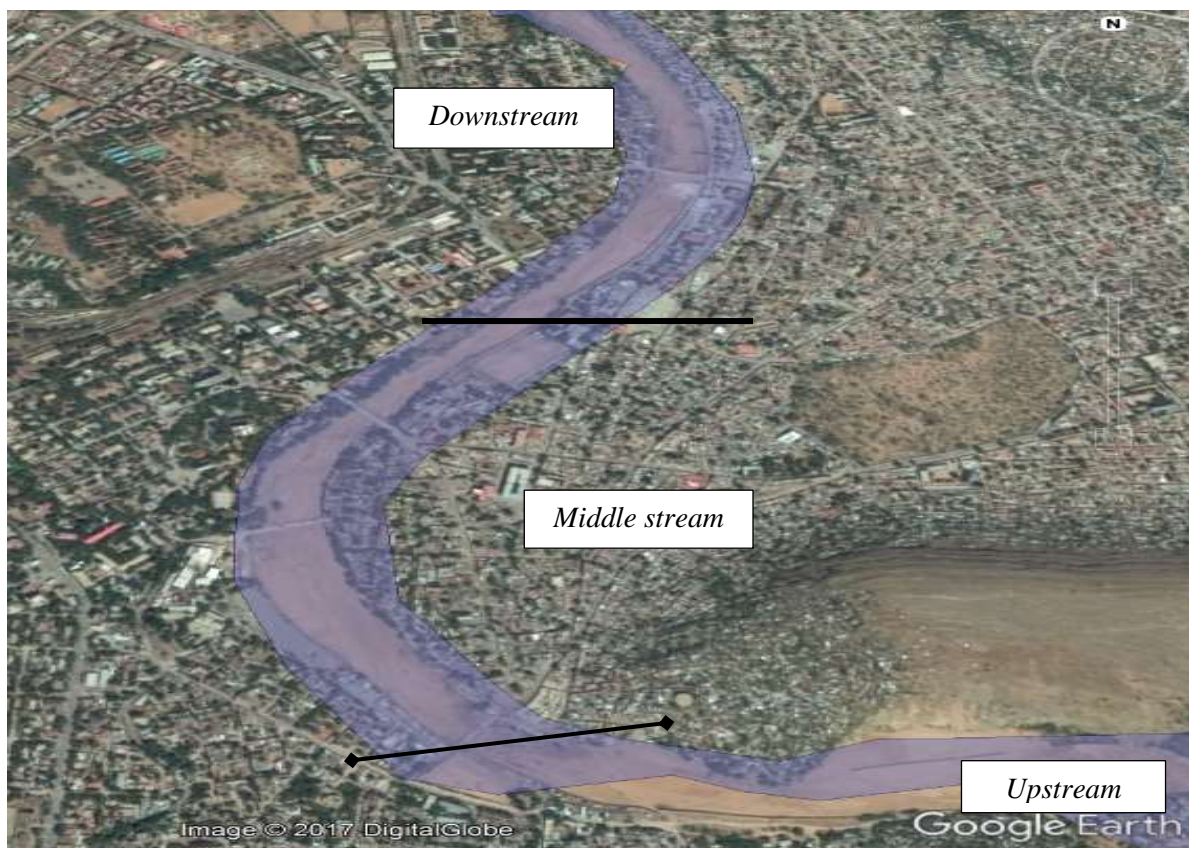


Figure 4.15 flood inundation map superimpose on satellite image (Google Earth) of 100 year.

The result of overlay (Google earth) showed that the middle and downstream areas especially built up areas which are located near the river side are affected more in 100 year flood. As the City is found at the foot hill and the maximum flow in 100 year from the upland area reaches to urban Dire Dawa with high speed because of altitude difference and there is nothing to decrease its speed as it is bare land and no wood land to infiltrate and decrease the runoff. Above all this, the shape of the watershed is elongate triangle which speeds up the time and acceleration of the runoff to reach to middle and downstream. The main cause of flooding in the low-lying area along the Dechatu River is the intense rainfall in the main rainy season from high land area of Dengego, Haramaya, Kersa and Langey (Eleni, 2011). This makes the area highly vulnerable to flood hazard. Since it was hard to get a historical stream flow data, some GPS coordinate points that indicate historical flooded area, and literatures were used to validate the model results. The inundated areas indicated by HEC-GeoRAS/HEC-RAS model are similar to that of the areas in the report from the DPPA in 2006. Similarly, according to Yonas, 2015 kebeles which are found near the river like Addis Ketema, Ginfilie, Kezira, Ashawa, Dechatu and Coca are the mostly affected area which agrees with this study (see appendix D1). In flood hazard disaster reduction, there are two techniques, structural and non-structural. Structural measures are any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems. Eventhough the Administrative council is doing some retaining wall work on Dechatu River so far it was not aduquate to withstand flood threats. According to Halcrow, (2008) the total length of Dechatu River which crosses the town is estimated around 7km. But there is a retaining wall for about 2km length on both sides of the river. The remaining 5km length (middle and downstream) of the river lefted as it is and some parts of the retaining wall were distructed by 2010 flood. This tells us more structural measures have to be taken in the upland areas where flood water sourced in order to reduce the velocity and volume of the water draining downstream. Non-structural measures are measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training and early warning systems. Inundation mapping (one of the non structural measure) would be helpful for planners to focus on specific areas during evacuation actions. In general, this information leads to a more effective and efficient way of providing a warning system before the flood occurs and for the evacuation after the occurrence of flood events.

5. CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The following conclusions are drawn from the results and discussion presented.

The proposed methodology is simple, easy and inexpensive (free software and minimum amount of data requirement); yet it is very effective in terms of pinpointing the flood-inundation locations in hydrological watersheds. The flood inundation area and stream flow value of the Dechatu Catchment quantified as (94.48ha, 460.05m³/s), (123.16ha, 890.23m³/s), (140.13ha, 1450.49m³/s), (152.76ha, 2110.61m³/s) and (173.66ha, 4148.01m³/s) respectively for 5, 10, 25, 50 and 100 years return period. Due to the increased stream flow in the 100 year return period, the inundated area was high relative to other return periods. The Analysis of flood inundated areas using HEC-RAS and GIS using current land use for different return periods shows increasing for the Dechatu River catchment. The comparison between inundated areas corresponding to the five different flood events leads to the conclusion that there is a little correlation between the increases in peak discharge flows and corresponding increases in flood plain areas. When comparing the flood inundation area of the previous study and the present study it can be concluded that they are more or less similar other than the fact that they are performed with different methodology. The current study also suggests that the middle and the downstream of Dechatu River are inundating more in 50 and 100 year return period. Integration of GIS and one dimensional hydraulic model HEC-RAS and HEC-Geo-RAS is an important option for flood inundation study. In conclusion, integration of Hydraulic Models and GIS to prepare flood inundation map is baseline for Flood Early warning.

5.2 Recommendations

Based on the result of the present study, the following recommendations are suggested for decision makers and future researchers:

- Using flood inundation map it is better to protect the middle and downstream areas of Dechatu River from house construction and Investment decision. It is also better to Use flood inundation map as a preliminary information guide for land use planning, policy making, as well as for security reasons.
- To minimize and alleviate the existing flood challenges and problems an early warning system, with modest flood forecasting capacity, City administration should be given priority. In this regard, the use of reliable and timely meteorological information is important. In addition, there should be fast communication system, which helps to circulate flood warning information. Also Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in Dire Dawa City.

For futures studies in this research area, the following recommendations should be considered.

- ✚ Higher spatial resolution of DEM is suggested in the future for better visualization as well as improves the reliability and should be conducted for the period of 200, 500 and 1000 return period design.
- ✚ Develop two-dimensional unsteady hydraulic models in order to understand the spatial flooding pattern more effectively.
- ✚ In addition to GIS and Hydraulic model, in future research other model for flood inundation mapping should be investigated.

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APPENDIX A Manning's n coefficient of different land use land cover

Types of channel and Description	Manning's Roughness (n) Values		
	Minimum	Normal	Maximum
Natural Streams			
1. Main channels			
1.1. Clean ,straight ,full ,no rifts or deep pools	0.025	0.030	0.033
1.2. Same as above ,but more stones and weeds	0.030	0.035	0.040
1.3. Clean ,winding ,some pools and shoals	0.033	0.040	0.045
1.4. Same as above ,but some weeds and stones	0.035	0.045	0.050
1.5. Same as above ,lower stage ,more ineffective slopes and sections	0.040	0.048	0.055
1.6. Same as "d" but more stones	0.045	0.050	0.060
1.7. Sluggish reaches ,weedy ,deep pools	0.050	0.070	0.080
1.8. Very weedy reaches ,deep pools or floodways with heavy stands of timber and brush	0.070	0.100	0.150
2. Flood plains			
2.1. Pasture no brush			
2.1.1. Short grass	0.025	0.030	0.035
2.1.2. High grass	0.030	0.035	0.050
2.2. Cultivated areas			
2.2.1. No crop	0.020	0.030	0.040
2.2.2. Mature row crops	0.025	0.035	0.045
2.2.3. Mature field crops	0.030	0.040	0.050
2.3. Brush			

\`conti...

