



**SCHOOL OF GRADUATE STUDIES
ADDIS ABABA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDRAULIC ENGINEERING STREAM**

**Assessment of River Bank Overtopping Problem
(In case of Sedie River, Abbay basin, Ethiopia)**

A Thesis submitted to the school of graduate studies, Addis Ababa institute of Technology in partial fulfillment of the degree of Masters of Science (MSc.) in Hydraulic Engineering.

By: Melaku Wendachew Gashu

Advisor: Dr. Daneal F/Sillassie

Addis Ababa, Ethiopia

June, 2020

Addis Ababa University
School of graduate studies
Addis Ababa institute of Technology

Assessment of River Bank Overtopping Problem

(In case of Sedie River, Abbay basin, Ethiopia)

A Thesis submitted to the school of graduate studies, Addis Ababa institute of Technology in partial fulfillment of the degree of Masters of Science in Hydraulic Engineering.

By

Melaku Wendachew Gashu

Approval by Board of Examiners

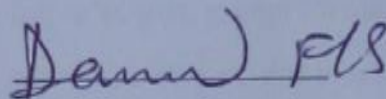
	Name	Signature	Date
1. Advisor	<u>Dr. Daneal F/Sillassie</u>	<u>Danne F/S</u>	<u>06/08/20</u>
2. Internal examiner	<u>Dr. Yilma Seleshi</u>	<u>Yilma S</u>	<u>06/08/20</u>
3. External examiner	<u>Dr. -Ing. Dereje Hailu</u>	<u>Dereje Hailu</u>	<u>04/08/20</u>
4. Chairman	<u>Mebruk Mohammed (Dr.-Ing.)</u>	<u>Mebruk Mohammed</u>	<u>07/08/20</u>

Mebruk Mohammed (Dr.-Ing.)
Dean, School of Civil & Environmental Engineering



CERTIFICATION

I, the undersigned, certify that I read and hereby recommend for the acceptance by Addis Ababa University a dissertation entitled: **Assessment of River Bank Overtopping Problem (In case of Sedie River, Abbay basin, Ethiopia)** in partial fulfillment of a degree of Masters of Science in Hydraulic Engineering stream.



Dr. Daneal F/Sillassie

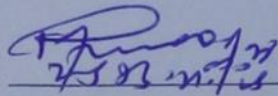
(Advisor)

Date: 06 / 08 / 20

Declaration and Copy right

I, the undersigned, declare that the thesis is my own work, and that it has not been presented and will not be presented to any other university for similar or any degree award.

Name: Melaku Wendachew Gashu

Signature: 

Email: melahabesha19@gmail.com

This dissertation is a copyright material protected under the Berne Convention, the Copy right Act, 1999 and other international and national enactments in the behalf, on the intellectual property. It may not be produced by any means in full or in part, except for short extracts in fair dealing, for research or private study, Critical scholarly review or disclosure with an acknowledgement, without written permission of the School of Graduate Studies, on the behalf of both the author and the Addis Ababa University.

DEDICATION

This MSc. thesis work is dedicated to my late father Ato Wendachew Gashu.

ACKNOWLEDGMENT

First of all it is better to thank the almighty God for giving me health and different opportunities for my life. My second appreciation belongs to my advisor Dr. Daneal F/Sillassie for your motivation, comment, advice and encouragement to finish my thesis work. It is better to give thank for all School of Civil and Environmental Engineering staffs specially for Hydraulic Engineering and Water Supply and Environmental Engineering stream instructors.

My gratefulness also belongs to organizations including Motta polytechnic college, for providing me leveling, graduated staff and GPS instruments for river cross section survey data collection and surveyor Muhabaw supported me by collecting survey data's from the river; MoWIE specially for GIS and hydrology department for providing me stream flow, land use/land cover and soil data; NMA for providing me a meteorological data and finally for Woldia university (MoSHE) for their financial support.

At last but not at least, I want to give thanks for my families, friends and my classmates; you are so kind and helped me a lot for the better achievement of these work. Thank you so much.

.

ABSTRACT

Flood forecasting is an important mechanism to prevent and manage the consequences of flood damage problem on agricultural areas. This study focuses on assessment of Sedie river flooding problem by preparing flood inundation map for different return periods. Different models including hydraulic model HEC Ras, hydrological model HEC HMS with integration of ArcGIS, HEC GEOHMS and Ras Mapper tools used for conducting this study. Primary data, surveyed river cross section and secondary data's such as rainfall, stream flow, DEM, Land use / land cover and Soil type data's collected and used for the study. Totally around 8 years of observed flow data 5 years (1996-2000) for calibration and 3 years (2001-2003) for validation used. After the analysis of the data it was found that HEC HMS calibration and validation result was good and the performance of the model checked with the coefficient of determination and Nash-Sutcliffe with good result of 0.84 and 0.83 for calibration, 0.74 and 0.73 for validation respectively. Due to the unavailability of observed water level and rating curves in the study area the HEC RAS model calibration and validation result compared qualitatively and relatively good result obtained. The calibrated manning roughness for the left and right bank obtained 0.035 and 0.025 for the main channel of the river. The flood inundation map prepared by using Ras Mapper tool and different flood inundation map results for different return periods obtained. The flood inundation map shows that for especially 50yr and 100yr return periods the flood damages 177.22 ha and 280.78 ha farming areas respectively. Therefore in order to mitigate this damages structural and non-structural measures recommended depending upon the severe of damage at each stations.

Key words: Arc GIS, Economic analysis, Flood mapping, HEC GEOHMS, HEC HMS, HEC RAS, Ras Mapper

TABLE OF CONTENTS

APPROVAL BY BOARD OF EXAMINERS.....	I
CERTIFICATION.....	II
ACKNOWLEDGMENT.....	V
ABSTRACT.....	VI
TABLE OF CONTENTS.....	VII
LIST OF FIGURES.....	XI
LIST OF TABLES.....	XIII
ABBREVIATIONS.....	XIV
1. INTRODUCTION	1
1.1 Background of the study	1
1.2 Statement of the problem.....	2
1.3 Objective of the study	3
1.3.1 General objective	3
1.3.2 Specific objective.....	3
1.4 Significant of the study	3
1.5 Scope of the study.....	4
1.6 Limitations of the study	4
1.7 Thesis outline.....	4
2. LITERATURE REVIEW	6
2.1 Background of flood analysis	6
2.1.1 Flooding problem.....	6
2.1.2 Flood mapping.....	6

2.2 Previous related research works	7
2.2.1 Research worked out of Ethiopia	7
2.2.2 Research worked in Ethiopia	8
2.3 Hydrologic Analysis	8
2.3.1 Rational Method.....	8
2.3.2 NRCS runoff curve number methods	8
2.3.3 Statistical analysis of stream gauge data.....	9
2.3.4 Regional regression equations	9
2.4 Hydraulic analysis	9
2.5 Review of selected models	9
2.5.1 HEC HMS model components.....	9
2.5.2 HEC RAS model components	10
3. MATERIALS AND METHODS.....	14
3.1 General description of the study area	14
3.1.1 Location	14
3.1.2 Land use/ land cover (Lu lc)	15
3.1.3 Soil type of the catchment.....	15
3.1.4 Rainfall.....	16
3.1.5 Topography	17
3.1.6 Climate	17
3.2 Materials used	17
3.3 Data collection methods	18
3.3.1 Primary data collection	18

3.3.2 Secondary data collection	20
3.4 General frame work for modelling flood inundation map for this thesis	23
4. DATA ANALYSIS.....	26
4.1 Meteorological data analysis	26
4.1.1 Filling of missing rainfall data	26
4.1.2 Checking Consistency.....	26
4. 2 Stream flow data analysis	27
4.3 Terrain preprocessing analysis	28
4.4 Model analysis	28
4.5 HEC HMS model analysis.....	29
4.5.1 Basin models	29
4.5.2 Meteorological model	35
4.5.3 Control specifications	36
4.5.4 Time series	37
4.5.5 Calibration and validation of the HEC HMS model.....	37
4.5.6 Flood frequency analysis	38
4.6 HEC RAS model analysis.....	39
4.6.1 Preprocessing of HEC Ras model analysis.....	40
4.6.2 Processing of HEC Ras model analysis	41
4.6.3 Calibration and validation of the HEC-RAS model	45
4.6.4 Post processing of HEC Ras model analysis	46
5. RESULT AND DISCUSSION	47
5.1 Calibration and validation of HEC HMS model result.....	47

5.2 Flood frequency results for different return periods.....	50
5.3 Calibration and validation of HEC RAS model result.....	52
5.4 FLOOD INUNDATION MAPPING.....	54
5.5 Appropriate mitigation measures for the study area.....	55
6. CONCLUSION AND RECOMMENDATIONS	57
6.1 Conclusion	57
6.2 Recommendations.....	58
REFERENCES	59
APPENDICES	62
Appendix A: Field data collection stations cross-sectional profile photo.....	62
Appendix B: Monthly rainfall data's.....	63
Appendix C: Daily stream flow data's at Sedie gaged station (m3/s).....	64
Appendix D: HEC HMS outputs.....	66
Appendix E: Flood inundation map result for different return periods.....	68

LIST OF FIGURE

Figure 2-1: HEC-RAS Main Window button bar.....	11
Figure 2-2: Standard step method profile.....	12
Figure 3-1: Geographical location of the Study area with its google earth image.....	14
Figure 3-2: Land use map of the study area.....	15
Figure 3-3: Land cover map of the study area	15
Figure 3-4: Soil type of the study Area.....	16
Figure 3-5: Spatial variability of the mean annual rainfall in Ethiopia.....	16
Figure 3-6: Materials photo used in the research during data collection.....	17
Figure 3-7: Main channel elevation with river station.....	18
Figure 3-8: Sample cross section profiles for Sedie River at different stations.....	18
Figure 3-9: Sample photos during field survey data collection.....	19
Figure 3-10: Interview with residents near the study area.....	19
Figure 3-11: Location of nearby meteorological station within and around the watershed.....	20
Figure 3-12: DEM of the study area.....	22
Figure 3-13: General frame work of the methodology for this study.....	24
Figure 3-14: Flow chart of conceptual framework for models calibration and validation.....	25
Figure 4-1: Double Mass Curve (DMC) for checking data trend for different stations.....	26
Figure 4-2: Average monthly rainfall in mm after filling (1996-2003).....	27
Figure 4-3: Daily stream flow data from (Jan1, 1996-Dec31, 2003).....	27
Figure 4-4: Areas where hydrological and hydraulically models used.....	28
Figure 4-5: The Study area sub-basins and reaches in HEC-HMS window.....	29
Figure 4-6 Soil type and Land use of the study area for CN determination.....	30

Figure 4-7: Regional classification based on rainfall distribution.....	36
Figure 4-8: Digital elevation model (DEM) of the study area in ArcGIS.....	39
Figure 4-9: The study area project, plan, geometry and unsteady flow profile on HEC RAS window...	39
Figure 4-10: Sedie River geometries prepared in RAS Mapper.....	40
Figure 4-11: River geometries with 500m x 500m gridded 2D flood area.....	41
Figure 4-12: Geometrical profile without Terrain of the study area at Ras mapper window.....	41
Figure 4-13: Geometrical profile with Terrain of the study area at Ras mapper window.....	42
Figure 4-14: sample cross section data profile at station 0.00 m in HEC Ras window.....	42
Figure 4-15: Unsteady flow analysis boundary condition in HEC-RAS.....	44
Figure 4-16: Unsteady flow analysis time window adjusted to run.....	45
Figure 5-1 simulated and observed flow graphical result at the outlet for calibration.....	48
Figure 5-2 simulated and observed flow graphical result at the outlet for validation.....	50
Figure 5-3: Flow values comparison of Frequency analysis and HEC HMS result for the study area.....	51
Figure 5-4: Calibration of HEC RAS model for 12JULY1996.....	53
Figure 5-5: Validation of HEC RAS model for 20JULY2001.....	53
Figure 5-6: Flood Inundated Map for 2 year and 100 year return periods.....	54
Figure 5-7: Flood inundated map with each stations location for 100 yr. return period.....	55

LIST OF TABLE

Table 3-1: Station name and coverage area.....	21
Table 3-2: Available, missed and used meteorological station rain fall data's for the thesis	21
Table 3-3: Annual maximum flow data of Sedie River at Sedie gage station.....	21
Table 3-4: Types, sources and purposes of data.....	22
Table 4-1: Sub-basins and area coverage.....	29
Table 4-2: Study area soil type, hydrologic soil group and area coverage	31
Table 4-3: Sedie Sub-basins and the corresponding Land use and area coverage.....	31
Table 4-4: Composite curve number	32
Table 4-5: Maximum retention(s) and initial abstraction (Ia).....	33
Table 4-6: Calculated loss determination parameters value	34
Table 4-7: General calculation for manning's roughness coefficient	43
Table 5-1: Initial and calibrated Curve Number for each sub-basins.....	47
Table 5-2 HEC HMS calibration performance result.....	48
Table 5-3 objective function result for calibration	48
Table 5-4 HEC HMS validation performance result.....	49
Table 5-5 Objective function result for validation	49
Table 5-6: Peak flood comparison of flow values of Frequency analysis and HEC HMS result....	51
Table 5-7: Initial and calibrated manning roughness coefficient.....	52
Table 5-8: Flood inundated areas for different return periods.....	55
Table 5-9: Appropriate structural and non-structural measures for the study area	56

ABBREVIATIONS

AAiT-Addis Ababa institute of Technology

C-Cover

CN-Curve number

CR- Crop residue

DEM- Digital elevation model

FIA-Flood inundated area

GIS- Geographic information system

HEC HMS- Hydrologic Engineering Center's hydrological modelling system

HSG-Hydrologic soil group

LU- Land use

Lc-Land cover

Masl-Mean above sea level

MoSHE-Ministry of science and higher education

MoWIE-Minister of Water, irrigation and energy

NMA-National meteorological agency

Ras-River Analysis System

Rp-Return period

RR-Rainfall Region

SCS-Soil Conservation Service

TIN-Triangular irregular network

USACE-United states army corps of engineers

1. INTRODUCTION

1.1 Background of the study

Water is vital to life in all parts of the world (Subramanya, 1984). Rivers play a main role in the human development as they are the main source of fresh water and transportation. On the other hand, occasionally this relationship is frequently disturbed because change in river discharge which leads to flood or drought. Floods has been considered as one of the most disturbing natural hazards/disasters causes vast immediate damage and long term loss on human activity, economic development of a society and also on the environment (Darshan Mehta et al., 2017). The interrelated of land and water always plays an important role in human activities; mostly at coasts, river banks or deltas settlements often located (Ahmad, 2017).

To support hydraulic modeling of floodplains, flood control channel design and environmental impact and assessment analysis; photogrammetric inspection and determination of the elevation of levees, spillways, dam's and floodwalls might be required (Hussein Roshun et al., 2012).

Flood problems make material losses and cause discomfort social activities. Flood might be resulting from natural factors and due to human activity itself. In every year, national media reported that flood problems result was intensely increased from previous flooding (R M S Prastica et al, 2018). Forecasting of river hydraulic appearances in contrast to probable flooding for minimizing damages is significant (A.R. Mardookhpour & H.Jamasbi, 2017).

In 2011 (P V Timbadiya et al., 2011) describes the discharge, river stage and other hydraulic properties are interconnected and depend upon the features of channel roughness. Channel roughness is extremely variable parameter which depends upon different factors such as surface vegetation, channel irregularities and channel alignment etc. In third world countries somewhere the farming sector plays a key role in their economic development, the managing of water resources is an item of maximum priority in their development actions (Subramanya, 1984).

Ethiopia is a country having great geographic diversity and its maximum land consists of a large highland at an elevation greater than 2,500 m.a.s.l in addition to high mountains and deep gorges, river gorges and lowland plains. In Ethiopia the rainy periods are concentrated in four months range between mid-Junes to mid-October while about 80 percent of the annual precipitation is expected as torrential downpours. The country Ethiopia is vulnerable to high flood damage problems that caused in destruction, damages to economic, livelihoods, infrastructure and health systems due to its topographic and climatic characteristics (Paolo Billi et al., 2013).

Through extended rain falling over huge areas the rivers are supported by a system of channels, streams and tributaries and flows build up to the point where the normal channel is overcome and water floods on-board nearby areas (Assefa, 2018). Human activities including unplanned fast settlement development, unrestrained construction of structures at large and major land use changes can impact the spatial and temporal array of vulnerabilities. There are some factors which contribute for overflowing problem prolonging from topography, engineering structures, climate, poor drainage and other local causes can be stated (ZELEKE, 2015).

The overflowing problem can be initiated by heavy rain, snow dissolve, rising of groundwater, land subsidence and also due to dam failures. Additionally the industrial rebellion and the climate alteration has been clearly manipulating several environmental and social sectors and also particularly has a significant influence on water resources (Getahun YS & Gebre SL, 2015).

The study area Sedie river watershed is located at north Gojjam sub basin of the big Abbay basin. In Sedie River the nearest maximum areas covered by pastor-agricultural and agricultural areas. Therefore the river flow condition should to be under taken and study before sever damage occurs. So that this study focused on assessing the river over topping problem in the study area by collecting necessary data's and analyzing the data's using Arc GIS, HEC HMS and hydraulic model HEC-RAS then after depending up on the result from the analyzed data, conclusion and recommendations drawn.

1.2 Statement of the problem

In different part of the world flood overtopping problem from the river bank affects human lives, damages crop production, destroying their home and change the environment. These problem directly affects the people's life living near to the river and indirectly affects geomorphology of the catchment. The damages caused by floods in terms of life, property and economic loss due to disruption of economic activity are all too well-known (Subramanya, 1984).

Flooding problem in different cities of developing countries is common due to poor planning and also poor project designing and execution. Causes that initiates the flooding damage problems are due to different reasons. Among them growth of population, outdated and non-functional poor drainage system due to heavily silted, poor waste management with poor erosion control measures, poor vegetative cover and unexpected heavier precipitation (Orale, 2015).

As (B.A.M.Talisay et al, 2018) states Flooding problem is one of the furthestmost happening natural risks in every year by exposing the lives and properties of the affected societies.

Urban and Residential developments in the flood plains and riverbanks, nevertheless of hydraulic and hydrological circumstances governing watershed and river and also it increases the danger of flooding damage problem and loss of a lots of investments in this nearly area (Hashemyan F et al, 2015). Flooding damage problem assessment is significant to manage the flood risk for the assessment of flood vulnerability, enlargement of flood risk map and flood management monetary evaluation (Noor Suraya Romalia et al, 2018).

The climate variation and also the land use changes raised the challenges connected with increased runoff and flood management. The flood risks which simply related with flooding damage problems have been increasing through development in flood plain and varying climate, which leads increasing in inundation of the flood plain (Balbhadra Thakur et al, 2017).

Depending up on the above listed points related to river flooding problem in Sedie river watershed at different time due to heavy rainfall of the upstream areas the flow capacity of rivers exceeded the river bank that origins the rising of water level and it causes flooding problem that damages agricultural areas, displaced residents and affects the transportation system. So that in almost every year the flood problem damages the crop production. Therefore the above mentioned problems should to be assessed unless severe damages occurs and the resident's life affected. So that this thesis focuses on assessment of river bank overtopping problem and preparation of flood inundation map in the study area.

1.3 Objective of the study

1.3.1 General objective

- The general objective of this research is to prepare flood inundation map and to recommend appropriate mitigation measures for Sedie River in Sedie flood plain.

1.3.2 Specific objective

- To calibrate and validate the models
- To produce the flood inundation map of the Sedie flood plain
- To recommend appropriate mitigation measures for the study area

1.4 Significant of the study

This research work will provide a significant advantage for future research workers as a reference and it will contribute in the reduction of the flood risk in the area.

The study contributes for

- Reduction of the flood damage to crops and other properties in the study area
- Future researchers in the study area, the study will contribute a significant role related to flood.
- Controlling flood in the farming areas by applying mitigation measures.
- Selecting mitigation measures depending on the flood inundation map result and the related cost estimated obtained from economic impact analysis.

1.5 Scope of the study

- Here in this study as the title describes it focuses only on assessment of flood damage problem in the study area including preparing flood inundation map and economic analysis. So that the study don't address these points including the channel stability assessment, water quality simulation and different sediment related studies.

1.6 Limitations of the study

- In the study area no research work held in the past related to flood so that obtaining secondary documented data's related to the flood damage was challenge.
- It was a challenge to obtain modern theodolite instead the leveling instrument and GPS used to collect the river cross section data.

1.7 Thesis outline

This thesis is structured as follows.

Chapter 1: Introduction part has presented general introduction about flood analysis in different part of the world including Ethiopia in general and in the study area in particular. It also covers the statement of problem, objectives of the research, significance, the scope, limitation and general outline of the research in summarized way.

Chapter 2: A literature review part covers and gives an overview of typically related works that are important for this study. Hydrologic analysis and hydraulic analysis for the determination of the flood peak, overview of software's and economic impacts of flood discussed.

Chapter 3: The methodology part describes the research methods used to accomplish this study, discusses about the general description of the study area, data's required for this study, materials used in the research, primary and secondary data collection methods and the general framework of the study described in detail.

Chapter 4: Data analysis part discusses about the hydrologic and hydraulic data analysis including filling of missing rainfall data's, the analysis of delineation of the study area, HEC HMS model

processing, the hydrological HEC HMS and hydraulic HEC RAS model calibration & validation analysis held on.

Chapter 5: Result and discussion part includes the models calibration and validation result outputs briefly discussed. Flood frequency forecasted for different return periods using different flood frequency analysis methods. The flood inundation map prepared using different flood values and economic impact analysis of the flood inundation area estimated and discussed.

Chapter 6: Conclusion and recommendation part summarizes the research work interest, the model out puts and finally appropriate mitigation measures for the study area recommended.

2. LITERATURE REVIEW

2.1 Background of flood analysis

2.1.1 Flooding problem

A flood is conditionally great stage in a river normally the level at which the river excesses its banks and inundates the adjacent areas (Subramanya, 1984). Flooding problem is a natural process that can occur at any time in extensive variety of locations. Flood from sea and rivers is possibly best known but extended, intense and localized rainfall can also cause sewer flooding, overland flow and also groundwater flooding. Flood has substantial impacts on human activities such as; it can intimidate people's lives, their property and the environment. Resources damage at flood risk may include housing, transport and public service infrastructure, commercial, industrial and agricultural enterprises (Sisay, 2015).

Concentrated rainfall occasions are the most common causative factor for flash flood creation. This type of flood is caused by heavy rainfall that occurred in a short period of time, mostly less than six hours (Constantin Buta et al, 2017). Furthermost floods are caused by storms in which a lot of rainfall drops in a short period of time. The method of evolving proper flood mapping method is to know the magnitude of the flooding of river so as to redirect the flows to the adjoining receiving waterway as capably as possible or building flood protection structures to keep areas vulnerable to flooding problem (ZELEKE, 2015).

2.1.2 Flood mapping

Flooding is a natural incidence. It is neither technically or financially possible to prevent all properties from flooding. As a result, floodplain hazard management strategies must be employed to enhance flood protection profits and minimize harm (Sisay, 2015). One of the main priorities for adversity risk reduction is to confirm decision makers, stakeholders and the public apprehend their exposure to disaster risk, accordingly they can take defensive action (Daniel Henstra et al, 2019). River bank protection mechanisms turned into water resources engineering and it became the perseverance of more sustainability works against river bank movement. River bank protection works are made by channelization or by building embankment laterally with the side of the river (Ahmad, 2017). Flood maps play gradually prominent role in government strategies for flood problem risk management. Flood maps are mechanisms not just for describing and communicating flood risks but also for regulating them and for justifying the unavoidable limits and failures of those controls (James Porter and David Demeritt, 2012). Flood maps are possibly valuable tools

for simplifying this understanding of flood risk, but preceding research has found that they vary substantially in accessibility and quality (Daniel Henstra et al, 2019).

2.2 Previous related research works

Different scholars wrote and published so many applicable journals and research papers (thesis's) about assessment of flood damage problem, river flood mapping, and economic analysis of flood damage in different part of the world.

2.2.1 Research worked out of Ethiopia

In 2017 (Darshan Mehta et al., 2017) worked out using a one dimensional Hydrodynamic model to assess geomorphic efficiency of floods on lower Tapi river basin. In his study, geometry of lower Tapi River, flood plain of Surat City and historical observed flood data have been used to develop a one dimensional integrated hydrodynamic model of the lower Tapi River, India. (P V Timbadiya et al., 2011) discusses on the constraint of multiple channel Manning roughness coefficient ' n ' values along the river has been presaged out through simulation of floods by using HEC-RAS, with support the photos of river reaches collected throughout the field visit of the lower Tapi River. In other hand (Hussein Roshun et al., 2012) discusses the application of computer skill for analysis of the rainfall-runoff process and for the hydraulics of natural rivers. In his work Hydraulic analysis was accomplished to forecast flow characteristic and water surface elevations in the Zaremrood River. Flood risk maps are also produced to identify the areas inside the city with high hazard of flooding problem (Muhammad Al-Zahrani et al, 2016).

The hydrologic HEC-HMS and hydraulic modeling HEC-RAS software supported by Arc GIS, were applied in flood modeling and flood inundation mapping (Mary Angeline Orlina Napay and Roger Luyun, 2018). In 2018 (N S Romali et al, 2018) assesses a river by using Hydrologic Modelling System (HEC-HMS) on behalf of hydrological modelling of Segamat River. The competence of the model was evaluated by comparing the past observed data with the simulation results of the particular flood events. The model calibration and validation effectiveness was verified using Nash-Sutcliffe model efficiency coefficient.

The application of Hec-RAS river analysis system as Hydrologic Engineering Center derived River Analysis System model to the formation of floodplain maps for Martil River. This exploration consequently, presents flood inundation mapping and classification of flood risk areas by using the Hec-GeoRas and Hec-Ras hydraulic modelling tools combined with the Arc GIS information system (Amina Azouagh et al, 2018).

2.2.2 Research worked in Ethiopia

In Ethiopia different studies related with flood studied. In 2018 (Assefa, 2018) presents a new universal paradigm for the assessment of flooding hazard and flooding problem risk in the riverine flood-prone areas. Special stress is given to the urban areas through mild terrain and complex topography by which two dimensional fully dynamic flood modeling is proposed. In 2015 (Sisay, 2015) discusses about flood, it has harmful consequence to human beings and properties even if it has positive effect. Since less consideration is paid for flood risk, it should be examined and quantified appropriately. This study has presented that the upper most part of the cultivated is further inundated than the middle and lower parts. The prospective effect of flood on dangerous hydrological occasions in Bantyeketu River in Addis Ababa assessed by using HEC HMS with combination of ARC-GIS modeling software (ZELEKE, 2015).

2.3 Hydrologic Analysis

According to (ERA, 2013) manual stream flow measurements for determining a flood frequency relationship at or near a site are usually unavailable. In some cases, it is a well-known practice to determine the peak runoff rates and hydrographs through using statistical and empirical methods. In common, results from using a number of methods should be compared. The discharge which reflects best in the local project conditions through the reasons documented should to be used.

2.3.1 Rational Method

The Rational Method provides estimates of peak runoff rates for small urban and rural watersheds of less than 50 hectares (0.5 square km) and in which natural or man-made storage is small. It is best suitable to the design of urban storm drainage systems, small side ditches and also median ditches with driveway pipes. This should be used with restraint if the time of concentration exceeds 30 minutes and here rainfall is a basic input for this technique of flow estimation.

2.3.2 NRCS Runoff Curve Number Methods

The Natural Resources Conservation Service (previously Soil Conservation Service) advanced the runoff curve number technique as a means of determining the amount of rainfall existing as runoff. This technique should to be used if and only if when the watershed has unique main channel or when there are two main channels which have approximately equivalent times of concentration; unless, a hydrograph technique should be used. Another different methods may also use when the channel or reservoir routing is required and/or where watershed storage is either greater than five percent or located on the flow path that used to calculate.

2.3.3 Statistical Analysis of Stream Gauge Data

Where stream gauge data are available, stream gauge data can be used to develop peak discharges. The Ministry of Water & Energy keeps annual stream gauge data. The method commonly used for estimating the peak discharges is usually Log Pearson Type III distribution. However, as the record length is increased, a Log-Normal distribution or General Extreme Value (GEV) distribution could also be used. The recent data analysis demonstrated that GEV can be used to estimate the peak flow in Ethiopia.

2.3.4 Regional Regression Equations

Regional regression calculations deliver estimates of peak discharge for the watersheds in a specific geographic regions. From these possible hydrologic approaches based on the available data, it would be noted that at the current time, only the rational and SCS approaches are applicable to the whole country. Regression equations and derivations from stream gauging stations (Gumbel, Log Pearson and General Extreme) are frequently chosen but rely on data not available.

