JIMMA UNIVERSITY

JIMMA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATES STUDIES

MASTER OF SCIENCE IN HYDRAULIC ENGINEERING

FLOOD INUNDATION MAPPING AND HAZARD ASSESSMENT: A CASE OF UPPER-MIDDLE GILO RIVER, ETHIOPIA.

A Thesis Submitted to Jimma Institute of Technology, School of Graduate Studies and Hydrology and Hydraulic Engineering Chair in Partial Fulfillments of the Requirement for the Degree of Master of Science in Hydraulic Engineering.

By: Tadele Shiferaw

November, 2018

Jimma, Ethiopia

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Main Advisor: Dr. Ing. Tamene Adugna (Associate Professor)
Co-Advisor: Mr. Mohammed Hussen (M.Sc.)

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DECLARATION

The research was funded by Ethiopian ministry of Education, and the study as part of program study for the requirement of the master degree in HYDRAULIC ENGINEERING in Jimma University, Ethiopia. All views and opinions expressed there in remain the sole responsibility of the author, and do not necessarily represent that of the institute and highly acknowledged.

FLOOD INUNDATION MAPPING AND HAZARD ASSESSMENT: A CASE OF UPPER-MIDDLE GILO RIVER, ETHIOPIA

Tadele Shiferaw	.......................…	....
Name	Signature	Date

This thesis has been submitted for examination with our approval as University supervisors.

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APPROVAL SHEET

The thesis entitled "(FLOOD INUNDATION MAPPING AND HAZARD ASSESSMENT: A CASE OF UPPER-MIDDLE GILO RIVER, ETHIOPIA)" submitted by TADELE SHIFERAW is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

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As members of the examining Board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by TADELE SHIFERAW. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

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External Examiner	_______________	___________	____________

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ABSTRACT

Flood is a natural disaster which causes loss of life and property destruction. Flood Hazard Assessment is particularly important for policy makers, in order to design mitigation strategies and implement flood risk management planning. This study aims to map flood inundation area and hazard assessment, for upper-middle Gilo River by using Geographic Information System, Analytical Hierarch Process, Hydraulic Engineering Center- River Analysis System and Hydraulic Engineering Center – Geometry River Analysis System software. Based on degree to flooding, the importance of selected parameter (Digital Elevation model, slope, rainfall, flow accumulation, drainage density, land use/cover and soil) are ranked to four flood hazard category, namely very low flooding (1), low flooding(2), moderate flooding(3) and high flooding(4). The weight coefficients are determined for each parameter by Analytical Hierarch Process (AHP) and overlay of ranked spatial information result the final flood hazard map of study areas. The flood hazard maps indicate that 76.26, 2410.29, 5817.44 and 598.06 km^2 corresponds with high, moderate, low and very low flood hazard respectively for upper-middle Gilo River. For this study, Log-Pearson Type-III was used to compute peak discharge. However, there is limited recorded data at the downstream interested point, so the transposing peak discharge from upstream catchment was employed by using Drainage Area Weighting (DAW) methods. The transposing Coefficient was estimated about 2. 794 (Appendix B). Thus, the final peak Discharges for 10, 25, 50 and 100 years was estimated 255.66, 314.64, 360.60 and 406.53m^3/s respectively. HEC-Geo RAS Software used for to develop river geometry such as: the river centerline, river bank, flow path and cut cross-section for upper-middle Gilo River. HEC-RAS, hydraulic analysis includes the computation of the water surface profiles. The flood extent area of inundation mapping for 10, 25, 50 and 100 years is estimated about 54.72, 57.13, 58.88, 60.51 km^2 and 71.76, 83.49, 85.98 and 88.12km^2 for steady and unsteady flood flow simulation respectively. Thus, the inundation mapping are developed for different return period with their extent areas from river course. Also, the flood hazard map gives the flood prone areas for upper-middle Gilo river catchment. Hence, most of the catchment areas are under low flooding and moderate flooding. Some parts are very low flooding and high flooding is less in areas. For further study, the smallest cell size Digital Elevation model, the historical flood existing map or flood record data are better to compare extent areas as well as flood prone areas with simulated flood map.

Key Words: AHP, Flood Hazard, GIS, HEC-Geo RAS, HEC-RAS, Inundation Mapping

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ACRONOYMS

AHP	Analytical Hierarch process
ASTER	Advanced Space borne Thermal Emission and Reflection
DEM	Digital Elevation Model
DAW	Drainage Area Weighting Methods
DPPA	Disaster prevention and preparedness
FAO	Food And Agricultural Organization
FDRE	Federal Democratic Republic of Ethiopia
FFA	Flood Frequency Analysis
FHI	Flood hazard Index
FHA	Flood hazard Assessment
FIM	Flood inundation mapping
GEV	General Extreme Value
GIS	Geographic Information System
Geo-RAS	Geographic River Analysis System
GOF	Goodness of Fit Test
GUI	Graphical User Interference
HEC	Hydraulic Engineering Center
IDW	Inverse Distance Weighting
KST	Kolmogorov –Semirnov Test

LP-III	Log-Pearson Type III
DRMFSS	Disaster Risk Management and Food Security Sector
NDMRC	National Disaster Risk Management Commissions
MoE	Ministry of Education
MoWE	Ministry of water and Energy Authorities, Ethiopia
RAS	River Analysis System
SAT	Spatial Analyst Tool
TIN	Triangular Irregular Network
WSE	Water Surface Elevation

1. INTRODUCTION

1.1. Background

Flood can be explained as excess flows exceeding the transporting capacity of river channel, lakes, ponds, reservoirs, drainage system, dam and any other water bodies, where by water inundates outside river courses. Flood is a continuous natural and recurring event in flood plains of rainfall season areas like Ethiopia, where over 80% of annual precipitation falls in the four wet months (Bishaw, 2012). Floods, a natural phenomenon in many low-lying deltaic areas, can be viewed as beneficial, especially for enhancing soil fertility on flood plains, but also as a hazard. It damages human life, property, the environment whether induced by natural event and human interference (Joy and LU, 2009). Natural disasters are happened every year and their impact and frequency seem to have greatly in recent decades, mostly because of environmental degradation such as deforestation, intensified land use and increasing population. Floods problem are among the most frequent and costly natural hazard in terms of human and economic loss affecting many countries or regions in the world through the time (FEMA, 1997).

River flood is defined as high flow that exceeds or over-tops the capacity either the natural or the artificial banks of stream (Solomon, 2012). Flooding results from excessive rain on the land or streams overflowing channels. Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow and duration of the rainfall event (Solomon, 2012). The most common types are: river floods, flash floods, coastal floods and urban floods. In general, factors causing flood in many parts of the world are climatology, changes in land- use and increasing population and land subsidence (Solomon, 2012).

Mankind does not have much choice rather than to accept the floods, because of unexpected natural occurrence of flooding. Therefore, to live with floods both have to have certain level of understanding, floods can be alleviated but not totally eliminated (Edna, 2007). Floods is a temporary conditions of partial or complete inundation of normally dry land area which may last from hours, days and months (Edna, 2007).

However, in order to find and fulfill basic human life requirement, human being practice on the River and live along the River such as unplanned rapid settlement development, uncontrolled construction of buildings and major land use changes can influence the spatial and temporal pattern of hazards.

There are several factors that contribute to the flooding problem ranging from topography, geomorphology, engineering structures failures, climate, poor drainage and other local factors can be mentioned.

Several factors need to be considered in accurate flood hazard mapping under conditions of data and other material scarcity that notify the situation in most studies in Ethiopian. For instance, flood generating parameters such as topography, soil, land use /cover, rainfall and stream flow was collected from GIS (Geographic Information System) department, Ministry of water and Energy Authorities, Ethiopian and National Metrological Agency.

Gilo River is found in the Gambela Region of southwestern of Ethiopia. It has a variety of names known as Ghelo, Ghila, Gila, Gilowenz and Jila River. From its source in the Ethiopian Highlands near MizanTeferi it flows to the west, to join the Pibor River on Ethiopia's border with Sudan. It originates from goder, mengesh and partly from Dima woreda districts. Its coordinate are located between latitude 7° 20' 00''-8° 10' 00''N and Longitude 33° 10' 00'' - 35° 50' 00''E.The catchment area of upper-middle Gilo River of the basin is estimated about 9100km^2 with respect to pour point selected.

1.2. Statement of the problem and justification

Flood is a natural hazard that causes damage of property and life. Now days world community have been impacted by consequences of flood risk such as property damage, life, infrastructure damage, migration of ecology, economic, poverty and drought (NDRMC, 2017; FEMA, 1997). Ethiopia is also one of the countries which suffer by such a flood problem during high rainfall season of the year (Solomon, 2012). High flood, which is normally due to the intensive rainfall in the lands of the watershed, sparse vegetation cover, topography, steep slopes, low infiltration capacity of the ground surface (Tesfay,2018).

The National Disaster Risk Management Commissions (2017) reported flooding in communities within the Awash River basin and the potential for additional flooding in areas that lie downstream. The Ethiopian flooding report (2014) indicate that, over 20,000 peoples in Oromia region are affecting by floods. Some areas in Gambela region have also reported flooding affecting about 13,000 peoples. Also, the lower part of Gumera catchment in Amhara region is known as one of the flood prone areas by annual flooding in the Fogera flood plain.

Owing to this, the author focuses his study on flood problem happen in Gambela region along Gilo River in Ethiopia. Peoples in this region are worried about over-using their social networks, here flood occurring more regularly (Alemseged, 2013). During high rainfall depth at summer season of the year the overflow of River course causes series flood hazard and risk consequence. In this Region most of the community lives along the River boundary in order to use water for Agro-economic development through crop production by Irrigation. However, as result of basic requirement of human life; that they are obliging to practice behind a river course and then unexpected time occurrence of flooding damages their property every year (Alemseged, 2013).

Figure1. 1 Flooding in Gambela Regional state, Ethiopia   source: Ethiopian flooding report, 2014

Flood hazard mapping is an integral part of land use and emergency planning (FEMA, 1997). In Ethiopia study focusing on flood hazard not coverage different parts of flood prone areas. Therefore, this research tries to have information regarding flood response, flood warning time, flood hazard level, flood depth, and mapping inundation area, that would be known and thereby peoples safe from flooding problems. Moreover, government should pay special attention and measurement be on flood planning and emergency action plan to reduce probability of flood risk problem as result of its consequence causes poverty, drought and economic disruption of the communities as well as the country.

1.3. Objectives of the study

1.3.1. General objective

The main objective of this study is to map flood inundation and hazard assessment of upper-middle Gilo River, Ethiopia.

1.3.2. Specific objectives

1. Peak discharges estimation for different return periods.
2. To simulate flood water surface profile for upper–middle Gilo River.
3. To develop flood inundation map for upper-middle Gilo River.
4. To develop flood hazard map for upper-middle Gilo River catchment.
5. To recommend mitigation measures.

1.4. Research questions

The following questions are going to addressed based on the study of research objective:

1. What is the peak discharges for different return periods?
2. What will be flood water surface profile for upper –middle Gilo River?
3. What will be the flood inundation of the areas?
4. Is it possible to develop flood hazard map for River at catchment scale?
5. How can be flood problem mitigated?

1.5. Significance of the study

Flood is a natural hazard that causes damage of property and life. Thus, some parts of Ethiopian are affected by flood. Owing to this, the author deal with assessment of flood hazard to have detail information about future potential natural flood magnitude, time occurrence and its frequency. The future flood information has been determined from past information or previous historic records of flood characteristics hydraulic, hydrological and metrological data of study area. Records and information about previous floods was providing important information to assist the development of the flood hazard. Also, the extent area of flood is to be identified along particular river site.

A better understanding of the flooding impacts can be used to develop new strategies for protecting flood-prone areas. This study promotes the sustainability of flood plain management decisions and guides future policy and planning decisions.

One of the importance of this study is to have detail information about future floods. Through determination of peak flood magnitude and time occurrence using flood frequency analysis and any others supporting techniques and flood plain areas along the river course is identified. Also, the flood characteristics like flood level, depth, flow velocity, hazard and others have to be evaluated.

Another importance of this study is to serve for flood preparedness and response having information about future flood: The occurrence of flood consequence is a probability occurrence at a certain future time period which was known by flood forecasting techniques. Therefore, the government, the people and any concerned body living along particular flood hazard and inundation areas should have enough flood information to be ready, flood hazard awareness and take alternative measurement to prevent flood risk and damage consequences.

1.6. Scope of study

The scope of study is bounded by objective of the study that have aimed flood inundation mapping and hazard assessment of Gilo River, Ethiopia. The flood hazard assessment is to be accomplished using GIS software package and by using flood generating parameter such as Digital Elevation Model (DEM), slope, rainfall, drainage, soil type and land use/ land cover. These parameters were used to develop flood hazard index for flood hazard rank or weight and mapping of flood hazard. In addition to this develop river geometry using HEC-Geo RAS and hydraulic parameters such as flood depth; flow velocity and others have simulated using HEC-RAS. Finally, flood inundation map gives extent areas of flooding from river course. Therefore, the vertical depth and horizontal length of this study have to be scoped to welcome with adequate, reliable, acceptable research result or outcomes and call objective.

1.7. Limitation of the study

Flood hazard assessment of the flood prone areas and mapping, in Ethiopia is not an easy task. There is a limitation of adequate and reliable rainfall, stream flow and soil data. The rainfall metrological station and stream flow gage station may not record at downstream of Gilo River. Beside this, the

Digital Elevation Model (DEM) may not extract drainage path correctly as it changes the direction of the river at the downstream. So, due to this, the study focused along the upper-middle river catchments.

1.8. Organization of the thesis

This thesis report consists of five chapters. The contents of each chapter are organized as follows: In the first chapter the background information, problem statement, general and specific objectives, Significance of the study and Scope of the study are discussed. In the second chapter, literature review about the subject matter is presented and it gives a scientific review of this study. In the third chapter methodologies followed for determination of flood hazard assessment and inundation mapping are presented step-by-step. Description of the study area, Data used in the study, their sources and the methods used for data quality control are mentioned. The fourth chapter presents the results and discussion. It gives a detailed about flood prone areas in catchment scale and flood extent areas along the river. The fifth chapter summarizes the conclusion and recommendation for future study.

2. LITERATURE REVIEW

2.1. Flood hazard

Historically, flood damage is greater than that of any other natural hazard. However, the impacts of flooding cannot be eliminated, a sound understanding of flood behavior enables informed decision making on the management of risk (to existing and future) where practical, feasible and cost-effective by Members of the BMT group companies in Queensland government (BMT, 2017). For a Gilo River, Ethiopia floodplain, this paper was focus on flood behavior and hazard can be studied and the likely location, type and scale of effects for a range of floods is determined within reasonable methods (ARC-GIS, HEC-Geo RAS/ HEC-RAS) to map flood inundation and hazard assessment.

There are many different definitions of hazard. According to Zein (2009) defines hazard as “the extreme natural events which may affect different places single or combination at different times over a varying return period”. On the other hand, according to Asian Disaster Preparedness Centre (ADRC) “hazard is an event or that has a potential for causing injuries to life and damaging property and the environment”. In order to know the important definition thing of hazard, UN- ISDR (2004) proposes four elements which are probabilities, a specific period of time, a specific area and the intensity. Hazards related to geological and geo-morphological processes such as earth quake, volcanic, eruptions, landslide and floods are called geo-hazard. According to Zein, (2009) floods are define as extremely high flows of river whereby water inundates flood plains or low laying area. Flood hazard is measured by probability occurrence of their damaging values generally as flood risk or by their impact on society and loss of lives.

Based on floods occurrence (Federal Emergency Management Agency) (FEMA, 1997) divides floods in six major classes. They are river flooding, alluvial fan floods, ice jam floods, dam break floods, local drainage and high ground water level and fluctuating lake level.

In some areas, floods in Ethiopia belong to the river floods which occur in low - land flood plains. The floods are caused by high intensity and duration of rainfall making a body of water rise in the river so that overtop natural or artificial banks of a river.