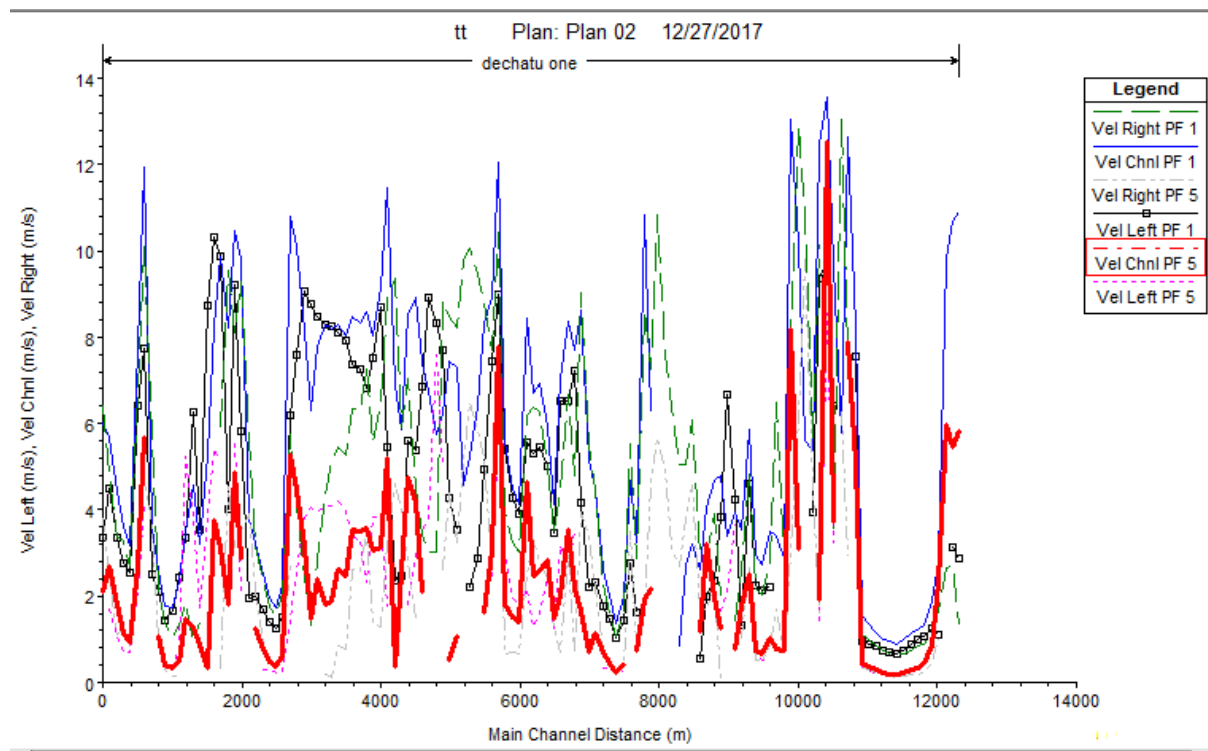
2.3.1. Scattered brush ,heavy weeds	0.035	0.050	0.070
2.3.2. Light brush and trees ,in winter	0.035	0.050	0.060
2.3.3. Light brush and trees ,in summer	0.040	0.060	0.080
2.3.4. Medium to dense brush, in winter	0.045	0.070	0.110
2.3.5. Medium to dense brush, in summer	0.070	0.100	0.160
2.4. Trees			
2.4.1. Cleared land with tree stumps ,no sprouts	0.030	0.040	0.050
2.4.2. Same as above ,but heavy sprouts	0.050	0.060	0.080
2.4.3. Heavy stands of timber ,few down trees ,little under growth ,flow below branches	0.080	0.100	0.120
2.4.4. Same as above , but with flow into branches	0.100	0.120	0.160
2.4.5. Dense willows, ,straight ,straight	0.110	0.150	0.200
3. Mountain streams ,no vegetation in channel banks usually steep ,with trees and brush on banks submerged			
3.1. Bottom : gravels ,cobbles ,and few boulders	0.030	0.040	0.050
3.2. Bottom : cobbles with large boulders	0.040	0.050	0.070

Appendix B Confusion matrix of 2017 land use classification of Dechatu catchment.

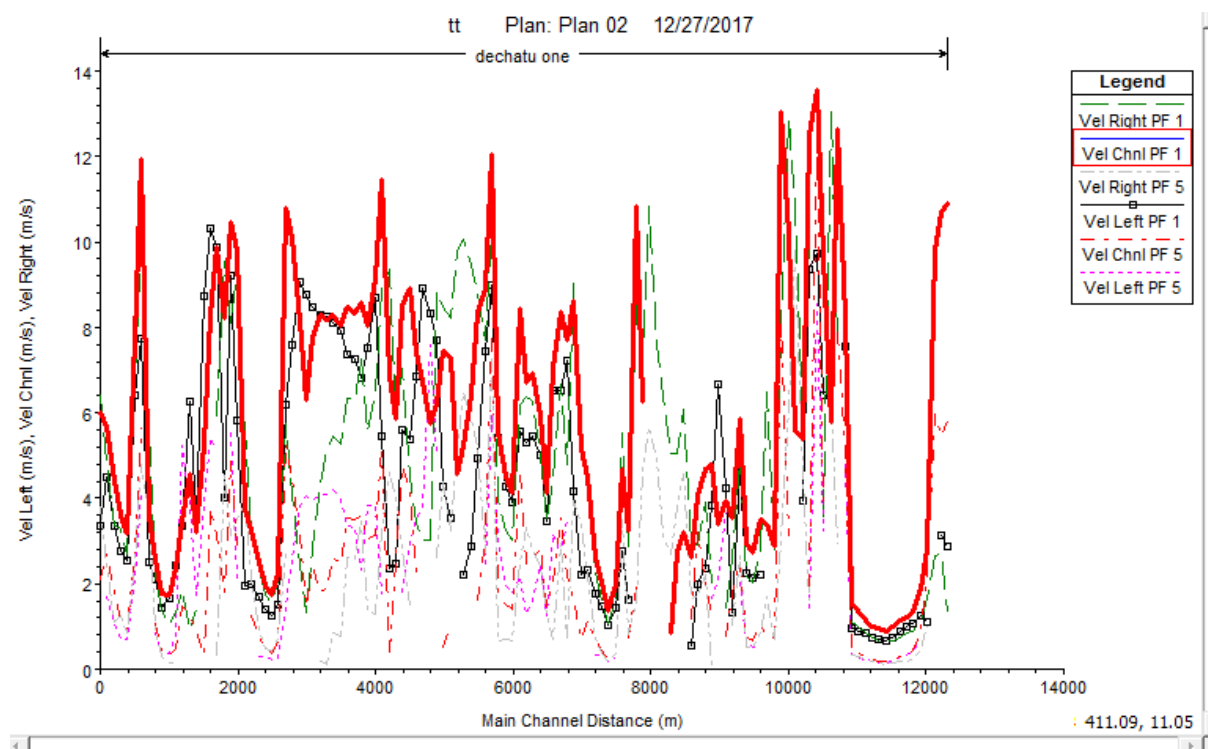
Classified					Reference Data	
Data	sand deposited	Bare land	shrub land	built up		
unclassified	0	0	0	0	-	
sand deposited	410	32	22	10	20	
Bare land	14	372	16	19	10	
shrub land	10	14	280	36	15	
built up	21	14	20	674	20	
Column Total	455	432	338	739	65	
				sum of diagonal	1736	
				sum of ground total	1962	
					0.88398	
				overall accuracy	88.40%	