2.4 Hydraulic analysis

The hydraulic analysis of a channel defines the depth and velocity by which a particular discharge will flow in a channel of well-known geometry, roughness and also slope (ERA, 2013). The depth and velocity of the flows are basic for the design and analysis of channel linings and highway drainage structures. A computer program importantly implements the hydraulic analysis of open channel problems. The recommended personal computer program is the US Army Corps of Engineers HEC-RAS River Analysis System. The Program was particularly developed on behalf of analysis of Highway Bridge and culvert backwater analysis. HEC-RAS River Analysis System is designed to perform one dimensional hydraulic calculations for a full network of natural and constructed channels and it has a capable of importing and also exporting GIS/CAD data.

2.5 Review of selected models

2.5.1 HEC HMS model components

The Model components are used for simulation of the hydrologic response in a watershed. The principal model components are basin model, meteorological model and control specifications. The model component has also input data components. A simulation computes the precipitation-runoff response in the basin model that take input from the meteorological model. The control specifications describes the time period and time step of the simulation and input data components data frequently required as parameter or boundary conditions in basin and meteorological models.

- **Basin model**

The basin model symbolizes the physical watershed and the user develops a basin model by adding and joining hydrologic elements. Hydrologic elements use mathematical models to define the physical procedures in the watershed. This basic representation of these runoff process does not consider for the storage and movement of water vertically within the soil layer. It is still adequate to model a flood hydrograph as the result of a storm. For this modeling determinations, the simplified hydrologic cycle is further divided into four main constituents as loss method, transform method, base flow method and routing method; which all are modeled separately.

- **Meteorological model**

The meteorological model computes the precipitation input essential by a sub basin element. The meteorological model can use both point and gridded precipitation and has the ability to model frozen and liquid precipitation beside with evapotranspiration and also the meteorological model comprises multiple snowmelt and evapotranspiration methods.

- **Control specifications**

The control specifications mainly established the time span of a simulation run. Information's in the control specifications includes a starting date with time, ending date with time, and also the computation time step.

- **Input data components**

The input data components includes time series data, paired data and gridded data. All this data's are often mandatory as parameter or boundary conditions in basin and meteorological models.

2.5.2 HEC RAS model components

HEC-RAS river analysis has been developed for the U.S. Army Corps of Engineers. HEC-RAS is a computer program which models the hydraulics of water flow through natural rivers and other channels. Preceding to the recent update the program was 1D, mean that there is no straight modeling of the hydraulic consequence of cross section shape changes and other 2 and 3D aspects of flow.

- **Governing equation**

Based on the conception of conservation of energy, the standard step method uses fundamental hydraulic equations to iteratively compute water-surface profiles and energy grade lines. Conservation of energy states that “within some problem domain, the amount of energy remains constant and energy is neither created nor destroyed.” Iteratively, the standard step method relates

conservation of energy by using the energy equation to compute water-surface elevations and energy grade lines beside the reach. For the determination of the standard step, the energy equation is written as:

$$y_2 + z_2 + \frac{\alpha_2 v_2^2}{2g} = y_1 + z_1 + \frac{\alpha_1 v_1^2}{2g} + h_t \dots \dots \dots \text{Equation 2.1}$$

Where α_1 = kinetic energy coefficient in downstream cross section;

α_2 = kinetic energy coefficient in upstream cross section; g = acceleration of gravity (ft/s²);

h_t = total energy loss between adjacent cross sections (ft);

v_1 = average velocity in downstream cross section (ft/s); v_2 = average velocity in upstream cross section (ft/s); y_1 = flow depth in downstream cross section (ft); y_2 = flow depth in upstream cross section (ft); z_1 = bed elevation in downstream cross section (ft); and z_2 = bed elevation in upstream cross section (ft);

Total energy loss is equal to Equation 2.2 between adjacent cross sections:

$$h_c = h_f + h_e + h_c \dots \dots \dots \text{Equation 2.2}$$

Where: h_c = minor loss due to channel contraction (ft); h_e = minor loss due to channel expansion (ft); h_f = energy loss due to friction (ft); h_t = total energy loss between adjacent cross sections (ft).

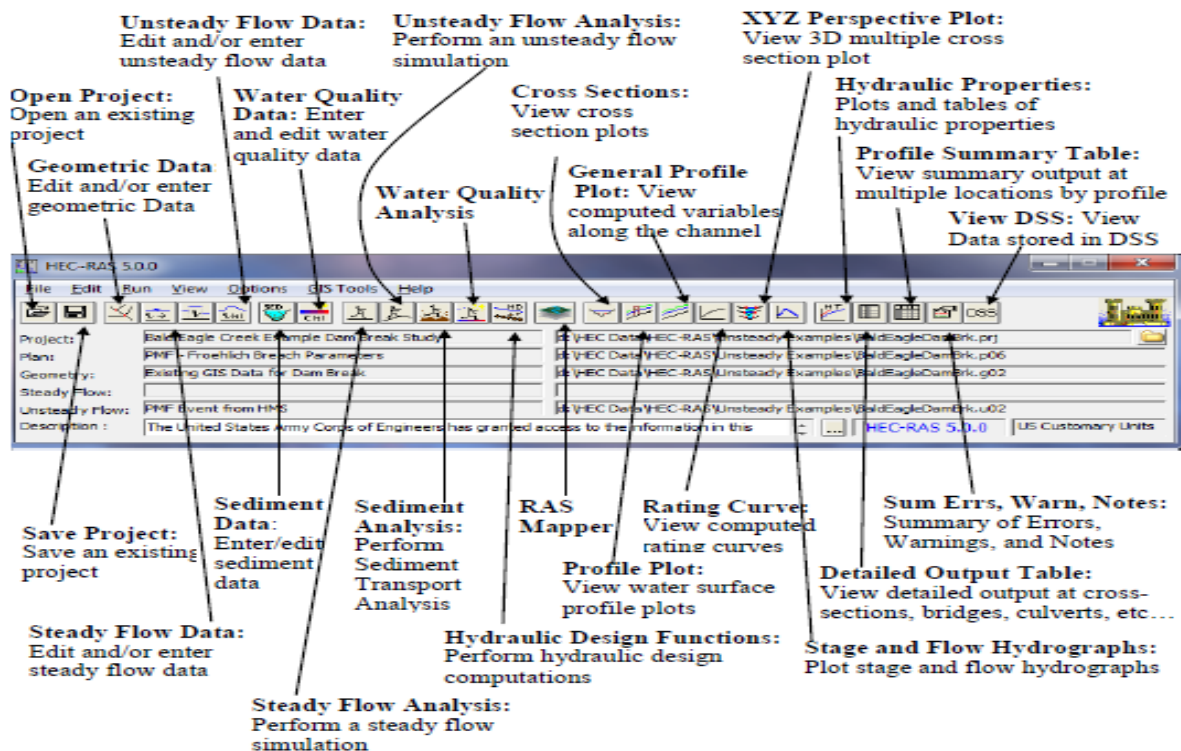


Figure 2-1: HEC-RAS Main Window button bar (source: USACE manual)

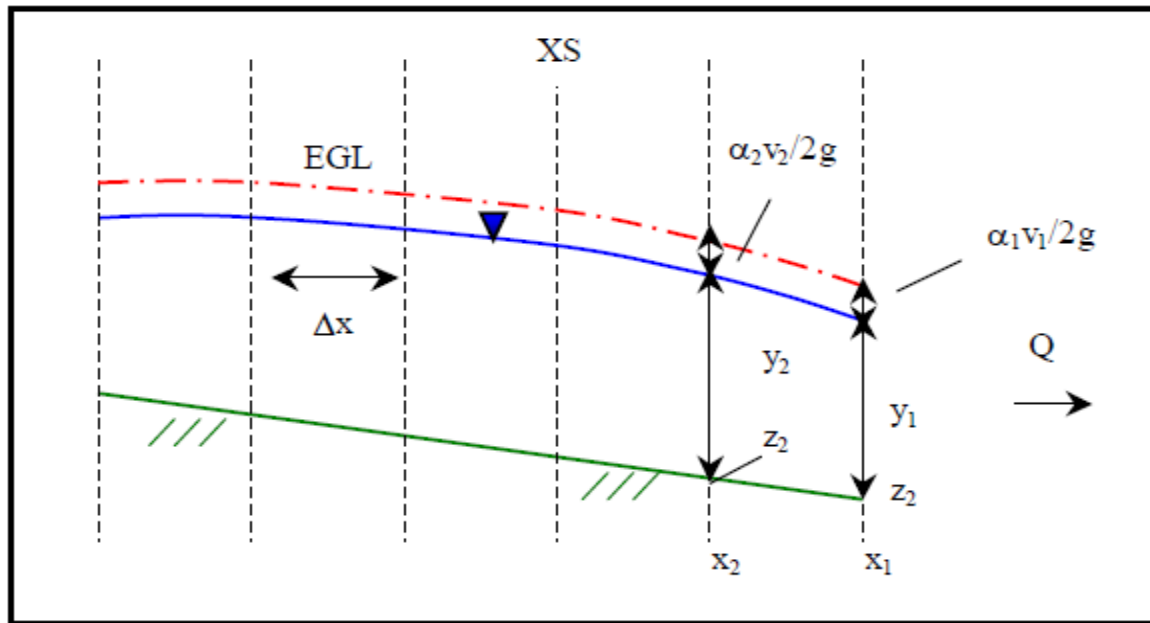


Figure 2-2: Standard step method profile

- **Boundary condition**

When a two dimensional flow area is selected for simulation of HEC RAS model, there are four different types of boundary conditions existed and this are Stage Hydrograph; Flow Hydrograph; Rating Curve and Normal Depth.

Flow Hydrograph

The required data for this type of boundary condition is that flow hydrograph (discharge vs time) and energy Slope (for computing Normal Depth).

The Energy Slope is used to compute Normal Depth from the actual flow rate and the cross section data (underlying terrain data) beside the Boundary Condition Line for each computational time step. A flow distribution in the cross section is then after calculated (depend on the normal depth water surface and the conveyance in the cross section) and this flow distribution is used to properly distribute the flow to the cells beside the boundary condition line that are wet. By any given time step, simply a portion of the boundary condition line may be wet and thus only the cells in which the water surface elevation is higher than the outer boundary face of their terrain will receive water. On the other hand, if the computed Normal Depth water surface is higher than all the boundary face elevation data beside the Boundary Condition Line, then all the cells will receive water based on a conveyance increment approach.

Stage Hydrograph

A Stage Hydrograph can be used to carry flow into and/or to take flow out of a two dimensional flow area. If the water surface elevation in the Stage hydrograph is greater than the cell water surface elevation (or dry elevation), flow will drive into the two dimensional Cells and if the water surface elevation of the Stage Hydrograph is lower than the water surface in the two dimensional flow area, flow will drive out of the two dimensional area. If a cell is arid and the stage boundary condition is lower than the two dimensional flow area cell smallest elevation, then no flow will spread since the flow is calculated on a per cell basis. For example, if the Stage Hydrograph water surface is higher than the water surface of some of the two dimensional boundary cells and lower than that of another two dimensional boundary cells, water will instantaneously enter and exit the Stage Hydrograph boundary.

Normal Depth

The Normal Depth boundary condition can only be used to take flow out of a two dimensional flow area. To use the Normal Depth boundary condition, it is must that the user is required to enter a friction slope for that specified area, just like they would do for a 1D cross section location. The friction slope must be based on the land slope in the vicinity of the two dimensional flow area boundary condition line. The Friction Slope is used in Manning's equation to compute a Normal Depth for respectively given flow, based on the cross section underneath the two dimensional Boundary Condition line. Similar with the Stage Hydrograph boundary condition, the Normal Depth boundary condition is computed on a per cell basis.

Rating Curve

The Rating Curve alternative can only be used to yield flow out of a two dimensional flow area. The user is required to enter a Stage or Water Surface Elevation versus flow correlation for this selection and the rating curve is also practical on a per cell basis.

Manning roughness

Manning's roughness 'n' is affected by numerous factors and its selection in natural channels depends greatly on engineering understanding. Photographs of channels and flood plains for which the flow has been determined and Manning's 'n' has been calculation is very useful. As soon as the Manning's 'n' values have been nominated, it is highly suggested that it should be verified with past high water marks and/or gauged stream flow data. Manning's roughness 'n' values on behalf of artificial channels are more easily defined than for natural stream channels (ERA, 2013).

3. MATERIALS AND METHODS

3.1 General description of the study area

3.1.1 Location

The study area Sedie River watershed is located in East Gojjam zone, Amhara region, Ethiopia at a distance of 360 km far from the capital city Addis Ababa and 120 km from the regional capital Bahir dar city. Geographically it located at a latitude of $11^{\circ} 2'N$ and longitude $37^{\circ}54'E$ with an elevation of 2403.0 meters above sea level. It is one tributaries of Abbay River basin and the river starts its flow at Choke, Gojjam area and joins the main Abbay at north part of Motta town.

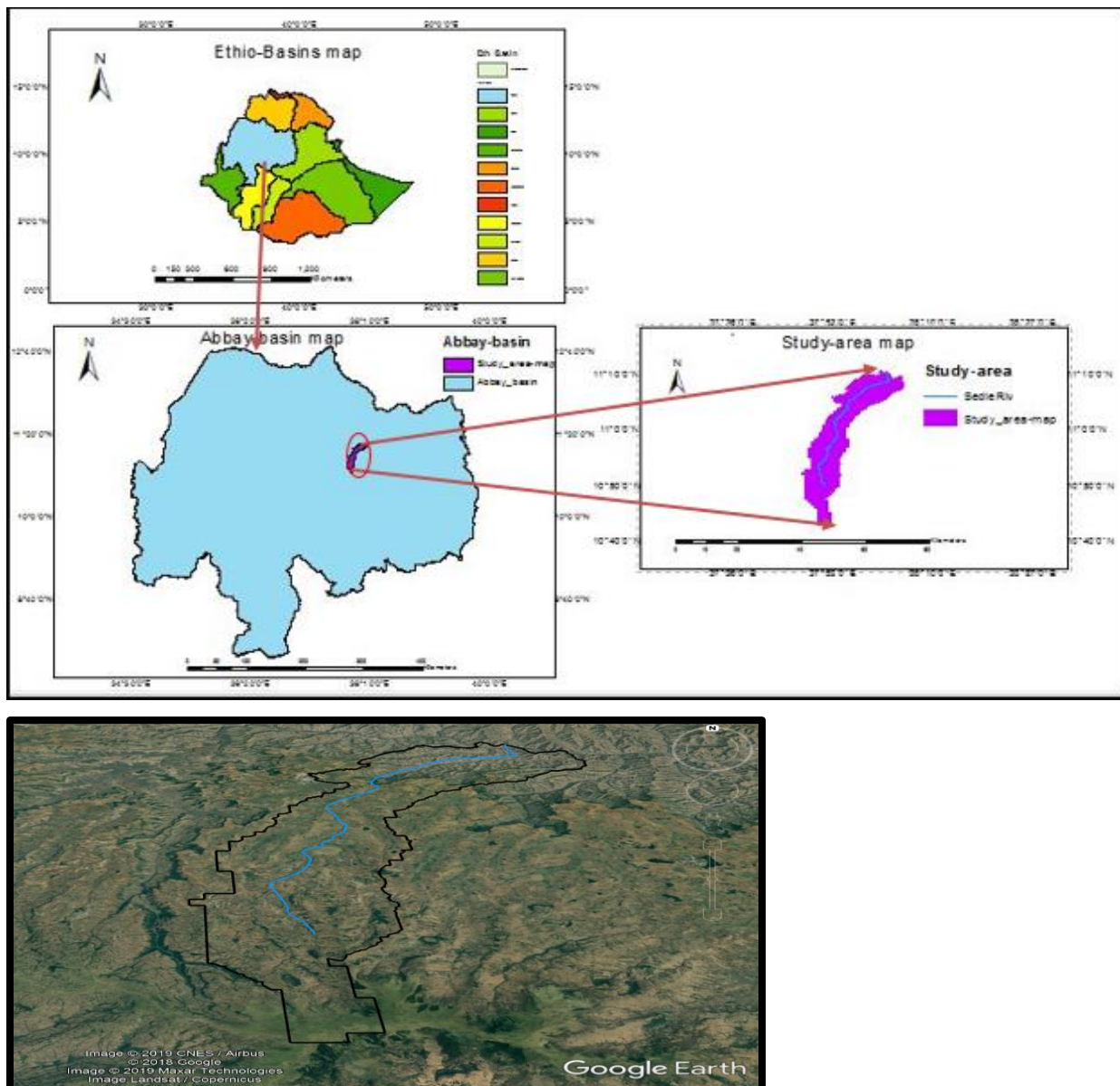


Figure 3-1: Geographical location of the Study area with its google earth image

3.1.2 Land use/ land cover (Lu lc)

According to the land use/or land cover data obtained from Ministry of Water, Irrigation and Energy. The land use of the study area is mainly agricultural land, Agro-pastoral and Pastoral but as shown in (fig 3-2) the land use map of the study is major part of the area is covered by agro-pastoral land use. The land cover data's as (fig3-3) below shows that afro alpine (mountain), dominantly cultivated, moderately cultivated and urban. But greater than 85% of the land use land cover is covered by moderately cultivated.

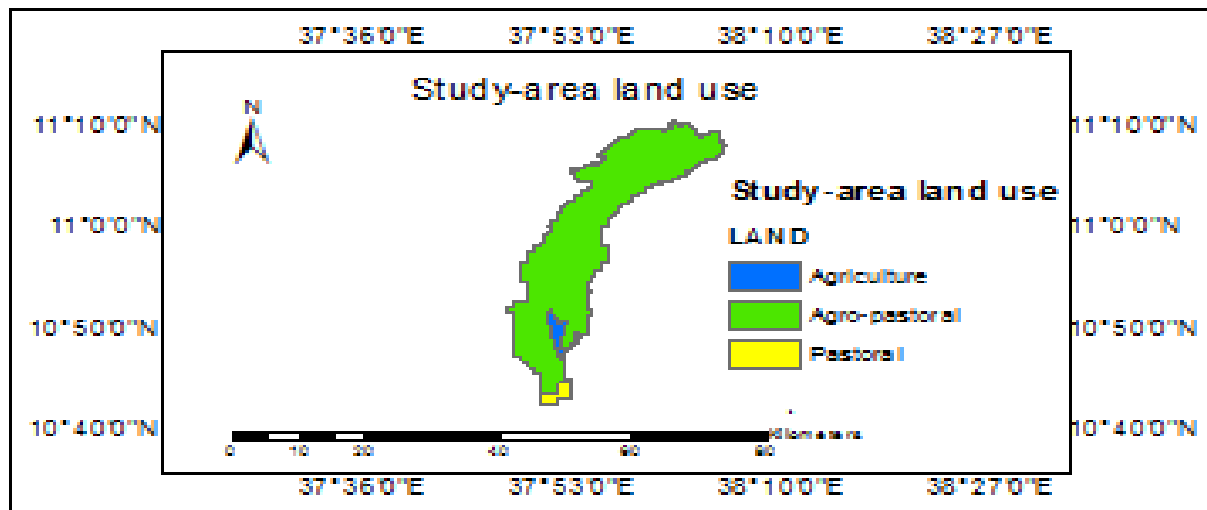


Figure 3-2: Land use map of the study area

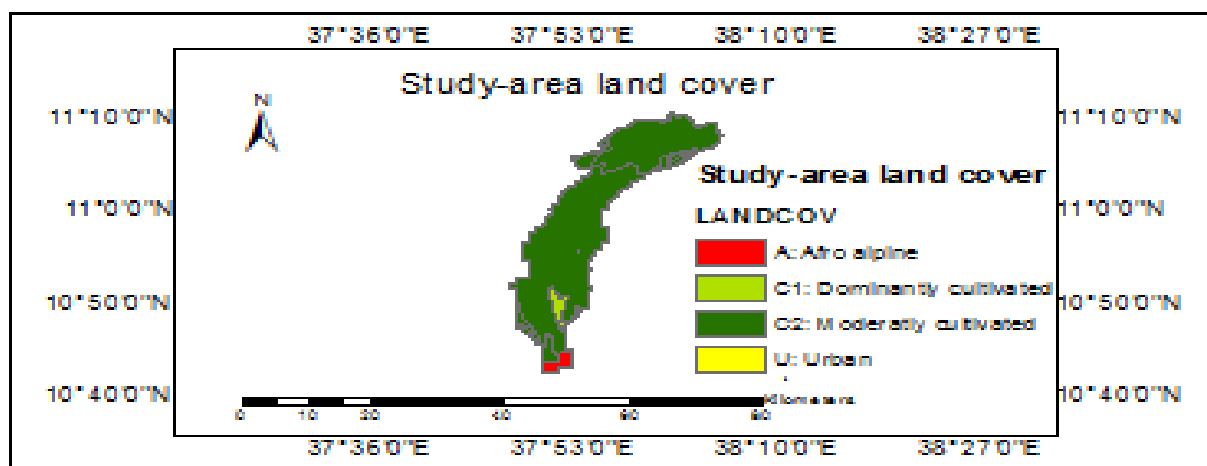


Figure 3-3: Land cover map of the study area

3.1.3 Soil type of the catchment

The study area major soil types are classified as Eutric leptosols, Eutric vertisols, Haplic Alisoils and Haplic luvisols. As it is shown in the soil map fig 3-4 below the study area is covered by different soil types among them Eutric vertisols and Haplic Alisoils are the dominant one which covers the maximum area in the study area.

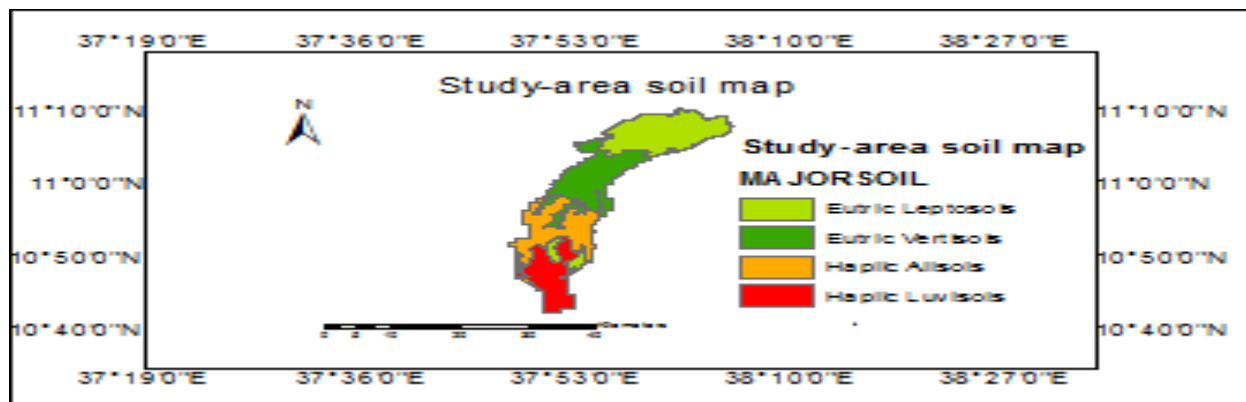


Figure 3-4: Soil type of the study area

3.1.4 Rainfall

In Ethiopia, rainfall is the consequence of multi-weather systems which includes Red Sea convergence zone, Subtropical Jet, Intertropical convergence zone, Tropical easterly jet and also Somali Jet (NMA 1996) (B. Berhanu et al., 2014). The local and global variation of the weather systems and also the topographic variation alongside with the seasonal cycles are responsible for the spatial variation of rainfall in the country. The magnitude of average yearly rainfall in the east, southeast and also in the northeast boundaries of the country is much less than 200 mm. Considering into the rainfall changeability of the country by river basins, the eastern flowing river basins (Genale-Dawa and Wabishebele) receive low to medium rainfall however those that flows to the west (Abbay, Omo Gibe, Baro Akobo and Tekeze) receives average annual rainfall of medium to high (Fig. below 3-5) (B. Berhanu et al., 2014). So that depending up on the above justification it can be conclude in the study area which locates in Abbay basin the mean annual rainfall shall be in the range of 1200mm to 2275.7mm.

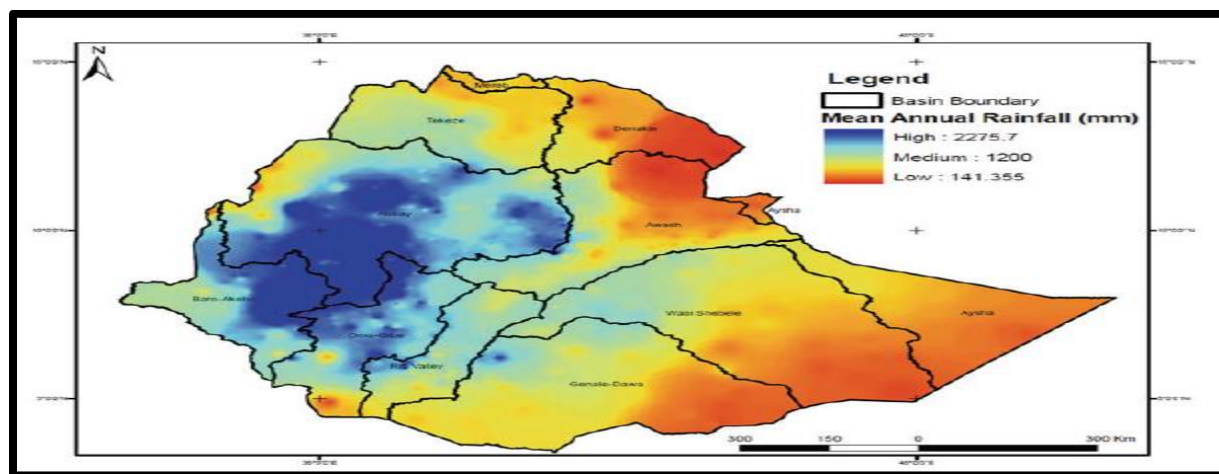


Figure 3-5: Spatial variability of the mean annual rainfall in Ethiopia (Source (B. Berhanu et al., 2014))

3.1.5 Topography

The study area has no marked a great variation of slope but flat slope, rolling slope and steep slope slightly existed. The elevation of the study area ranges from 1275 m - 4087 m. Among this Flat slope is the dominant slope which covers the maximum percentage of the area.

3.1.6 Climate

The climate in the study area is relatively warm and dry with a low precipitation condition and at a time of high precipitation it becomes cold too. Averagely it is recorded 2.9 0c minimum temperature and 29.2 0c maximum temperature from the data obtained from national meteorology station. It can be determine the mean annual temperature ranges from 13 0c to 27 0c. The study area relative humidity weather condition is considered as semi-arid and cool environment.

3.2 Materials used

Tape: Tape used to measure the distance between station to station and width difference at each station for cross section data collection

Digital camera: Digital camera used to capture the data collection system in field.

Leveling instrument: levelling instrument used to read the elevation of each station data.

Graduated staff: graduated staff used to show the exact station elevation in dimension that the specific point location.

GPS: GPS used to determine the cross sections of the study area datum, latitude and longitude for each station point.



Figure 3-6: Materials photo used in the research during data collection

3.3 Data collection methods

To achieve the specified objective of this study; quantitative as well as qualitative data types used. The research data collected from the two main source of data. From primary sources considering of field observations, field survey, measurements and interview: Whereas the secondary data obtained from journals, books, previous related work and organizations used in order to reinforce the primary data sources.

3.3.1 Primary data collection

- **Field measurement**

The total distance taken for this specific study was 4.5 km by taking in account the downstream direction of the river flow as starting point and from left to right side of the river cross section at different stations with a distance of 0.5 km the Survey data (stage-elevation or cross section data) were collected. The river cross section data at different stations surveyed and the sample cross section profiles of the river stations are shown in fig 3-8 below and fig 3.7 below shows that the main channel distance with its specific elevation. Here before the survey data collection field reconnaissance study was done and sample photos (in fig 3-9) showed the procedures that were captured during data collection time with the surveyor and site assistances.