The hazard assessment identifies the probability of occurrence of a specific hazard, in a specific future time, as well as its intensity and area of impact. Hazards can be single, sequential or combined in their origin and effects (Getahun and Gebre, 2015). Each hazard level is characterized by its location, intensity and probability. The flood hazard assessment need to be presented using a simple as possible, such as indicating very high, high, medium, low and very low hazard rank.

2.1.1. Flood characteristics and frequency analysis

There are various characteristics of flooding that influence flood hazard and inundation area, of which some may be more significant than others. These parameters of flood characteristics are more importance to some categories of hazard and flood hazard map. For example, extent area, depth, duration, velocity, rate of rise of flood water, contamination and debris loads of the flood water, whether the water is fresh or salt water, warning time and previous experience of flooding are the flood character parameter. In practice, much of the focus on estimating the potential hazard that causes by flooding is flood depth and velocity presumes an important parameter in flood hazard assessment (Getahun and Gebre, 2015).

An important problem in hydrology is the estimation of flood magnitudes, especially because planning and design of water resource projects and flood plain management depend on the frequency and magnitudes of peak discharges (Bedassa, 2016). Flood Frequency Analyses are used to predict or design flood for sites along the River. In flood frequency analysis, a relationship between a flood magnitude Q and its return period T is developed by statistical modeling of a times series of peak flows (Samiran, 2012). The technique involves using observed annual peak flow discharge data to compute statistical information such as mean values, standard deviation, skew and recurrence intervals. This statistical information's are used to construct frequency distributions.

2.2. ARC-GIS, HEC-GEORAS/HEC-RAS based flood hazard and mapping

GIS is one of the key information technologies widely used to collect, store, analyze and display a large amount of spatially-distributed information in layers. Many GIS integrated modeling applications capitalized on using the GIS as a data base manager and visualization tools. Data requirements, flood inundation extent and depth are the main area where these procedures might need to be modified and differ from the manual flood hazard map declination processes (Vu Thanh, 2009). So, GIS can be used to construct a map of susceptibility to flooding, which indicates the areas where flood is most likely to occur.

GIS is effective tool to determine the high risk of flood prone areas down to small hydrological basins. In addition, GIS has its capability to manipulate multi-dimensional phenomena of natural hazards using spatial component (Kamonchat, 2017).

The physical factors used in GIS needs to be associated with a procedure referred to as multi-criteria analysis (MCA) that weights the parameters logically. One of the methods to determine the relative importance of the factors is Analytical Hierarchy Process (AHP) (Kamonchat, 2017) that has been used in many applications (Kamonchat, 2017). This study assesses flood hazard area using spatial multi-criteria index to understand the relative importance of the parameters used. Then, the produced flood hazard map is compared and discussed with an observed flood extent from secondary data source.

HEC–Geo RAS and HEC-RAS computer modeling used for determination of river characteristics as well as delineation of flood hazard affected areas. HEC-Geo RAS is an ARC-GIS extension tool used to develop river cross section and alignment which serve for input data for HEC-RAS. HEC- RAS is a computer program that simulates the hydraulics of water flow through natural rivers and other channels. It is developed by US Department of Defense, Army Corps of Engineers in order to manage the rivers and other public works. It has found wide acceptance by many others since its public release in 1995. HEC-RAS software is uses as converter tool between ARC-GIS and HEC-Geo RAS software (Getahun and Gebre, 2015).

2.3. Flood hazard assessment

According to Vu Thanh (2009) flood hazard assessment depend on many parameters such as flooding depth, flooding duration, velocity of flood flow, timing and frequency of occurrence. Hazard index (HI) represents the level of flooding impacts. The hazard zone areas are determined from hazard factors which represents the combination of all hazard parameters.

According to Vu Thanh (2009) the flood depth categories is taken under equal of 0.5m, thus $d < 0.5$m (Low), 0.5m $< d <$ 1m (moderate), 1.5m $< d <$ 3m (high) and $d >$ 3m (very high). Also hazard index for flooding duration are given as short $t <$ 3hr), medium (3hr $< t <$ 7hr, long (7hr $< t <$ 25) and very long ($t >$ 25hr).

According to Zein (2009) explain a flood hazard map as a map that shows the inundation area for a scenario with a certain return period in single or several flood scenarios. The maps illustrate the intensity of flood situations and their associated exceed probability. Whereas, the maps without exceed probability called flood danger maps which is illustrated historic or synthetic flood events. Flood hazards are estimated based on flood depth and duration.

As recommended by Karim (2010) four hazard categories were used and each category was represent by a hazard Index. A hazard index (HI), is introduced to represent degree of hazard corresponding to different flood depths. To devise a scale for hazard index flooding areas were divided in to four depths categories based on three critical depths 0.8m, 1.0m and 3.5m. Different breaking values were checked based on the expert knowledge, local information and different possible realization and from previous knowledge. Based on the three critical values of flood depth (d), hazard is to be classify as low ($d < 0.8m$), Medium ($0.8m \leq d < 1.0m$), High ($1.0m \leq d < 3.5m$) and very high ($d \geq 3.5m$). As recommended by Karim, (2010) a linear scale of hazard index (Hi = 1, 2, 3 and 4) are used to represents Very low, low , medium, and high hazards respectively.

As recommended by Wildschut (2013), Flood Hazard Mapping is flood map illustrating the flood hazard prone area (the intensity of flood situations and their associated probability). Usually, flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth and flow velocity. The hazard aspect of the flood is related to the hydraulic and the hydrological parameters.

According to Mohammed (2017) flood hazard level are grouped in to three: depth less than 0.76m categorized as low hazard level, depth with the range between 0.76m – 1.5m categorized as moderate hazard level and depth more than 1.5m categorized as high hazard level. Previous study (Mohammed, 2017) suggests that flood hazard for each region should have different categories depending on its topographic and flood characteristics exist in the area.

2.4. Inundation mapping

Previous studies by Merwade and Olivera, *et all* (2008) recommends that flood inundation extent is represented as a deterministic map without consideration to the inherent uncertainties associated with various uncertain variables (precipitation, stream flow, topographic representation modeling parameters and techniques and geospatial operations) that are used to produce it. Therefore, it is unknown how the uncertainties associated with topographic representation, flow prediction, hydraulic model and inundation mapping techniques are transferred to the flood inundation mapping. Additionally, by using sample data set, probabilistic flood inundation map is articulated and an integrated framework approach that will connect data, models, and uncertainty analysis techniques in producing probabilistic flood inundation maps is presented.

Moore and Gilles, (2010) suggest that inundation maps are the most useful results produced from flood simulations, but uncertainties must be considered because error is introduced throughout the development process. The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing and theoretical assumption can cause result inaccurate. The most important parameters (roughness coefficients, geometry, topography (high resolution DEM), and boundary condition) need pay care in predicting inundation map.

According to Dewberry (2011) Flood Inundation mapping process includes implementing the hydrologic, hydraulic and geospatial analyses required to develop inundation mapping products. The hydrologic analyses include the determination of the peak discharges that result in a certain return period. The hydraulic analysis includes the computation of the water surface profiles. The geospatial analysis determines the flood inundation area or flood extent area from river bank

An inundation mapping showing areas that would be affected by flooding from overflowing river courses due to high rainfall depth. An inundation map displays the spatial extent of probable for different scenarios and can present flood extent areas (Getahun and Gebre, 2015).

Jung and Merwade, (2015 suggest a need for more accurate flood inundation maps has recently arisen because of the increasing frequency and extremity of flood events. Flood inundation modeling involves hydrologic modeling to estimate peak flows, hydraulic modeling to estimate water surface elevation and terrain modeling to estimate the inundation areas.

According to Ebrahim *et al*, (2017) studied on sustainability based flood hazard mapping. The frame work uses a hydrologic model for rainfall – runoff transformation, a 2D unsteady hydraulic model flood simulation and a GIS-based multi-criteria decision –making techniques for flood hazard mapping. The result was better by showing the overall hazard with respect to hazard weights of hazard components was investigated. There by it provides a more sustainable perspective of flood management and can greatly help the decision makers to make better-informed decisions by clearly understanding the impacts of flooding on economy, social and environment.

2.5. Flood risk in Ethiopia and their mitigation measure

In Ethiopia, the past, there have been floods which have taken both human lives and destroyed properties. As a result of prolonged and intensive rainfall, the soil in most areas, particularly in the western, central highlands and northwestern parts of the country became saturated causing an overflow of rivers and flash floods in many areas (Dawit, 2015).

According to Joint Government and Humanitarian Partners (2006) Dire Dawa, SNNPR, Amhara, Oromiya, Gambella, Tigray, Somali and Affar Regions, the flood situation resulted in considerable human death, displacement and suffering as well as loss of property and crop damage. The current problem is the worst that has been observed in recent years. The most affected areas are Dire Dawa, South Omo Zone of SNNPR, and parts of Amhara, Oromiya, Gambella, Somali and Tigray regions. In Gambella region, areas affected by the flood are Gambella Zuria, Jikawo, Itang and Gillo woredas (Dawit, 2015). So far, the impact of the flood on human beings is not yet serious. However, it has affected a large area of crop fields. All rivers in the Region are full. High rainfall throughout the coming year in the western highlands could cause severe flooding (Dawit, 2015).

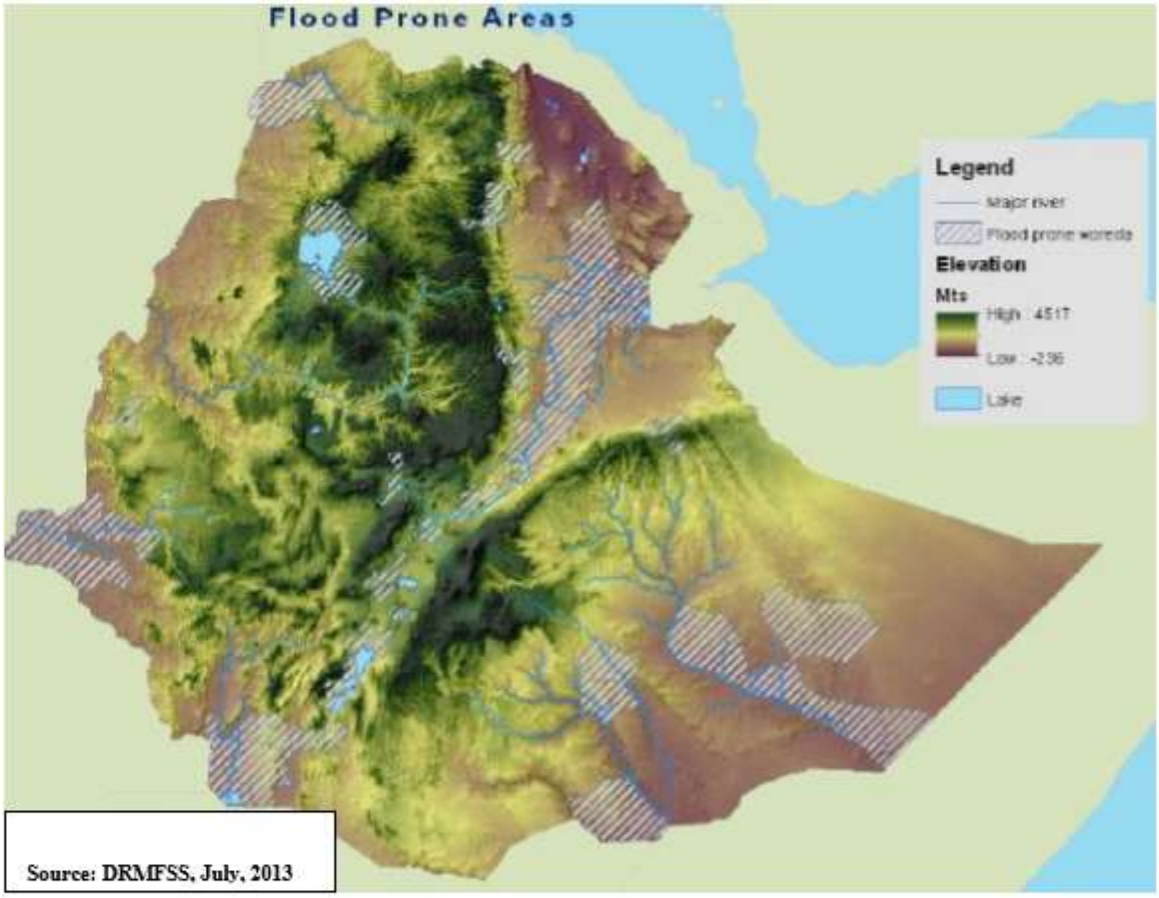


Figure 2. 1 Flood prone areas in Ethiopia

According to the latest information issued by the Ethiopian Government Disaster Prevention and Preparedness Agency (DPPA) (2006), the water storage effect of vegetation, soil, shallow groundwater, wetlands and drainage has a direct impact on the flood level in downstream areas. Each of these storage media retain certain quantities of water for various periods of time and can influence the timing of tributary flows and hence their contribution to a flood event. The storage effect can be likened to a sponge and is dependent on the antecedent conditions and the magnitude of the flood (DDPA, 2006).

According to FDRE (2013) the practice of reducing flood risk through systematic efforts to analyze and manage the causal factors of flooding, including reduced exposure to hazards, lessened vulnerability of people and poverty, wise management of land and the environment and improved the preparedness for adverse events.

Flood risk assessment of the flood prone areas, in Ethiopia is not an easy task. There is a limitation of adequate and reliable rainfall, water and soil data. Flood risk is the combination of flood hazard and flood vulnerability. Flood hazard is dangerous phenomena, substance, human activity or condition that may cause loss of life, injury or other healthy impacts, property damage, loss of livelihoods and services, social and economic disruption, or environment damage (Tarekegne, 2014). Flood vulnerability is the characteristics and circumstances of a community, system or asset that make it susceptibility to the damaging effects of flood hazard. It deal with Exposure means people, property, systems or other elements of exposure under hazard zones that are there by subjected to flooding (potential loss) (Tarekegne, 2014).

Flood based previous study by Samson (2008) in Gambela region, state that, engineering structures are not practiced along the river to prevent flood hazard consequence. Because, the region was faced by others problem like HIV, Poverty and Drought as result of this, considering responsible office may not pay attention at flood damage. But, the problem of flooding (through overflow of river in the region (Baro, Akobo, Alwero and Gilo)) increasing as it a damage property throughout the year.

Tefera (2015) suggest that flood hazard mitigation plans could be implemented as either structural or non-structural measures, depending on the particular case. These measures involve managing the effects of flooding and preventing the negative consequences. Structural measures, including levees, high flow diversion, channel modification and dams, could be implemented to mitigate flood risk by reducing the volume of run-off, water level or extent of the area of flooding. However, non-structural methods, such as flood insurance, land use regulation and flood forecasting, serve as preventive measures for reducing flood hazards.

According to Tesfay (2018) mitigation measures provides a critical foundation on which to reduce loss of life and property by avoiding or lessening the impact of hazard events. This creates safer the communities and the facilities resiliency by enabling communities to return to normal function as quickly as possible after a hazard event. Flood mitigation actions generally fall in to the following categories: Preventative Measures, Property Protection Measures, Natural Resources Protection Activities, Emergency Services (ES) Measures, Structural Mitigation Projects (so-called Engineering Structures Measures), Public Education and Awareness Activities (Tesfay, 2018).

3. MATERIALS AND METHODOLOGY

3.1 study area

Gilo River is located in the Gambela Region of southwestern of Ethiopia. It has a variety of names known as Ghelo, Ghila, Gila, Gilowenz and Jila River. It is lies between latitude7° 20' 00" - 8° 08' 00" N and Longitude 33° 10' 00" - 35° 50' 00" E. The river reach within study area is approximately 321.86km in length running from North to southwest. The catchment area of Upper middle Gilo River of the basin is computed about 9100km^2. From its source in the Ethiopian Highlands near MizanTeferi it flows to the west, to join the Pibor River on Ethiopia's border with Sudan. The region is divided in to six woredas (districts), namely Abobo, Akobo, Gambella, Godare, Gog-Jor, Itang and Jikawo. Four major river (Akobo, Baro, Aluwero and Gilo) and several small tributaries crisscross the region.