Appendix C HEC RAS output.

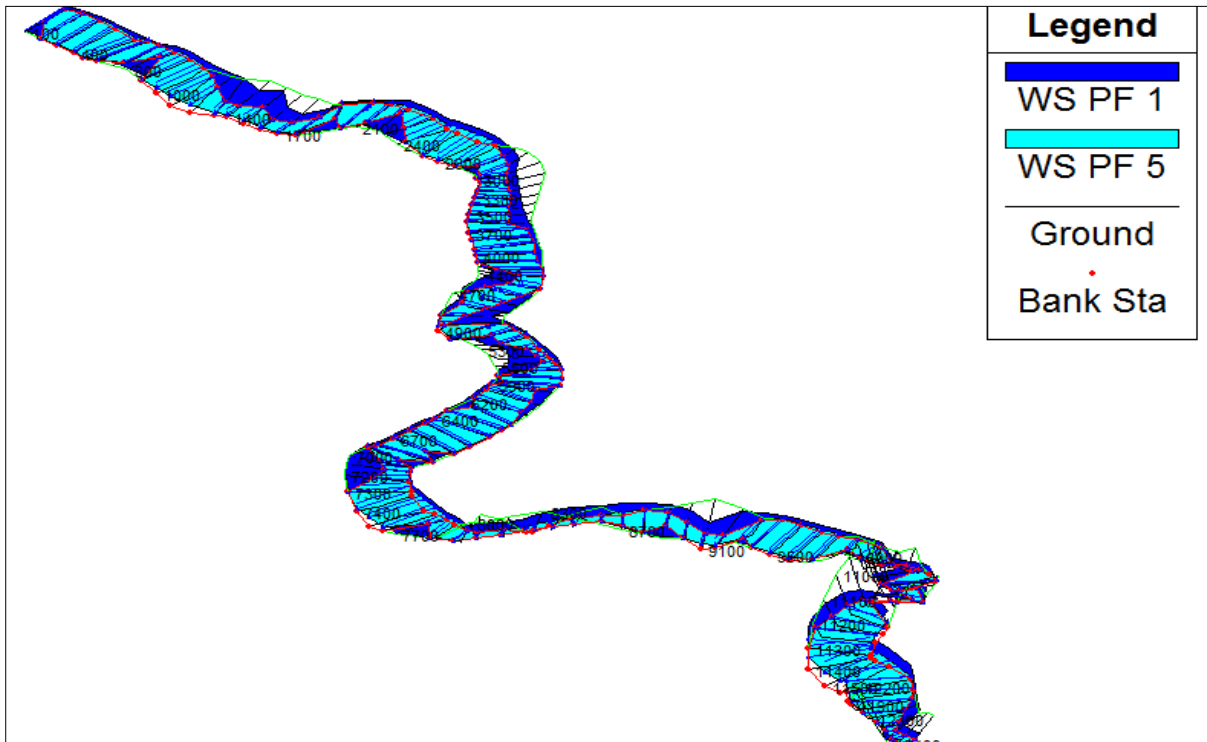
C 1.1 General profile plot for velocity map of study area for 5 year return period (red)