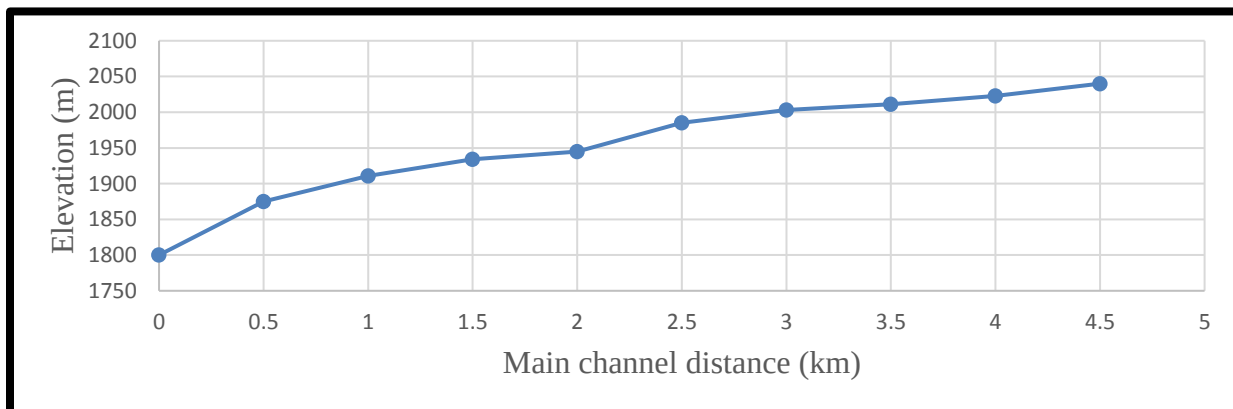


Figure 3-7: Main channel elevation with river station



Figure 3-8: Sample cross section profiles for Sedie River at different stations



Figure 3-9: Sample photos during field survey data collection

- **Interview**

It was advantageous to held interview with the floodplain dwellers in the study area for obtaining exact information about the flood problem challenges. So that interview was held for obtaining detail information about flood damage impact on the study area.



Figure 3-10: Interview with residents near the study area

3.3.2 Secondary data collection

In addition to the above mentioned primary data's Secondary data's required for this thesis in order to strengthen the data.

- **Rainfall data**

The rain fall data collected from Ethiopian National meteorological agency for different near and surrounding stations for the study area. The stations which is nearest to the study area were analyzed and clipped by using ARC-Gis thiessen polygon method. So that the nearest and surrounding stations were Felege Birhan, Feres Bet, Motta and Rob Gebya (in fig 3 -11 below). Among these four stations Motta contributes the maximum area almost 75% around 191.64 km^2 area and the remaining stations Feres Bet, Felege birhan and Rob gebya covers 30.99 km^2 , 74.51 km^2 and 10.08 km^2 respectively as shown in table 3-1 below.

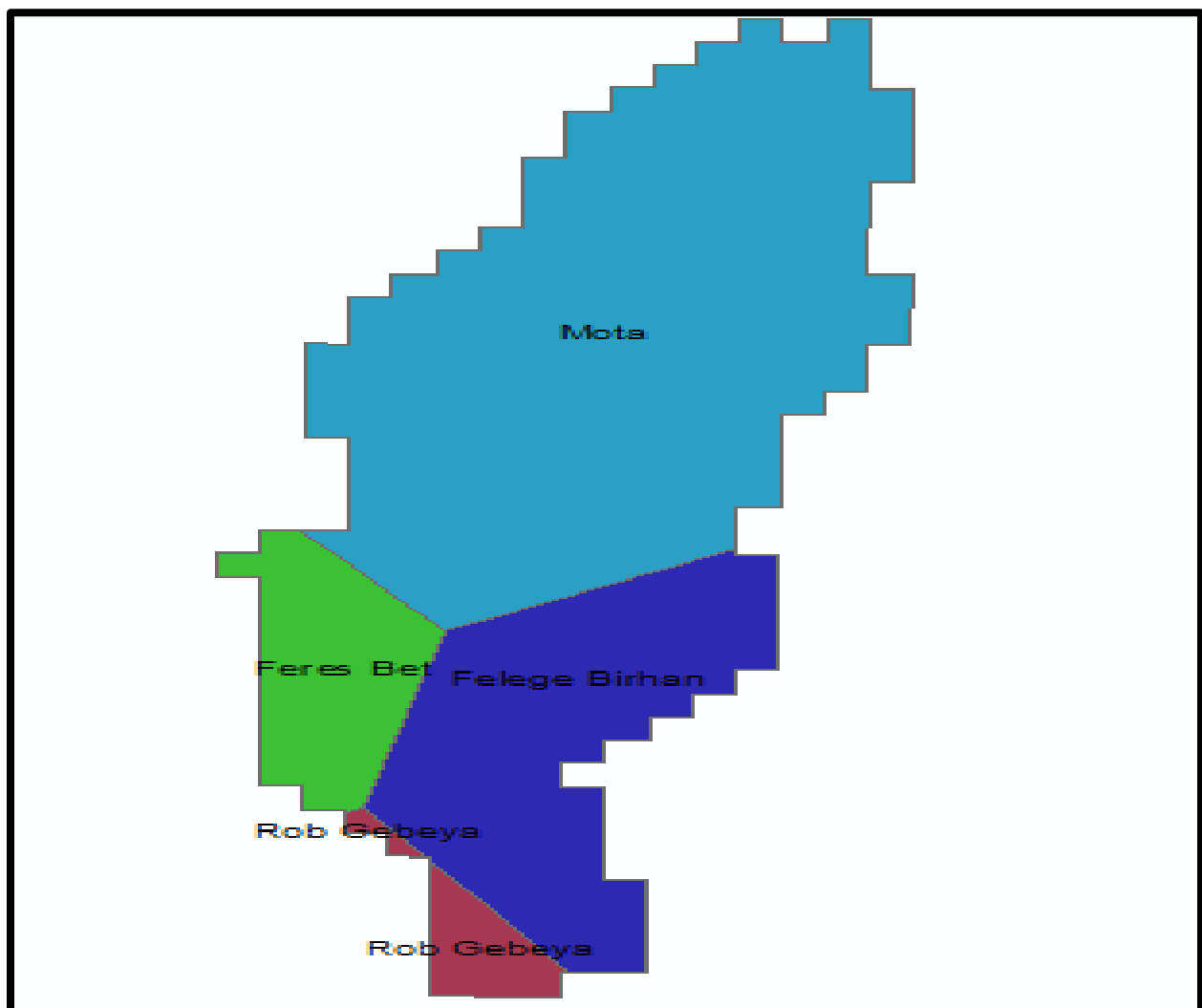


Figure 3-11: Location of nearby meteorological station within and around the watershed

Table 3-1: Station name and coverage area

Station name	Longitude	Latitude	Altitude (m)	Annual-Rain(mm)	Coverage area(km^2)
Motta	37.8808	11.0758	2410.27	1415.2	191.64
F. Bet	37.599	10.8528	3025.57	1777.99	30.99
F. Birhan	38.0572	10.7424	2790.39	1175.02	74.51
R. Gebeya	37.7641	10.5476	2864.85	1650.3	10.08

But here all the data's of these four stations obtained from National meteorological agency were not fully available, some years and daily rain fall data's missed.

Table 3-2: Available, missed and used meteorological station rain fall data's for the thesis

Station	Recorded	Data missed	Data used for analysis
F.Birhan	1954-2007	1954-1983	1996-2003
F.Bet	1959-2007	1959-1979 ,1983-1987	1996-2003
Motta	1984-2011	1984	1996-2003
Rebu Gebya	1970-2008	1970-1986	1996-2003

- **Hydrological data**

The stream flow data used for different purposes such as for calibration and validation, for predicting the flood for different return period and also for analyzing the past maximum flood occurrence. Here in this study the available daily discharge data collected from the ministry of water, irrigation and energy. The study area gaged station is located near to Motta town and the available yearly maximum flow data's tabulated in table 3-3 below.

Table 3-3: Annual maximum flow data of Sedie River at Sedie gage station

Year	Maximum flow (m ³ /s)
1996	134.00
1997	104.30
1998	97.60
1999	100.90
2000	71.50
2001	121.60
2002	80.50
2003	110.40

- **DEM data**

Digital Elevation Model (DEM) is the digital representation of the land surface elevation with respect to any reference datum and it is used as an input for ARC-GIS software for catchment delineation and estimation of catchment characteristic. The lower and higher elevation of the study area were 1275 m and 4087 m respectively.

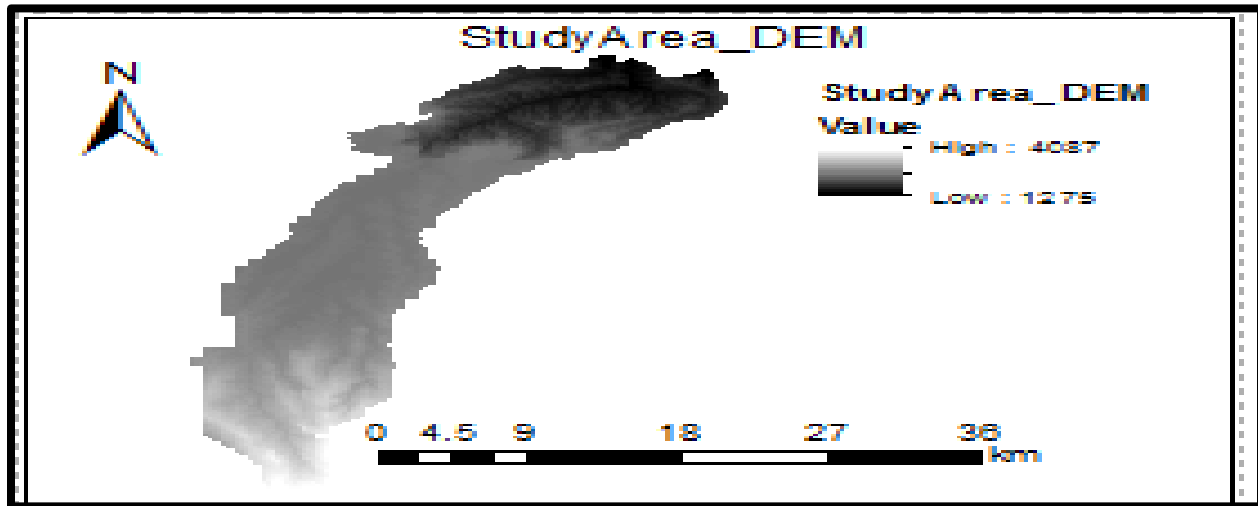


Figure 3-12: DEM of the study area

- **Types, sources and purposes of data's**

Generally for this specific study this mentioned data's used for analysis and running the models for determining the result for preparing the flood map. So that each data's source and purpose also shown in the table 3-4 below.

Table 3-4: Types, sources and purposes of data

Types of data	Sources of data	Purposes of data
Rainfall data	NMA Addis Ababa, Ethiopia	For HEC HMS model
Hydrological data (stream flow data)	MoWIE Addis Ababa, Ethiopia	For calibration and validation
DEM data	MoWIE Addis Ababa, Ethiopia, GIS department	To prepare TIN for HEC RAS input
Survey data	Own field survey	For input to HEC RAS simulation
Land use / land cover data	MoWIE Addis Ababa, Ethiopia	For determining CN value
Soil type data	MoWIE Addis Ababa, Ethiopia	For determining CN value

3.4 General frame work for modelling flood inundation map for this thesis

HEC-Ras river analysis model widely applied in the hydraulic design of rivers and for preparation of flood inundation map with help of other tools like ArcMap and Ras mapper. In this study, in order to assess river overtopping problem and to prepare flood inundation map both hydrologic and hydraulic modelling were used. Hence the hydrologic modelling (HEC HMS) used to prepare flood frequency for water surface simulation and for preparing flow hydrograph for upstream boundary condition.

As shown in fig 3-13 below the thesis work comprises both hydrological and hydraulic models. So that in the general framework figure shows the steps followed in this specific thesis work how the data collection methods, data analysis and result integrated and followed one another.

As the thesis work uses simulation models it was a must calibration and validation to be held on for verification of the models. So that the steps for calibration and validation of the models used in this specific thesis work shown in fig 3-14.

In the hydrological modeling(HEC-HMS) there were data's required for simulation such as precipitation, land use or/and land cover and soil type for the preparation of curve number which directly used as an input of HEC-HMS model simulation.

In hydraulic modelling (HEC-RAS) simulation the steps followed were digitizing of the river center line, cross sectional cut lines, bank lines, and flow path center lines. Following it surveyed river cross section required as an input for hydraulic modelling in HEC-Ras simulation. After that 2d flood area generation, editing geometric data's, setting manning roughness, setting 1D/2D boundary conditions, setting contraction/expansion coefficient and finally importing and editing flow data's for different return period.

For hydrological modelling calibration and validation held on by comparing the HEC-HMS model simulation value with the recorded observed one. To come up this values approximately equal, it was better to change and adjust curve number value. This process continues until the required result obtained and the model performance efficiency value satisfied. In the other hand for the hydraulic modelling (HEC-Ras model); by downloading flood extent image of remote sensing and Landsat imagery analysis for the specific study area for a specific time and compared with the simulation flood inundation map obtained from HEC-Ras simulation. The calibration and validation process held on by changing and adjusting Manning roughness value then after the process continues until the simulation and observed map becomes approximately equal.

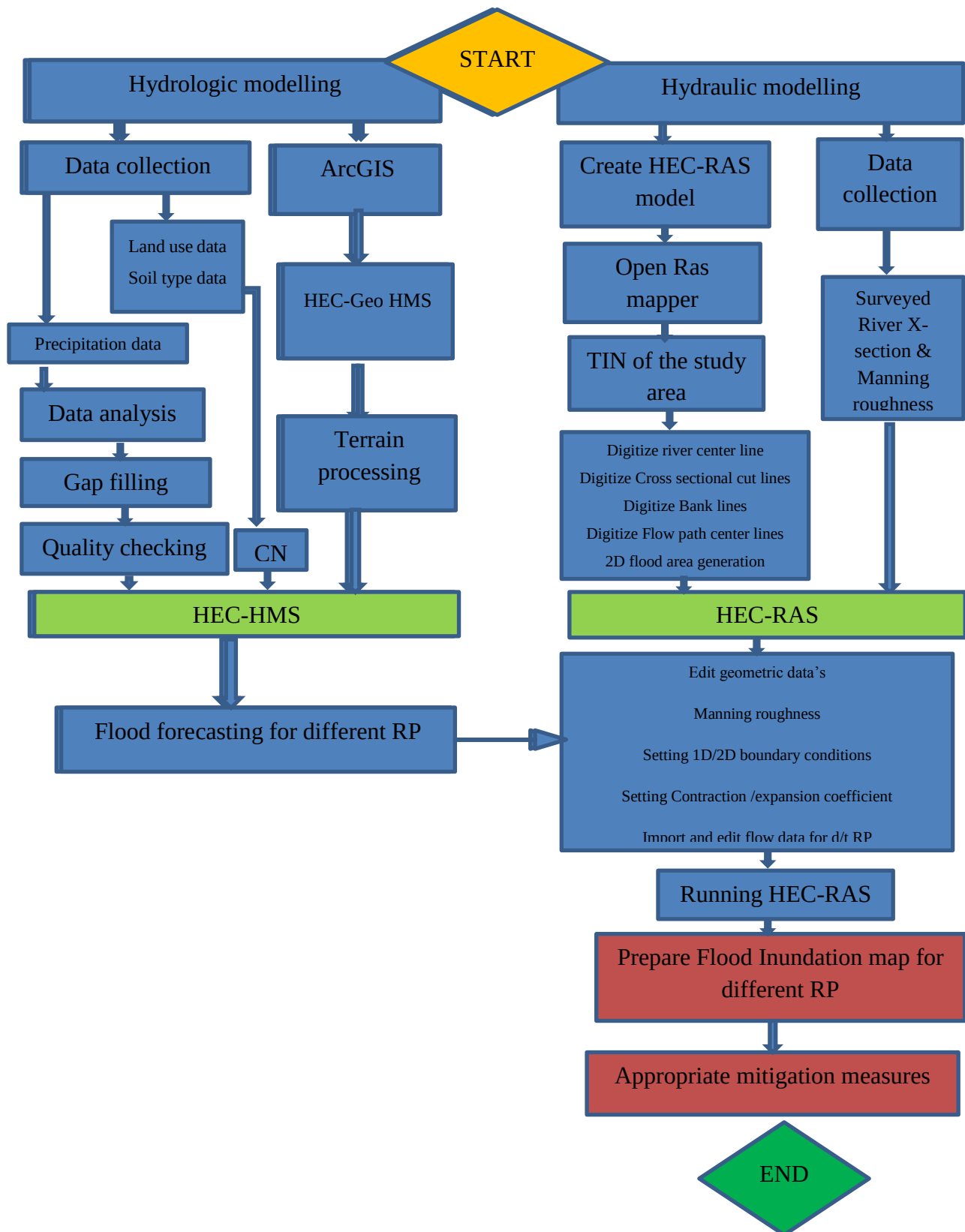


Figure 3-13: General frame work of the methodology for this study

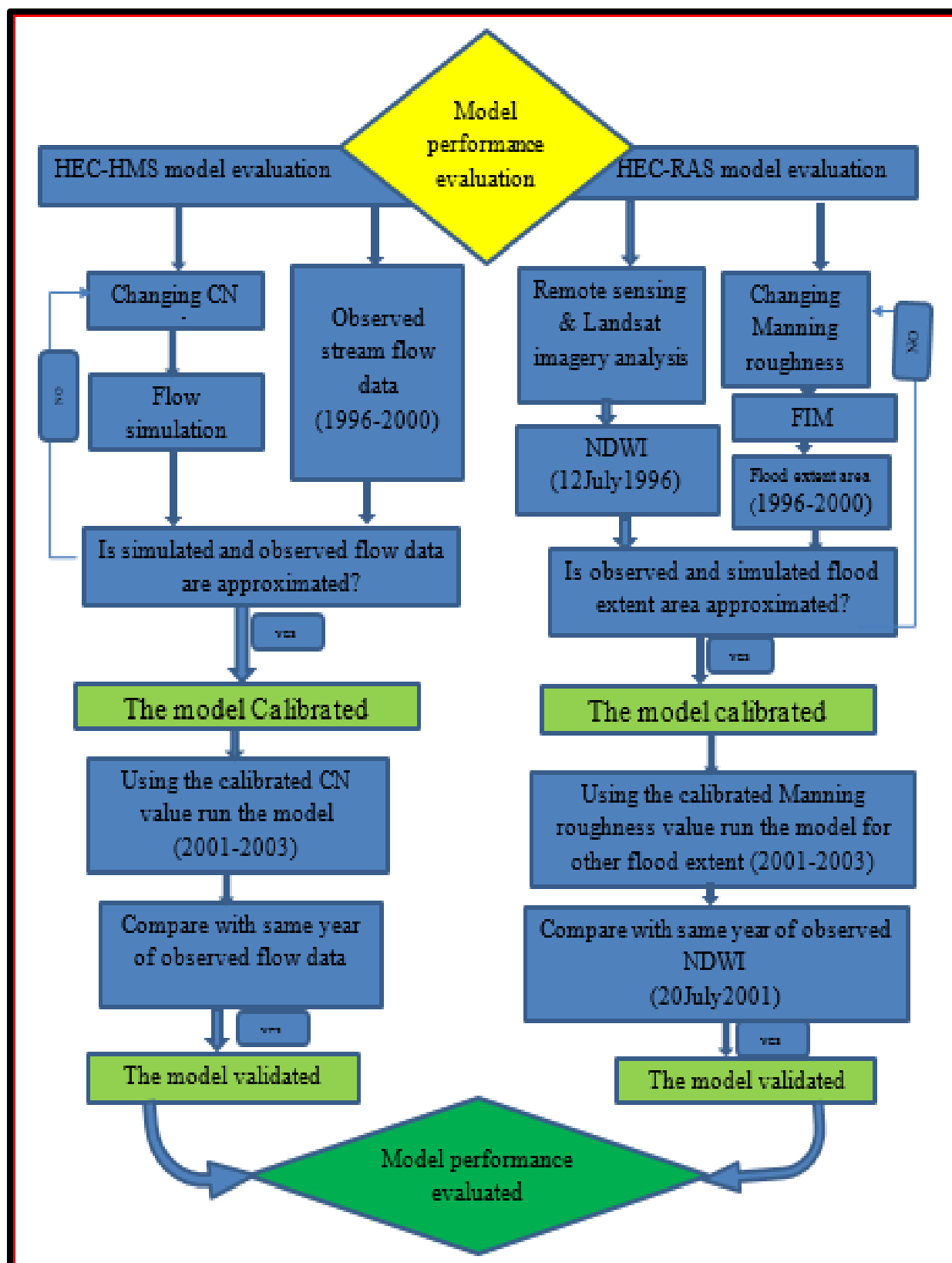


Figure 3-14: Flow chart of conceptual framework for models calibration and validation

4. DATA ANALYSIS

4.1 Meteorological data analysis

4.1.1 Filling of missing rainfall data

For both hydrological and hydraulic modelling to use meteorological data mostly requires filling; due to missing of the data's when recorded. For this specific study in order to fill missing rainfall data both station average and linear regression methods used. Hence after determining the level of missed data for the different meteorological stations, the missing level determined and the method of data filling chosen. For determining missing level number of years used for the study, total days in the study and missed days used. Therefore for stations Motta, Feresbet and Felege Birhan linear regression method and for Rob Gebya station average method used.

4.1.2 Checking Consistency

Most of the time in order to study flood damage analysis in a river it is difficult to obtain full available rainfall data's in a station. In most cases when a gauge location is changed and/or inactive then inconsistency of record occurred. Therefore to overcome these problem hydrologists perform a Double Mass Curve (DMC) analysis. DMC analysis is a graphical analysis method for isolating or adjusting inconsistencies in a station record by compare and contrasting its time trend with those of other nearby stations to obtain a consistent record mean that a characteristics of the record have not changed with time (Subramanya, 1984).

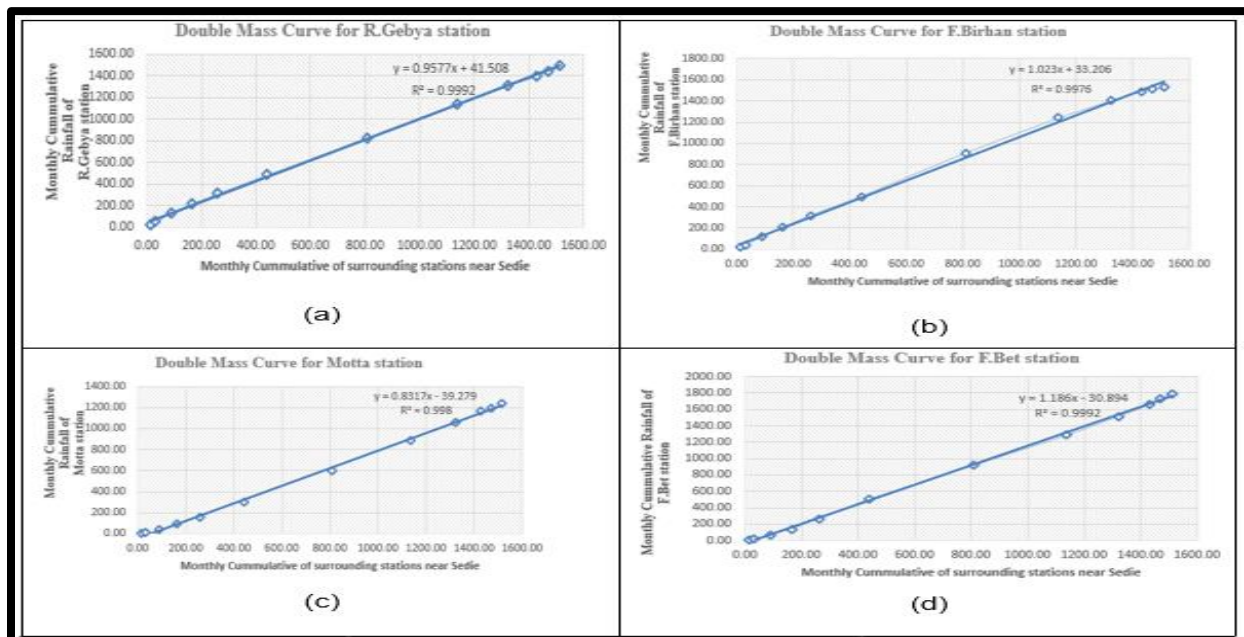


Figure 4-1: Double Mass Curve (DMC) for checking data trend for different stations

a) For R.Gebya station b) For F.Birhan station c) For Motta station d) For F.Bet station

After filling of precipitation the data's become consistent as shown in Fig 4-1 above. The study area meteorological stations monthly average rainfall data shown in Fig 4-2 below and the maximum and minimum amount of rainfall occurs in July and January respectively.

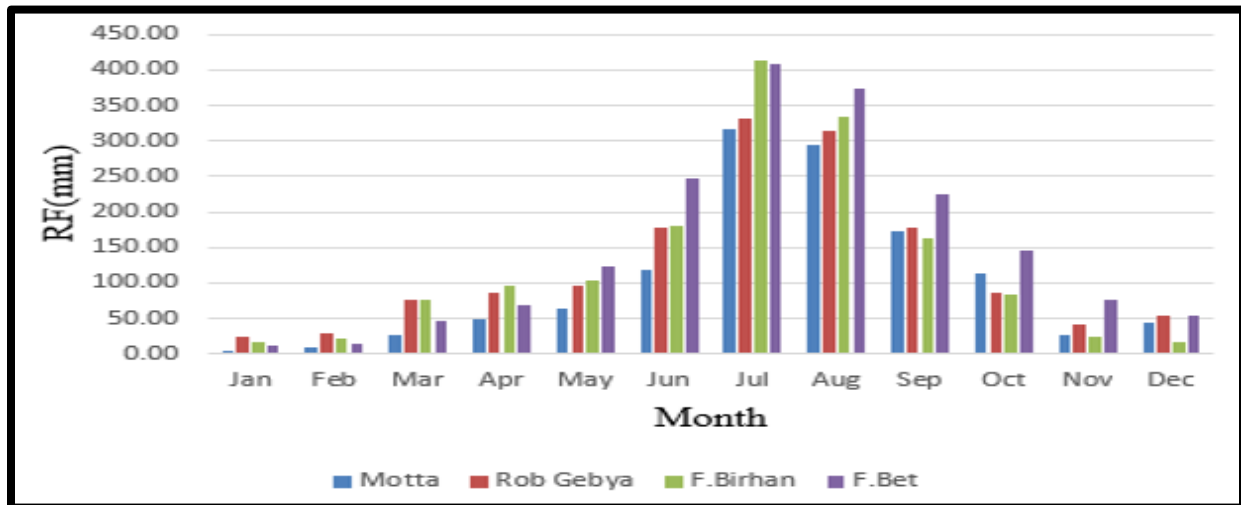


Figure 4-2: Average monthly rainfall in mm after filling (1996-2003) (Ref APPENDIX: B)

4. 2 Stream flow data analysis

In this specific study area the gage station located at Sedie near to Motta town at Sedie Bridge. For this specific study eight year daily stream flow data's obtained and collected from Ministry of Water, Irrigation and Energy. The collected stream flow data's were almost full continuous daily data's as shown in fig 4.3 below.

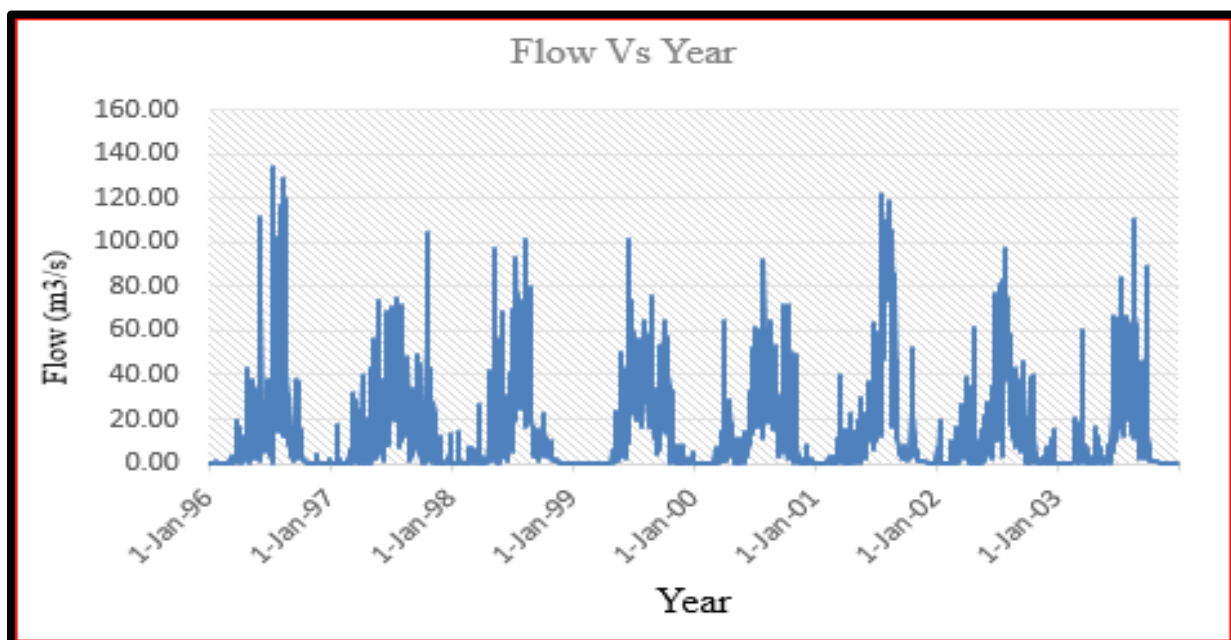


Figure 4-3: Daily stream flow data from (Jan1, 1996-Dec31, 2003) (Ref APPENDIX: C)

4.3 Terrain preprocessing analysis

In order to delineate the watershed of the study area it was a must to pass steps in ArcGIS model with integration of Hec-GeoHMS analysis tool to generate the drainage network and to obtain the study area sub basins. To drive the drainage network, it was a must to use the terrain data as input and then terrain preprocessing followed. It starts by preparing DEM of the study area after that Fills sinks, flow direction, flow accumulation, stream definition, Stream Segmentation, catchment grid delineation, catchment polygon processing then the drainage line processing and Adjoint catchment processing followed. Tools are available on the basin dispensation menu which then gives the users for the ability to delineate and also edit basins accordingly with the project specifications. Then after following these steps listed above the study area delineated and the upstream part of the area used for preparing flow hydrograph for upstream boundary condition.