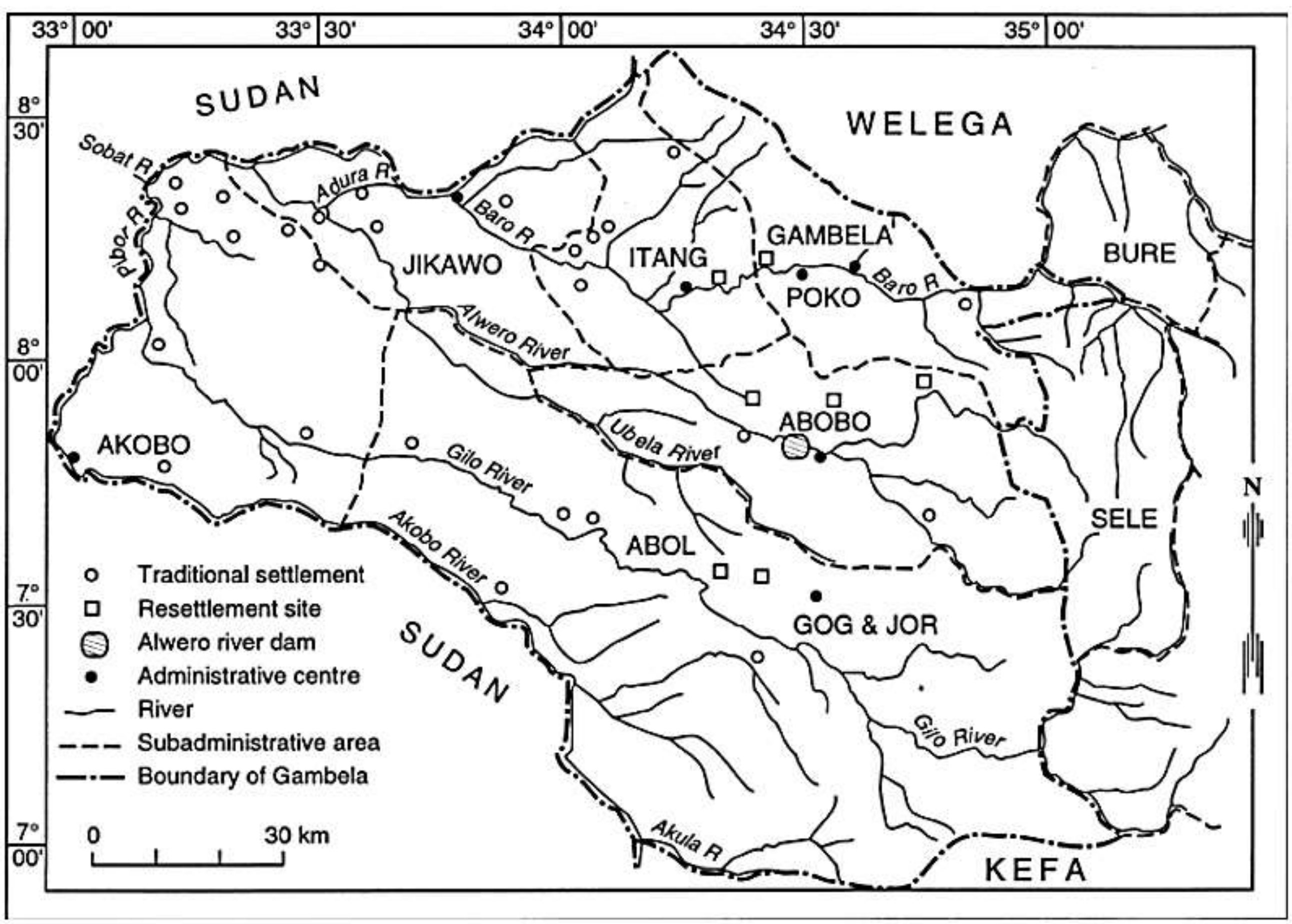


Figure 3. 1 Map showing Gambela region and river in the region (source: woube, 1999)

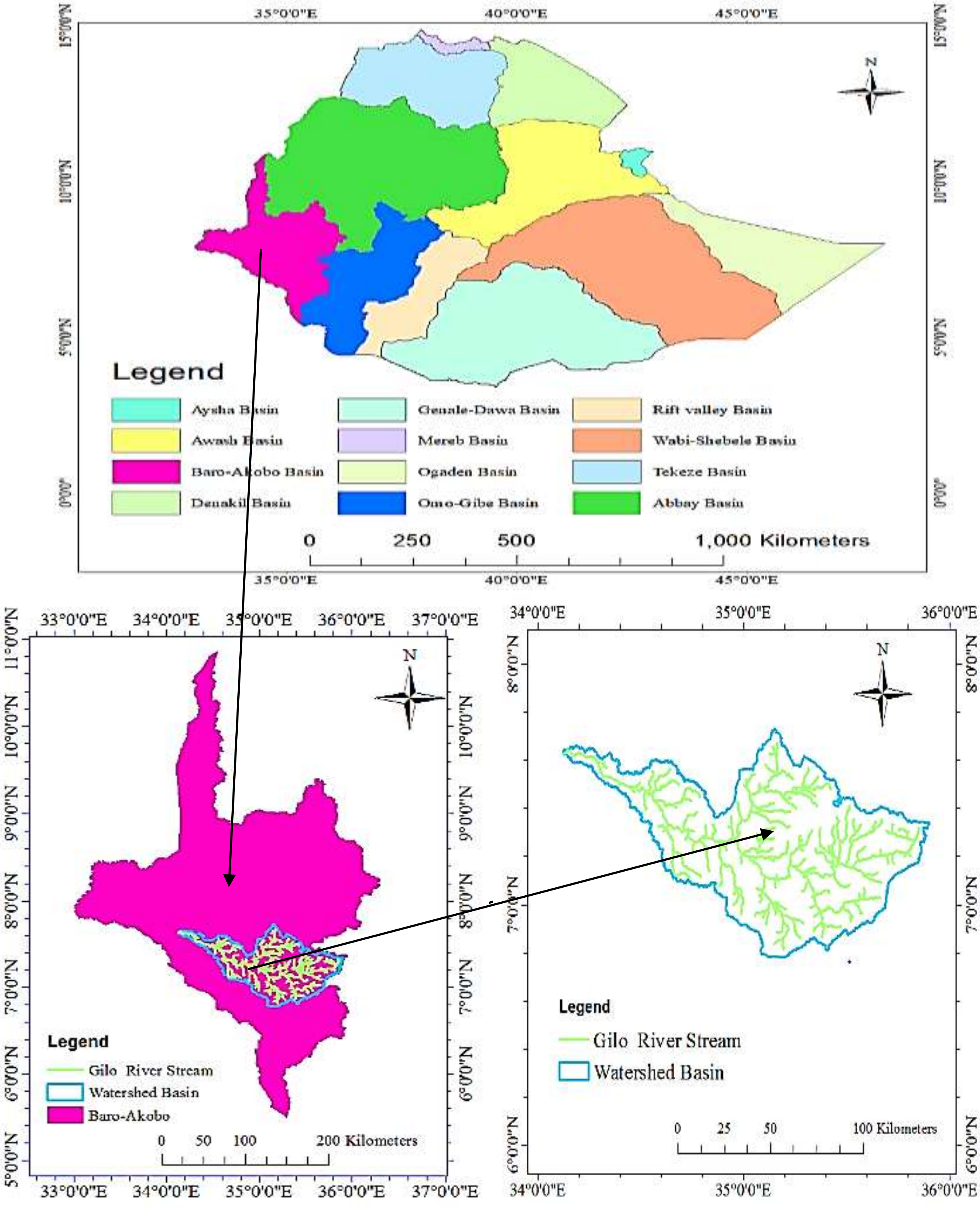


Figure 3. 2 Location of study Area source: Ethiopian River Basins

3.1.1. Topography

The topography of Gambela Region is characterized by a variety of elevation. The eastern part has an elevation of 2000-1000m above sea level. The middle part has of 900 -500m above sea level and the western part has an elevation of 500- 300m above sea level. This trend shows progressive decline from East to West. Thus, Gilo River is found in western part having elevation about 285m above sea level (Samson, 2008).

3.1.2. Climate

The climate is generally warm and humid with a prolonged rainy season which begins in late April and continues until the beginning of November with a mean annual rainfall exceeding 980mm and relative humidity between 45% and 75% (National metrological service, unpublished report). The annual rainfall in the Gambela region ranges between 800 – 1200mm and it is considered as all year rain fall regime, but about 85% of the rain as May – October with less rain from February – April.

3.1.3. Land use /land cover

The terms land use and land covers are often used interchangeably even though the distinction between the two is important. Land use refers to the actual economic activity for which the land is used whereas land cover refers to the cover of the earth’s surface. Land use can be seen as the ultimate expression of everything else that is going on in the basin. The land use of study area can be categorized mainly Forest, agricultural, closed and open grass, shrub, water bodies, wet and bare land.

3.2. Data preparation and processing

The various input data are required to achieve the objective of this study and to have accurate results. For this study the required secondary data was collected from GIS (Geographic Information System) department, Ministry of water, Irrigation and Energy, Ethiopia (MoWE), Ethiopian National Metrological Agency (NMA). The data collected for study area, that’s Gilo River Ethiopia such as: Digital Elevation Model (DEM), soil, land use / cover, rainfall and stream flow.

Table 3. 1 Sources of Required Data

Data	Source
Digital Elevation Model(30m by 30m)	Geographic Information System Department
Stream Flow and Soil	Ministry of water, Irrigation and Energy, Ethiopia (MoWE)
land use / cover	Ethiopian Geospatial Information Agency
rainfall	National Metrological Agency (NMA)

The daily recorded data for 21 years (1997 to 2017) for rainfall and 25 years (1990 to 2014) for stream flow was collected for different gage station from National Metrological Agency (NMA) and Ministry of water, Irrigation and Energy, Ethiopia (MoWE) respectively. The following table shows the different gage station with their coordinate location.

Table 3. 2 Rainfall station

Station name	Latitude (in Degree)	Longitude (in Degree)
Gog	7.5833	34.3833
Abobo	7.85	34.43
Fugnido	7.65	34.417
Dippa	7.65	34.2
Aman	6.95	35.56667
Yeki	7.2	35.3333
Tepi	7.2	35.4333

Table 3. 3 Stream Flow Gage Station

Station name	Site	Latitude (in Degree)	Longitude (in Degree)
BEGWOHA	Nr. Tepi	7.12	35:26
BEKO	Nr. Showa	7.12	35.28

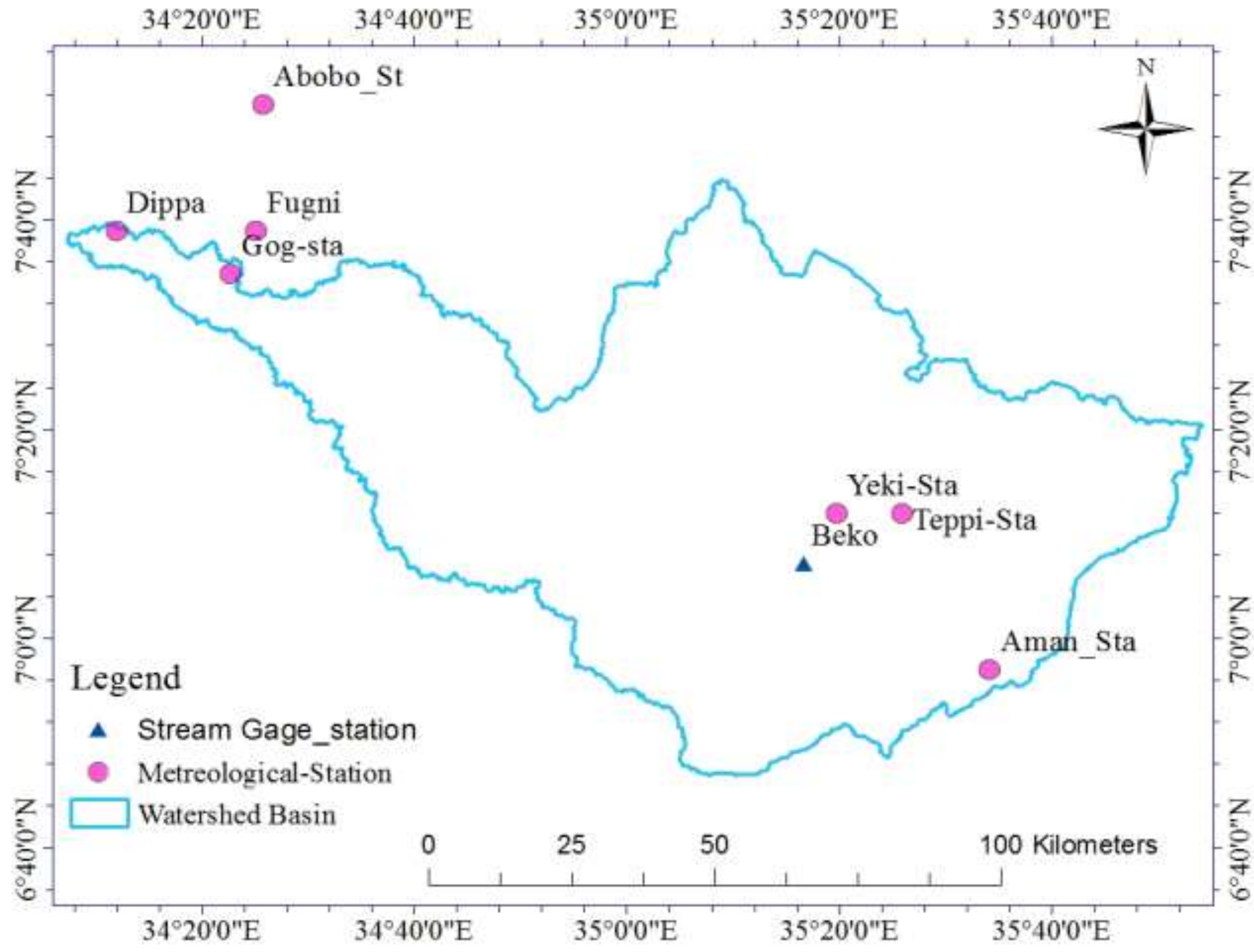


Figure 3. 3 Stream and Rainfall station at Study

Table 3. 4 Stream Flow at Beko Station

year	1990	1991	1992	1993	1994	1995	1996	1997
Q(m^3/s)	59.898	64.14	36.88	44.19	38.37	63.71	81.32	65.23
Year	1998	1999	2000	2001	2002	2003	2004	2005
Q(m^3/s)	85.42	27.2	20.87	19.49	25.17	36.25	34.11	26.78
Year	2006	2007	2008	2009	2010	2011	2012	2013
Q(m^3/s)	39.93	48.28	33.23	19.93	45.4	35.29	32.18	51.94
Year	2014							
Q(m^3/s)	32.91							

3.2.1. Filling missing data

The accuracy of the result was based on the quality of available data. Thus, before using collected data for analysis it has to be mandatory to check missing data, inconsistency and accuracy. The period of missing data has to be filled by different methods. For this study missing value was filled using linear Regression methods by XLSTAT software. In many cases XL STAT is using for filling of missing temperature, rainfall and stream data, checking of trend and homogeneity. XL STAT is the richest tool for the data analysis and the statistical treatment with MS Excel. It can execute preparing, describing, visualizing, analyzing and modeling data, correlation tests, parametric and non-parametric tests, testing for outliers, homogeneity and trends. For quantitative data, XLSTAT allow to: Remove observations with missing values, Use a mean imputation method, Use a nearest neighbor approach and algorithm. This study uses a nearest neighbor approach to fill missing data.