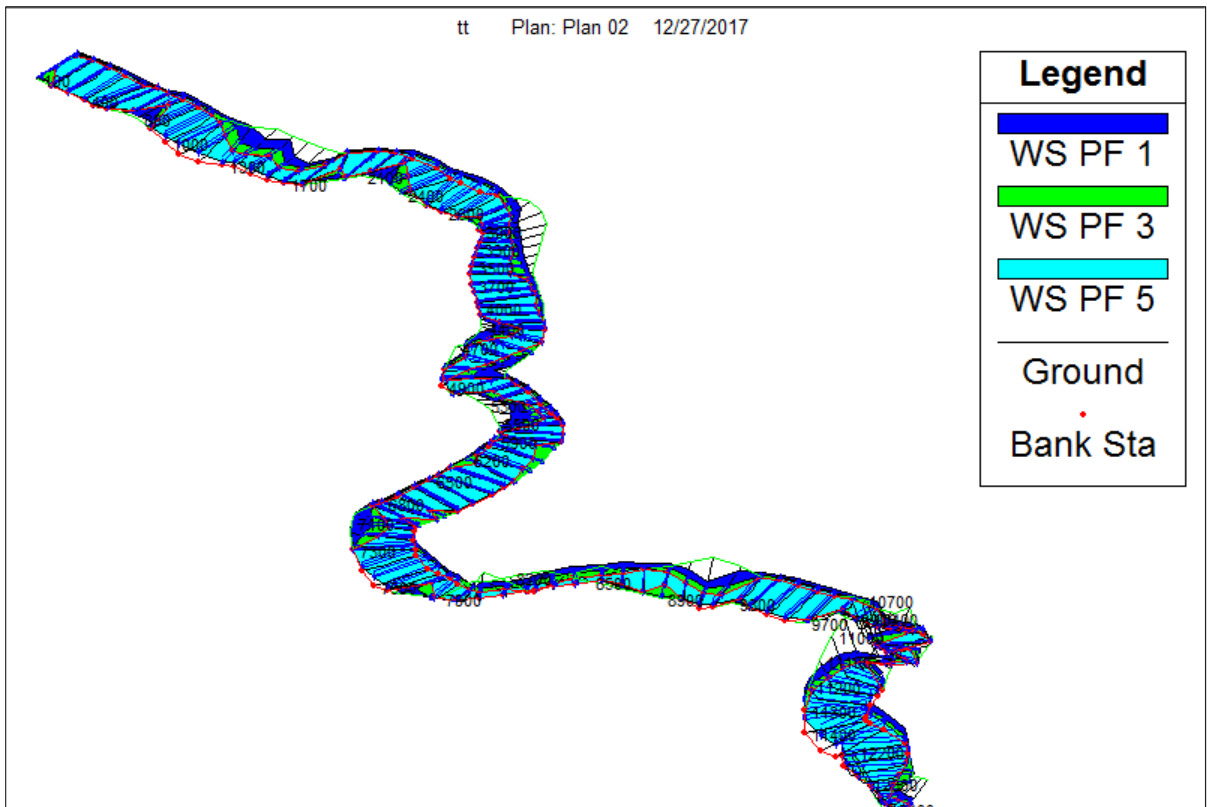
C1.2 General Profile plot for velocity map of study area 100 year return period (red)



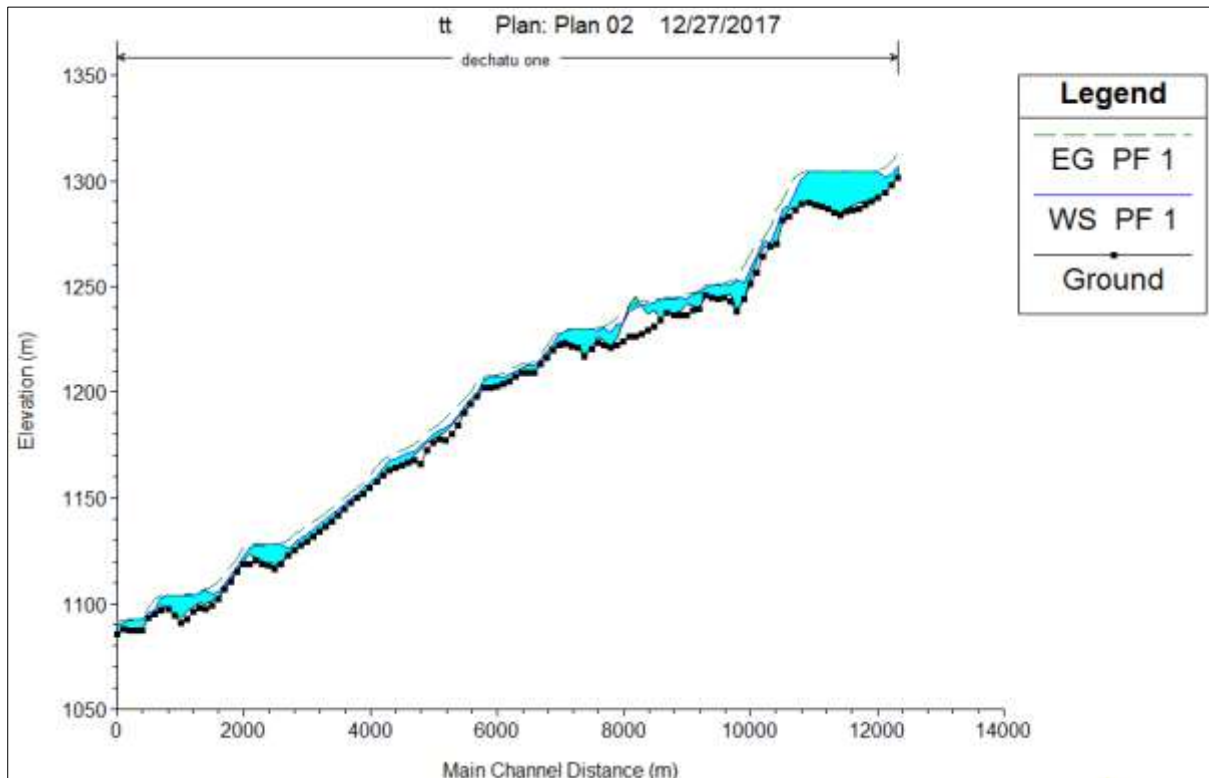
APPENDIX C 2:1 3D Perspective View Of Floodplain For 100 and 5 (WS PF1,WS PF5) year return period.