4.4 Model analysis

For this specific thesis work both hydrological model (HEC-HMS) and hydraulic model (HEC-RAS) with integration of ArcGIS used. The two models were used for different parts of the specific study area; the area which filled with lotus pond green color were analyzed by hydrological model and the remaining part filled with Lapis lazuli color were analyzed by using the hydraulic model as shown in fig 4-4 below.

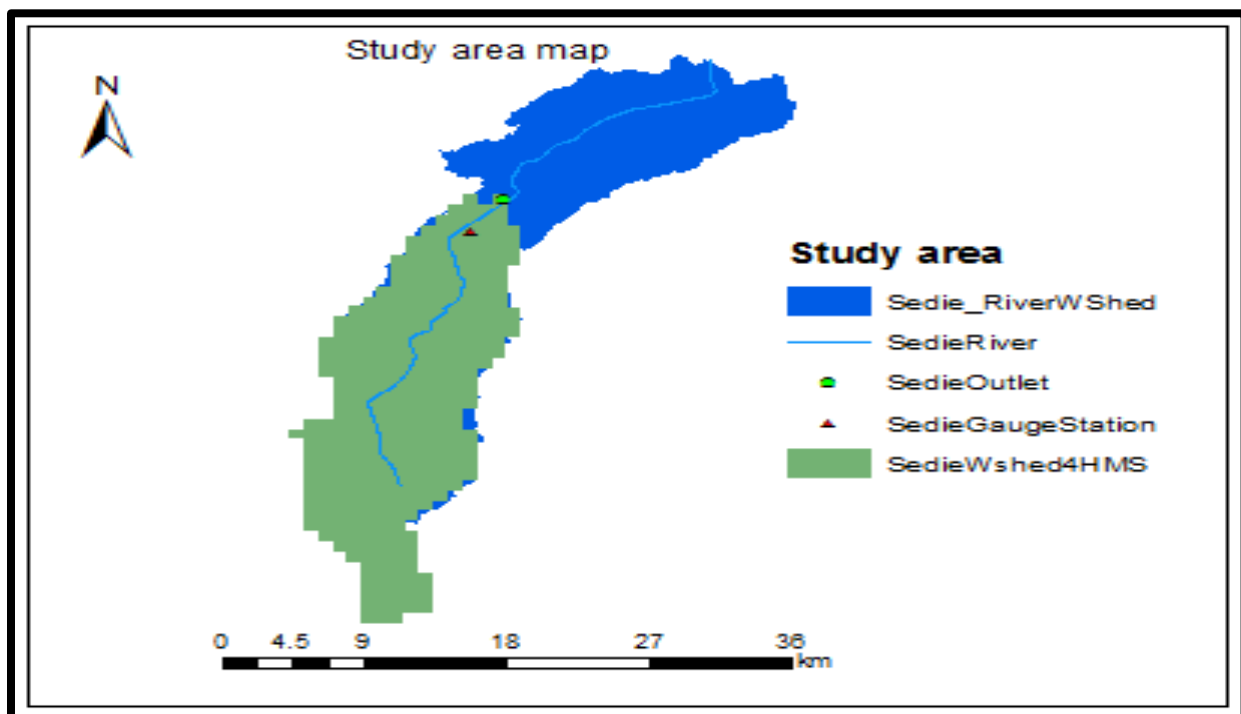


Figure 4-4: Areas where hydrological and hydraulically models used

4.5 HEC HMS model analysis

4.5.1 Basin models

The physical illustration of a watershed is simply accomplished by a basin model. Hydrologic fundamentals are linked in a dendritic network for simulation of runoff processes. In this stage the user is provided with a variety of interactive and batch-mode tools to delineate sub basins.

It is simply the tools shows the users to visualize the delineation outcomes to evaluate, to accept or reject the resulting delineation in the specified interactive mode. Once the user marks interactive basin processing then simply the program will ready the user to confirm the results. In the batch mode the users simply give the outlet locations & the program delineate sub basins on behalf of the locations. It holds without interface to observation and also review. In the basin model description for this specific thesis it was a must to determine loss, transform, base flow and routing in order to simulate the flow so that the mentioned parameters determined accordingly.

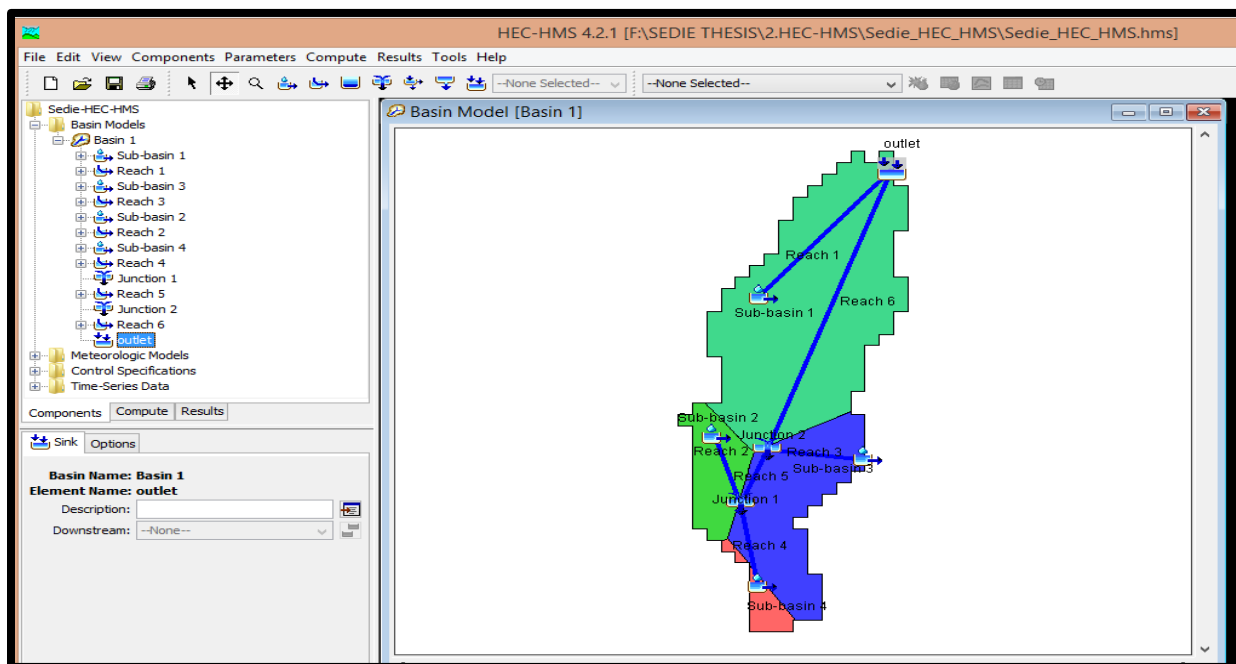


Figure 4-5: The Study area sub-basins and reaches in HEC-HMS window

Table 4-1: Sub-basins and area coverage

Sub-basins	Area (km ²)
Sub-basin 1	191.64
Sub-basin 2	30.99
Sub-basin 3	74.51
Sub-basin 4	10.08

- **Loss determination**

Different methods used for determining loss for different interest of studies. Among different methods SCS curve number (CN) chosen for this specific study; the reason is that according to ERA drainage manual 2002 this method is used for a gaged data for less than 10 year record data. So that the study area has 8 year available stream flow data's and here one parameter is required CN from LU and soil type. After selecting the method three parameters curve number, initial abstraction and impervious (%) are required to compute the loss.

A. Curve number determination

For the precipitation loss determination using SCS curve number (CN) method it is a basic thing to determine curve number for each specific sub basin in the study. The curve number calculation requires the soil type and land use of each sub basin (shown in fig 4-6a and b) respectively. Soil properties influence the relationship between runoff and rainfall since soils have differing rates of infiltration. Permeability and infiltration are the principal data required to classify soils into Hydrologic Soil groups. As shown in table 4-2 below the study area soil type defined by their hydrologic soil group and area coverage for the purpose of determining the curve number and also as shown in table 4-3 below all the sub basins for this specific thesis defined with their land use and area coverage with the help of ArcGIS clip interface analysis tool.

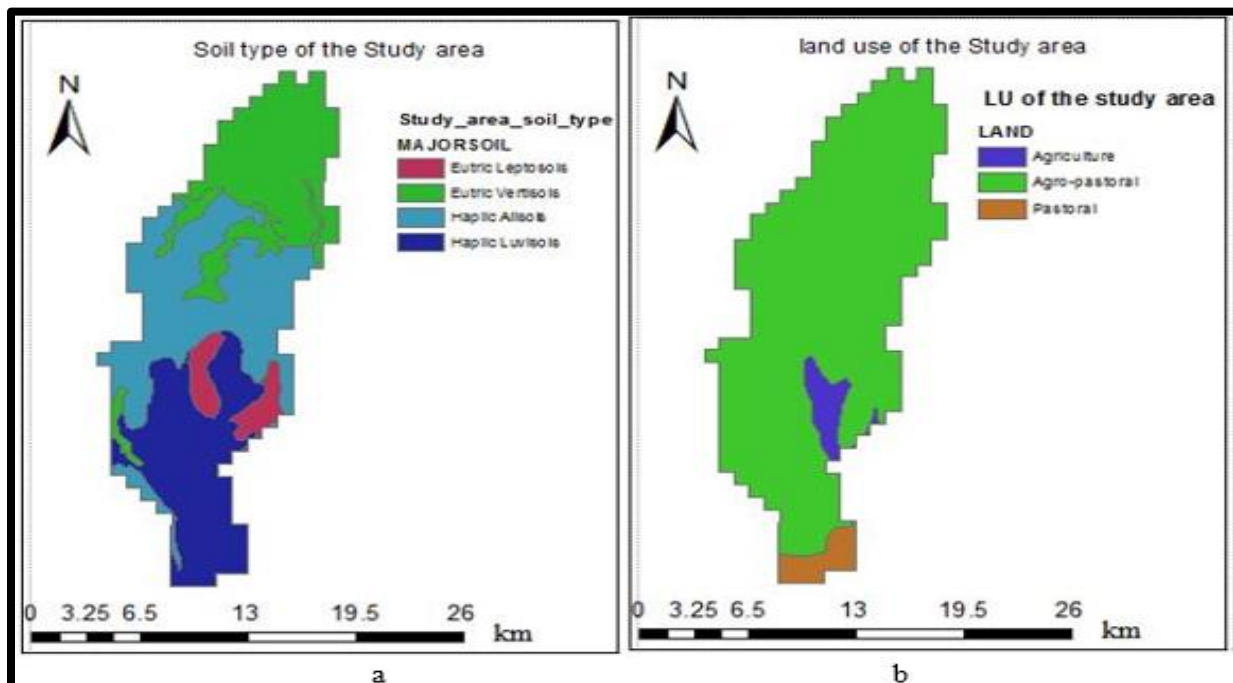


Figure 4-6 Soil type and Land use of the study area for CN determination

(a) Soil type of the study area (b) land use of the study area

Table 4-2: Study area soil type, hydrologic soil group and area coverage

Sub-basin name	Soil type	Hydrologic soil group	Area (m2)
Sub-basin 1	Haplic alisoils	B	84670200
	Haplic luvisols	B	9198680
	Eutric vertisols	D	89752050
	Eutric leptosols	B	4643490
Sub-basin 2	Haplic alisoils	B	13114100
	Haplic luvisols	B	13222000
	Eutric vertisols	D	2739190
Sub-basin 3	Haplic alisoils	B	6254940
	Haplic luvisols	B	55562300
	Eutric leptosols	B	11832820
Sub-basin 4	Haplic alisoils	B	1278170
	Haplic luvisols	B	7261940

Table 4-3: Sedie Sub-basins and the corresponding land use and area coverage

Sub-basin name	Land use	Area (m2)
Sub-basin 1	Agro-pastoral(fallow-crop residue)	186952000
	Agriculture (fallow-cover)	1312170
Sub-basin 2	Agro-pastoral (fallow-crop residue)	29075300
Sub-basin 3	Agro-pastoral(fallow-crop residue)	57483700
	Agriculture (fallow-cover)	10424800
	Pastoral	5741570
Sub-basin 4	Agro-pastoral (fallow-crop residue)	3760700
	Pastoral	4779410

- **Composite curve number**

The curve number used in the simulation of hydrological modelling should be a composite curve number. Hence the curve number should represent all of the different soil group and land use combinations in the sub basin but the composite curve number should not include any impervious area that will be specified separately as the percentage of impervious area if an impervious area existed at the specified area it should be calculated for it only.

For a watershed that consists of more than one soil types and land uses; a composite curve number calculated as shown in the equation 4.1 below.

$$CN_{composite} = \sum \frac{CN_i * A_i}{A_i} \dots\dots\dots \text{equation 4.1}$$

In which, $CN_{composite}$ = the composite CN used for runoff volume computations;

i = an index of watersheds subdivisions of uniform land use and soil type;

CN_i = the CN for subdivision i; and

A_i = the drainage area of subdivision i.

For determining composite CN the soil group and the land use should to be justified and determined in order to analyze the composite curve number. Therefore for this specific study by merging the soil type and land use, areas for each soil group and land use obtained. Finally the composite curve number calculated as shown in table 4-4 below.

Table 4-4: Composite curve number

Sub-basin name	Soil type	HSG	Land use	CN	Area (m2)	$\sum(CN_i * A_i)$ (km2)	Area $\sum A_i$ (km2)	CN composite $\sum \frac{CN_i * A_i}{A_i}$
Sub-basin 1	Haplic alisoils	B	(fallow-CR)	85	84670200	16717.87	188.26	88.80
	Haplic luvisoils	B	(fallow-CR)	85	8940780			
			(fallow-C)	83	257895			
	Eutric vertisoils	D	(fallow-CR)	93	89752050			
	Eutric leptosoils	B	(fallow-CR)	85	3589220			
			(fallow-C)	83	1054280			
Sub-basin 2	Haplic alisoils	B	(fallow-CR)	85	13114100	2493.31	29.08	85.75
	Haplic luvisoils	B	(fallow-CR)	85	13222000			
	Eutric vertisoils	D	(fallow-CR)	93	2739190			
Sub-basin 3	Haplic alisoils	B	(fallow-CR)	85	6254940	6101.61	73.65	82.85
	Haplic luvisoils	B	(fallow-CR)	85	42470100			
			(fallow-C)	83	7350640			
			Pastoral	61	5741570			
	Eutric leptosoils	B	(fallow-CR)	85	8758680			
			(fallow-C)	83	3074150			
Sub-basin 4	Haplic alisoils	B	(fallow-CR)	85	1039770	611.20	8.54	71.57
			Pastoral	61	238397			
	Haplic luvisoils	B	(fallow-CR)	85	2720920			
			Pastoral	61	4541010			

B. Initial Abstraction (Ia)

The initial abstraction defines the amount of precipitation that must fall before surface excess results. From analysis of results from many small experimental watersheds, the SCS developed an empirical relationship of Ia and S in equation below.

$$S = \frac{25400}{CN} - 254 \dots \dots \dots \text{equation 4.2}$$

$$Ia = 0.2S \dots \dots \dots \text{equation 4.3}$$

Where S=the maximum retention, CN= the composite curve number (CN composite) and
Ia =initial abstraction.

Table 4-5: Maximum retention(s) and initial abstraction (Ia)

Sub-basin name	Soil type	HSG	Land use	CN composite	Maximum retention (s)	initial abstraction (Ia)
Sub-basin 1	Haplic alisoils	B	(fallow-CR)	88.80	32.04	6.408
	Haplic luvisols	B	(fallow-CR) (fallow-C)			
	Eutric vertisols	D	(fallow-CR)			
	Eutric leptosols	B	(fallow-CR) (fallow-C)			
Sub-basin 2	Haplic alisoils	B	(fallow-CR)	85.75	42.21	8.442
	Haplic luvisols	B	(fallow-CR)			
	Eutric vertisols	D	(fallow-CR)			
Sub-basin 3	Haplic alisoils	B	(fallow-CR)	82.85	52.58	10.516
	Haplic luvisols	B	(fallow-CR) (fallow-C)			
			Pastoral			
	Eutric leptosols	B	(fallow-CR) (fallow-C)			
Sub-basin 4	Haplic alisoils	B	(fallow-CR) Pastoral	71.57	100.90	20.18
			(fallow-CR)			
	Haplic luvisols	B	(fallow-CR) Pastoral			

C. Impervious (%)

Here in this specific study area no area that is impervious contributed in all sub basins. In the SCS curve number loss determination method this impervious value is one required parameter; therefore it considered as null (0 %) for each sub-basins and taken as 0 in the HEC HMS loss editor window.

No loss calculations are carried out on the impervious area; all precipitation on that portion of the sub basin becomes excess precipitation and subject to direct runoff. Generally for loss determination the required parameters area of each sub basins, curve number, initial abstraction and impervious are obtained and shown in table 4.6 below.

Table 4-6: Calculated loss determination parameters value

Component	Parameters	unit	Value
Sub-basin 1	Area (A)	Km^2	191.64
	Curve number (CN)	-	88.80
	Initial abstraction (Ia)	mm	6.408
	Impervious (Im)	%	0
Sub-basin 2	Area(A)	Km^2	30.99
	Curve number (CN)	-	85.75
	Initial abstraction (Ia)	mm	8.442
	Impervious (Im)	%	0
Sub-basin 3	Area(A)	Km^2	74.51
	Curve number (CN)	-	82.85
	Initial abstraction (Ia)	mm	10.516
	Impervious (Im)	%	0
Sub-basin 4	Area(A)	Km^2	10.08
	Curve number (CN)	-	71.57
	Initial abstraction (Ia)	mm	20.18
	Impervious (Im)	%	0

- **Transform determination**

However a sub basin element theoretically signifies surface runoff, infiltration and sub surface processes interrelating together. The actual surface runoff calculations accomplished by a transform method within the sub basin. Different methods are included for transforming excess

precipitation into surface runoff. For this specific study the SCS unit hydrograph method selected, since the river is gauged so that it is possible to develop SCS UH from observed RF-RO relationship then the prepared unit hydrograph taken for the hydrological model HEC HMS. Similarly in US this method used for a small agricultural watershed simulation.

In SCS unit hydrograph the description relates to a peak rate factor of 484, which incorporates the proportion of unit runoff formerly the peak calculated entire time base and unit conversions when applying the calculations within the US Customary unit system. The percentage of unit runoff happening earlier the peak flow is not uniform across the entirely watersheds why because it depends on flow length, ground slope and other properties of the watershed.

- **Base flow determination**

Although a sub basin element theoretically represents infiltration, surface runoff and subsurface processes interrelating together then the actual subsurface calculations are accomplished by a base flow technique contained within the sub basin. Different methods are included for representing base flow contributions to sub basin outflow. But for this specific study base flow not considered since no specifically logic obtained to use the methods listed.

- **Routing determination**

However a reach element ideally represents a subdivision of stream or river, the actual calculations are accomplished by a routing method contained within the reach. For this specific thesis work the lag method selected. Since the lag routing method is preeminent suited to small stream segments with a predicable travel time that doesn't fluctuate with flow depth.

The only parameter considered for this method is the lag time in minutes. Lag method is selected for river flow routing. Hence these routing method is the most widely used when calibration (optimization) is considered to obtain optimum and reliable model parameters and simply using Arc GIS (and/or HEC-Geo HMS) the input parameters can be determined so relatively simple to other routing techniques.

4.5.2 Meteorological model

Meteorological models are one of the main components in a project. The principle purpose is to prepare meteorological boundary conditions for sub basins. Consequently, it is a must to create at least one basin model before creating a meteorological model. For this specific study gage weights method was chosen because in this method users specified weights to user defined precipitation gages and of its inputs required are Sub basins, gage precipitation and gage weights. Since all the

contributed stations taken a gage weight of unity because before importing to the HEC HMS model the sub basins merged to four stations depending up on the land use land cover map and the rainfall distribution.

As shown in fig 4-7 below the rainfall distribution of this specific study area classified under Rainfall Region A2; therefore the stations (metrological) are same distribution of rainfall. So that there are stations (but not functional) which were substituted by available (active) stations located in the study area.

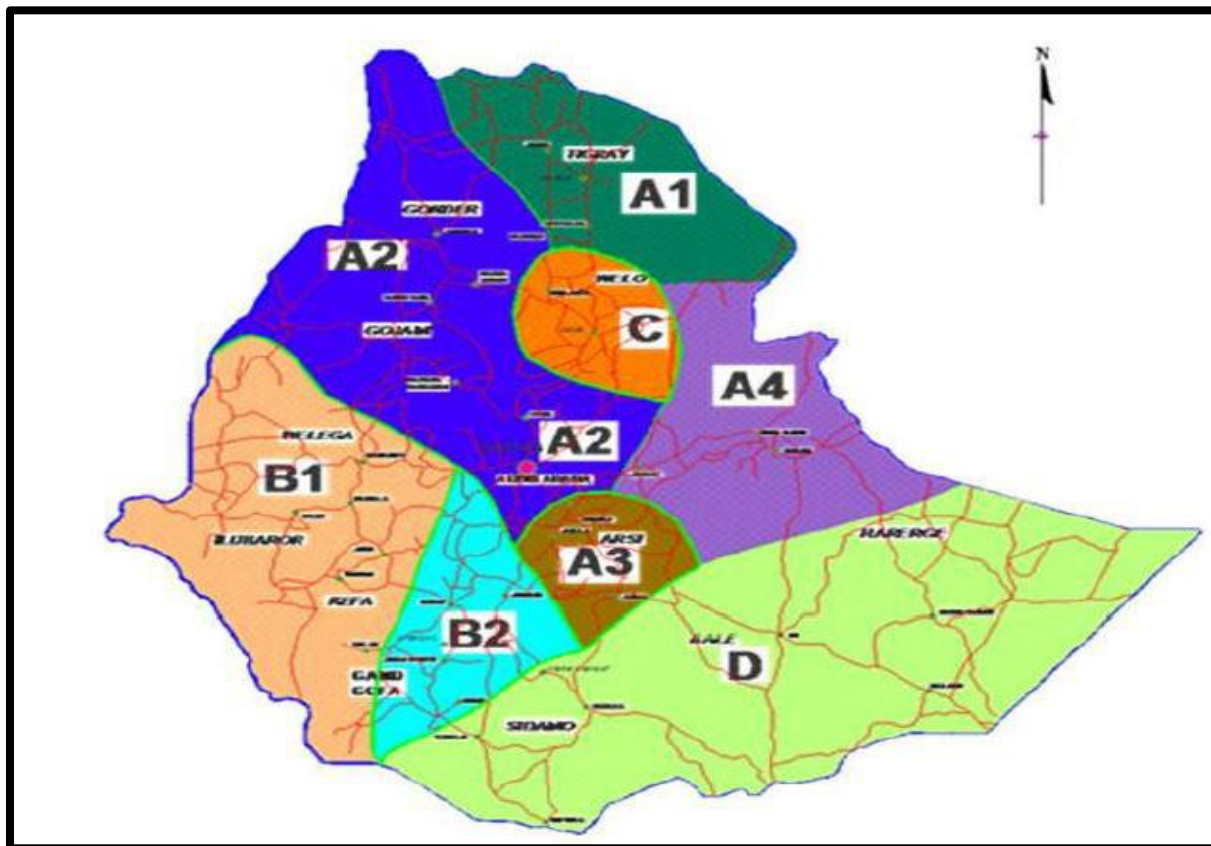


Figure 4-7: Regional classification based on rainfall distribution (Source: ERA manual, 2013)

4.5.3 Control specifications

Control specification is also another part of the HEC HMS model where the different parameters controlled. Different information's in the control specifications includes a starting year, date and time and also an ending year, date and time with a computation time interval required. After putting this required information's the model runs and the results obtained in the form of table and graph. In this specific study totally around 2920 days (8 years) used for calibration and validation the time range divided in to two. The first controlling time staring from Jan1, 1996 to Dec 31, 2000 and the second time interval controlled from Jan1, 2001 to Dec 31, 2003.

4.5.4 Time series

The time series data basically includes precipitation as well as flow data in a given period of time in a specific study. In this study the time series data used to calibrated, validate and to determine peak discharges for the pre-defined return periods using frequency analysis methods. The time used for this specific study ranges from Jan1, 1996 to Dec 31, 2000 for calibration and the other from Jan1, 2001 to Dec 31, 2003 for validation with time interval of 1 day (24hr) specified for the simulation and used to the control specification component.

4.5.5 Calibration and validation of the HEC HMS model

In any means of hydrological and hydraulic modelling using different models it is a must to calibrate and validate using observed data in the specified study area unless difficult to use for any flood analysis. Even if it is difficult to obtain enough observed stream flow data, it is necessary to try the calibration and validation of the model with the existed available data. In this study area 8 year daily observed stream flow data's were recorded and obtained from Ministry of Water, Irrigation and Energy.

- **Calibration of HEC HMS model**

Calibration is a process of changing the parameters and/or coefficients of a hydrologic method so that it estimate peak discharges & hydrographs consistent with local rainfall and stream flow data. The calibration process simply involves changing input parameters until a good agreement exists between measured & simulated values (ERA, 2013). For this study due to the limitation of data's only five years (1996-2000) around 1825 daily flow data used for calibration and all the five years daily stream flow continues data's attached and obtained at (APPENDIX: C).

- **Validation of HEC HMS model**

Hydrologic model validation delivers an assessment of the model's capability to accurately reproduce well-known results. This is performed by running the model at the high flowrate with the calibrated curve number CN-values obtained in the calibration process. Simply used to re Checking of flood with another observed data (exclude of calibrated data) for future assessment to know the model performance in neutral data. Therefore three year daily stream flow data (Jan1 2001- Dec31 2003) around 1,095 daily observed data's used (Ref APPENDIX: C).

Performance/ efficiency of the HEC HMS model

To check the performance of the hydrological model, mostly it depends on the size of the data used for the simulation. For this specific study due to the shortage of data obtained for simulation Coefficient of Efficiency (Nash Sutcliffe Efficiency) and Coefficient of determination used.

A. Coefficient of Efficiency (Nash Sutcliffe Efficiency)

As proposed by (Nash and J.V. Sutcliffe 1970) the performance of Nash Sutcliffe efficiency values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value; which indicates unacceptable performance.

$$ENS = 1 - \frac{\sum_{i=1}^n (qoi - qsi)^2}{\sum_{i=1}^n (qoi - qoa)^2} \dots\dots\dots \text{Equation 4.4}$$

Where, qoi = observed value at the ith time interval, qsi = simulated value at the ith time interval and qoa = average value of observed discharge

B. Coefficient of determination

This measure estimates how well the dispersion of the measured data is predicted by the model. Its value ranges between 0.0 and 1.0 with the zero being no correlation at all and value one perfect attach. As R² ranges from 0.0 to 1.0 with higher values indicating less error variance and typically values greater than 0.5 are considered acceptable (Legates and McCabe, 1999).

$$R^2 = \frac{[\sum_{i=1}^n (qsi - qsa)(qoi - qoa)]^2}{\sum_{i=1}^n (qsi - qsa)^2 \sum_{i=1}^n (qoi - qoa)^2} \dots\dots\dots \text{Equation 4.5}$$

Where qoi = observed value at the ith time interval, qsi = simulated value at the ith time interval, qoa = average value of observed discharge, qsa = average value of simulated discharge and n = number of sample data.

4.5.6 Flood frequency analysis

Flood frequency analysis is a vital and an important mechanism for any hydrological as well as for hydraulic simulation of any flood damage assessment. So that it has an important role for preparation of flood hazard and to prepare remedial measures before damage occurred. In order to determine the flood frequency for different return periods it can be used frequency analysis methods such as Gumbel distribution, Log-Normal distribution, Log-Pearson Type III and the hydrological model (HEC HMS model) used.