Besides filling missing data, inconsistency problem should be checked, while data due to instrument malfunction, the records may be fail for continuity. Double mass curve is used for checking for data consistency. The plot line should be straight and the R-squared value is found between, 0.6 - 1. As seen from the figure below the R-squared is found about 0.9 which is close to 1. So, the data is a consistent, it can be used for analysis.

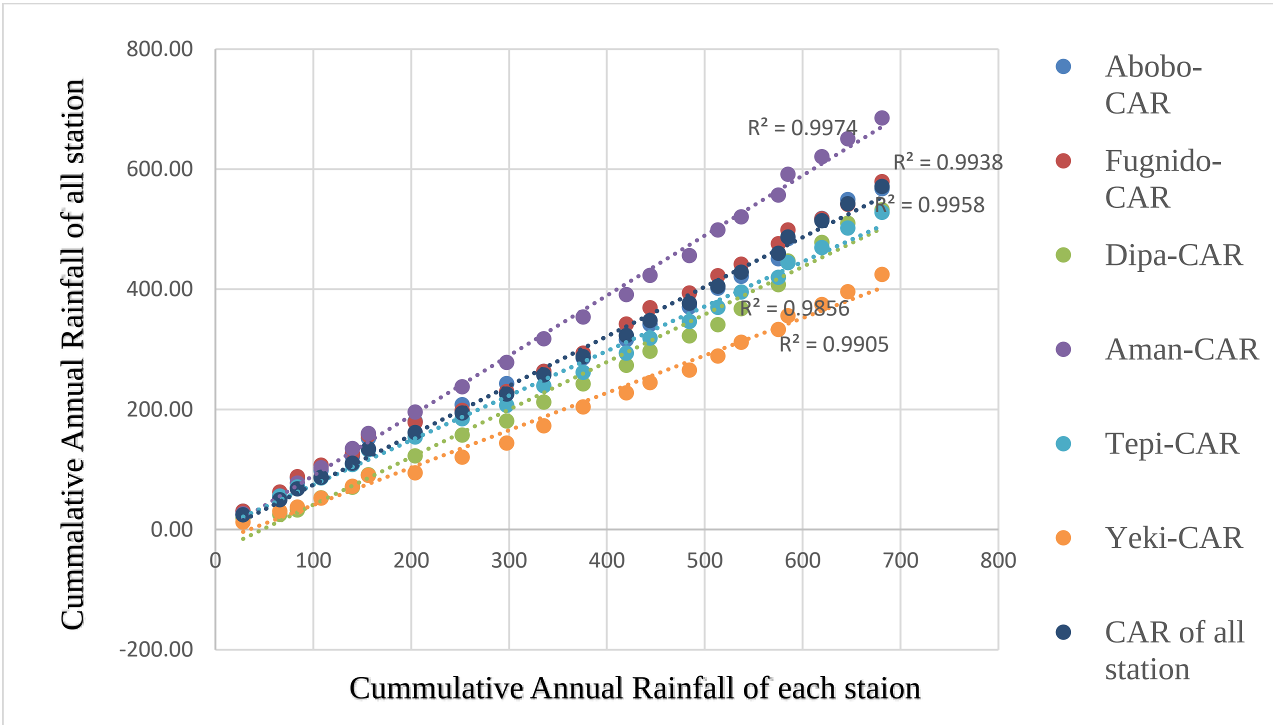


Figure 3. 4 Double mass curve

3.2.2. Test for outliers

The Water Resources Council method recommends that adjustments be made for outliers. Outliers are data points that depart significantly from the trend of the remaining data. The retention and deletion of these outliers significantly affect the magnitude of the statistical computed from the data, especially small size (Ven Te Chow, 1988, 2010).

According to Water Resources Council (1981) recommends that if the station skews is greater than +0.4, test for higher outlier are considered. If the station skews is less than -0.4 test for lower outlier and if the station skew is between ±0.4 tests for both outliers. The skew coefficient for this study was CS = 0.8856, which is greater than 0.4, require check for higher outlier test.

The following frequency, equation can be used for outliers test:

Y_H = Ymean ± KnSy Eq3.1

Where: Y_H= high (+) / low (-) outlier threshold, Sy = standard Deviation. Kn = Factor based number of sample size (e.g. 25 number of data) for 10% level of significance in normally distributed data Kn = 2.486 (Ven Te Chow, 1988, 2010).

Y_H = 42.725 + 2.486 *18.267= 88.14m^3/s, Thus, as seen from above table, all data are below higher outlier test. Therefore, all are used for analysis. Also, hydrological record data should be checked for variability. This used to check consistency of data and by using variability formula.

$$\alpha = \frac{Sy}{\sqrt{N} * Ymean} \qquad \text{.......Eq 3.2}$$

$\alpha = \frac{Sy}{\sqrt{N} * Ymean} = \frac{18.267}{\sqrt{25} * 42.725}$ = 0.085<1 or 8.5 %< 10%. Acceptable. Thus, 8.5% < 10%, therefore all data are reliable and adequate.

3.3. Fitting probability distribution

Performing flood frequency analysis requires a good understanding of probability theory and statistics and in most instances sound engineering judgment. The probability distributions are the basic concepts of statics. Probability function is a function representing the probability of occurrences of a random variable (Ven Te Chow, 1988, 2010), (FEMA, 2007). The probability models selected for this study includes: Log-Logistic, Log-Logistic (3P), General Extreme Value (GEV), Pearson5 (P5), and Log -Person5 (LP3), Pearson 6 (P6), and Log -Person 6(LP4).

The choice of distribution to be used in flood frequency analysis has been a topic of interest for a long time (Samiran, 2012). The choice of distribution is influenced by many factors, such as methods of discrimination between distributions, methods of parameters estimation, the availability of data, etc. Normally, there is no global agreement as to a preferable technique of model choice and no single on distribution accepted universally (Bedassa, 2016).

Thus, Easy Fit is a data analysis and simulation application allowing fitting probability distributions to sample data, select the best model, and apply the analysis results to make better decisions. There are a number of well-known methods which can be used to estimate distribution parameters based on available sample data. For selected distribution, Easy Fit implements one of the following parameter estimation methods: method of moments (MOM)**,** maximum likelihood estimates (MLE)**,** least squares estimates (LSE) and Method of L-moments**.** For many distributions, Easy Fit uses the maximum likelihood estimates (MLE) method involving the maximization of the log-likelihood function. Estimation by the ML method involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations (Dawit, 2015). The maximum likelihood method (MLM) is considered the most efficient method since it provides the smallest sampling variance of the estimated parameters, and hence of the estimated quintile's, compared to other methods (Dawit, 2015).

3.3.1. Goodness of fit test (GOF)

The Goodness Fit Test (GOF) is used to select the best probability distribution. It used for checking the validity of specified or assumed probability distribution model (Samiran, 2012), (Alam, 2017). There are different evaluation criteria while this study considers the distribution test below.

1. Kolmogorov –Smirnov Test (K-S test)

Kolmogorov-Smirnov (KS) test is another widely used goodness –of –fit besides Chi-square test. This test is based on the deviation of the sample distribution function from the specified continuous hypothetical distribution function, providing a comparison of a fitted distribution with the empirical cumulative distribution function (ECDF) (Kalkidan, 2015).

2. Anderson –Darling Tests (A-D Test)

The Anderson –Darling procedure is a general test to compare the fit of an observed cumulative distribution function to an expected cumulative distribution function. This test gives more weight to the tails than the kolmogorov – Smirnov test.

3. Chi-square Method

The Chiq-Square test is used to determine if a sample comes from a population with a specific distribution. This test is applied to binned data, so the value of the test statistic depends on how the data is binned. Also, it is available for continuous data only.

3.3.2. Summary of statics information

Table 3. 5 Descriptive Statics

Statistic		value	percentile	value
Sample size		25	Min	19.49
Range		65.93	5%	19.622
Mean		42.725	10%	20.494
Variance		333.69	25%(Q1)	29.69
Std. Deviation		18.267	50%(median)	36.88
Coif. Of variation		0.42755	75%(Q3)	55.919
Std. Error		3.6534	90%	71.666
Skewness		0.8856	95%	84.19
Excess Kurtosis		0.11654	Max	85.42

Table 3. 6 Fitting Results

Distribution	Parameters
Gen. Extreme Value	$K = 0.07238$ $\mu = 33.733$
Log-logistic	$\alpha = 3.9374$ $\beta = 38.039$
Log-logistic(3p)	$\alpha = 2.7843$ $\beta = 26.32$ $\gamma = 11.902$
Log-pearson3	$\alpha = 265.37$ $\beta = 0.02559$ $\gamma = -3.1201$
Pearson6	$\alpha = 6.3116$ $\beta = 228.62$
Pearson5(3p)	$\alpha = 7.1407$ $\beta = 278.5$ $\gamma = -2.4174$

Pearson6	α_1 = 61.72 α_2 = 6.9548 β= 4.1488
Pearson 6(4p)	α_1 = 2.865 α_2 = 12.696 β = 114.43 γ = 14.537

Table 3. 7 Goodness of Fit - Summary

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gen. Extreme Value	0.08624	3	0.22267	1	0.23905	7
Log-Logistic	0.10105	7	0.27198	8	0.00437	1
Log-Logistic (3P)	0.08605	2	0.24898	6	0.10961	6
Log-Pearson 3	0.08414	1	0.22406	2	0.26354	8
Pearson 5	0.09176	6	0.2442	5	0.07799	4
Pearson 5 (3P)	0.08898	5	0.23914	4	0.05998	2
Pearson 6	0.08785	4	0.23661	3	0.06189	3
Pearson 6 (4P)	0.10144	8	0.25934	7	0.09977	5

As shown from the above table of the GOF indicate that Kolmogorov- Smirnov test gives Log Pearson Type-III, Anderson Darling test gives General Extreme Value (GEV) and chi- squared test gives Log-logistic. However, Log - Pearson _III gives maximum value of peak discharge for different return period (Appendix B), K-S test for Goodness fit test (GOF) used for this study.

3.3.3. Log- Pearson type-III (LP3)

Many distributions are in common use in engineering applications. Among the well-known extreme value distributions are Gamble distribution, General extreme value (GEV) and Log-Person type-III are widely used in hydrology to describe statics of information and stream flow (FEMA, 2007). The Log-Pearson-III uses for computing peak flood magnitude in hydrologic Engineering (Haan, 1977).

The location of the bound ϵ in the log-Pearson Type III distribution depends on the skewness of the data. If the data are positively skewed, then log $X \geq \epsilon$ and ϵ is a lower bound, while if the data are negatively skewed, log $X \leq \epsilon$ and ϵ is an upper bound. The log transformation reduces the skewness of the transformed data and may produce transformed data which are negatively skewed from original data which are positively skewed. In that case, the application of the log-Pearson Type III distribution would impose an artificial upper bound on the data.

3.3.4. Transposing peak discharge

Methods for making flood peak estimates can be separated on the basis of the gauged versus un-gauged site. For un- gauged site where data are not available at the point of interest, peak discharges can be made by either supplementing or transposing peak flow (linear regression or Drainage Area weighting). Drainage Area Weighting (DAW) is a widely used technique in many cases where limited stream flow data are available (Harlan, 2002). Drainage Area weight methods are applicable for the size between the gauged to un- gauged approximate to small (about 25%) (Harlan, 2002).

This method is most valid in condition where watershed are similar catchment parameter like land use, soil types, slope and similar stream patterns (Harlan, 2002). Peak flow is estimated using Drainage-Area weighting using the following method.

$$Q_U = \left(\frac{Au}{Ag}\right)^b Q_g \quad \text{...Eq3.3}$$

Where: Au = Drainage Area of un-gauged station, Ag = Drainage Area at Gauged station, Q_u = Peak Discharge at Un-gauged Station, Q_g = peak Discharge at gauged station and b = Coefficient of Drainage Area (Appendix B).

3.4. Flood hazard mapping

The flood hazard map is essential tool to assess susceptibility of flood prone areas (Kamonchat, 2017). The flood hazard generating factors for flood hazard assessments are slope, elevation, rainfall, drainage density, land use and soil. Based on susceptibility to flood and flooding capacity these flood generating factors are classified and ranked in to different flood hazard category. Such, hazard level or rank has to be defined as extreme, high, medium, low and very low hazard consequence.

3.4.1. Elevation (E)

As water flows from higher to lower elevation, lowland areas are more prone to flooding occurrences (Olga, 2017). The elevation map is obtained from the reclassification of the DEM. The topographic elevation of upper - middle Gilo River catchment is varied from 341m to 2753m. The upstream elevation is very high and the lowest at the downstream. Thus, at upstream due to high elevation and steep slope there is high runoff during high rainfall and cause high flooding at the downstream as result the slope of the land is flat, river course allowed overflow.

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A DEM in needed for raster-based hydrological analysis in a GIS. The ASTER DEM has a spatial resolution of 30 my 30m, which was used for flood inundation mapping.