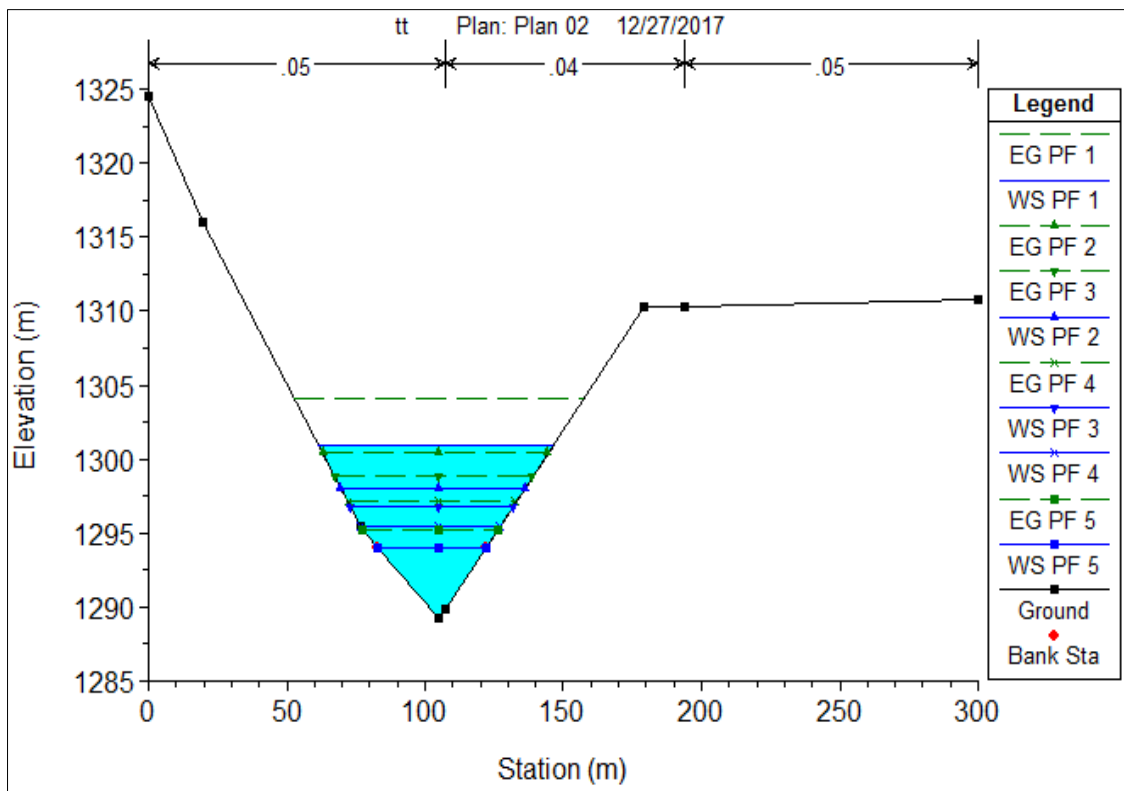
C2.2. 3D Perspective View of Floodplain For 100,25 And 5 (WS PF1,3,5) year return period.