After the analysis of each frequency analysis and the model; the best fit result chosen and used for the hydraulic model analysis. The above mentioned frequency analysis and the HEC HMS model forecasts for the different return periods of 2yr, 5yr, 10yr, 25yr, 50yr, and 100yr. Then after the obtained flood result used for the preparation of flood map for different scenarios at different time.

4.6 HEC RAS model analysis

In HEC Ras model analysis basically there are steps to follow to perform the steady/or unsteady flow simulation. The steps followed here in this specific study were preprocessing, processing and lastly post processing stages followed to reach the final output of the HEC Ras model. For the simulation of the model in Ras mapper it was a must to generate DEM in order to digitize the river center line, flow path line, cross sectional cut lines and bank lines.

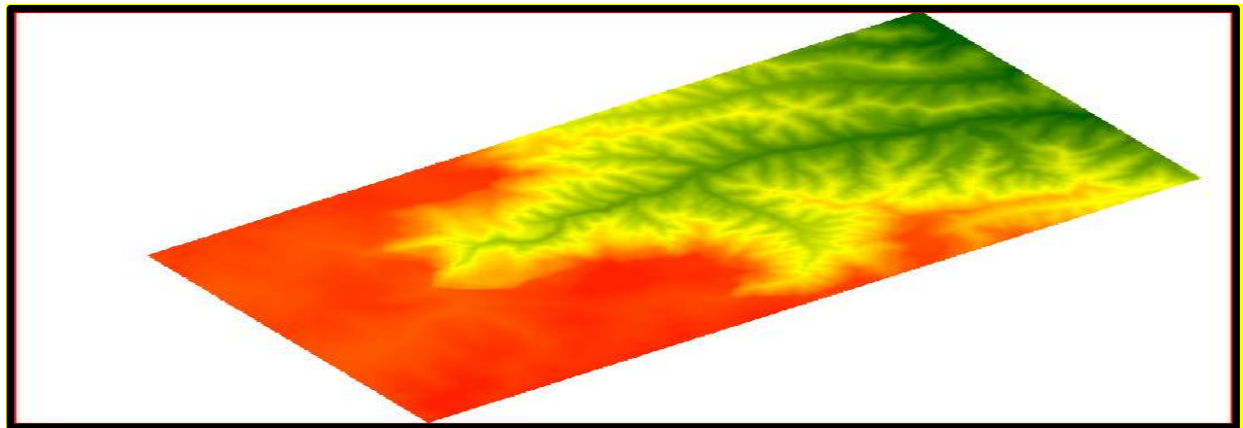


Figure 4-8: Digital elevation model (DEM) of the study area in ArcGIS

In HEC RAS simulation there are required parameters that should be adjusted in order to run the model. Basically after giving the project name; the plan data, the geometric data and the flow data's required to run the model and to obtain result from the model. The plan data: it comprises information that are related to the model specifications for the description of the flow regime, Geometric data: it comprises the size, shape and connectivity of the stream cross-sections and the flow data: contains the flow rate for different return periods. The SI unit system also should be adjusted unless error may occur; for this study international system (metric system) used.

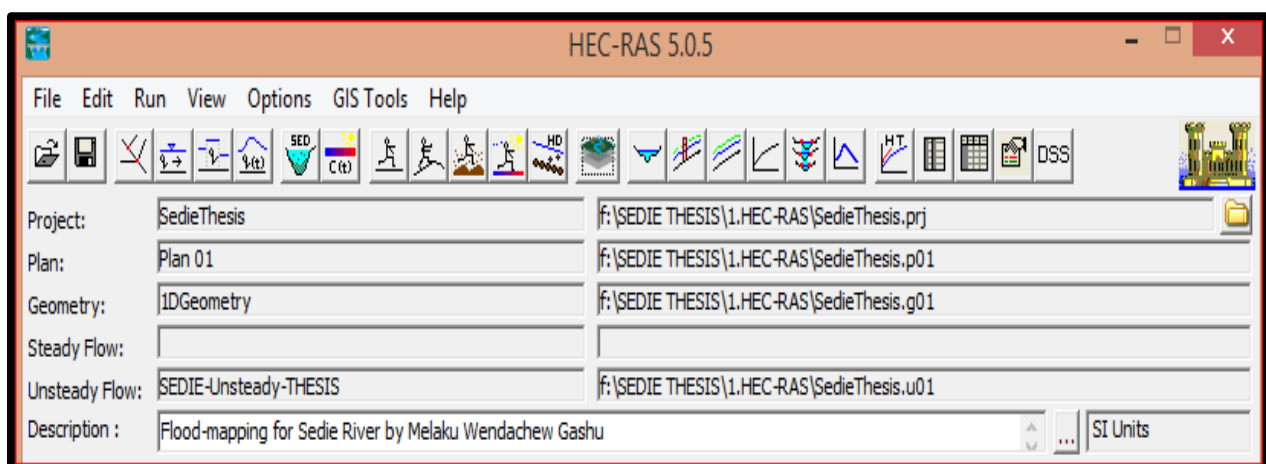


Figure 4-9: The study area project, plan, geometry and unsteady flow profile on HEC RAS window

4.6.1 Preprocessing of HEC Ras model analysis

- **Digitizing Sedie River centerline:** this digitizing of the river held on Ras mapper for identifying the river used to know the river network.
- **Digitizing Flow path centerline:** digitizing the flow path is important for identifying the center of mass of flow in the main channel and overbanks to determine the downstream reach lengths between the cross sections.
- **Digitizing and editing cross sections cut lines:** digitizing the cross section cut lines has an importance to know the elevation bisects from the DEM at a specified location at different places at different stations.
- **Digitizing bank lines:** digitizing the bank lines has an advantage for identifying the main channel from over bank areas with the help of cut lines; to understand the cross section of the specified river.
- **2D Mesh grid:** these 2D mesh grid determination has an importance to know the flow area on the specified river.

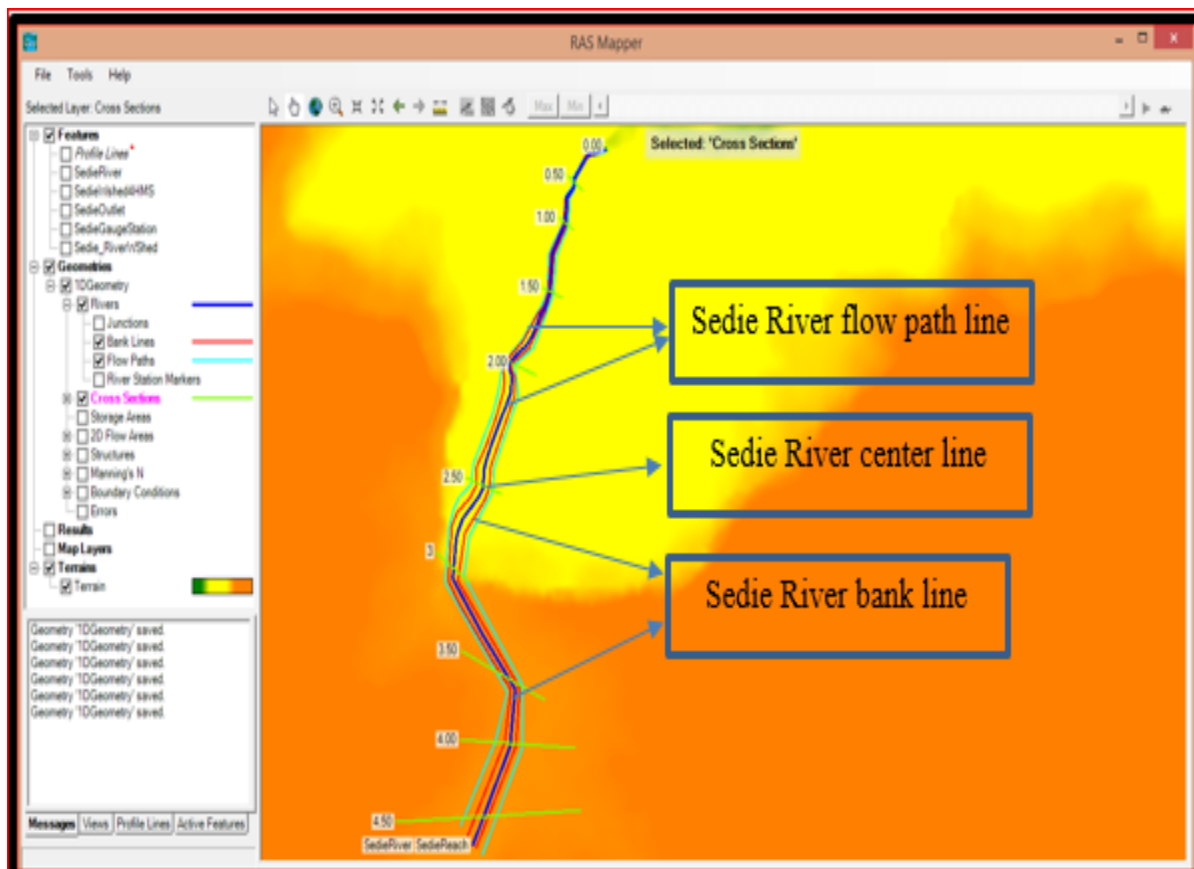


Figure 4-10: Sedie River geometries prepared in RAS Mapper

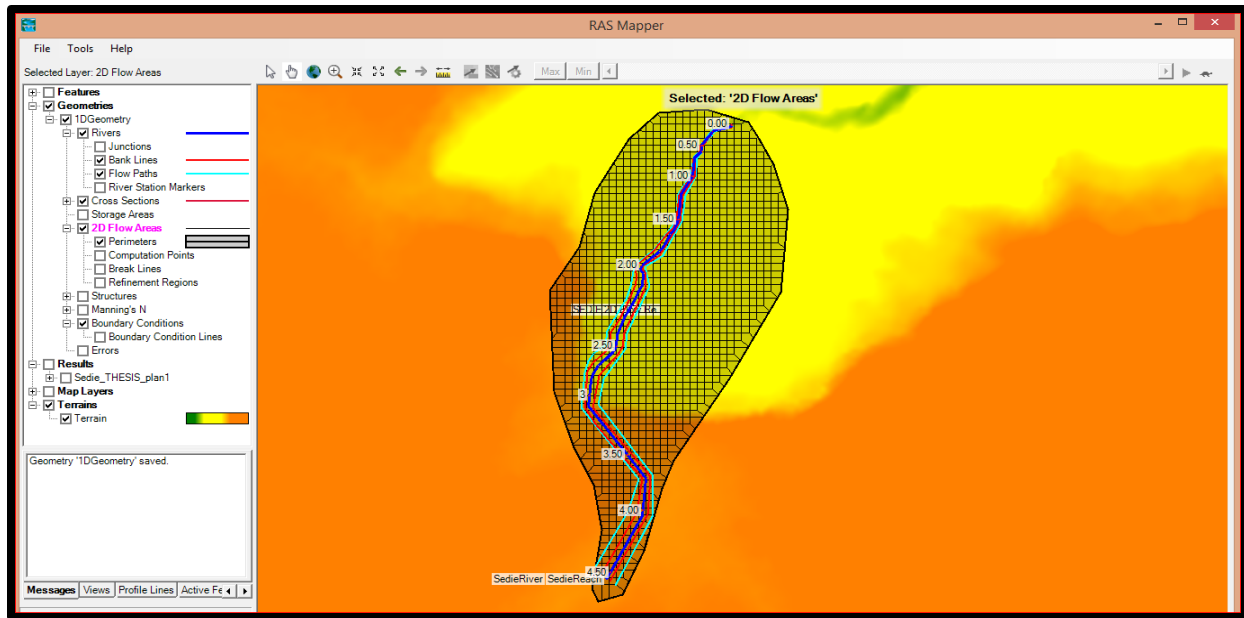


Figure 4-11: River geometries with 500m x 500m gridded 2D flood area

4.6.2 Processing of HEC Ras model analysis

- **Importing and editing geometric data**

For HEC RAS simulation importing and editing geometric data is necessary. So that for this specific study the data collected primarily from field. For each cross section in different stations around ten cross sectional cut line data's collected using GPS, graduated staff and leveling instrument after that interpolation held between each cross section. So that the survey data's collected at each stations was using GPS, so that the geometric data editing held by checking and comparing with the DEM elevation at Ras mapper window that imported from ArcGIS.

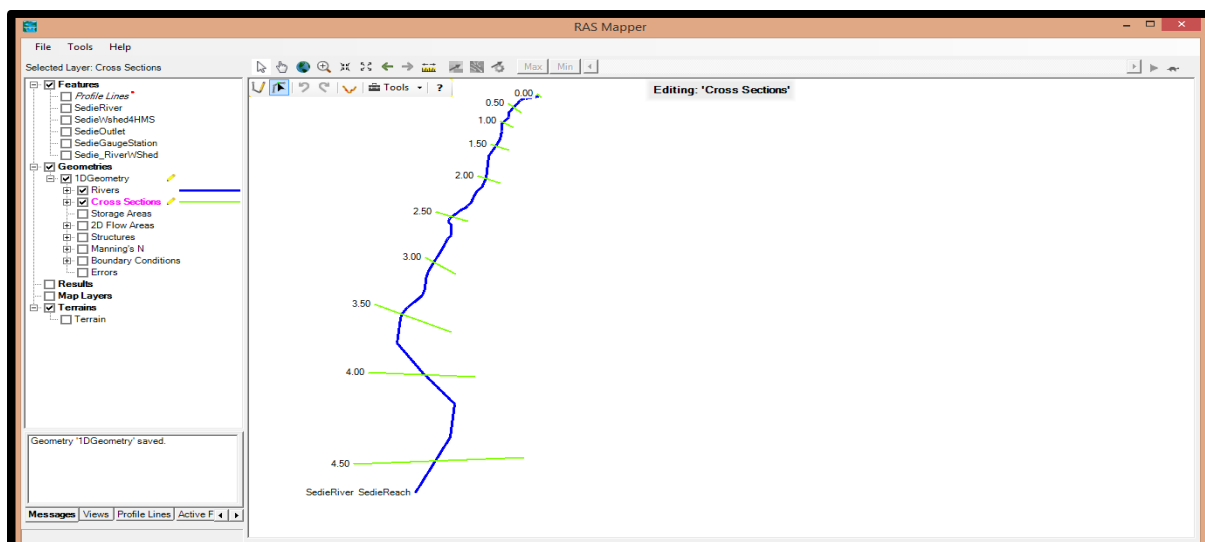


Figure 4-12: Geometrical profile without Terrain of the study area at Ras mapper window

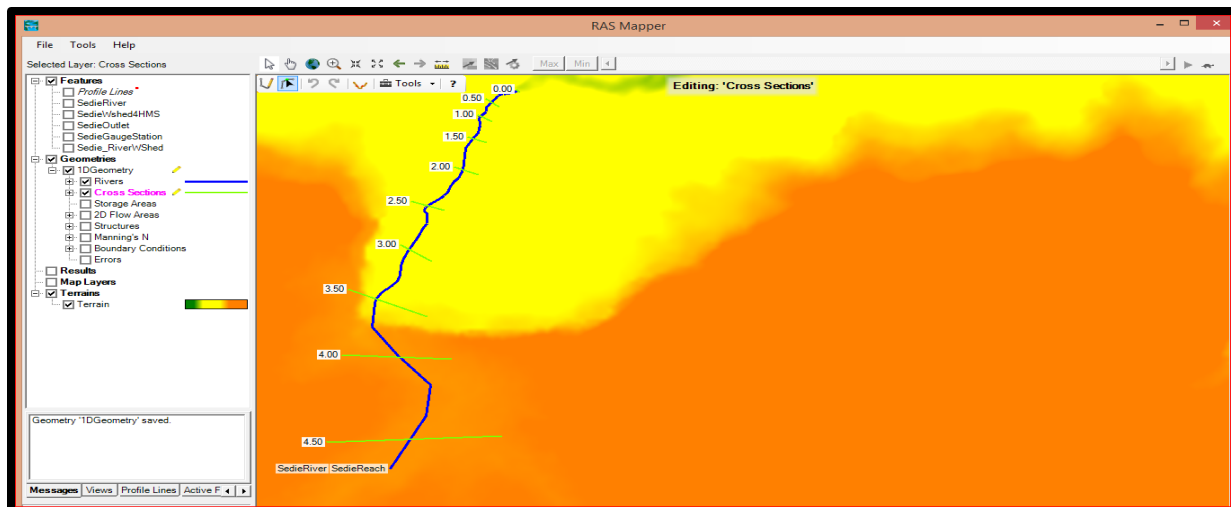


Figure 4-13: Geometrical profile with Terrain of the study area at Ras mapper window

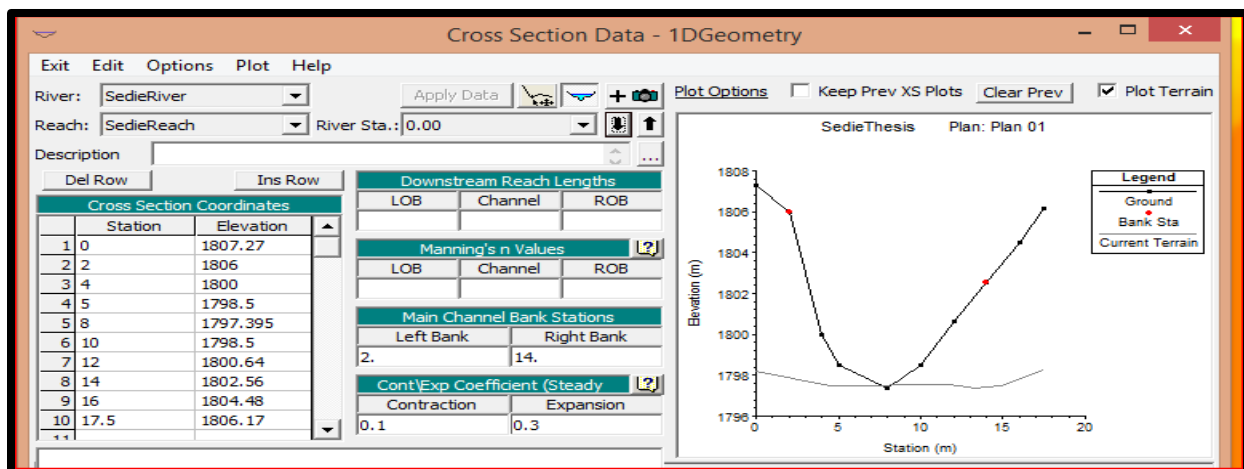


Figure 4-14: Sample cross section data profile at station 0.00 m in HEC Ras window

- **Manning roughness coefficient**

The manning roughness of a surface disturbs the appearances of runoff, whether the water is on the surface of the watershed or in the channel. Cowan method is potentially more accurate method and it is required for a number of hydraulic computations. Therefore for this thesis work the manning “n” values given based on the characteristics of Sedie River channel and floodplain area. For each representative n-value given based on the parameters description value obtained from (Cowan, 1956) depending on the study area field survey photos, the evaluation system held and the manning values determined.

The general procedure for estimating n involves first, the selection of a basic value of n for a channel and floodplain materials involved; then, through critical consideration of the factors listed above, the selection of a modifying value associated with each factor.

To obtain n for the channel the basic value (n_1) should be added to the modifying values including Correction for channel irregularity (n_2), Correction for cross-section variation (n_3), Correction for obstructions (n_4), Correction for vegetation (n_5), Correction for channel meandering (n_6).

Table 4-7: General calculation for Manning's roughness coefficient

Variable	Description alternatives	Recommended value	Actual value of channel	Actual value of floodplain
Basic (n_1)	Earth	0.02	$n_1 = 0.022$	$n_1 = 0.02$
	Rock	0.025		
	Fine-gravel	0.024		
	Coarse gravel	0.028		
Irregularity (n_2)	Smooth	0.000	$n_2 = 0.005$	$n_2 = 0.005$
	Minor	0.005		
	Moderate	0.010		
	Severe	0.020		
Cross section (n_3)	Gradual	0.000	$n_3 = 0.0125$	$n_3 = 0.000$
	Occasional	0.005		
	Alternating	0.010-0.015		
Obstructions (n_4)	Negligible	0.000	$n_4 = 0.000$	$n_4 = 0.000$
	Minor	0.010-0.015		
	Appreciable	0.020-0.030		
	Severe	0.040-0.060		
Vegetation (n_5)	Low	0.005-0.010	$n_5 = 0.0075$	$n_5 = 0.0375$
	Medium	0.010-0.020		
	High	0.025-0.050		
	Very high	0.050-0.100		
Meandering (n_6)	Minor	0.000	$n_6 = 0.00705$	$n_6 = 0.000$
	Appreciable	$0.15 \cdot n_s$		
	Severe	$0.30 \cdot n_s$		
Total Reach n			$n = 0.054$	$n = 0.0625$

Therefore the total reach “ n ” values were obtained by using the above table by giving value for different variables for main channel of Sedie River and floodplain.

From the table above the final calculation of a Manning roughness coefficient value of 0.054 for the main channel and 0.0625 for the left and right bank of the floodplain used as initial Manning roughness value for the simulation of the HEC RAS model.

- **Boundary condition**

Boundary conditions are necessary to establish the starting water surface at the ends of the river system upstream and downstream. In a subcritical flow regime, Boundary conditions are only necessary at the downstream ends of the river system. If a supercritical flow regime is going to be calculated, Boundary conditions are only necessary at the upstream ends of the river system.

If the mixed flow regime calculation is going to be made, then Boundary condition must be entering at all ends of the river system. According to the model, there are four types of boundary conditions namely: Known water surface elevation, Normal depth, Critical depth and Rating curve. For this specific study mixed flow regime, with upstream boundary condition the flow hydrograph and for downstream normal depth selected.

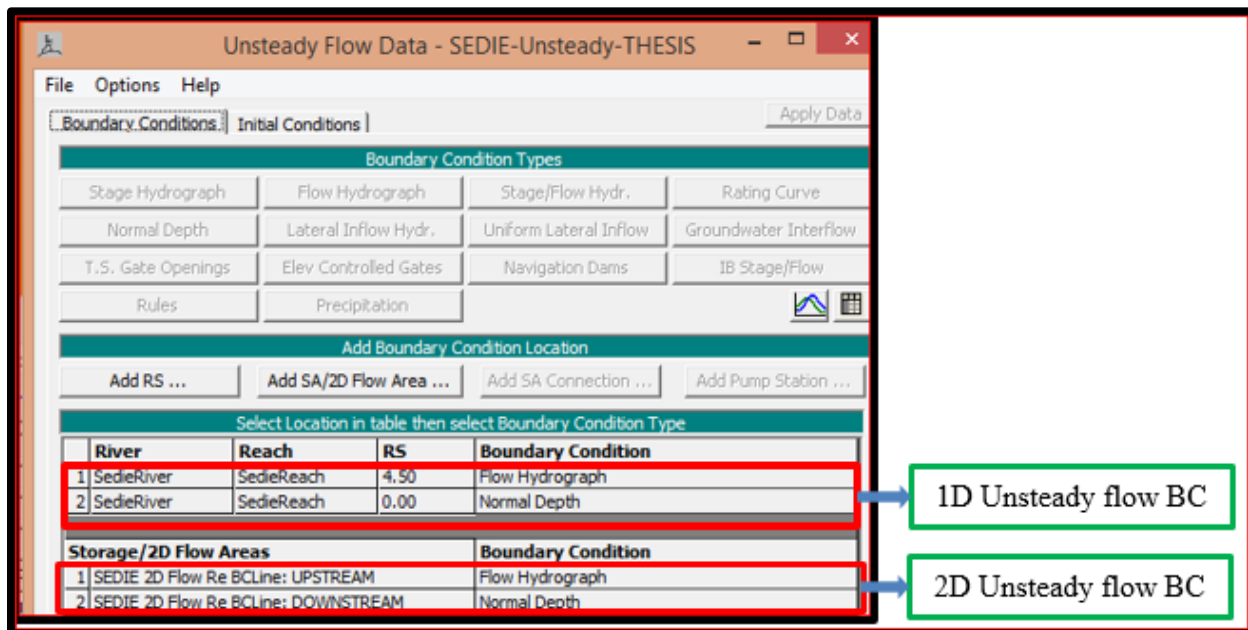


Figure 4-15: Unsteady flow analysis boundary condition in HEC-RAS

- **Expansion and contraction coefficient**

In this specific study there was no reasonable curvature seen in the study reach, therefore the effect of meandering has been neglected and the expansion and contraction coefficient value can be considered as 0.3 and 0.1 respectively.

- **Unsteady flow analysis**

For hydraulic model HEC Ras in the case of unsteady flow it is necessary to adjust the simulation starting and ending date with the start and ending time of the simulation. So that the simulation time window for the different return periods shown in fig 4-16 below fixed from 13Aug2001 to 19Nov2001 for the start and end of the unsteady flow simulation.

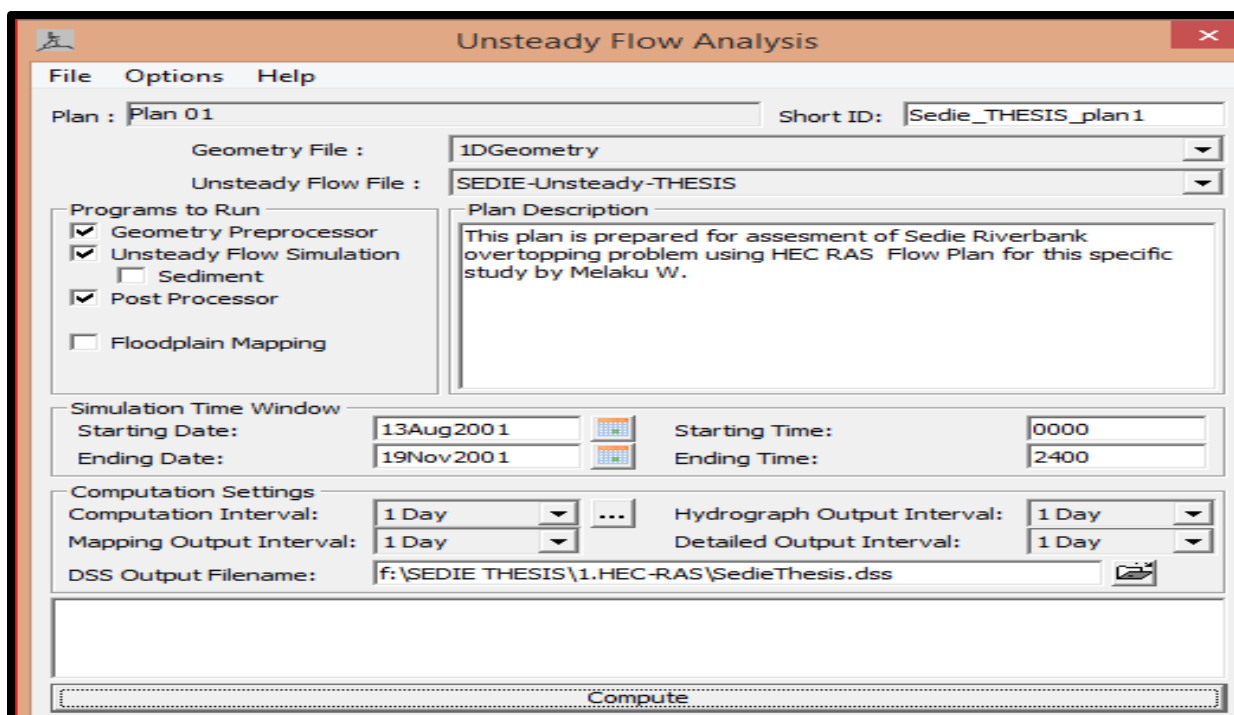


Figure 4-16: Unsteady flow analysis time window adjusted to run

4.6.3 Calibration and validation of the HEC-RAS model

For the calibration and validation HEC RAS model has a complex characteristics. But it has two options, quantitatively it can be calibrate and validate using observed water level on the other hand qualitatively using satellite image and it can be compared with the simulated flood using Normalize Difference Water Index (NDWI) that used for the water bodies analysis. The NDWI can enhance water information efficiently in most cases. For this specific study the NDWI calculated using the Landsat 7 data since the satellite image obtained was at 1996 and 2001.

Therefore depending on the data obtained the NDWI can be calculated by following formula:

For Landsat 7 data, $NDWI = (Band\ 4 - Band\ 5) / (Band\ 4 + Band\ 5)$ equation 4.6

- **Calibration of the HEC-RAS model**

Calibration is a process of varying the parameters or coefficients of a hydrologic method so that it can estimate simulated water level and flood map consistent with local observed water level and flood inundated map. Hydraulic parameters which are varied include roughness coefficients and expansion and contraction coefficients. The HEC-RAS model is calibrated against the Manning's roughness coefficient (n-value) using the measured water surface elevation data from the low flow case. For this specific study the model calibrated by comparing the simulated flood inundated map with satellite image extracted from Landsat on 12July1996.