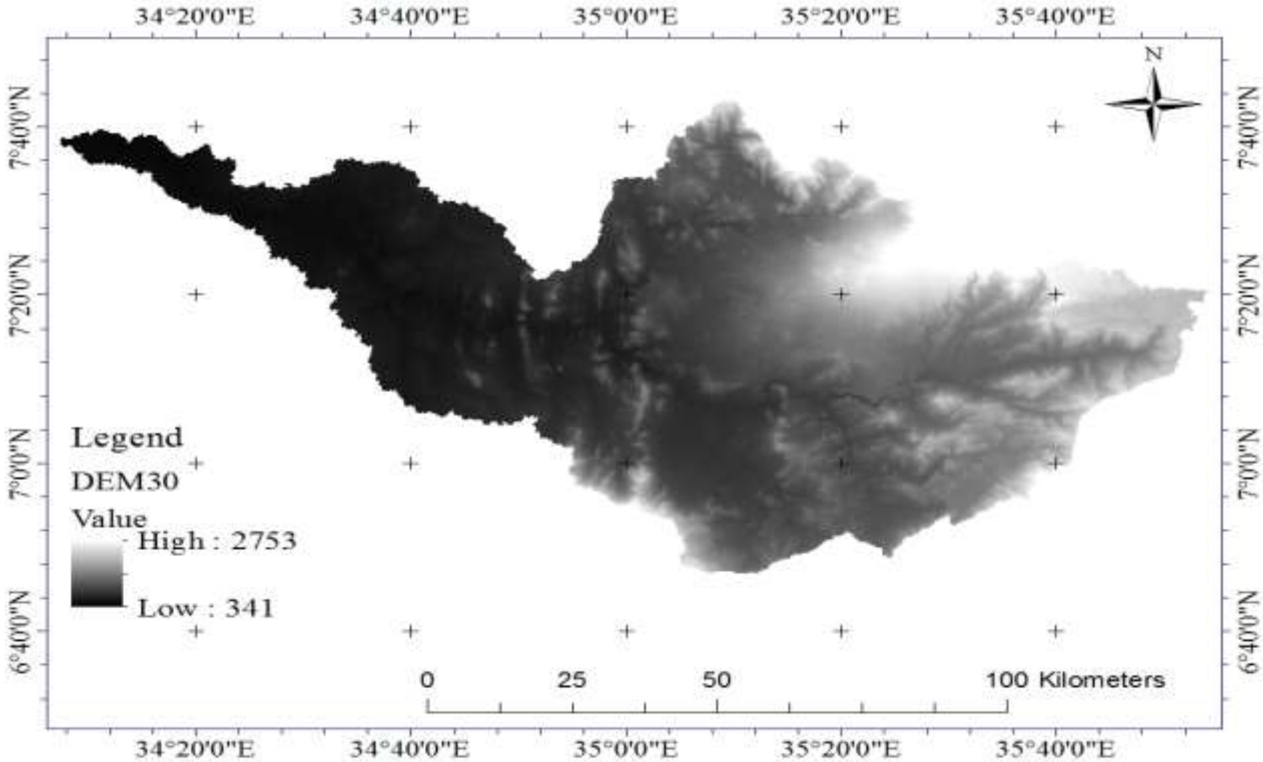


Figure 3. 5 DEM of study Area

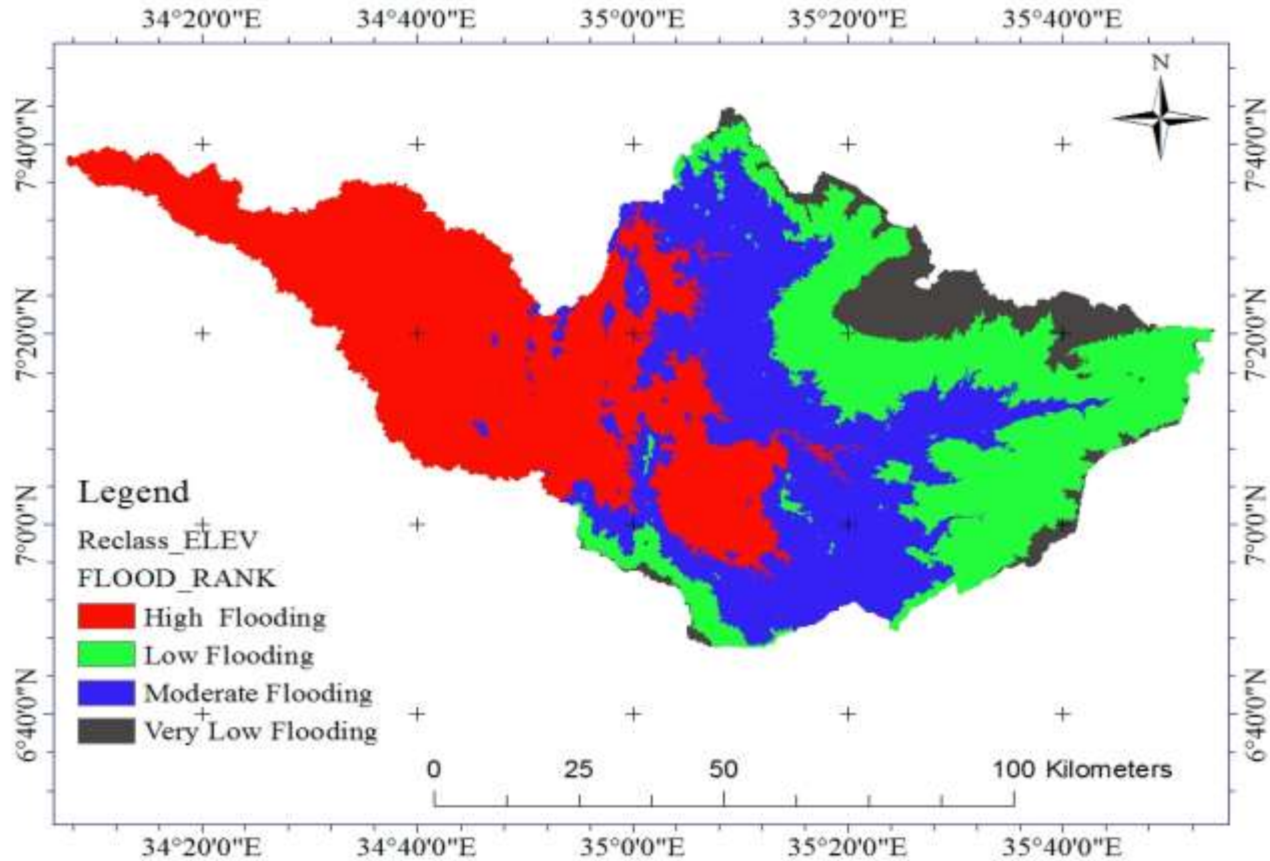


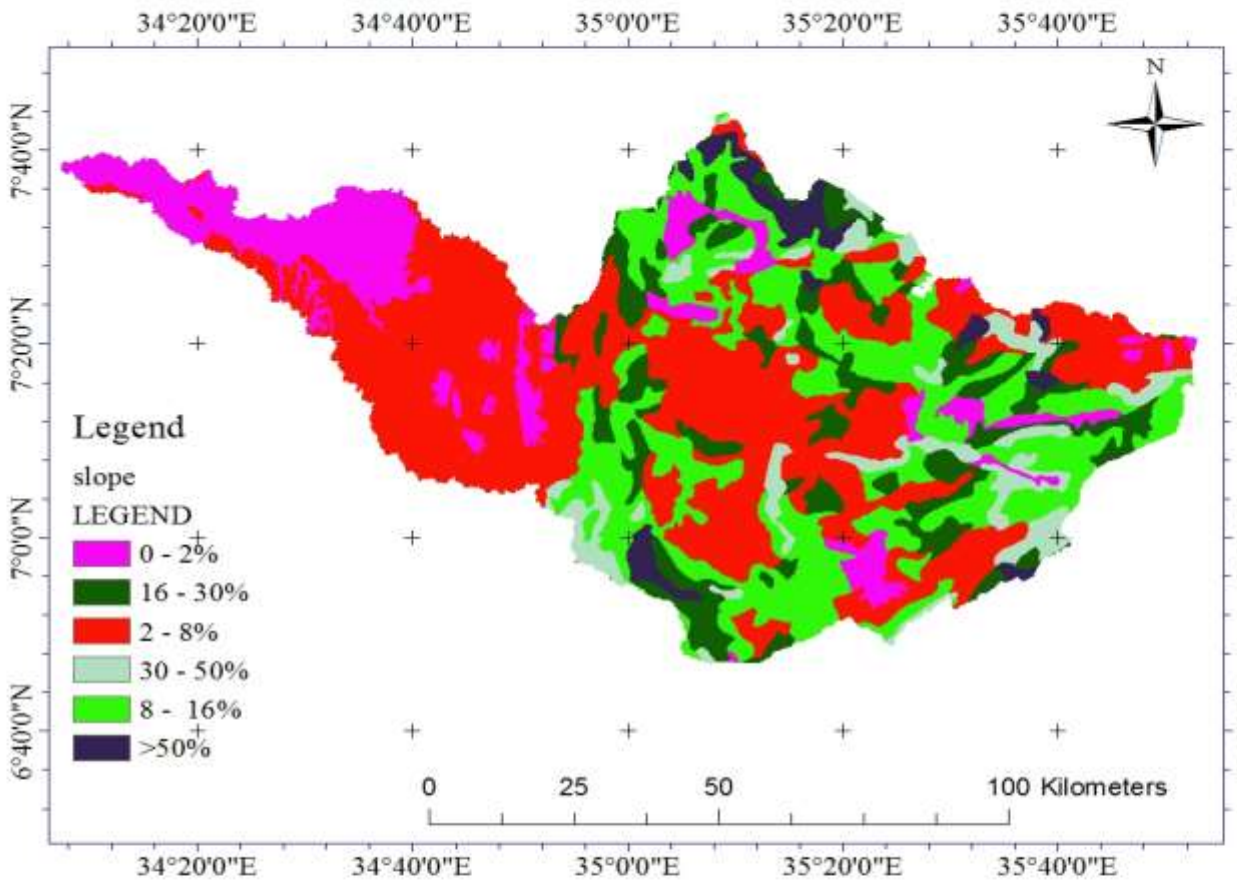
Figure 3. 6 Re-classification of Elevation

3.4.2. Slope (S)

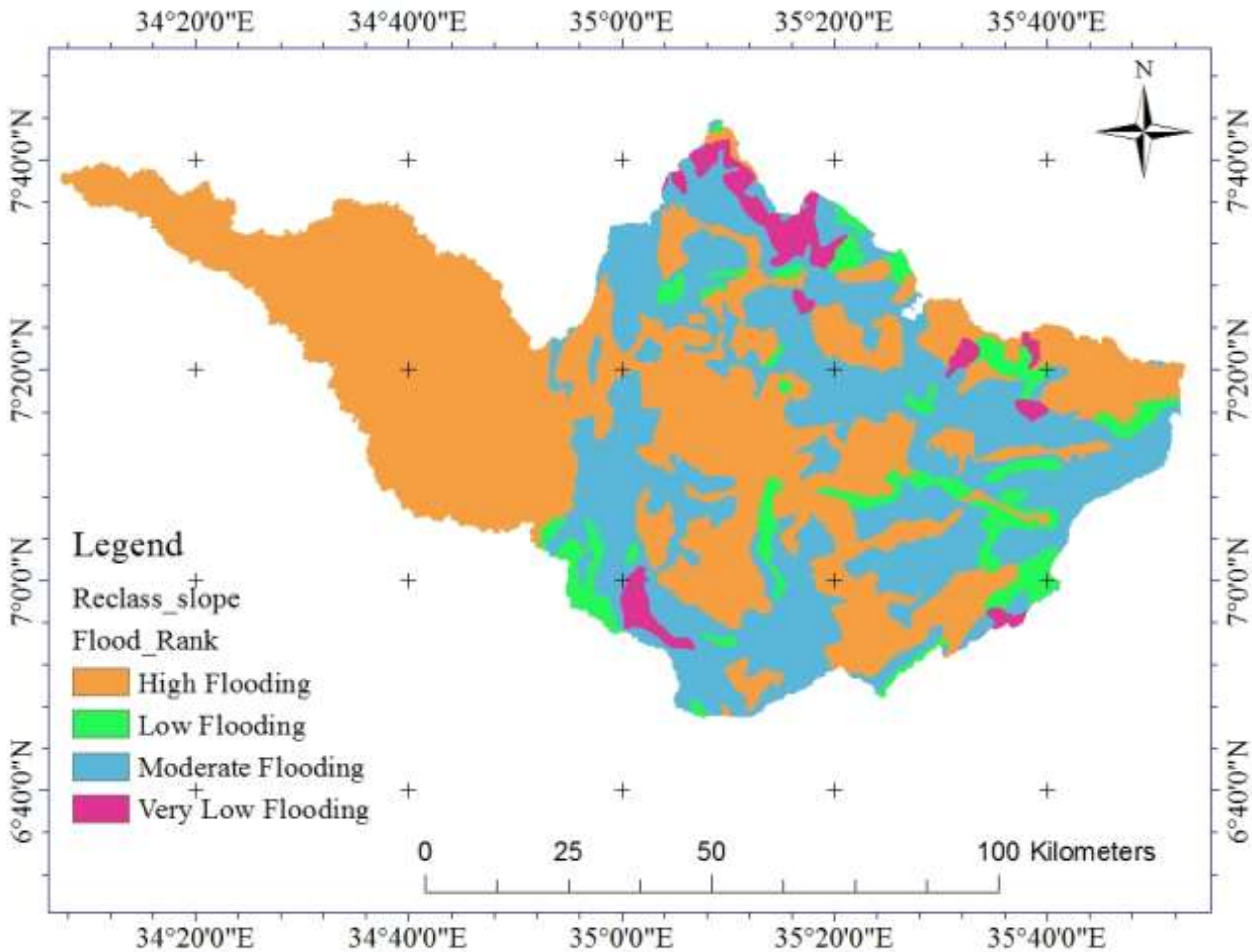
Elevation and slope are an integral part of land surface. It can be described in two different ways. One is degree of slope, which indicates the angle between ground surface and horizontal plane (Dai, 2016). The other one is percentage slope which used for this study, indicates the percentage ratio of elevation change on horizontal distance change (Dai, 2016).

Also, it influences drainage, runoff exposure accessibility (Olga, 2017). Slope is highly correlated to both the volume and the velocity of the surface runoff, as well as the infiltration to the groundwater (FAO, 1990, 2006). Flat areas flood quicker than inclined areas where runoff flows further down. For this study, based on the susceptibility to flooding the slope was ranked in to class-1 (very flat in 0-2%), class-2 (gently undulating in 2%-8%), class-3 (moderate steep in 8%-30%) and class-4 (steep above 30%) (FAO, 2006).

A parameter that can be derived from further analysis of Digital Elevation Model (DEM) for further analysis is the slope of terrain, which is most widely and distributed known topographic size element. The slope of the map of study area resulted from the processing of digital elevation models (DEM) using the software Arc Map (Spatial Analyst Extension).



a.



b.

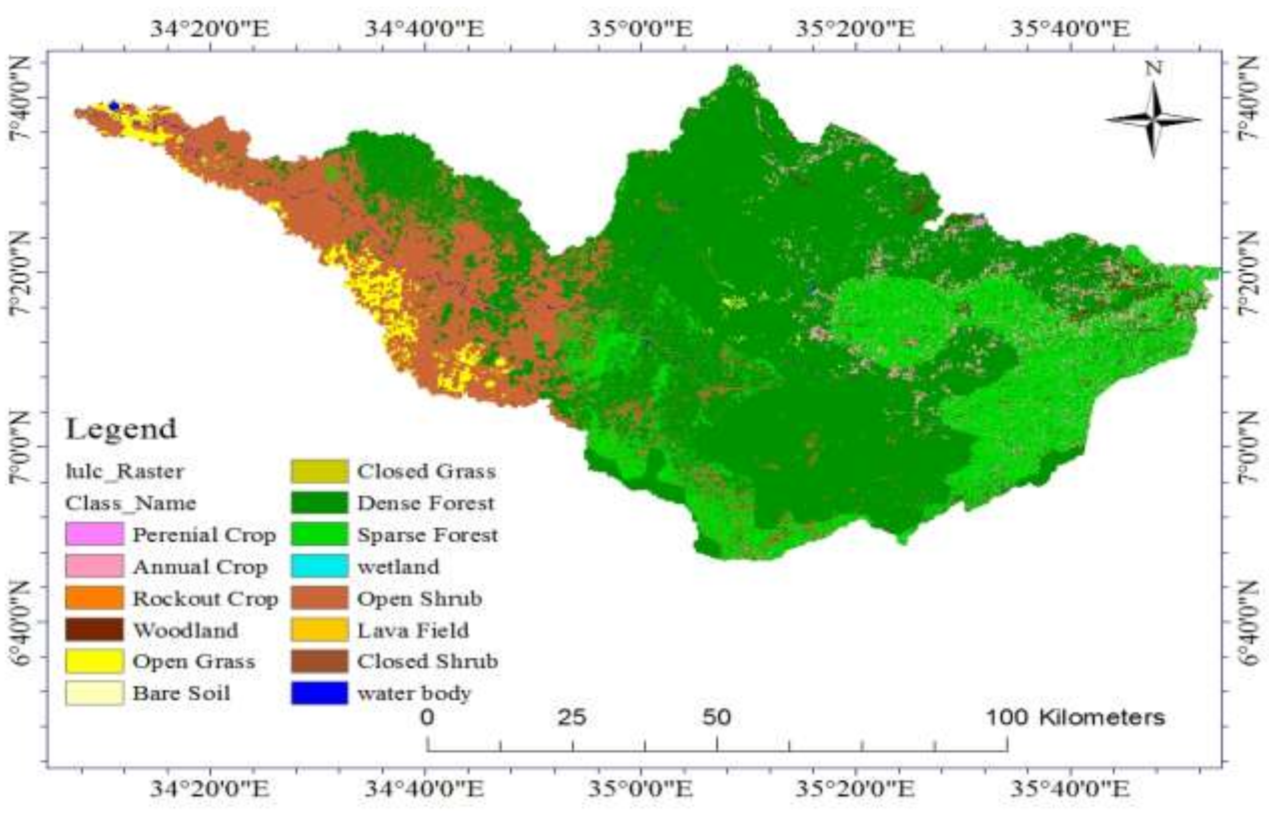
Figure 3. 7 Slope (a.) and Re-class Slope (b.) for upper-middle Gilo River