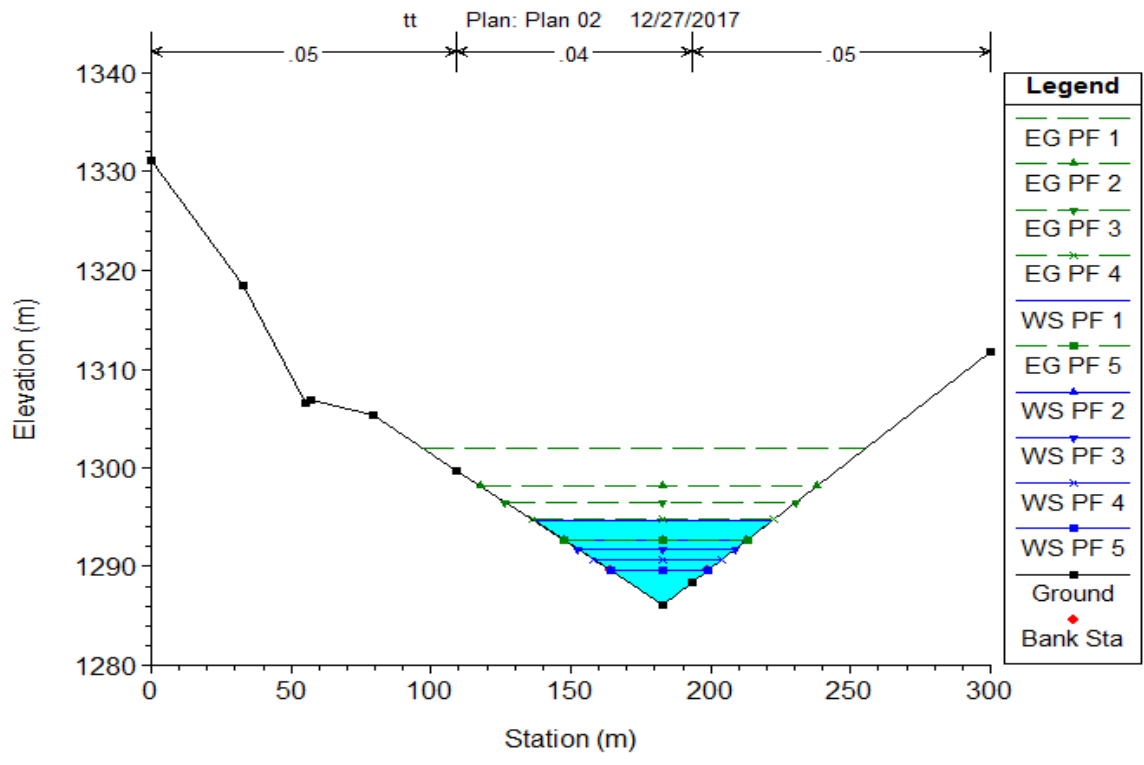


APPENDIX C3 Water surface profile for 100 year return period

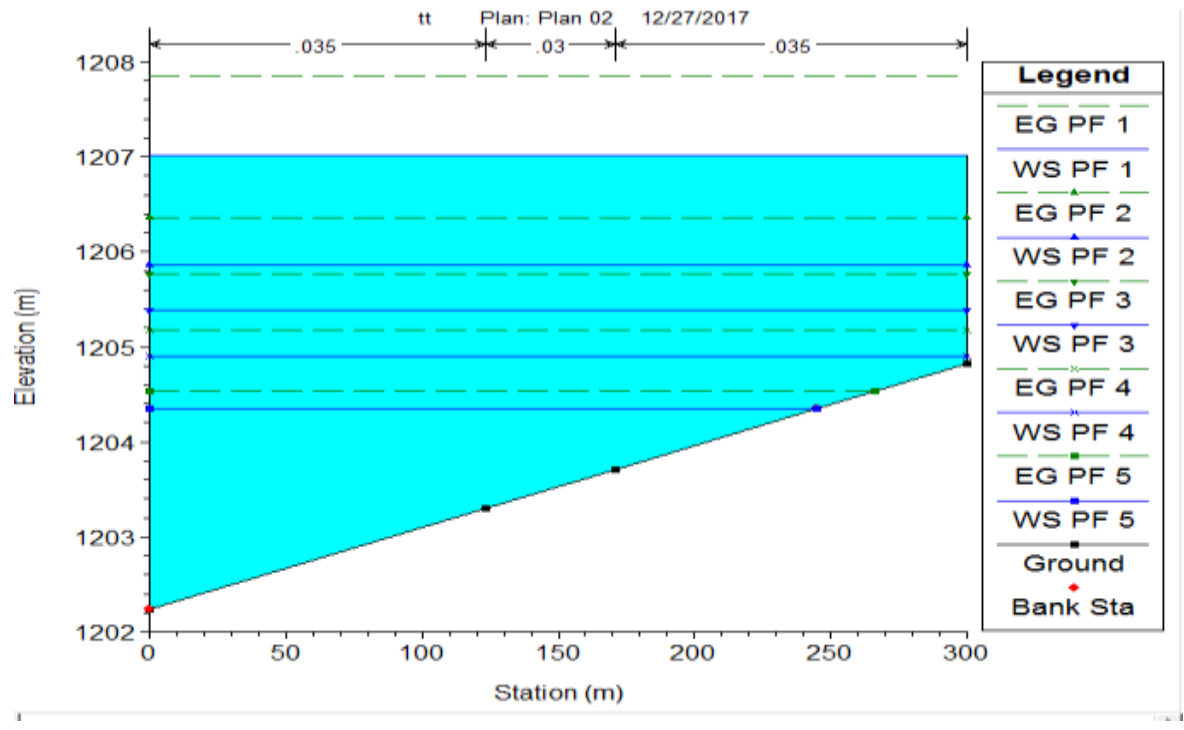


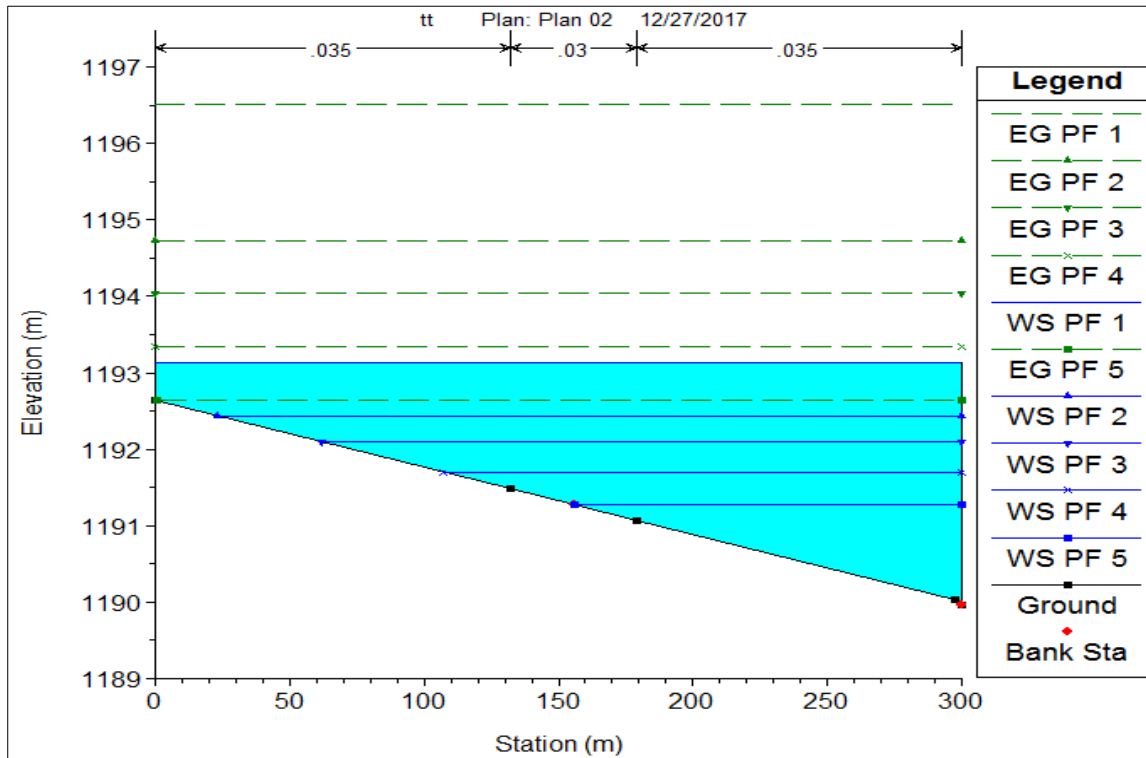
Appendix C4:1 Representative Upstream cross section of Dechatu River at 10900 & 10800 stations respectively for all return period respectively.