- **Validation of the HEC-RAS model**

Model validation provides an assessment of the model's ability to accurately reproduce known results. This is performed by running the model at the high flowrate with the calibrated n-values. The computed flood inundated map is compared to the satellite image. For this specific study the satellite image extracted from Landsat image on 20July2001 used to validate of the model

- **HEC-RAS model Performance/ efficiency**

For HEC RAS model efficiency or performance checking both quantitative or/and qualitative methods can be used. But for this specific study there was no observed water level data so that qualitative method selected and satellite images were used as observed flood map and compared with the one simulated map obtained from HEC RAS simulation for two different time periods.

4.6.4 Post processing of HEC Ras model analysis

Flood inundation map can be prepared after the analysis of all the necessary input data's prepared for the running of the HEC-RAS model. Then after it can be prepared for different flow data's for different return periods and the area can be calculated by digitizing all the inundated parts of the map. This flood inundation map prepared for six different return periods, after the calibration and validation process held on the HEC RAS model.

5. RESULT AND DISCUSSION

5.1 Calibration and validation of HEC HMS model result

The HEC HMS model calibration and validation result for these specific study was done using the objective function of the peak weighted root mean square error. These objective function gave emphasis for large errors and gives accurate result in different hydrological modelling and the calibration showed that a good agreement was obtained between the simulated and observed flow of Sedie River. The calibration and validation was done by changing curve number of each sub basins until a good correlation and/or similarity between the simulated and observed flow of Sedie River obtained.

Therefore for each sub basin the initial value specified and the calibrated/optimized curve number value obtained as shown in table 5-1 below. The simulated peak flow obtained 155 m³/s in 12 Jul 1996 similarly the observed peak flow was 134.0 m³/s in the same day of the simulated one. The detailed calibration result for the year (01 Jan 1996- 31 Dec 2000) shown in fig 5-1 below and the hydrograph attached at the appendix D1.

Depending up on the model performance checking methods; the coefficient of determination correlation result obtained was 0.84 (less than 1) and for Nash-Sutcliffe obtained 0.83 (less than 1) as shown in table 5-2 so that the model performance or/and efficiency was good and it shows better performance of the model.

Table 5-1: Initial and calibrated Curve Number for each sub-basins

Optimized Parameter Results for Trial "Melaku_optimize 7"					
Project: Sedie-HEC-HMS			Optimization Trial: Melaku_optimize 7		
Start of Trial: 01Jan1996, 00:00			Basin Model: Basin 1		
End of Trial: 31Dec2000, 00:00			Meteorologic Model: MetrologicalStation		
Compute Time: 09Dec2019, 16:44:21					
Element	Parameter	Units	Initial Value	Optimized Value	Objective Func... Sensitivity
Sub-basin 1	SCS Curve Number...		88.80	81.906	0.02
Sub-basin 2	SCS Curve Number...		85.75	80.707	0.00
Sub-basin 3	SCS Curve Number...		82.85	77.978	0.00
Sub-basin 4	SCS Curve Number...		71.57	68.758	0.00

Table 5-2 HEC HMS calibration performance result

Calibration				
Gaged station	Year	Simulated (Q peak)	Observed (Q peak)	performance/efficiency
Sedie	(01 Jan 1996- 31 Dec 2000)	155.0	134.0	ENS=0.828 $R^2=0.8347$

Table 5-3 objective function result for calibration

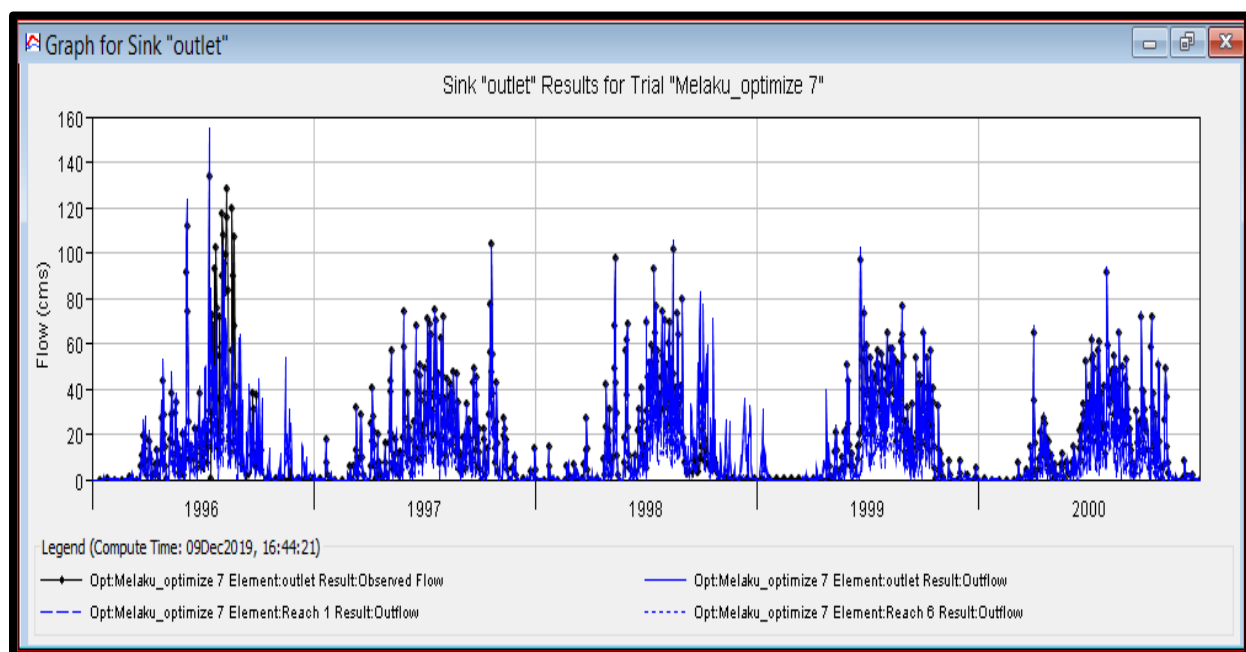
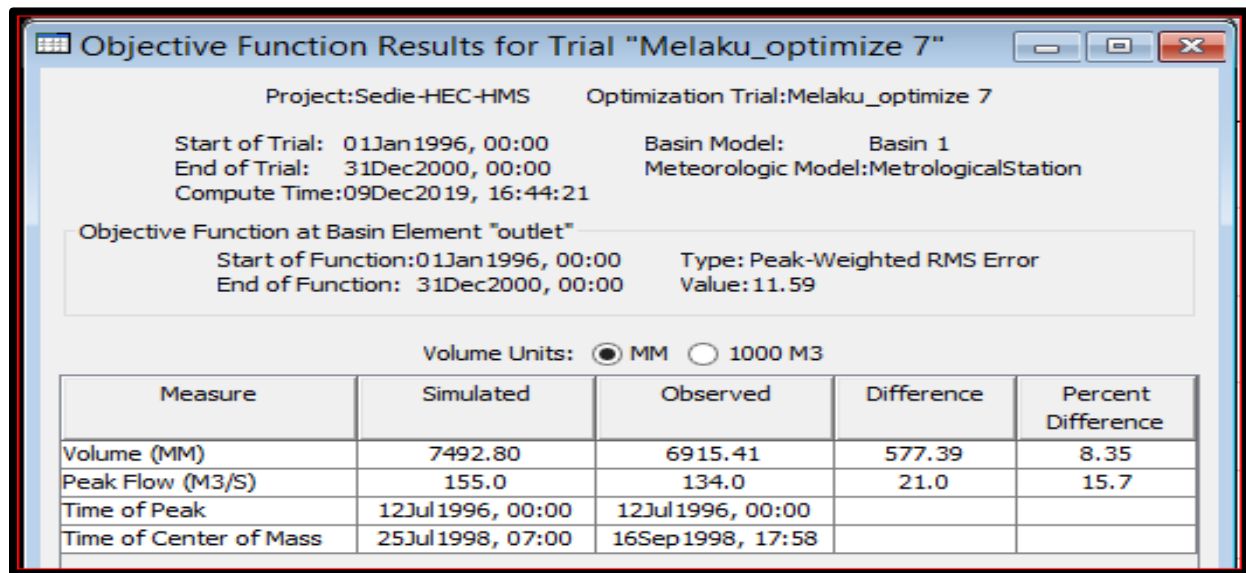


Figure 5-1 simulated and observed flow graphical result at the outlet for calibration

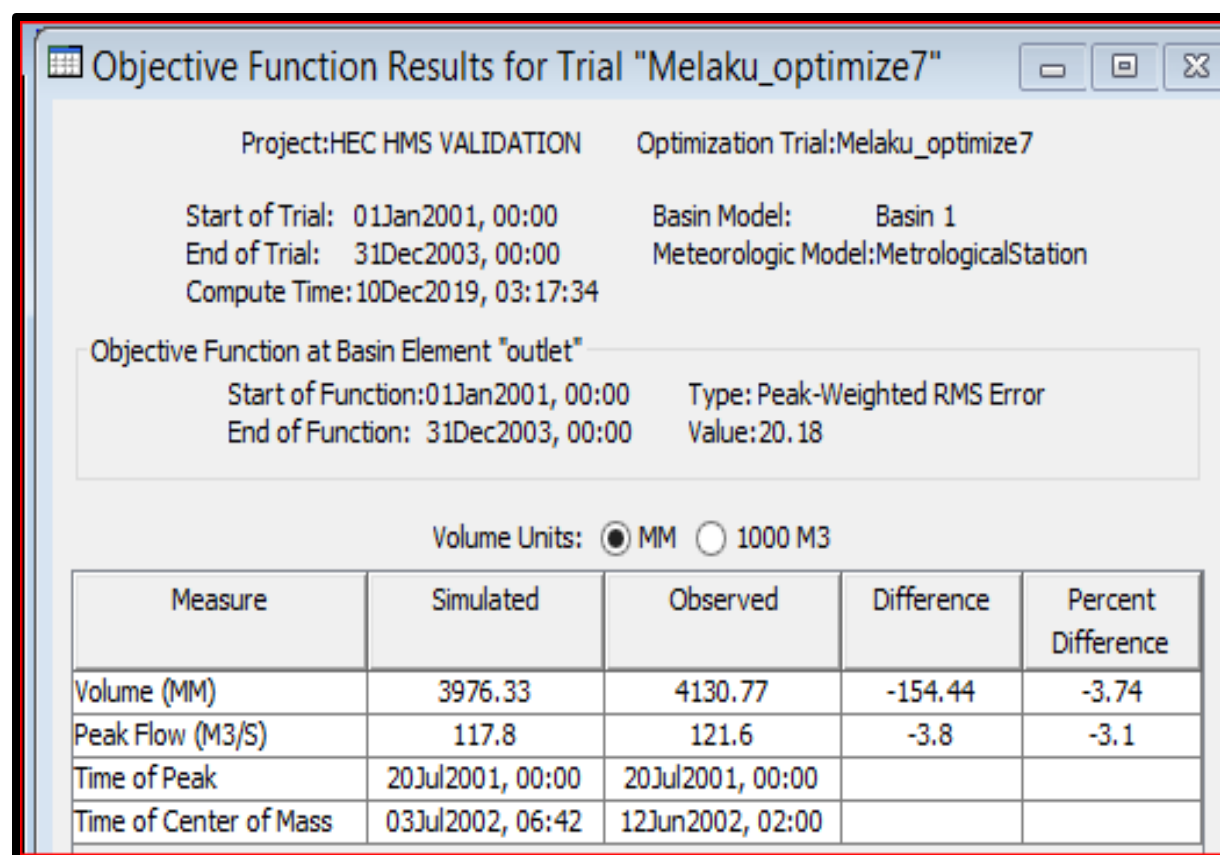
The model validation held on by using the calibrated curve number values 81.91, 80.71, 77.98 and 68.76 for sub basin 1, sub basin 2, sub basin 3 and sub basin 4 respectively for the year (01 Jan 2001- 31 Dec 2003) which was different time period from the data's used for calibrated. The validation was done and the simulated peak flow obtained 117.8 m³/s in 20 Jul 2001 similarly the observed peak flow obtained 121.6 m³/s in the same day of the simulated one and the hydrograph result attached at the appendix D2.

The detailed calibration result for the year (01 Jan 2001- 31 Dec 2003) shown in fig 5-2 below and the performance values was good as shown in table 5-4 below.

Table 5-4 HEC HMS validation performance result

validation				
Gaged station	Year	Simulated (Q peak)	Observed (Q peak)	performance/efficiency
Sedie	(01 Jan 2001- 31 Dec 2003)	117.8	121.6	ENS=0.737 $R^2=0.7375$

Table 5-5 objective function result for validation



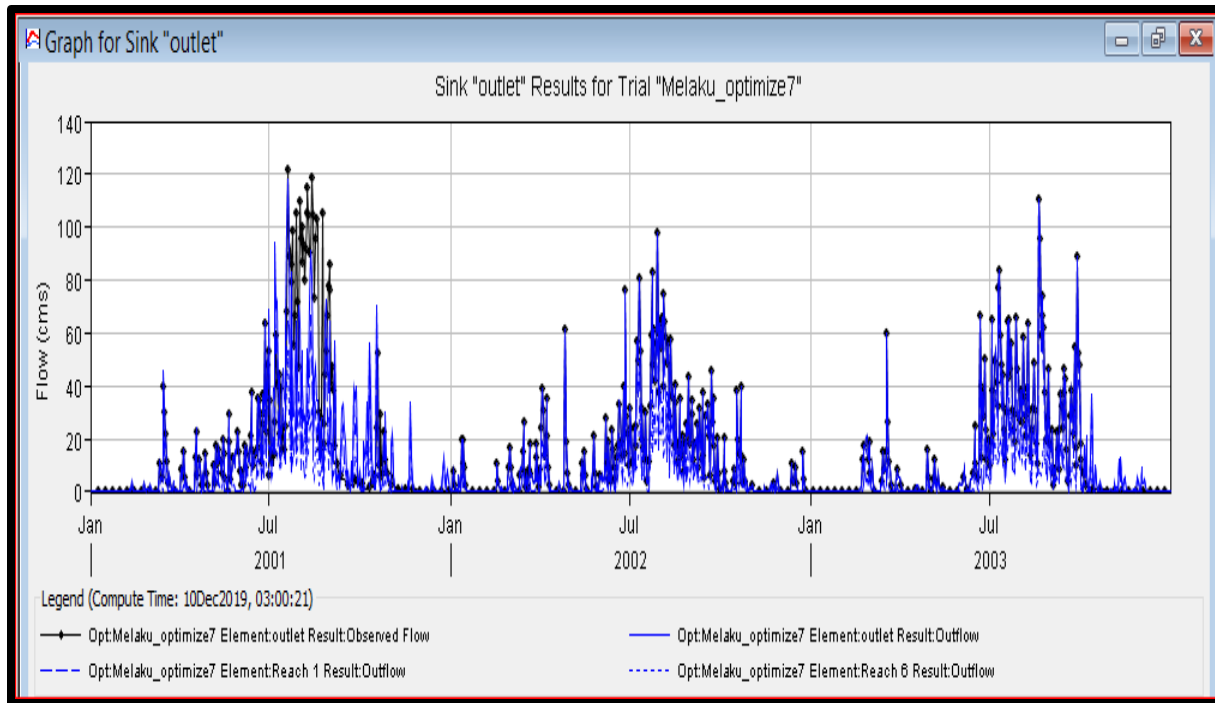


Figure 5-2 simulated and observed flow graphical result at the outlet for validation

5.2 Flood frequency results for different return periods

Certain hydrologic procedures use rainfall and rainfall frequency as the basic input rather than flood frequency. It is commonly assumed that the 10-year rainfall will produce the 10-year flood. Depending on antecedent soil moisture conditions, and other hydrologic parameters, there may not be a direct relationship between rainfall and flood frequency (ERA, 2002). Therefore HEC HMS flood values for different return periods obtained by using frequency storm of a 24 hour storm duration rainfall depth obtained from (ERA, 2002) drainage manual IDF curve of A2 regions.

In this specific study Gumbel distribution, Log-Normal distribution and Log-Pearson Type III used as techniques of flood frequency analysis methods. But this analysis techniques used only to compare with the HEC HMS model flood result values as shown in table 5-6 and fig 5-3 below. The above mentioned flood frequency analysis techniques used only to know the difference of flood magnitude from the HEC HMS model result rather the HEC HMS model result used for further simulation of flood mapping for HEC RAS model.

As described in (ERA, 2002) flood frequency analysis methods used, for a study having equal and/or more than ten years stream flow data but for this specific study the available data used for analysis was eight years.

In addition to this point considering on (ERA, 2002) in hydrologic analysis for determining a peak discharge for a study area which has less than 10 years of stream gaged data and without Ponding or detention storage recommends to use SCS or Unit Hydrograph method. So that for this specific study the flood analysis for different return periods done by using the frequency storm method with integration of SCS Curve number method. Finally as shown in table 5-6 below the flow values result for different return periods obtained and the graphs of the flood values shown in the Appendix D3.

Table 5-6: Peak flood comparison of flow values of Frequency analysis and HEC HMS result

Methods		Frequency Analysis			HEC-HMS
		Gumbel extreme-value distribution	Log-Normal distribution	Log-Pearson Type III	
Qt (m ³ /s)	2	53.58	45.71	43.65	68.2
	5	96.69	91.2	89.13	113.0
	10	125.29	131.83	134.9	188.7
	25	161.35	194.98	218.78	250.0
	50	188.09	251.19	295.12	325.8
	100	214.68	316.23	398.11	406.0

As shown in the fig 5-3 below all the flow values of frequency analysis and HEC HMS result drawn in the same graph. In all return periods the flows are maximum in the HEC HMS simulation result and used for the simulation of the HEC RAS model for preparing of flood inundation map.

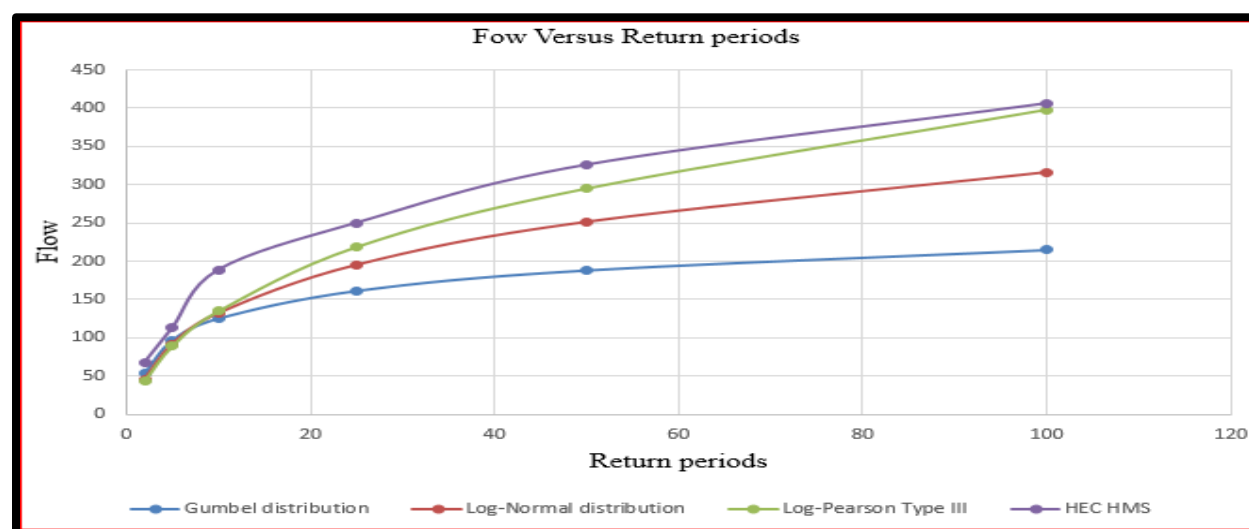


Figure 5-3: Flow values comparison of Frequency analysis and HEC HMS result for the study area

5.3 Calibration and validation of HEC RAS model result

The calibration and validation of the HEC RAS model for this specific study was a very difficult and challenged process that took several time. Even if it was a very vital model for simulation of flood inundation map, the calibration and validation was challenged. The reason is that it was difficult to obtain observed water level, rating curve and also observed flood extent of the study area throughout the past flood event. Therefore for calibration and validation of the model; past observed flooded area downloaded in remote sensing analysis from Landsat image of NASA for different two consecutive times the one used for calibration and the other for validation.

For this specific study, even if there were much past observed data were available from the satellite imagery, the resolution were lower. Therefore two time spans of flood event 12July1996 and 20July2001 of LANDSAT geo tiff image of Band-4 and Band-5 downloaded and relatively has good resolution for further analysis of Normalized Difference Water Index (NDWI) to compare with the model simulation flood inundation map and for this study the calibration and validation of the HEC RAS model obtained depending up on (TAZIN, 2018).

As shown in table 5-7 below the initial manning roughness that obtained from (Cowan, 1956) has been substituted with the value from calibration of the HEC RAS model through trial and error steps. Therefore for this specific study the calibrated value of the right bank and left bank obtained 0.035 for both right and left banks and 0.025 for the main channel. One thing here to consider is that these calibrated manning roughness values obtained by comparing the satellite observed and the simulation of the model qualitatively through a stepwise trials.

Table 5-7: Initial and calibrated manning roughness coefficient

Parameters	Initial manning roughness	calibrated manning roughness
Right bank	0.0625	0.035
Main channel	0.054	0.025
Left bank	0.0625	0.035

For this specific study different simulation time period used for calibration and validation depending up on the observed satellite image obtained from NASA. Therefore the time period from (1Jan1996-31Dec2000) specifically 12July1996 and from (1Jan2001-31Dec2003) specifically 20July2001 were used for comparison of the model with the observed SAT image of 12July1996 and 20July2001 for calibration and validation respectively.

In this specific study it was a must to use a trial and error by changing the manning roughness coefficients for the case of calibration until the observed flood extent obtained from remote sensing and that of the flood inundation map from HEC RAS simulation became approximated and alike. Therefore the flood depth for calibration of the model for the observed past flood and also for the model simulation shows minimum of 0 and maximum of 0.4 m depth. The validation of the model result in depth for observed and for simulation obtained a maximum of 0.36 m and 0.37 m respectively. Finally the calibration and validation of observed and simulated result maps obtained and shown in fig 5-4 and fig 5-5 below.

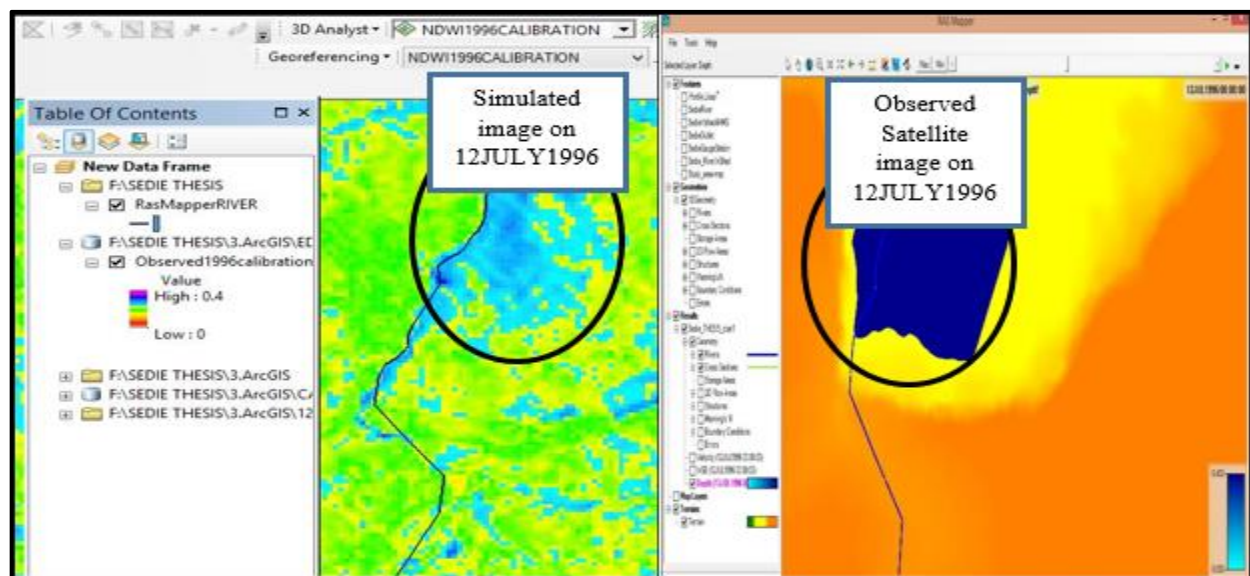


Figure 5-4: Calibration of HEC RAS model for 12JULY1996

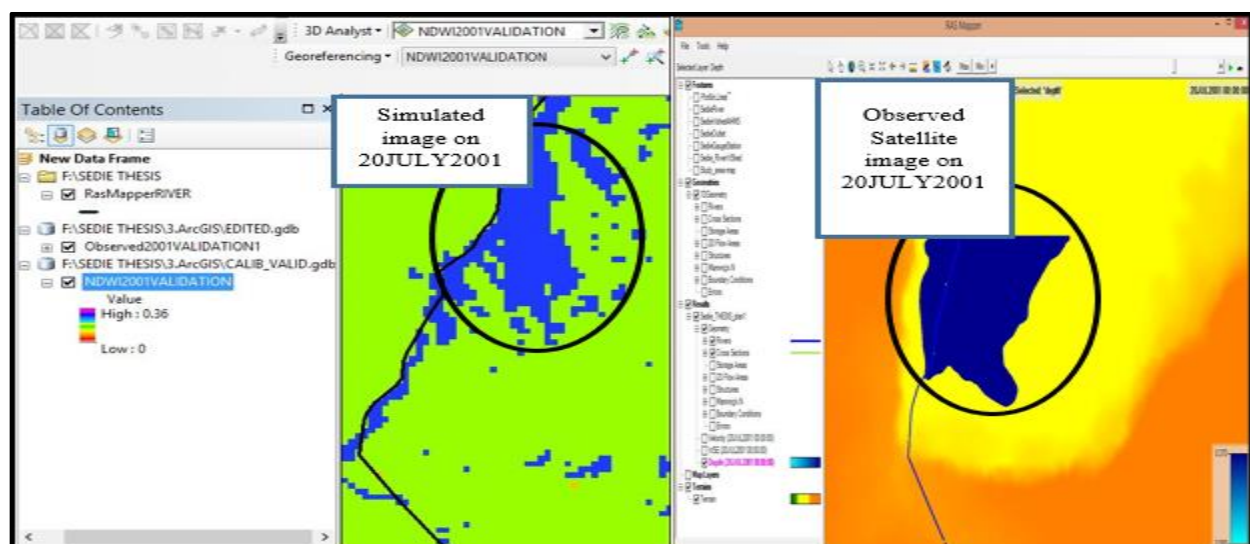


Figure 5-5: Validation of HEC RAS model for 20JULY2001

5.4 FLOOD INUNDATION MAPPING

Flood inundated mapping is an important mechanism for a river flood assessment in a hydraulic simulation. These forecasting of flood areas for different return periods has a vital role for making a prevention technique before the flood occurred.

For this specific study in HEC RAS simulation the flood inundated map determined using the Ras mapper tool without the help of ArcGIS tool. For different return periods the flood inundated area determined by using Ras mapper tools and the sample maps for 2yr and 100yr return period shown in fig 5-6 below and the different flood inundated maps for the remaining return periods attached at appendix E. As shown in the fig below for 2yr return period flood inundated map stations such as station 1.25, station 1.5, station 1.75, station 2.0 and station 3 are highly inundated areas. On the other hand for 100yr return period flood inundated map station 1.25, station 1.5, station 1.75, and station 2 including from station 3.0 to station 4.5 are highly inundated areas. Some stations; station 1.25, station 1.5, station 1.75, station 2.0 and station 3.0 are highly inundated areas obtained from the simulation of HEC RAS result in all cases of return periods displayed on Ras mapper.