3.4.3. Land use /cover (LULC)

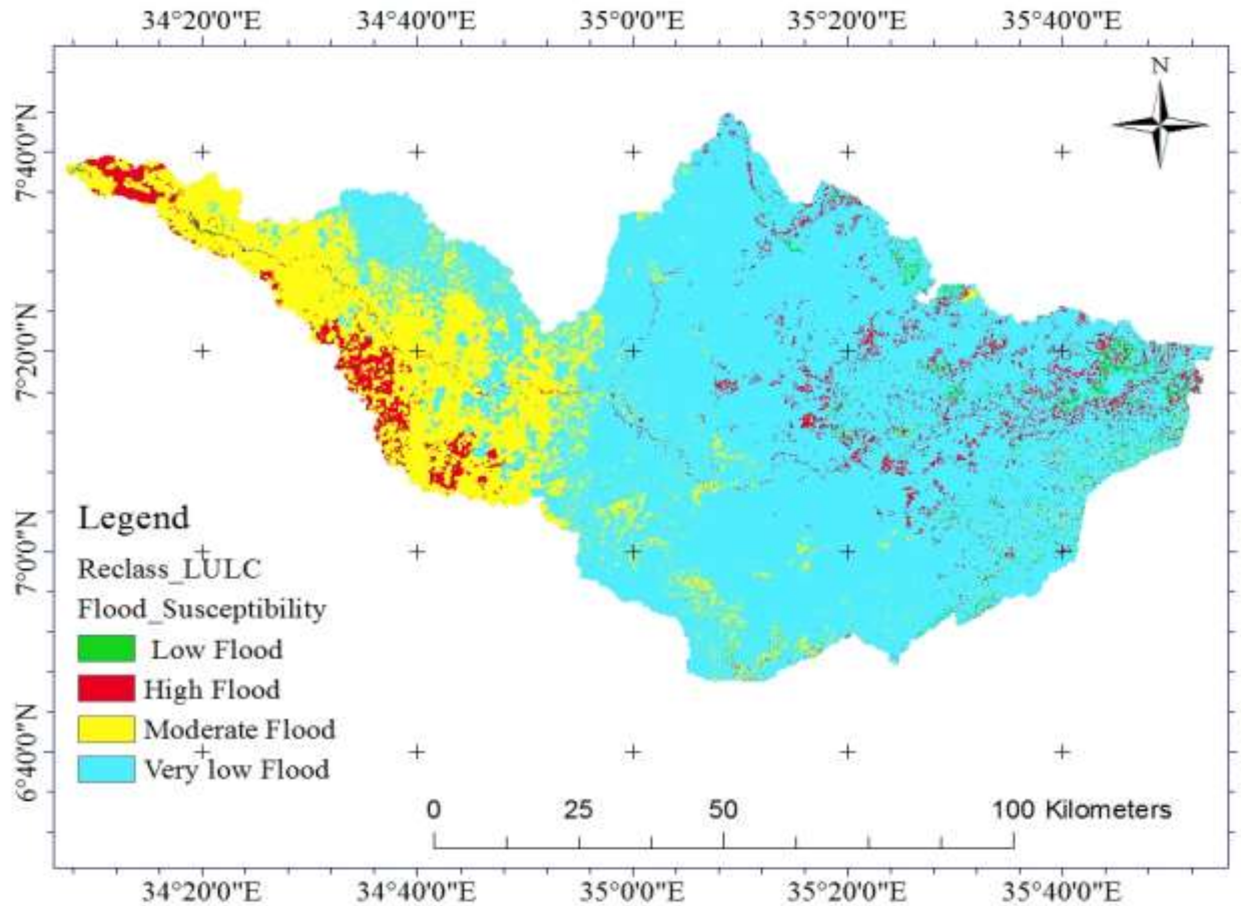
The land use parameter is mainly related to the infiltration rate as a result of the existing correlation between the surface characteristics that affect (sub)surface runoff; groundwater infiltration and debris flow (Mati, 2006 ; Olga, 2017). The modification of natural land use cover lead to changes rainfall – runoff characteristics of the river basin which consequently change the river flow regimes (Mati, 2006 , Olga, 2017). Land use information was taken from Ethiopian Geo-Spatial Information Mapping Agency, showing that a large part of the studied area is covered by forests, Grass, shrub, bare land, wet land, water body and Crop. Based on susceptibility to flood, they are classified and ranked from low to high flooding by using Spatial Analyst Tool (SAT) with GIS. Forest generally favors infiltration, rating low flooding while agricultural areas allow more water to flow in the form of surface or subsurface runoff tends high flooding.

Table 3. 8 LULC degree to Flooding

Class name	Degree to Flood Susceptibility
Dense forest, Sparse Forest	Very Low Flooding
Wood Land, closed Grass, closed Shrub	Low Flooding
Perennial crop, open Shrub	Moderate Flooding
Annual crop, Rock out crop, open grass, bare soil, wet land, lave field, water body	High Flooding



a.



b.

Figure 3. 8 LULC (a) and Re-class LULC (b) for upper-middle Gilo River

3.4.4. Soil

Knowing the different morphological and other physical characteristics of the soil gives better understanding found on guideline for soil description (FAO, 1990, 2006).There are various soil of upper-middle Gilo River as shown figure below. The soil feature type is converted in to Raster layer using conversion tool in Arc-GIS "To Raster". Thus, the reclassification in to four flood hazard level considering the degree causing flooding.

Table 3. 9 Soil degree to flooding

Class name	Degree to Flood Susceptibility
Calcic and Eutric cambisols, Dystric Fluvisols, Gypsic Yermosols, Orthic Solonchaks	Very Low Flooding
Calcic fluvisols, Dystric Nitosols, Orthic Acrisols	Low Flooding
Chromic Luvisols, leptosols	Moderate Flooding
Dystric Campisols, Eutric Fluvisols	High Flooding

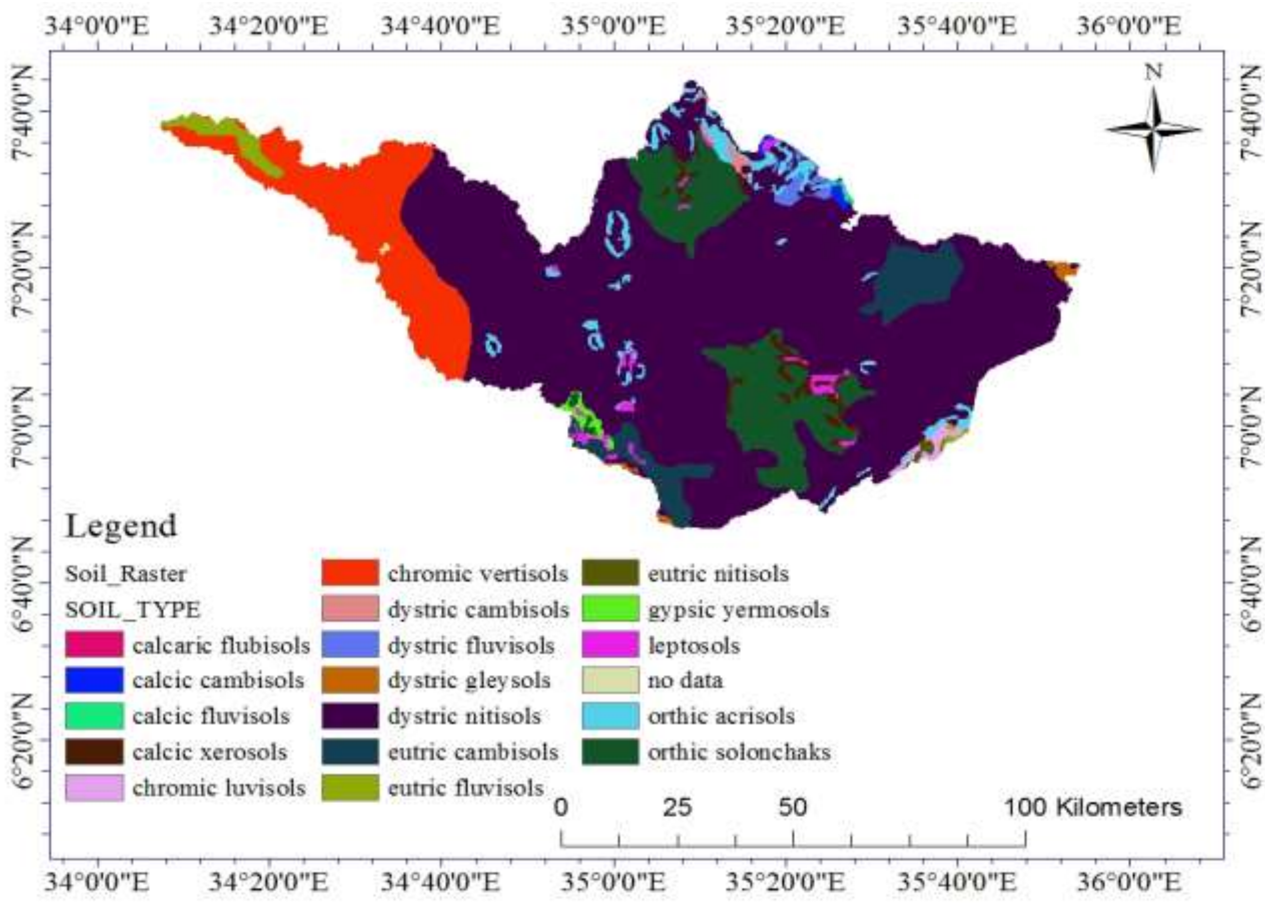


Figure 3. 9 Soil Type at study Area

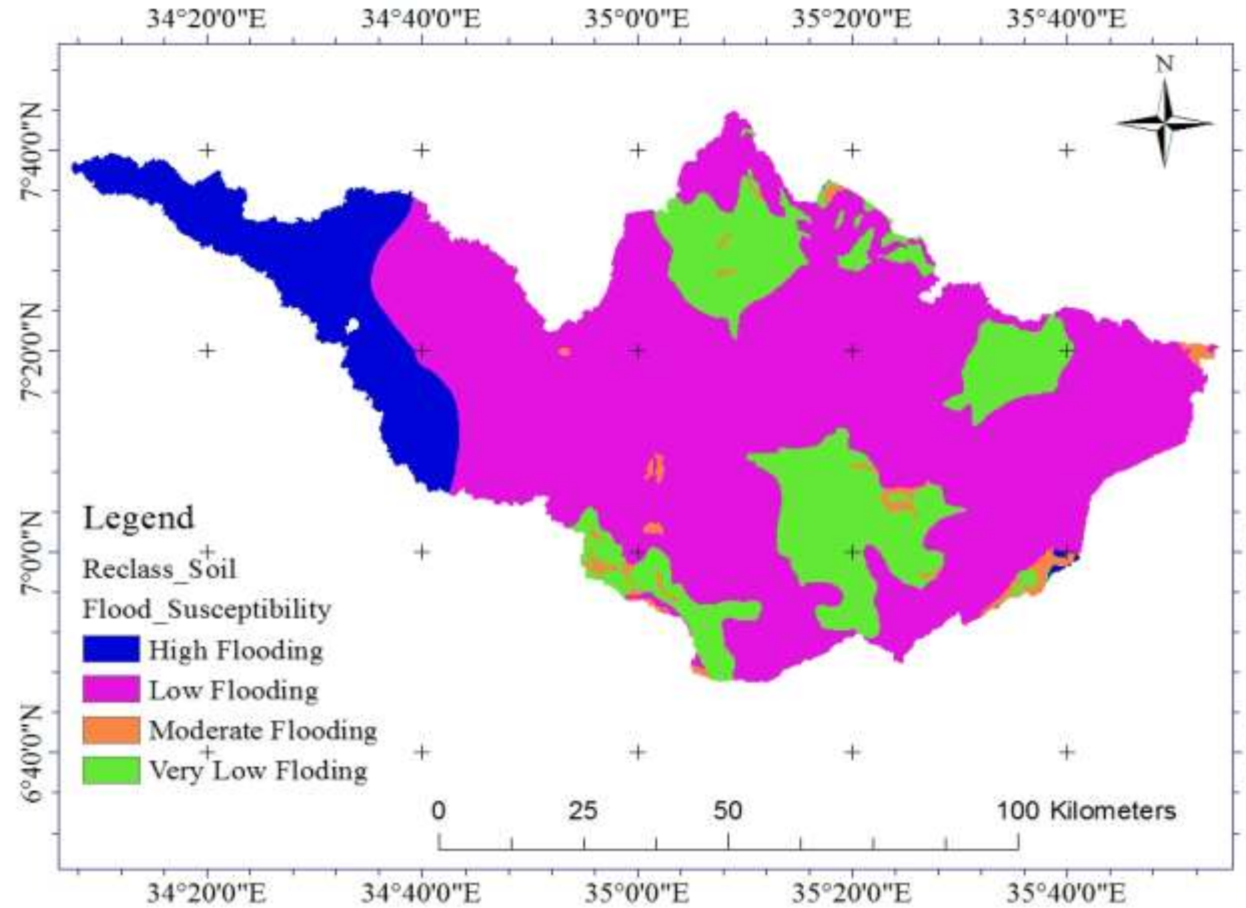
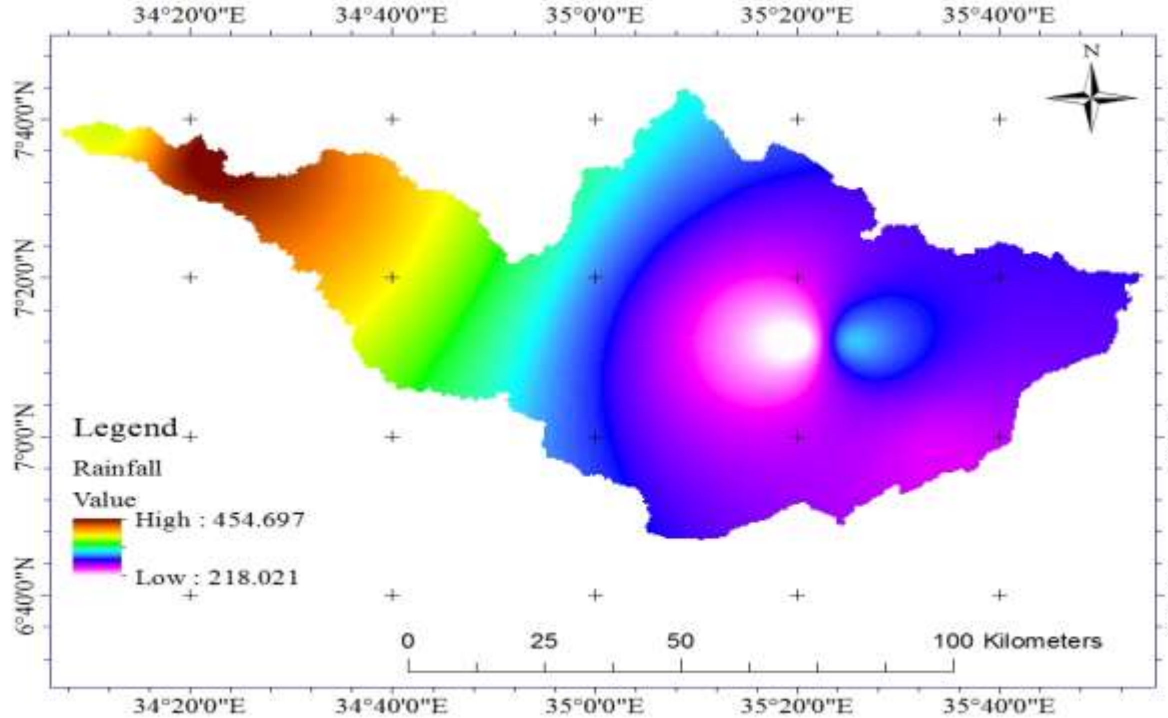