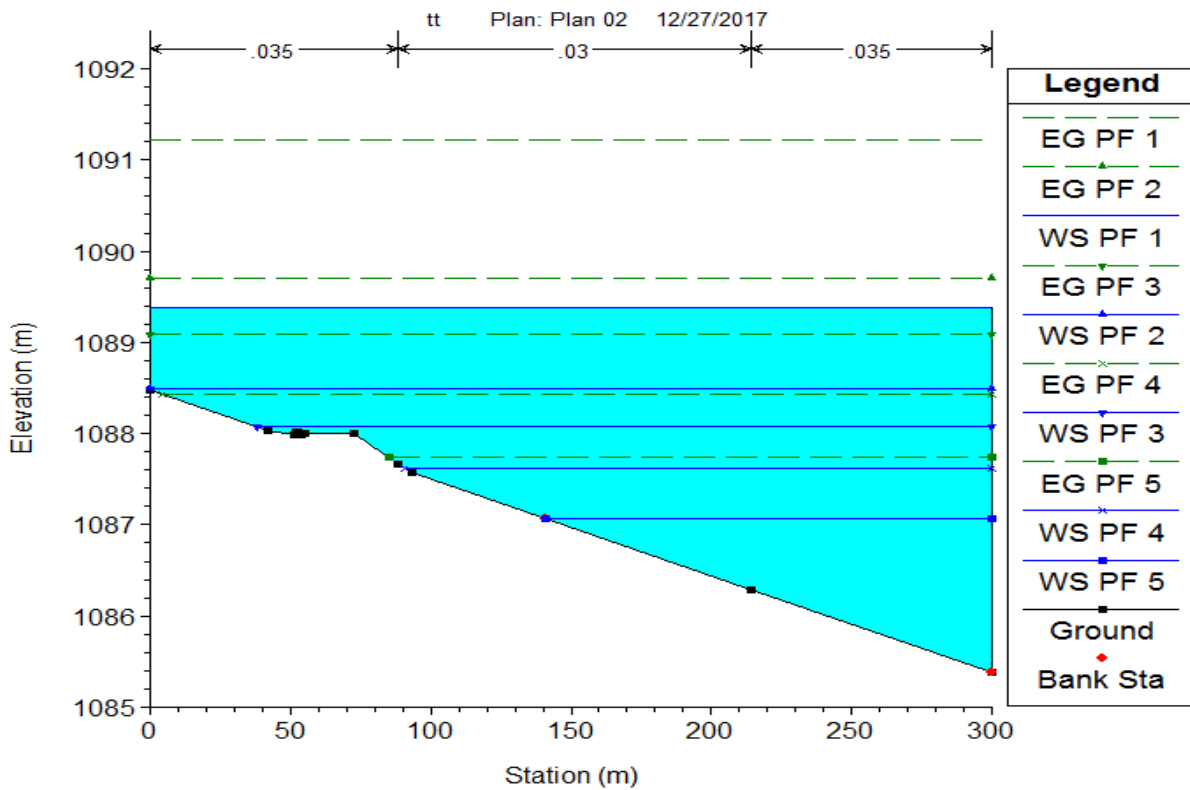


C 4.2 Representative Middle stream cross section Dechatu River at station 6200 and 6000 respectively for 5,10,25,50 and 100 year return period respectively.





C 4.3 Representative downstream cross section of Dechatu River for station 100 for 5, 10, 25, 50 and 100 year return period respectively.



APPENDIX.D.1 Flood Inundation Map for Dechatu Catchment By Yonas, 2015 Used for Validation the model for the current study.



Appendix D.2 flood inundation map for 100 year superimpose on Google earth.



Appendix E. Rainfall Data of dechatu station from the Year Of 1990-2015 (25yr)

year	annual rainfall (mm)	Year	annual rainfall (mm)
1990	49.81	2003	51.19
1991	50.73	2004	47.15
1992	54.02	2005	37.78
1993	59.46	2006	348.00
1994	59.33	2007	59.06
1995	49.17	2008	41.68
1996	79.64	2009	34.56
1997	74.30	2010	80.53
1998	73.77	2011	62.34
1999	51.31	2012	62.34
2000	218.30	2013	60.82
2001	56.93	2014	49.84
2002	44.39	2015	9.29