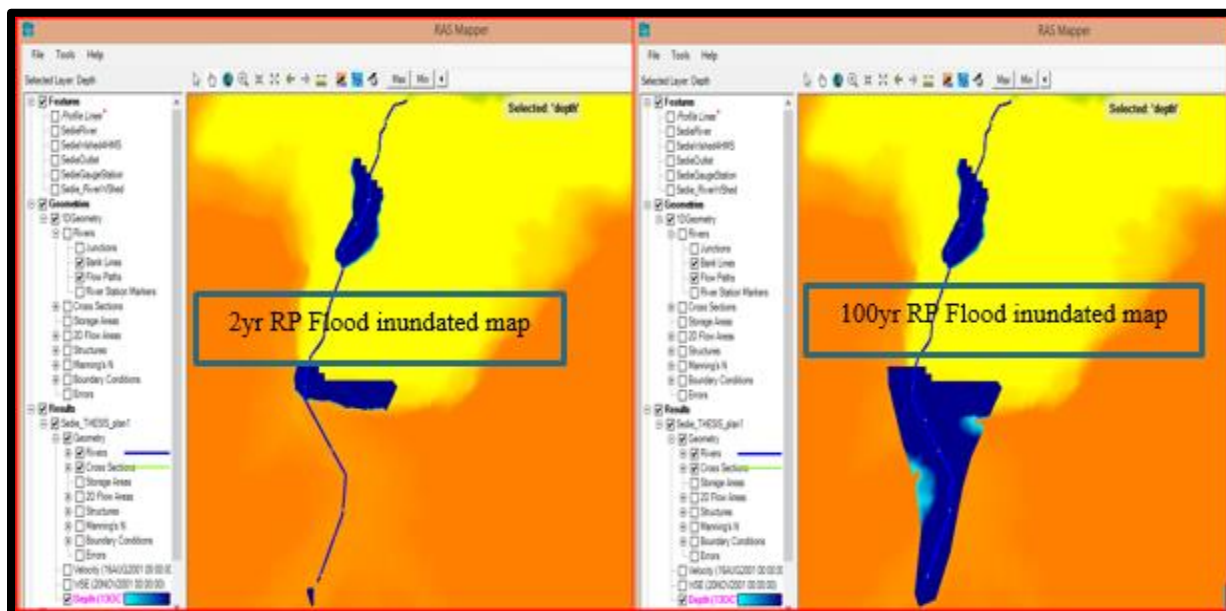


Figure 5-6: Flood inundated map for 2 year and 100 year return periods

For further analysis of the flood inundate map in the fig 5-6 above; it was a must for calculating the flood inundated area for determining the risk of the flood for different return periods. Therefore after the analysis of all the flood inundated maps the inundated area for the different return periods determined and shown in table 5-8 below. As shown in the table the minimum and maximum area inundated obtained 39.67 ha and 280.78 ha for 2yr and 100yr return periods respectively.

Table 5-8: Flood inundated areas for different return periods

RP		2yrs	5yrs	10yrs	25yrs	50yrs	100yrs
FIA	m2	396735.08	474264.94	1013300.24	1470777.48	1772249.23	2807808.71
	ha	39.67	47.43	101.33	147.08	177.22	280.78

5.5 Appropriate mitigation measures for the study area

Depending up on the flood inundated area map obtained for different return periods, it indicated that the map specifically for 50 yr. and 100 yr. return periods inundated 177.22 ha and 280.78 ha areas respectively. Therefore it shows that it is a must to recommend appropriate mitigation measures for the study area unless severe damage will occur.

For 100yr return period the flood inundated map as shown in fig 5-7 below shows that station 1.25, station 1.5, station 1.75 and station 2 including from station 3.0 to station 4.5 are highly inundated areas. Some stations Station 0.00, Station 0.50, Station 0.75, Station 1.00, Station 1.25, Station 2.25 and Station 2.50 are not risky areas that obtained from the simulation of HEC RAS result displayed on Ras mapper.

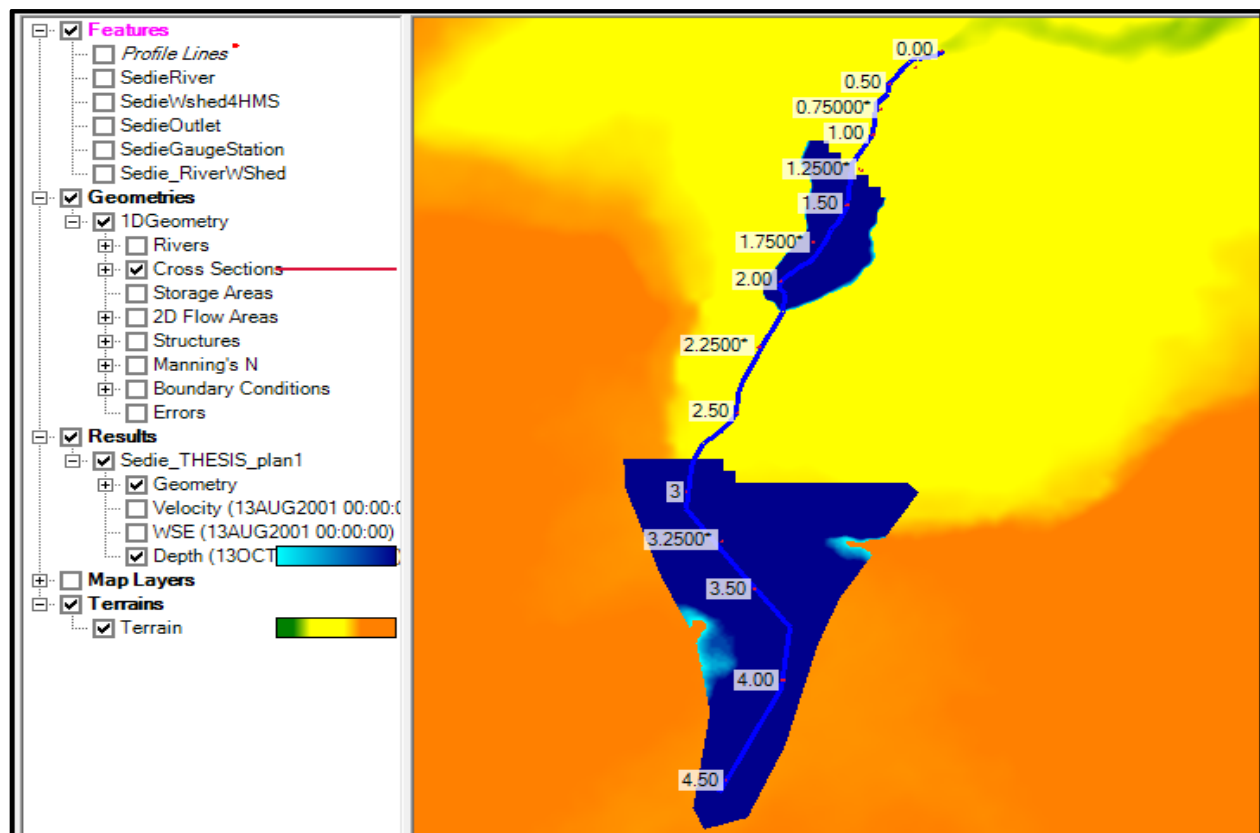


Fig 5-7: Flood inundated map with each stations location for 100 yr. return period

Therefore as shown in the table 5-9 below non-structural measures recommended for stations which aren't highly vulnerable for flood damage; for this stations it is possible to mitigate the problems without any structure by using non-structural measures including vegetation trees, changing land use .and by creation awareness for the people living around the study area.

Structural measures recommended for stations which are highly risky and vulnerable to flood; in this highly flood inundated risky stations the agricultural areas may damage due to flood. Therefore for this specific stations structural measure including constructing dikes, diverting channels, constructing dam at the upstream part of the study area and levee recommended. But to select the preeminent structure it is advisable to perform economic analysis and also HEC FDA simulation analysis since this part not included in the scope of this specific study.

Therefore in order to protect the damage of the agricultural areas from flood the mentioned appropriate mitigation measures should to be apply and the local government should to concern on flood protection measures.

Table 5-9: Appropriate structural and non-structural measures for the study area

Stations (in km)	Distance in (m)	Appropriate mitigation measures	
		Non-structural	Structural
Station 0.00	1250	✓	
Station 0.50			
Station 0.75			
Station 1.00			
Station 1.25			
Station 1.50	750		✓
Station 1.75			
Station 2.00			
Station 2.25	1000	✓	
Station 2.50			
Station 3.00	1500		✓
Station 3.25			
Station 3.50			
Station 4.00			
Station 4.50			

6 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

This study was conducted to assess the river bank over topping problem specifically to calibrate and validate the hydrological and hydraulic models, to produce the flood inundation map of the Sedie flood plain and finally to assess the economic impact of the flood inundated area in Sedie river floodplain by using the hydraulic model HEC Ras, hydrological model HEC HMS with integration of ArcGIS extensions, HEC GEOHMS and Ras mapper tools.

Different data collection methods used for performing this study and the two data types used for the study. Primary data like surveyed river cross section and secondary data's Rainfall data, Hydrological data (stream flow data), DEM data, Land use / land cover data and Soil type data collected and used for the study. Due to the shortage of data only around 8 years of observed flow data 5 years (1996-2000) around 1825 daily flow data for calibration and 3 years (2001-2003) around 1,095 daily observed data's for validation used.

After the analysis of data it was found that HEC HMS calibration and validation result was good. The optimized curve number values obtained for sub basin 1, sub basin 2, sub basin 3 and sub basin 4 were 81.91, 80.71, 77.98 and 68.76 respectively. The performance of the hydrological model (HEC HMS) and hydraulic model (HEC RAS) checked with their own performance evaluation methods. So that HEC HMS model evaluated by the coefficient of determination and Nash-Sutcliffe with good result of 0.84 and 0.83 respectively. In other hand the HEC RAS model calibration and validation result compared qualitatively and relatively good result obtained. The calibrated manning roughness for the left and right bank obtained 0.035 and for the main channel of the river 0.025 obtained.

The flood inundation coverage map indicates 39.67 ha for 2yr, 47.43 ha for 5yr, 101.33 ha for 10yr, 147.08 ha for 25yr, 177.22 ha for 50yr and 280.78 ha for 100yr. specifically for 100yr return periods the flood damages 280.78 ha agricultural area. Therefore both Structural and non-structural measures recommended for stations depending on the flood damage extent and the vulnerability of the areas for flood. Therefore depending up on the result of the models it is possible to conclude that, the models calibration and validation performance evaluation parameter results were good and the flood inundation map shows that farming areas nearest to the study area are at risk with a maximum probability of flooding problem to be occur. Therefore appropriate mitigation measures should to be undertake to overcome the flood damage problems.

6.2 Recommendations

Depending up on the result obtained from the model for different return periods the flood inundated area coverage obtained high especially for 50yr and 100yr return periods. Therefore the following recommendations are advice for dwellers and for concerned responsible bodies.

- In order to minimize the flood risk, magnitude of flood and damages to crops; it is better to adopt soil conservation practices and to construct flood protection structures (like dike) in flood prone areas.
- In order to reduce the crop damage effect in flood prone areas; it is recommended to adopt appropriate land use and land cover practice.
- Researches on flood prediction and mitigation measures on the specific study area should to be motivated and appreciated to decline the flood risk.
- It is recommended to perform flood damage analysis study using (HEC-FDA model) to determine a suitable structure type for the flood prone areas.

REFERENCES

1. A.R. Mardookhpour and H.Jamasbi: Flood zoning estimation & River management using HEC-Ras & GIS Model [Journal]; International J. Energy Water Resources, 2017.
2. Ahmad Tanveer A Study on River Bank Protection Works For the Baleshwar River in Pirojpur District [Journal] // Research Gate. - 2017.
3. Amina Azouagh, Rabei El Bardai, Ismael. Hilal and Jamal. Stitou el Messari Integration of GIS and HEC-RAS in Floods Modeling of Martil River (Northern Morocco) [Journal]: European Scientific Journal, 2018.
4. Amir Abbas Mosaddegh Khaghan & Barat Mojaradi:The integrate of HEC-Hms and HEC-Ras models in GIS integration to simulate Flood (Case study: the area of Karaj) [Journal]:// Current World Environment, 2016.
5. Assefa Tesfay Hailekiros Flood Risk Assessment in Ethiopia [Journal] // Civil and Environmental Research. - 2018.
6. B.A.M.Talisay, G.R. Puno and R.A.L. Amper: Flood map in urban area using combined hydraulic and hydologic models & Geo spatial technologies [Journal] ://2018.
7. Balbhadra Thakur, Ritu Gupta, Ajay Kalra, Sajjad Ahmad & Ranjan Parajuli Coupling HEC-RAS and HEC-HMS in Precipitation Runoff Modelling and Evaluating Flood Plain Inundation Map [Journal]: university libraries University of Nevada, Las Vegas , 2017.
8. Belete Berhanu Kidanewold, Yilma Seleshi and Assefa M Melesse Surface Water and Groundwater Resources of Ethiopia: Potentials and Challenges of Water Resources Development [Journal] - Switherland : Springer International Publishing, 2014.
9. Constantin Buta, Geanina Mihai and Mădălina Stănescu Flash floods simulation in a small drainage basin using HEC-RAS hydraulic model [Journal]: Ovidius University Annals Series, 2017.
10. Cowan W. L. Estimating of Hydraulic roughness coefficients:// Agricultural Engineering, 1956
11. Daniel Henstra, Andrea Minano, and Jason Thistlethwaite Communicating disaster risk? An evaluation of the availability and quality of flood maps [Journal]: Naural Hazards and Earth System Science, 2019.
12. Darshan Mehta Et Al. Dr. S. M. Y & Mrs. Sahita I. Hec-Ras Flow Analysis in the River Tapi [Journal] // Researchgate. 2017.

13. ERA Ethiopian Roads Authority Drainage Design Manual - 2002.
14. ERA Ethiopian Roads Authority Drainage Design Manual - 2013.
15. Gary W. Brunner and CEIWR-HEC HEC-RAS River Analysis System user manual: US Army Corps of Engineers, 2016.
16. Getahun Ys & Gebre Flood hazard assessment and mapping of Flood Inundation Area of Awash River Basin in Ethiopia Using Gis and Hec-Georas/Hec-Ras Model [Journal] Civil & Environmental Engineering. - 2015.
17. Hashemyan F., Khaleghi M.R. & Kamyar M.: Combination of HEC-HMS & HEC-RAS models in GIS to simulate Flood (Case study: Khoshke Rudan river in Fars province, Iran) [Journal]:// Research Journal of Recent Sciences, 2015.
18. Hussein Roshun Et Al. Karim Solaimani, Abdulvahed Khaledi Darvishan & Ghorban Vahabzadeh Employing Gis To River Hydraulic Analysis Using Hec-Ras Model (Case Study: Zaremrood River, Mazandaran Province) [Journal] // Researchgate. - 2012.
19. James Porter & David Demeritt: Flood risk management, mapping & planning the institutional politics decision to support in England [Journal]:// Environmental & planning agency, 2012.
20. K Subramanya:Engineering Hydrology [Book]:NEW DELHI:// Tata McGraw-Hill Publishing company limited, 1984.
21. K. K. L. B. Adikaram M. A. Hussein, M. Effenberger & T.: Becker data transformation technique improve the outlier detection power of Grubbs: // Test for data expected to follow linear relation, 2015.
22. Mary Angeline Orlina Napay and Roger Luyun Hydrological Modeling and Flood Mapping at Quinali Watershed, Albay, Philippines by using HEC-HMS and HEC-RAS [Journal] researchgate, 2018.
23. Muhammad Al-Zahrani, Ahmed Al-Areeq and Hatim Sharif Flood analysis using HEC-RAS model: a case study for Hafr Al-Batin, Saudi Arabia [Journal]: Web of Conferences, 2016.
24. N S Romali, Z Yusop, and A Z Ismail Hydrological Modelling using HEC-HMS for Flood Risk Assessment of Segamat Town, Malaysia [Journal]: researchgate, 2018.

25. Noor Suraya Romalia, Zulkifli Yusopa, Muhammad Sulaiman and Zulhilmi Ismaila flood risk assessment:review of flood damage estimation model for malaysia [Journal]://researchgate, 2018.
26. Orale Ronald Flood Risk Assessment in Post Antiao River Control Project in Catbalogan City ,Philippines [Journal]: researchgate, 2015.
27. P V Timbadiya, Prem Lal Patel and Prakash D. Porey: Calibration of HEC-Ras model prediction of Flood for lower Tapi River, India [Journal]:// J. of Water Resource & protection, 2011.
28. Paolo Billi , Rossano Ciampalini & Yonas Tadesse Alemu The increased frequency of flash floods in Ethiopia: climate change or human impact? [Journal] // Research Gate. - 2013.
29. R M S Prastica, C Maitri, A Hermawan, E Anggraheni, D Sutjiningsih & P C Nugroho: Estimating design flood and HEC-Ras modelling approach flood analysis in Bojonegoro city [Journal]:// Materials Science and Engineering, 2018.
30. Saleh Yousefi, Somayeh Mirzaee, Nicola Surian, Saskia Keesstra, Hamid Reza Pourghasemi, Hamid Reza Zakizadeh and Sahar Tabibian Effects of an extreme flood on river morphology (case study: Karoon River, Iran) [Journal]: researchgate, 2017.
31. Scharffenberg W. HEC HMS Hydrologic modeling system user's Manual: //US Army Corps of Engineers, 2016.
32. Sisay Dawit: Flood risk analysis in Illu Floodplain, Upper Awash River Basin, Ethiopia:// Msc Thesis; School of Graduate studies, Addis Ababa University, 2015.
33. Tasmia Tazin Flood Hazard Mapping Of Dharla River Floodplain Using Hec-Ras 1d/2d Coupled Model Dhaka-2018
34. U.S. Army Corps of Engineers Engineering and Construction Bulletin - 2017.
35. Woube Mengistu Flooding and Sustainable Land–Water Management in the Lower Baro–Akobo River Basin, Ethiopia - 1999.
36. Zeleke Elias Flood mapping case study: //On Bantyeketu River in Addis Ababa MSc thesis Addis Ababa University- Addis Ababa, Ethiopia 2015.

APPENDICES

Appendix A: Field data collection stations cross-sectional profile photo



Appendix B: Monthly rainfall data's

Appendix B-1: Motta meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	0.30	2.10	66.40	61.40	111.30	223.17	310.90	371.35	164.00	58.40	70.50	27.70
1997	0.40	0.00	54.40	58.70	142.40	186.15	295.00	237.00	183.30	188.20	43.00	8.50
1998	5.70	1.00	18.20	34.40	119.60	94.00	378.40	368.60	180.70	211.80	53.20	130.00
1999	18.80	0.00	0.00	22.60	54.65	118.95	300.40	404.49	175.20	228.90	5.50	6.70
2000	0.00	0.00	7.60	111.50	8.00	52.25	243.10	302.80	160.20	209.80	63.00	0.00
2001	0.00	15.30	53.20	30.25	70.20	165.00	464.10	349.45	144.20	148.70	37.20	12.90
2002	10.80	0.30	30.80	93.00	25.10	127.90	310.70	288.70	193.10	66.90	4.50	10.00
2003	0.00	11.55	33.60	8.50	8.80	76.50	348.70	358.77	265.30	52.80	14.70	0.00

Appendix B-2: F. Bet meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	0.30	2.10	108.70	166.50	149.00	187.10	549.10	466.70	247.40	82.90	108.00	16.30
1997	16.00	1.25	15.30	65.75	299.40	222.50	471.20	308.50	182.30	358.10	187.80	10.00
1998	13.10	3.90	57.70	20.90	204.70	174.50	403.10	569.30	266.00	251.20	56.70	0.00
1999	35.70	0.00	3.40	43.70	179.20	327.50	453.50	513.40	239.60	331.10	30.70	48.90
2000	0.10	0.00	33.70	154.20	77.70	293.60	447.20	456.00	404.30	217.50	90.20	27.70
2001	0.00	29.80	53.70	52.60	131.10	284.50	565.90	485.10	242.10	206.30	39.50	33.90
2002	32.00	14.80	82.20	79.60	44.90	300.10	376.60	419.50	209.10	125.50	36.20	82.40
2003	0.00	46.60	45.40	18.20	21.60	245.50	396.00	366.30	280.40	41.70	111.50	6.20

Appendix B-3: F. Birhan meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	23.40	1.80	82.90	174.68	118.90	183.40	396.80	321.40	88.20	6.50	67.90	12.20
1997	34.00	4.60	59.00	124.00	108.10	167.50	374.90	220.80	130.50	145.50	31.70	6.70
1998	5.60	27.10	54.60	28.70	237.40	196.70	376.40	307.20	164.20	247.20	8.10	0.00
1999	63.80	0.00	5.30	81.80	68.30	446.80	409.70	298.10	135.30	200.00	0.40	5.90
2000	0.00	0.00	19.80	139.40	68.00	186.70	368.00	333.10	209.90	168.20	39.40	20.45
2001	0.00	38.60	104.60	93.70	150.30	208.30	405.10	334.70	94.30	51.60	5.50	17.40
2002	54.40	21.60	122.00	72.90	21.00	111.90	324.80	305.10	97.30	37.90	8.90	11.80
2003	0.00	67.50	160.20	12.00	15.90	178.00	407.20	285.10	115.20	24.10	7.60	18.60

Appendix B-4: R. Gebeya meteorological station

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	48.00	19.00	134.00	163.00	148.00	143.70	313.10	215.00	189.50	4.50	116.50	34.50
1997	26.50	0.80	68.80	92.40	122.80	194.80	254.70	253.10	116.40	180.70	135.40	54.90
1998	98.50	25.70	38.30	35.50	191.00	205.10	340.90	311.70	143.20	160.90	41.59	160.90
1999	48.80	0.00	4.50	25.20	54.90	212.10	429.40	389.50	215.80	273.70	14.50	13.80
2000	3.30	0.00	8.10	131.30	137.00	188.10	257.30	270.70	214.00	188.50	109.90	40.20
2001	0.50	56.30	77.20	81.70	147.40	243.50	346.30	368.50	67.60	138.90	66.90	24.50
2002	64.60	49.60	176.80	35.60	28.70	271.30	323.10	288.90	175.05	7.20	16.00	53.44
2003	0.00	105.80	86.90	43.70	6.80	202.70	338.40	436.30	210.80	5.60	3.00	48.00

Appendix C: Daily stream flow data's at Sedie gaged station (m3/s)

1996	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.20	0.70	5.80	2.10	6.10	17.00	32.10	6.20	0.40	0.40
2	0.00	0.20	1.10	0.30	1.70	1.00	7.10	89.40	16.30	10.70	0.40	0.40
3	0.00	0.10	0.80	2.90	0.40	20.20	3.40	117.00	6.60	15.80	0.40	0.40
4	0.00	0.00	0.20	16.60	0.60	9.30	3.70	108.00	6.20	7.30	0.40	0.30
5	0.00	0.00	1.10	16.80	0.20	91.10	24.70	60.10	5.80	13.10	0.40	0.30
6	0.00	0.00	0.60	9.00	0.10	111.50	16.50	63.60	5.20	4.30	0.40	0.30
7	0.00	0.00	2.90	6.40	4.30	73.80	16.30	95.30	4.20	4.90	0.40	0.30
8	0.00	0.00	1.40	11.60	17.50	25.70	21.90	83.00	3.30	2.90	0.40	0.30
9	0.00	0.00	0.60	6.50	20.70	15.20	7.40	99.40	4.90	2.10	0.40	0.30
10	0.00	0.00	0.60	2.10	28.90	14.20	7.10	128.40	2.60	1.90	0.40	0.30
11	0.00	0.00	0.30	0.50	38.00	8.90	14.50	116.00	2.20	1.60	0.40	0.30
12	0.00	0.00	0.10	1.60	16.10	6.80	134.00	83.90	2.60	1.30	0.40	0.30
13	0.00	0.00	0.00	2.20	11.20	14.70	30.50	83.00	2.00	1.30	0.50	0.30
14	0.00	0.00	0.00	6.40	6.30	13.50	30.50	17.20	2.10	1.10	0.60	0.30
15	0.00	0.00	0.00	4.00	4.40	15.10	0.50	33.30	1.70	1.00	0.60	0.30
16	0.00	0.00	0.00	7.80	2.50	8.90	72.80	12.30	1.50	1.00	0.50	0.30
17	0.00	0.00	0.00	12.80	29.20	7.00	47.00	11.90	2.10	0.90	0.50	0.30
18	0.00	0.00	0.00	6.80	34.30	11.60	58.70	56.80	3.20	1.00	0.60	0.30
19	0.00	0.00	0.00	2.10	16.30	22.50	29.70	119.60	5.10	0.80	0.60	0.20
20	0.80	0.00	1.50	1.50	20.20	20.80	31.70	89.40	10.20	0.80	0.40	0.20
21	0.40	0.00	0.80	0.80	11.60	11.50	93.30	16.30	38.20	0.70	0.70	0.20
22	0.10	0.10	5.70	2.20	8.10	4.90	58.70	68.10	16.30	0.70	4.20	0.20
23	0.10	0.10	10.40	7.30	2.90	14.40	102.60	106.90	30.90	0.60	1.30	0.20
24	0.00	0.00	9.90	26.70	14.00	22.60	76.00	41.20	12.30	0.60	4.00	0.30
25	0.30	0.20	6.90	12.80	5.30	22.40	25.40	29.70	9.80	0.50	0.80	0.30
26	0.30	0.40	19.20	7.40	9.60	38.30	14.10	12.30	5.80	0.50	0.50	0.30
27	0.20	0.20	13.90	43.50	4.50	21.70	17.70	13.70	5.40	0.50	0.50	0.20
28	0.10	0.10	9.40	28.80	4.00	7.50	54.80	16.10	37.30	0.50	0.40	0.20
29	0.00	0.00	18.80	19.80	9.50	20.50	72.00	8.10	11.80	0.50	0.40	0.20
30	0.00	0.00	8.50	14.60	20.20	14.00	35.90	26.00	6.80	0.50	0.40	0.20
31	0.00	0.00	2.30	8.30	0.00	21.60	14.50	0.00	0.40	0.00	0.20	0.00

1997	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.60	0.00	1.40	0.10	0.30	23.80	19.00	45.50	10.30	11.90	1.10	0.30
2	2.40	0.00	5.80	0.10	0.00	12.00	49.40	72.10	3.80	4.10	3.70	0.00
3	0.90	0.00	1.80	0.00	2.60	14.20	38.30	26.20	2.90	1.00	6.80	0.00
4	0.20	0.00	0.40	6.00	1.10	8.90	25.20	35.70	18.20	0.10	2.00	0.00
5	0.00	0.00	0.10	24.80	16.00	38.30	32.70	18.80	20.60	0.00	0.50	0.00
6	0.00	0.00	0.00	16.70	43.50	16.90	33.20	10.60	17.00	0.00	0.20	0.00
7	0.00	0.00	0.00	40.20	21.10	23.10	70.60	17.10	5.00	1.30	0.10	0.00
8	0.00	0.00	5.60	21.30	38.60	17.80	52.50	44.20	7.60	17.70	3.00	0.00
9	0.50	0.00	4.10	27.70	56.50	8.90	27.90	41.70	33.40	22.70	18.90	0.00
10	0.20	0.00	1.60	15.60	19.10	7.80	68.80	23.60	18.10	7.40	27.30	0.00
11	0.30	0.00	12.70	5.60	4.30	2.40	38.70	20.90	25.00	1.70	22.40	0.00
12	0.10	0.00	31.80	1.80	1.80	3.00	64.10	29.30	19.60	0.30	17.70	0.10
13	0.30	0.00	9.70	0.40	10.50	1.20	28.80	36.80	26.30	3.60	12.30	0.00
14	0.10	0.00	2.20	0.50	6.10	25.10	19.90	42.30	27.10	13.40	17.50	0.00
15	0.00	0.00	4.10	0.20	8.30	23.70	21.10	22.70	11.10	12.60	13.70	0.00
16	0.00	0.00	8.10	20.10	18.00	9.70	30.40	38.30	17.90	10.70	4.00	0.00
17	0.00	0.00	9.30	7.60	20.60	14.60	19.90	15.10	7.30	28.40	0.80	0.00
18	0.00	0.00	5.50	2.20	14.10	68.10	36.30	47.70	6.20	55.90	0.20	0.70
19	0.00	0.00	28.80	7.60	11.50	47.70	74.90	46.70	9.60	77.10	0.00	0.80
20	0.20	0.00	28.50	4.80	7.50	38.90	44.10	29.90	43.10	47.10	0.30	0.30
21	17.60	0.00	9.70	6.00	2.10	29.60	45.20	29.80	49.20	104.30	0.70	0.30
22	7.20	0.00	6.60	1.80	2.60	14.10	70.10	19.50	26.60	55.20	0.30	0.40
23	2.00	0.00	2.00	0.30	11.80	8.40	37.00	12.00	19.60	38.40	1.90	0.20
24	0.40	0.00	0.40	0.40	9.70	50.80	20.10	46.40	16.70	39.80	5.00	3.50
25	0.10	0.10	0.10	2.60	4.20	46.20	46.60	20.90	13.10	36.50	8.10	1.50
26	0.00	2.40	1.00	2.70	10.80	35.20	18.20	12.90	45.20	13.80	8.20	2.60
27	0.20	1.30	1.90	5.70	7.30	21.30	7.60	34.30	37.20	7.60	9.80	2.40
28	1.80	0.50	1.30	15.70	18.20	10.90	9.50	10.80	16.20	25.40	11.90	2.00
29	2.60	0.00	0.40	7.10	74.00	8.20	34.90	4.60	5.80	42.60	6.00	0.60
30	0.90	0.00	0.10	1.70	58.10	23.60	62.40	1.40	22.50	15.70	1.70	0.10
31	0.20	0.00	0.00	27.00	0.00	33.00	7.40	0.00	5.90	0.00	13.50	0.00