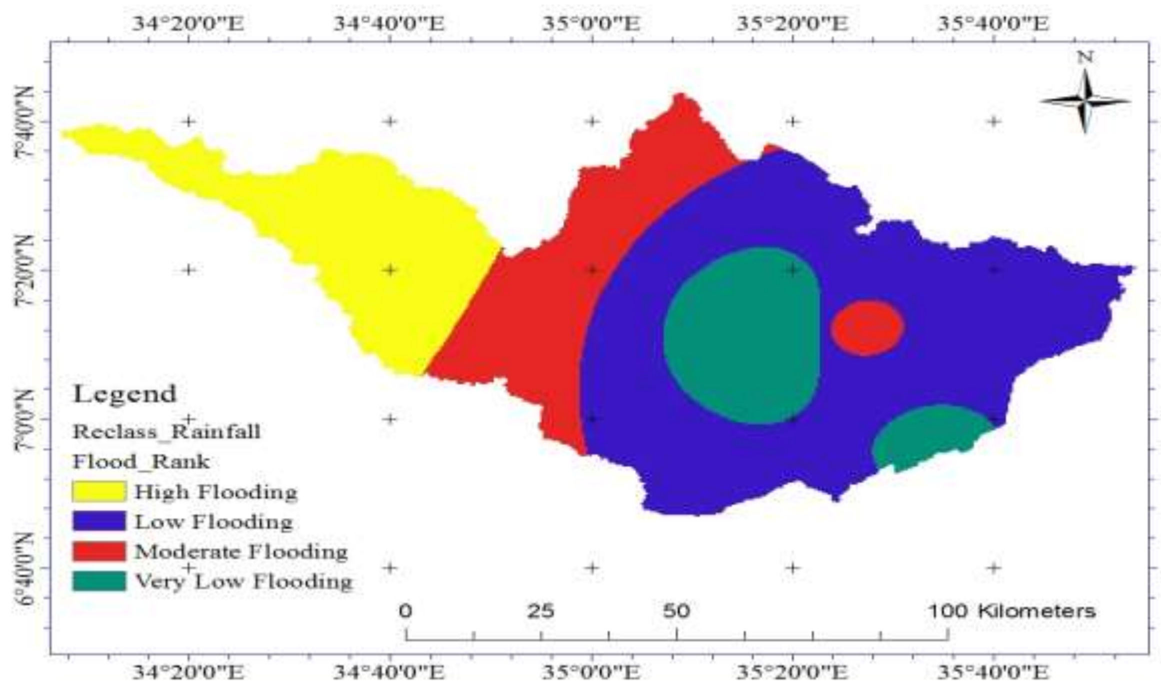
Figure 3. 10 Soil re-classes susceptibility to flooding

3.4.5. Rainfall

The parameter of rainfall intensity is expressed using the modified Fournier index (MFI), which is the sum of the average monthly rainfall intensity recorded by the rain-gauge stations (Olga, 2017). The spatial distribution of this criterion is found using the Inverse Distance Weighted (IDW) method. The spatial distribution of the values of rain intensity is illustrated in figure below with the higher values located in the southwest part of the studied area. For this study, rainfall parameter is very important, because it cause overflow of river that cause flooding. Thus, high rainfall depth has degree to high flooding and low rainfall depth causes low flooding.



a.



b.

Figure 3. 11 Rain fall (a) and Re _class Rainfall (b) for Upper –Middle Gilo River

3.4.6. Catchment delineation

Catchment basin, also called drainage basin, is the extent of an area where water flows to a single point and pours to another water body (Dai, 2016).The watershed delineation was done by using Spatial Analyst Tool in Arc GIS. The watershed is very important in hydrology, as indicate the flow direction that drain to stream or river. Watershed is land area that drains water to the outlet during a rainstorm. Boundary of watershed consists of the line drawn cross the contours joining the highest elevations surrounding the basin.

1. Flow Direction

The downstream flow (flow direction) in each pixel of DEM depends on the elevation of this point relative to its neighbors (Kafira, 2012). The possible flow directions are eight, namely E, SE, S, SW, W, NW, N and NE (Nikolaidou, 2009). Flow direction calculates the direction of flow for a given matrix. The water that is stored in each cell will flow to the steepest neighboring cells following low altitude.

The direction of flow must be known for each cell, because its direction of flow that determines the ultimate destination of water flowing across the surface (Kafira, 2012). The flow direction turned in to the raster below, with a legend of colors, each color corresponds to a number and each number indicates the flow direction between the gauging stations considered.

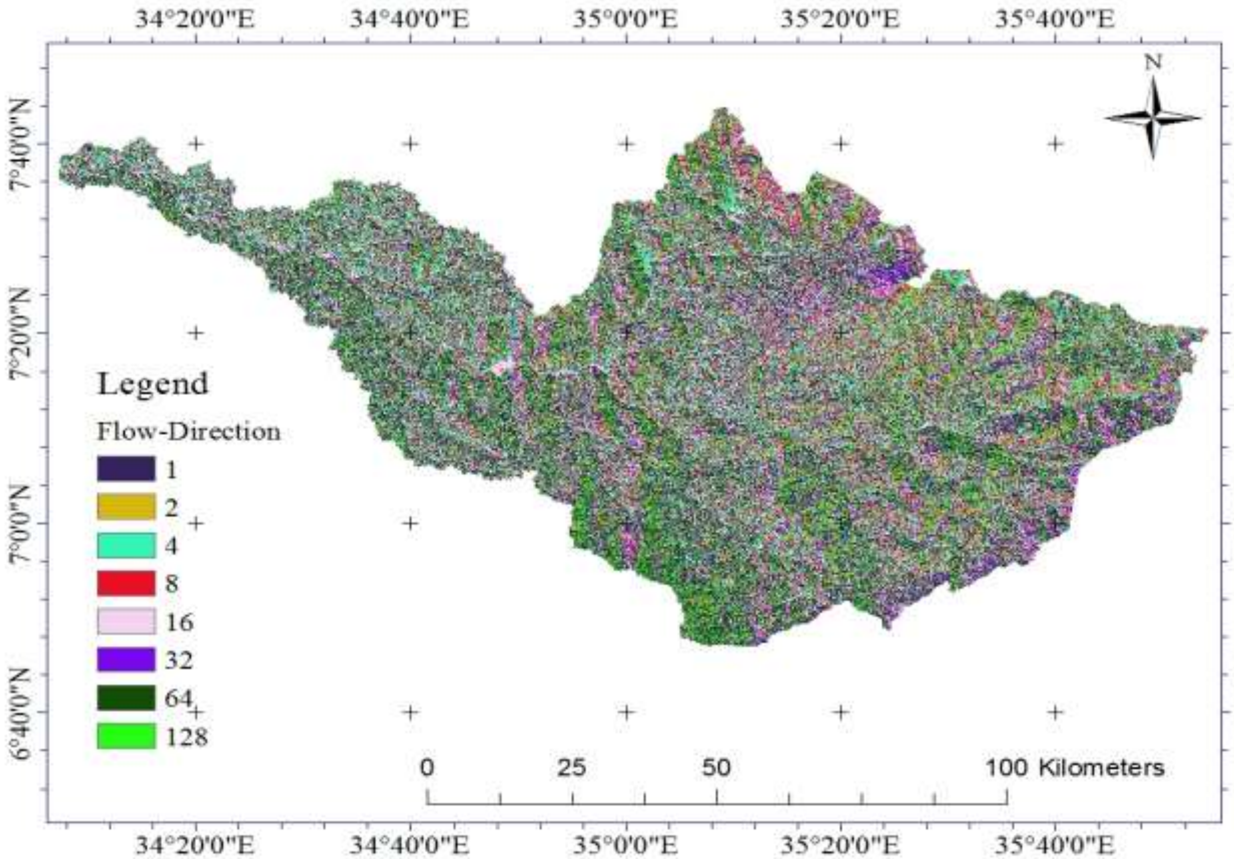


Figure 3. 12 Flow direction for Upper-middle Gilo River catchment

2. Flow Accumulation (F)

The accumulation of flow is the quantity of water, which is move to each pixel from its neighbors and eventually accumulated to it (Kafira, 2012). The calculation of total flow that is concentrated in each pixel is possible, based on the flow direction of the neighboring points (Kafira, 2012).The maximum accumulated path gives the drainage path. In this study, using hydrology modeling tools of Arc Map and the DEM of study area the flow direction was calculated for each pixel.

The accumulated flow is an important criterion of flood occurrence. It does so by aggregating water flows from uphill to lower elevation at the output raster (Olga, 2017). High values of accumulated flow indicate cells in which the flowing water tends to concentrate (Olga, 2017). Such areas are more prone to the flood hazard. For this study, flow accumulation values are in the range 0– $1.05*10^7$ computed by Spatial Analyst Tool (SAT). The figure below shows the distribution of the flow accumulation index in the study area, with the high values only occurring in the tributaries and their outflows.

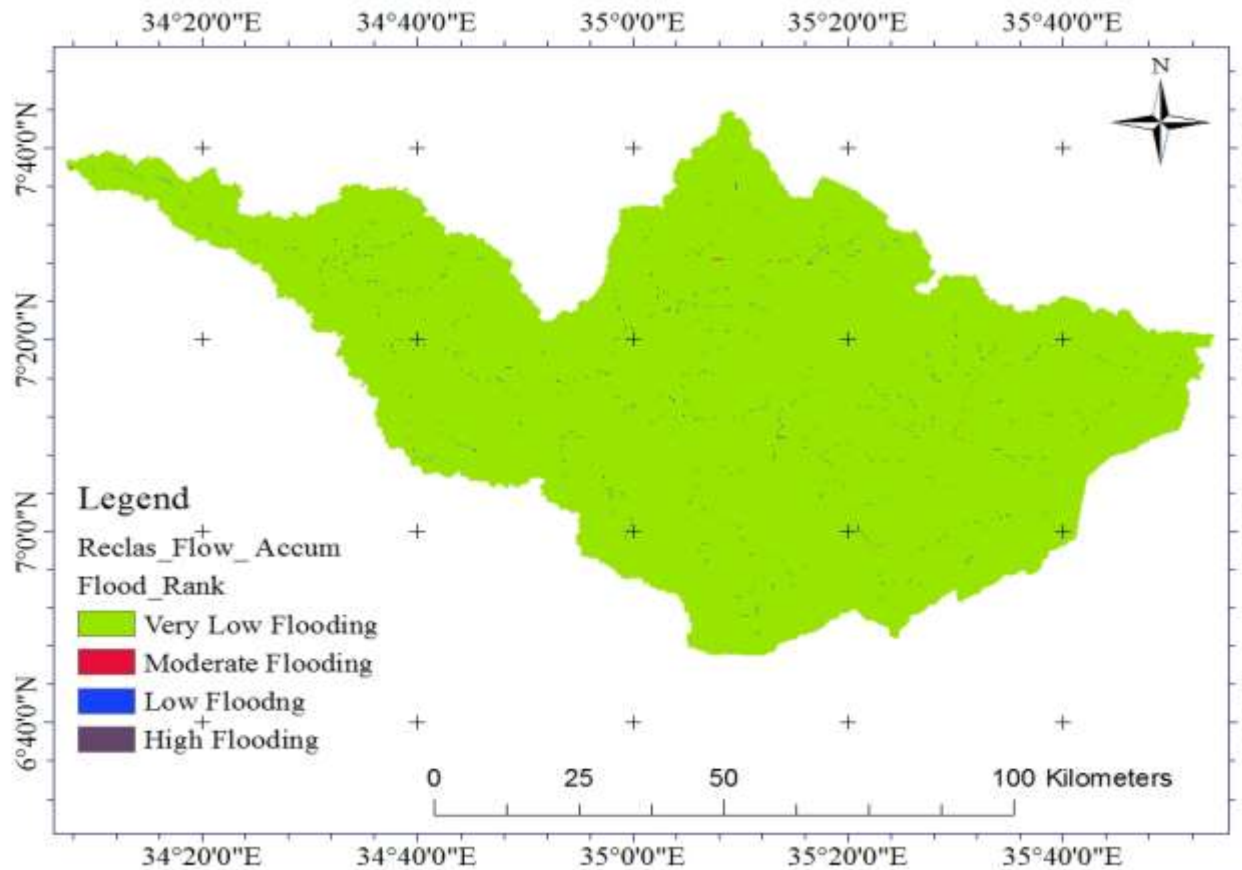


Figure 3. 13 Flow Accumulation for Upper –Middle Gilo River to flood Susceptibility

3. **Drainage Density** (DD)

Drainage Density (DD) was defined by Horton (1945) as the ratio of the total length of streams in a watershed over its contributing area. DD is higher in arid areas with sparse vegetation cover and increases with increasing probability of heavy rainstorms (Niranjan, 2016). The drainage density also higher, highly branched basins with relatively rapid hydrologic response (Niranjan, 2016). An increasing drainage density implies that floods peaks. Many methods have been used to find out the drainage density; uses of computer tool (GIS software) give much important. The drainage density for Gilo River sub-basin is estimated about 1.92km/sq.km, which indicates that the basin not very high and it tend to flooding.

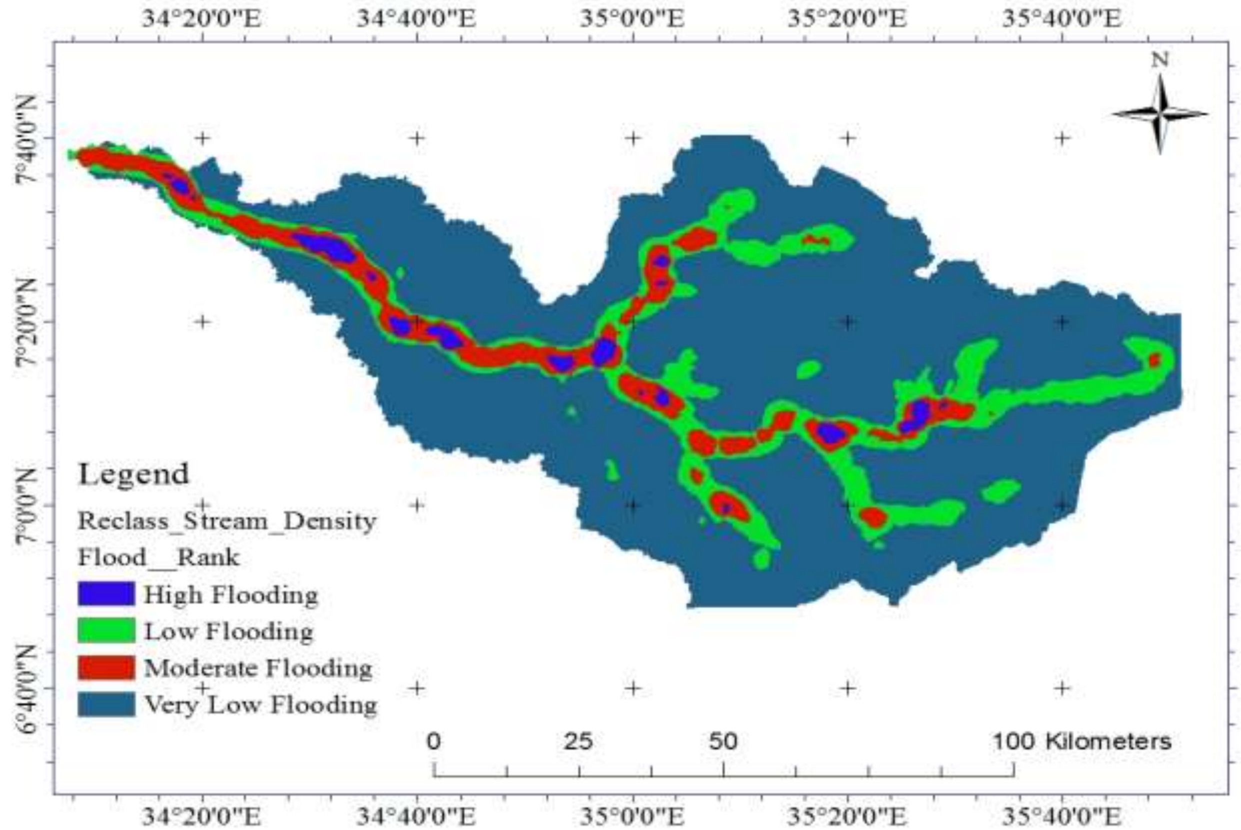


Figure 3. 14 Re class-Drainage Density of Upper-Middle Gilo River to flood susceptibility

3.5. Analytic hierarch process (AHP)

In this study weighted approach was uses based on Analytic Hierarch Process (AHP). AHP is a multi – criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information (Getahun and Gebre, 2015). It is a methodology to systematically determine the relative importance of a set of criteria by pair wise comparison. The weighted method uses to prioritize the relative importance of each factor relative to another factor (Kamonchat, 2017). The hierarchical weights calculates for all layers based on the given pair - wise comparison (Kamonchat, 2017). Thus, the iteration repeats until the consistency ratio becomes less than 0.1 or 10% is acceptable (Getahun and Gebre, 2015).