1998	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	4.60	0.50	0.70	0.00	10.50	61.60	13.70	35.10	18.70	9.30	1.70	0.50
2	1.20	0.10	0.30	0.00	15.40	68.70	5.20	70.20	16.20	14.50	1.80	0.50
3	0.30	0.00	0.20	0.00	31.20	25.00	69.40	39.80	7.30	11.30	1.60	0.50
4	0.00	0.00	1.60	2.80	21.40	10.40	30.40	32.80	5.50	22.20	1.50	0.50
5	0.00	0.00	2.80	1.20	7.20	5.10	22.60	50.40	4.80	18.40	1.40	0.50
6	0.50	0.00	7.00	0.30	2.20	3.20	45.10	35.10	4.90	8.60	1.30	0.40
7	0.20	0.00	2.50	0.10	1.30	4.60	34.50	24.60	5.80	7.10	1.20	0.40
8	0.60	0.00	0.50	0.00	5.50	7.90	51.70	50.90	3.10	17.80	1.10	0.40
9	0.20	0.00	0.10	0.00	4.70	6.00	52.50	59.70	3.90	20.30	1.10	0.40
10	0.10	0.00	4.20	0.00	9.50	3.10	19.90	69.50	3.30	13.50	1.10	0.40
11	0.00	0.00	2.80	0.20	49.00	4.50	31.60	30.70	3.10	11.30	1.60	0.40
12	0.00	0.00	3.20	0.60	67.60	4.70	59.00	24.30	3.00	9.50	1.90	0.40
13	0.00	0.00	2.30	2.20	97.60	9.00	41.40	52.60	5.20	6.50	1.80	0.40
14	0.00	0.00	1.40	0.90	43.10	10.90	26.90	31.10	2.90	5.00	1.40	0.40
15	0.00	0.00	0.50	0.20	29.70	3.60	56.50	16.40	3.10	5.10	1.30	0.40
16	0.00	0.00	0.10	0.00	10.40	1.20	93.20	101.40	3.20	4.70	1.20	0.40
17	0.00	0.00	0.20	0.00	2.30	1.40	44.60	46.30	3.00	8.60	1.10	0.30
18	0.00	0.00	1.40	0.00	0.40	5.30	64.70	30.90	5.80	3.60	1.00	0.30
19	0.00	0.00	0.60	0.00	0.00	21.60	76.40	25.40	0.80	9.60	0.90	0.30
20	0.00	0.30	0.20	0.00	0.00	31.30	52.50	40.60	8.00	4.20	0.80	0.30
21	0.60	0.90	0.00	0.00	0.00	22.10	28.20	25.60	15.90	3.60	0.80	0.30
22	3.70	5.50	6.70	0.00	0.00	16.80	56.50	26.60	10.20	3.40	0.70	0.30
23	14.30	4.10	3.90	8.90	0.00	21.80	24.50	73.20	6.20	8.30	0.70	0.30
24	5.90	5.80	9.30	5.90	0.00	15.90	29.10	63.90	3.40	7.70	0.70	0.30
25	2.30	7.60	13.20	2.10	0.00	40.70	30.70	33.00	8.10	4.40	0.60	0.30
26	0.70	3.80	26.90	0.80	0.00	25.10	37.00	21.90	6.30	10.00	0.60	0.30
27	0.10	1.50	13.50	25.50	7.30	15.20	31.20	20.00	3.70	3.90	0.60	0.30
28	0.30	1.60	4.10	42.00	18.40	10.90	45.20	40.80	3.70	3.00	0.60	0.30
29	1.30	0.00	0.90	15.90	21.00	6.10	73.90	36.70	3.90	5.00	0.50	0.30
30	0.60	0.00	0.10	13.00	56.80	14.70	54.30	34.90	9.80	2.70	0.50	0.30
31	1.10	0.00	0.00	37.00	0.00	30.70	79.60	2.00	0.00	0.00	0.30	0.00

1999	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.20	0.10	0.00	0.00	6.00	43.50	37.10	16.50	26.10	41.70	6.90	3.40
2	0.20	0.10	0.00	0.00	3.30	41.80	59.30	48.70	11.80	30.80	5.10	8.10
3	0.20	0.10	0.00	0.00	1.20	15.00	44.00	44				

2000	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.00	2.90	10.60	0.40	33.60	59.00	27.60	31.20	3.50	0.00
2	0.00	0.00	0.00	65.00	11.70	3.10	18.30	60.70	53.30	25.90	6.20	0.20
3	0.00	0.00	0.20	34.80	5.10	7.50	40.80	58.80	31.20	21.50	8.90	0.10
4	0.00	0.00	0.10	15.90	1.40	3.70	23.50	33.00	40.40	25.20	26.00	0.00
5	0.00	0.00	0.00	4.60	0.30	9.40	16.60	34.20	27.30	25.60	48.70	0.10
6	0.00	0.00	1.20	0.90	7.00	4.70	61.70	29.10	21.60	25.30	45.70	7.90
7	0.00	0.00	7.10	2.70	7.00	14.70	52.70	46.30	15.60	17.70	36.50	6.70
8	0.00	0.00	3.30	1.50	3.50	12.10	31.80	40.20	22.40	12.60	14.80	2.20
9	0.00	0.00	0.90	8.00	2.20	5.00	54.50	35.80	18.70	4.90	7.80	0.50
10	0.20	0.00	0.20	9.20	1.00	3.00	49.30	48.60	13.20	1.70	3.10	0.10
11	0.10	0.00	0.00	11.30	0.30	8.40	32.50	28.90	11.90	4.50	4.10	2.00
12	0.00	0.00	0.00	4.70	1.80	6.00	23.70	28.30	7.20	58.10	1.60	2.60
13	0.00	0.00	0.00	20.80	1.10	4.00	36.00	54.30	3.90	71.50	2.70	2.60
14	0.00	0.00	0.00	24.30	1.30	6.50	17.00	42.40	3.60	31.80	2.00	1.10
15	0.00	0.00	0.70	12.90	0.60	5.40	35.40	24.40	6.40	16.40	0.80	1.50
16	0.00	0.00	2.70	11.00	6.50	13.90	56.80	18.20	2.80	37.70	0.20	0.70
17	0.00	0.00	1.90	13.70	4.00	21.70	24.90	48.00	5.40	13.70	1.40	0.20
18	0.00	0.00	0.80	27.00	11.00	17.10	22.70	37.20	30.50	8.50	0.60	0.00
19	0.00	0.00	0.50	29.10	4.80	8.40	60.60	28.90	16.30	5.10	0.20	2.00
20	0.00	0.00	4.10	9.90	2.80	24.00	30.70	31.80	19.20	28.50	0.00	1.00
21	0.00	0.00	1.70	25.00	1.20	26.80	23.80	64.80	24.50	11.00	0.00	0.60
22	0.00	0.00	2.60	12.40	0.30	28.60	38.10	42.20	11.40	19.60	1.70	0.30
23	0.00	0.00	1.60	18.50	1.80	33.00	34.60	21.70	14.50	9.60	0.80	0.10
24	0.00	0.00	3.50	12.80	2.90	22.70	24.70	24.70	17.00	9.10	0.20	0.00
25	0.00	0.00	4.10	7.00	7.80	13.90	24.60	20.00	26.10	50.20	0.00	0.00
26	0.00	0.00	1.90	16.50	4.50	24.20	41.50	50.00	71.80	48.50	0.00	0.00
27	0.00	0.00	1.30	10.00	9.10	52.50	22.30	30.30	40.00	17.10	0.00	0.00
28	0.00	0.00	14.50	3.20	6.20	30.10	20.10	15.50	24.00	5.40	0.00	0.00
29	0.00	0.00	9.30	2.90	2.60	22.80	11.60	28.40	30.00	1.40	0.00	0.00
30	0.00		5.50	6.30	1.60	26.60	23.80	19.80	38.80	0.20	0.00	0.00
31	0.00		2.20		1.10		91.70	44.20		1.20		0.00

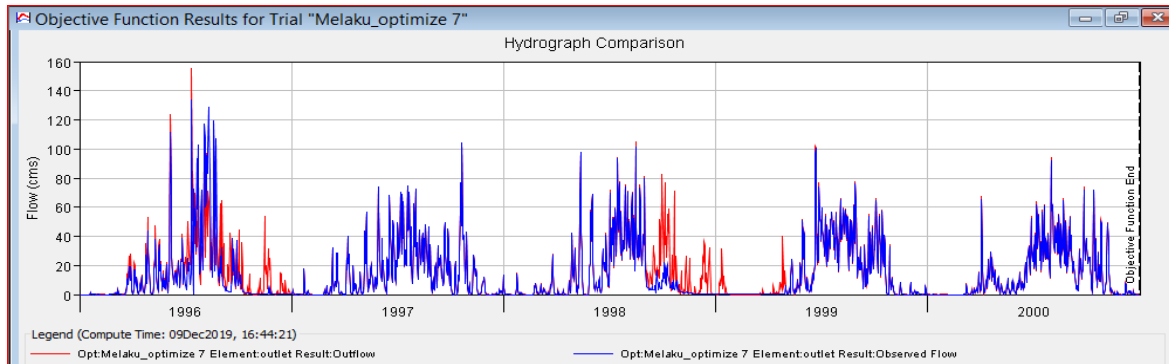
2001	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	0.40	0.10	0.60	8.10	6.50	109.70	76.30	2.30	2.70	0.70
2	0.00	0.00	2.70	0.10	0.20	2.50	34.70	96.00	40.50	2.40	5.00	0.70
3	0.00	0.00	1.40	8.80	0.00	7.50	12.30	87.00	47.40	3.00	6.70	0.70
4	0.00	0.00	0.50	5.70	0.00	6.50	15.60	100.50	38.10	2.30	2.30	0.60
5	0.00	0.00	0.20	15.50	10.40	2.30	9.90	93.60	17.60	1.60	1.90	0.60
6	0.00	0.00	0.10	5.80	9.60	17.40	26.30	80.10	17.40	1.50	1.80	0.60
7	0.00	0.00	0.00	5.50	3.70	9.00	14.20	91.70	14.60	1.40	1.60	0.60
8	0.00	0.00	0.00	4.60	17.50	14.30	58.90	105.70	11.00	1.40	1.60	0.60
9	0.00	0.30	0.00	1.90	10.90	16.80	40.90	115.20	7.50	2.40	1.50	0.60
10	0.00	0.80	0.00	1.50	10.50	11.40	36.70	104.40	6.90	2.10	1.40	0.60
11	0.00	0.70	0.90	0.50	16.10	12.30	21.90	90.50	6.00	1.70	1.30	0.60
12	0.00	3.40	10.90	0.10	13.80	21.20	44.60	88.10	5.40	4.80	1.20	0.60
13	0.00	1.10	9.30	0.00	11.40	37.40	38.80	118.80	5.00	2.10	1.10	0.50
14	0.00	0.20	5.90	0.00	6.80	16.20	16.00	104.40	4.70	1.80	1.10	0.50
15	0.00	0.00	7.10	0.00	20.00	10.00	24.50	103.70	4.80	6.20	1.10	0.50
16	0.00	0.00	40.20	0.00	14.50	13.60	16.40	73.60	4.00	5.20	1.10	0.50
17	0.00	0.00	30.10	13.20	5.40	14.30	12.30	95.40	3.70	6.90	1.00	0.50
18	0.00	0.00	21.60	22.60	5.50	16.90	24.70	103.00	3.30	24.20	1.00	0.40
19	0.00	0.00	11.20	6.70	2.30	35.60	68.50	101.10	3.00	52.70	1.00	0.40
20	0.00	0.00	3.60	6.10	0.60	16.70	121.60	30.30	2.90	9.80	1.00	0.40
21	0.00	0.00	1.30	12.20	29.30	34.70	89.30	20.30	2.60	5.80	1.00	0.40
22	0.00	0.40	6.60	8.50	18.70	29.40	91.70	16.40	2.50	29.40	1.20	0.40
23	0.00	0.30	3.10	2.80	4.90	11.20	79.00	28.00	2.50	12.30	1.00	0.40
24	0.00	3.20	0.80	0.60	7.10	25.50	86.40	105.00	2.40	7.20	1.60	0.40
25	0.00	1.30	0.20	5.80	12.90	36.50	98.50	25.80	2.10	22.40	0.90	0.40
26	0.00	0.50	3.90	2.50	14.00	29.80	55.30	18.50	4.60	12.60	0.90	0.40
27	0.00	1.20	1.40	14.40	9.60	63.50	66.50	44.60	3.30	8.40	0.80	0.40
28	0.00	0.90	0.60	7.30	15.40	22.90	105.70	53.60	6.10	12.50	0.70	0.40
29	0.00		0.80	2.50	14.30	48.30	105.70	66.50	8.40	6.90	0.70	0.40
30	0.00		0.20	1.30	22.50	53.50	72.10	77.90	3.00	4.50	0.70	0.40
31	0.00		0.10		15.30		47.00	85.80		3.00		0.40

2002	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.50	0.10	9.60	8.90	0.50	6.40	52.00	63.80	19.70	0.50	1.10	0.20
2	1.70	0.00	17.00	7.40	0.90	5.10	24.50	55.00	34.70	0.50	2.30	0.30
3	2.40	0.00	9.20	24.10	1.90	6.70	24.20	66.00	29.70	5.00	0.80	0.20
4	7.60	0.00	2.50	38.80	0.70	4.10	11.90	39.50	12.50	1.00	0.20	0.20
5	2.60	0.00	0.50	30.70	0.10	5.00	10.10	74.70	18.20	20.40	0.00	0.40
6	0.80	0.00	4.00	13.60	0.00	6.10	24.30	64.10	19.70	7.70	0.00	0.20
7	0.90	0.00	2.90	13.00	0.00	27.70	17.60	58.80	14.60	3.40	0.00	0.40
8	0.40	0.00	0.90	35.10	0.00	10.60	25.30	49.10	25.40	2.00	0.00	0.20
9	6.40	0.00	0.20	21.20	0.00	5.10	57.10	56.40	9.30	0.50	0.00	0.30
10	2.80	0.00	0.00	9.30	0.10	18.90	49.20	28.90	31.30	0.10	0.00	0.70
11	0.80	0.00	0.00	2.50	0.10	8.60	80.50	27.30	20.30	0.00	0.00	0.60
12	19.80	0.20	6.20	0.50	0.00	3.80	53.60	57.90	12.10	0.00	0.00	11.10
13	10.50	0.10	9.60	0.10	0.10	23.30	20.00	36.20	37.60	0.90	0.00	8.10
14	19.90	0.00	8.60	0.30	10.80	16.00	31.60	38.70	14.00	4.30	0.00	4.30
15	9.50	0.00	15.60	0.10	6.30	9.60	16.70	17.60	5.50	8.60	1.90	3.60
16	2.50	2.50	26.20	0.00	15.50	5.10	12.40	40.80	28.40	3.00	0.70	9.00
17	0.50	10.50	8.10	0.00	6.40	2.40	30.20	33.60	30.30	3.40	0.20	3.40
18	0.10	4.20	1.70	0.00	3.90	12.80	12.40	18.90	28.30	38.60	0.00	1.00
19	0.00	1.70	6.00	0.00	1.20	17.50	4.20	11.30	52.90	19.40	0.50	0.50
20	0.00	1.30	2.00	0.20	0.20	33.10	3.50	17.70	20.90	14.40	0.20	0.50
21	0.00	1.50	8.50	3.70	0.00	34.50	11.80	35.10	6.00	11.50	1.50	0.50
22	0.00	0.50	18.00	1.30	0.20	29.80	32.50	18.60	45.90	39.90	3.00	0.20
23	0.00	0.10	7.20	0.30	0.10	18.80	59.10	13.70	26.20	13.60	1.90	0.20
24	0.00	0.00	6.90	0.10	4.60	13.60	82.90	21.00	35.70	3.10	3.50	15.00
25	0.00	0.00	5.00	0.00	4.80	39.70	48.20	7.50	17.70	12.60	1.30	4.80
26	0.00	0.00	3.40	0.00	21.10	14.30	61.50	1.90	4.40	4.00	0.30	1.10
27	0.00	1.40	4.10	61.20	7.10	76.80	41.90	14.80	2.20	5.00	5.10	0.30
28	0.00	4.40	13.20	19.30	2.00	29.00	56.40	26.00	20.60	1.80	7.00	0.50
29	0.00		18.10	7.00	0.80	21.70	97.70	21.40	6.80	0.40	2.60	0.40
30	0.00		7.70	2.60	2.70	10.10	60.20	43.50	1.40	0.70	0.80	0.10
31	0.30		1.90		1.10		57.80	18.60		2.00		0.00

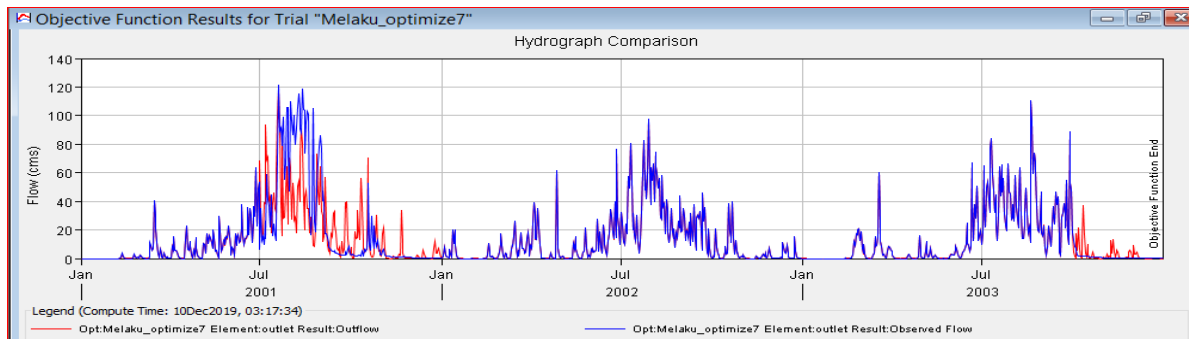
2003	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.00	0.00	18.70	5.40	1.90	3.30	9.90	29.10	16.00	18.30	0.70	0.40
2	0.00	0.00	7.30	2.50	0.50	2.40	18.70	38.00	23.10	12.40	0.70	0.40
3	0.00	0.00	3.40	0.90	0.10	2.50	65.20	26.50	7.10	8.50	0.60	0.40
4	0.00	0.00	9.70	0.20	0.20	5.60	38.50	58.40	2			

Appendix D: HEC HMS outputs

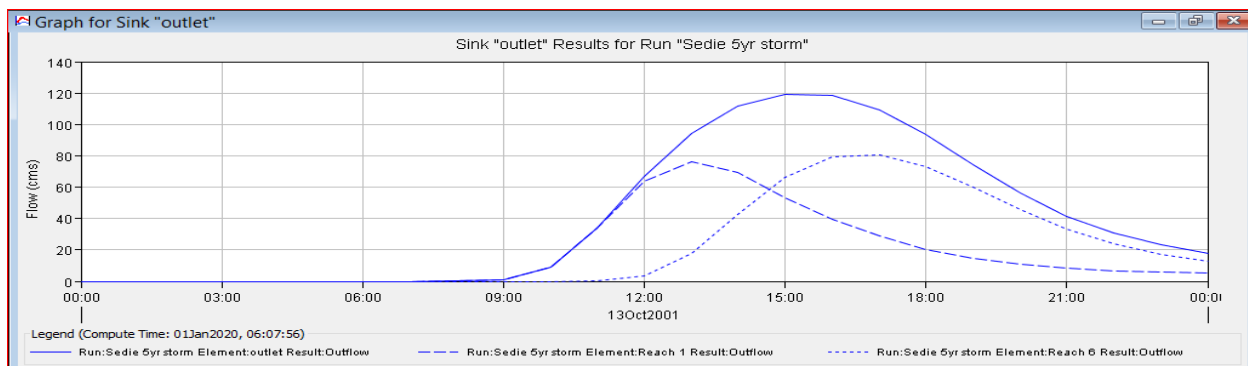
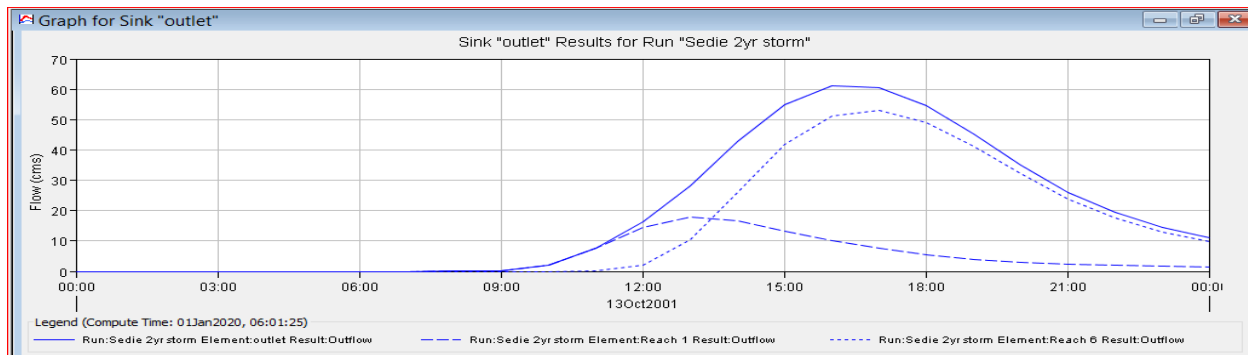
Appendix D 1: Objective function calibration hydrograph result (1996-2000)

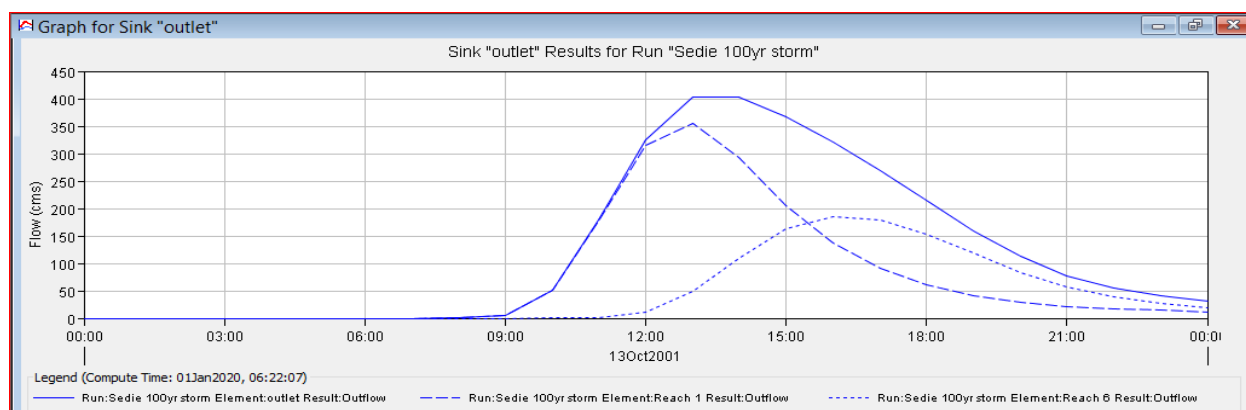
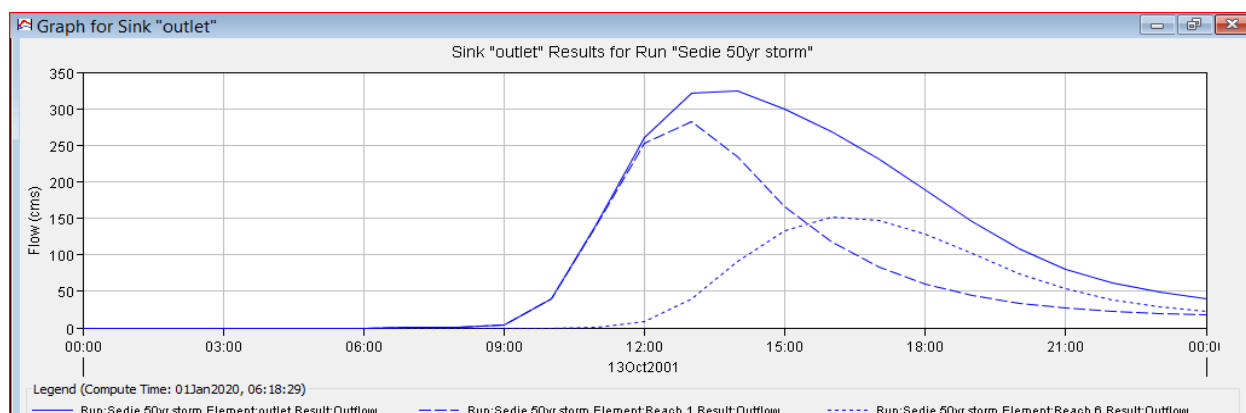
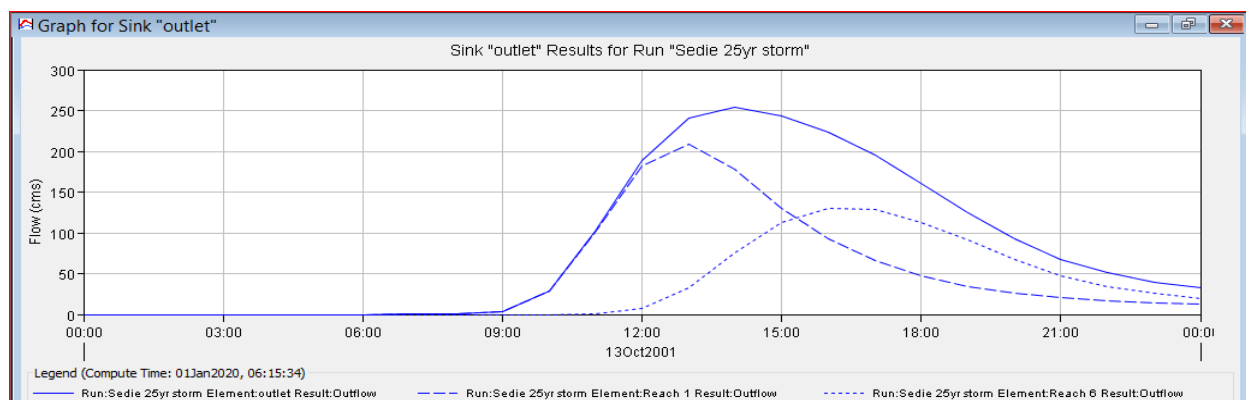
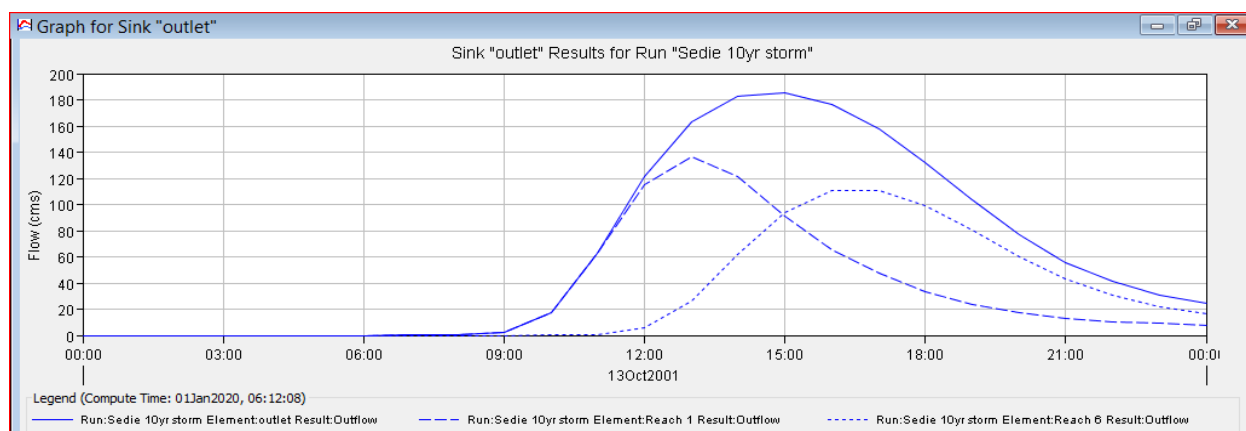


Appendix D 2: Objective function validation hydrograph result (2001-2003)



Appendix D 3: Flood values for different return periods





Appendix E: Flood inundation map result for different return periods