Finally, the computed Eigen values uses as coefficient for the respective flood factors that is elevation, slope, drainage density, Flow accumulation, rainfall, land use and soil layers to be combined in weighted overlay in Arc GIS to generate the final flood hazard map of the upper –Middle Gilo River Ethiopia using the following relationships.

Flood Hazard = Elevation coefficient *Elevation + drainage coefficient *Drainage density + Flow coefficient* Flow accumulation + Slope coefficient* slope + rainfall coefficient *rainfall + land use coefficient *land use + Soil coefficient *soil.

The frame work of generating flood hazard using Arc GIS is shown below.

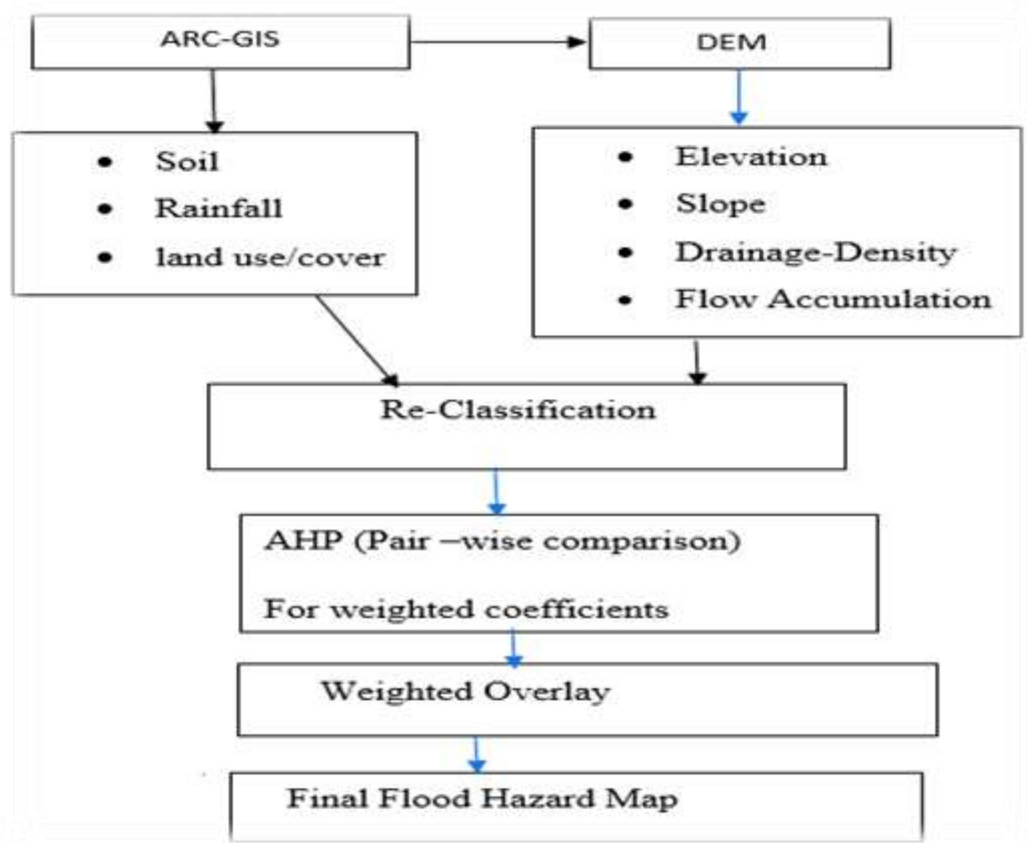


Figure 3. 15 Flood hazard map

3.6. Flood inundation mapping

The general procedure adopted for inundation modeling consists basically of five steps: i) Preparation of terrain (DEM or TIN) in Arc GIS, ii) HEC Geo RAS for Pre Processing to generate HEC –RAS import file, iii) Running of HEC RAS to calculate water surface profiles, IV) post-processing of HEC-RAS result) Flood plain mapping.

3.6.1. RAS pre- processing

The RAS pre-processing is the task one's done in River Analysis system (RAS). For this, study River geometry was done by HEC-Geo RAS software. The HEC-Geo RAS is a GIS extension with a set of procedures, tools and utilities for the preparation of river geometry (Sean, 2011). HEC–Geo RAS software uses Digital Terrain Model (DTM) to create river geometry. The DEM (30 by30) was taken from department Geographic Information System, Ethiopia.

In via GIS Environment, Triangular irregular Network (TIN) for Gilo river catchment was developed from DEM of the study data using the 3D spatial analysis extension. A TIN is a set of adjacent, non-overlapping triangles, computed from irregularly spaced points with x/ y coordinates and z- values (Dewberry, 2011). The TIN data structure is based on irregularly spaced point, line and polygon data interpreted as mass points and break lines. Thus, TIN allows efficient generation of surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as stream banks that are critical for hydrologic and hydraulic analyses (Dewberry, 2011).

Further, the river center line, River bank, flow path; XS cross-section, 3d river centerline, 3d river cross -section developed by HEC-Geo RAS. The river stream center line, bank lines, flow path center lines, and cross section lines has to be digitized from a previous river file and topographical datasets using HEC-Geo RAS interface. The river reach (river segment between junctions), cross- section and other related data is store in the geo-database file of HEC- Geo RAS. The following section describes how each individual layers created (digitized).

1. Creating River Centre line: The River centerline layer is very important, because it represents the river network for HEC-RAS. The digitizing of stream centerline start with selecting the sketch tool from the Editor Toolbar and digitization proceed in the direction of a river flow (Slobodan, 2009).The process begins from upstream end to the downstream end of the middle Gilo River. After digitizing all of reaches, the user assigns the name of the river. This was accomplished by the selection of Assign River code / Reach Code menu item and assigning appropriate names.

2. Creating River bank

The interface extracts the geometric data in export RAS data in GIS2RAS.RASImport.sdf format. The bank lines layer is used to define river channel from overbank areas. The bank lines are created in similar way as the river centerline. The digitizing of bank lines starts from the upstream end, with the left bank (looking in downstream direction) being digitizing first.

3. Creating Flow paths

The flow path layer is a set of lines that follows the center of mass of the water flowing down the river, during the flood event (Meyer and Olivera, 2007; Slobodan, 2009). For Flood plains, the flow path centerlines are digitized to represent created water flow within the flood plain. Flow path centerlines are created in the upstream to downstream flow direction.

4. Creating cross-sections

Cross-sections are one of the most important inputs to HEC-RAS. Cross-section cut lines are used to extract the elevation data from the terrain and to create a ground profile across the flow (Dragon and Slobodan, 2009). The intersection of cut line's with other RAS layers such as centerline and flow path lines are used to compute HEC RAS attributes such as bank stations (locations that separate main channel from floods plain) and downstream reach length (distance between cross-section) (Slobodan, 2009). The following important basic rules were followed during the process of drawing cross section cut lines (Meyer and Olivera, 2007; Slobodan, 2009): Cut lines are drawn perpendicular to a direction of flow, Cut lines are drawn directionally from left to right bank, looking downstream direction and Cut line's do not intersect each other.

For this study, there are about 310 cut line's was created for upper-middle Gilo river. Thus, for each cut line's, the 2D feature class XS Cut lines are intersected with the TIN to create a feature class with 3D cross-section.

Finally, Creating GIS import file for HEC-RAS so that it could import the GIS data to create the geometry file. First, choosing layer set up window and under required surface choose TIN, under required layers select river layer, XS-Cut line's layer and XS-Cut line's 3D layer, under optional layers choose banks, flow path, River 3D and optional tables are not used in this study, show all null value.

3.6.2. RAS post-processing

Hydraulic models are utilized in order to simulate the behavior of the flow in the main channel and the flood plain of a river. The peak flood discharge which was generated from probability distribution methods is used as the main input for hydraulic modeling. The other important input for RAS Post processing is geometry data of the river which was prepared using HEC –Geo RAS extension. HEC_RAS5.0.3 is hydraulic model created by the hydrologic Engineering center which was utilized as hydraulic model in this study. HEC_RAS is well -known and popular hydraulic model which widely has been utilized in different water resources studies in different parts of the world (Sina, 2010). HEC_RAS has the capability of performing the analysis in steady state (simplicity approach; flow does not change through time) and unsteady state (more complex and realistic approach) (Sina, 2010).

The HEC-RAS software is accomplished by the following Stepwise procedures.

1. Create new project

2. View and Edit Geometric Data

3. View and Edit steady or unsteady Flow Data

4. Perform a steady or an unsteady flow simulation

3.6.2.1. Import RAS geometry

The RAS geometry is imported to HEC-RAS in GIS format. The imported Geometry file containing head, stream network and cross section information and used for hydraulic modeling in HEC-RAS (Raluca-Iustina, 2015).

These importing file in to geometric editors (Graphical User Interface (GUI)), which is managing geographic data. In this editor, the manning’s roughness coefficient values is enters for the cross section of the reach. This coefficient is not easy to determine, cannot be measured directly and is varying constantly (Edna, 2007). It is influenced by various factors such as topographic heterogeneity, the bed material, the surface irregularity on the floodplain, obstructions, the variation in shapes and size and the vegetation for flood plain (Cowan's, 1956).

Roughness values for channels and flood plains should be determined separately (Cowan's, 1956). Thus, the physical shape and vegetation of a flood plain can be quite different from those of a channel.

The roughness coefficient for flood plains is determined by selecting a base value for natural base soil surface of the flood plain and adding adjustment factors due to surface irregularity, obstructions and vegetation (Cowan's, 1956). Cowan's (1956) altering that, the following equation can be used to estimate the roughness values for flood plain.

$$n = (n_b + n_1 + n_2 + n_3 + n_4)\, m \quad \text{.......... Eq3.4}$$

Where: nb = a base value of n for flood plain's natural bare soil surface, n1 = a correction factor for the effect of surface irregularity on the flood plain, n2 = a value of variation in shape and size of flood plain cross section (assumed 0), n3 = a value for obstruction for flood plain, n4 = a value for vegetation on flood plain, m = a correction factor for sinuosity of the flood plain, equal to 1.0 and n = roughness coefficient. For upper –middle Gilo River the roughness estimation adopted for this study was based on theoretical adjustment factors and Appendix D show detail information about roughness value.

3.6.2.2. Steady and unsteady flow data

Similarly, for flow data, unsteady flow was assumed as dealing with flood flow depth, discharge varied throughout the river. A peak flood computed for different return period 10, 25, 50 and 100 years was used for input data. For example for 100 years unsteady flow distribution shown in the Appendix E.

In HEC-RAS, hydraulic analysis is crucial to properly describe the boundary condition. Boundary condition plays a role as a connecting node that defines flux relationship between the simulation area and surrounding area (Edna, 2007). Boundary condition needs to be defined at the upper and lower boundary of the simulation domain area can be represented by either series of constant discharge, Q or series of water level, H (as function of time) (Edna, 2007). A wrong choice of boundary conditions may generate a misleading water balance of the system and consequently resulted in serious propagation of errors throughout the simulation, thus giving ambiguous results (Edna, 2007). For this study, based on the availability of data the critical depth for steady flow analysis and flow hydrograph for unsteady flow analysis is selected for boundary conditions.

3.6.2.3. **Steady and unsteady flow analysis**

Usually, a steady flow approach is used for floodplain management and flood insurance studies whereas unsteady flow approach is used for subcritical flow regimes (Brunner 2002, Niraj, 2017).

The steady and unsteady flow analysis is the computation of hydraulic results by taking the input data of geometry data for geometry preprocessor, steady and unsteady flow data, for steady and unsteady flow simulation and the post-processor computed various RAS results (Dewberry, 2011). While, run steady and unsteady flow analysis, via performing flow analysis in HEC-RAS5.0.3 software and river cross section output was displayed in different format such as figure and table.

Finally, export the computation results (water surface elevation) in GIS format. In the GIS Export, all four profile results (for the 10, 25, 50 and 100 years flow scenarios) are selected and exported using format RASexport.sdf.

3.7. RAS mapping

HEC-Geo RAS is used to generate flood inundation maps. The initial step for the HEC – Geo RAS mapping process is to transform the HEC- RAS results in to GIS format (Sean, 2011). The HEC RAS results is in RAS Export.sdf File type and have to be convert to RAS.xml File format to read in GIS data base.

3.7.1 Create layer set-up

Establishing the layer setup is a necessary step for processing the HEC-RAS results. In the layer setup window, the type of analysis and the input and output data are identified. In the layer set up for post processing, first select new analysis and named it (e.g. Flood 100year). Browse .RASexport.xml for RAS GIS Export File from user working folder. Select single terrain type and lookup from working folder. Set the output directory for HEC processing results. The default 20 map units for Rasterization cell size in layer setup window. Basically, the smaller number of map unit (1 or 2) results in a better representation of the resulting flood plain boundary during the floodplain delineation (Slobodan, 2009). Due to the large covered by the upper-middle Gilo river, it's post-processing is quite complicated and requires the creation of a very large TIN. So, user computer hardware limitation cause the program not able to handle 1 to 5 cell resolution and 10 map units are used for best possible rasterization for this study.

3.7.2. Import RAS data

The input data entered in the layer set up, the HEC-RAS results have to be imported into the GIS in order to continue with post-processing. The RAS results introduces in a new data frame with following feature classes: River2D, XS cut lines, bounding polygon water surface elevation and bank points. This is creating a bounding polygon, which basically defines the analysis extent for inundating mapping, by connecting the endpoints XS Cut lines.

3.7.3. Inundation mapping

Floodplain mapping is performed using the water surface elevations on the XS cut line, within the limits of the bounding polygon (Slobodan, 2009). Flood plain mapping or inundation mapping includes two steps such as water surface TIN and Floodplain delineation.

3.7.3.1. **Water surface generation**

In this step, create water surface TIN from the cross section water surface elevation for the selected profile. For each selected water surface profile, a water surface TIN is created without consideration of the terrain model (Slobodan, 2009). The TIN is created using the ArcGIS triangulation method. This allowed for the creation of a surface using cut lines as hard break lines with constant elevation (Slobodan, 2009).

3.7.3.2. **Floodplain delineation**

The floodplain delineation proceeds by HEC-Geo RAS software through convert raster to grid to feature. There was a series message seen during execution. The first step, water surface TIN is converted to a GRID (water surface GRID) and subtract the terrain GRID from water surface GRID (Slobodan, 2009); Maurer, 2015). Also, add water depth GRID to map for a different water surface profile. Additionally, convert flood plain GRID to polygon for different water surface profile. The areas which of little interest are still included in the water surface TIN. These areas are removed in the process of delineation (Maurer, 2015). Finally, a floodplain feature flood inundation depth, extent area of flood inundation map was developed along upper-middle Gilo River, Ethiopia.

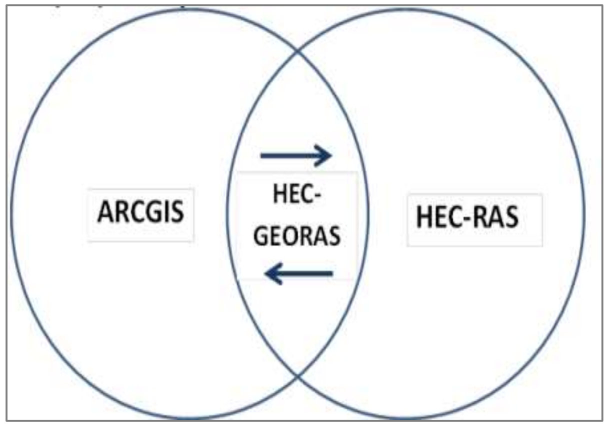


Figure 3. 16 Schematics representation of the used computer software for FIM

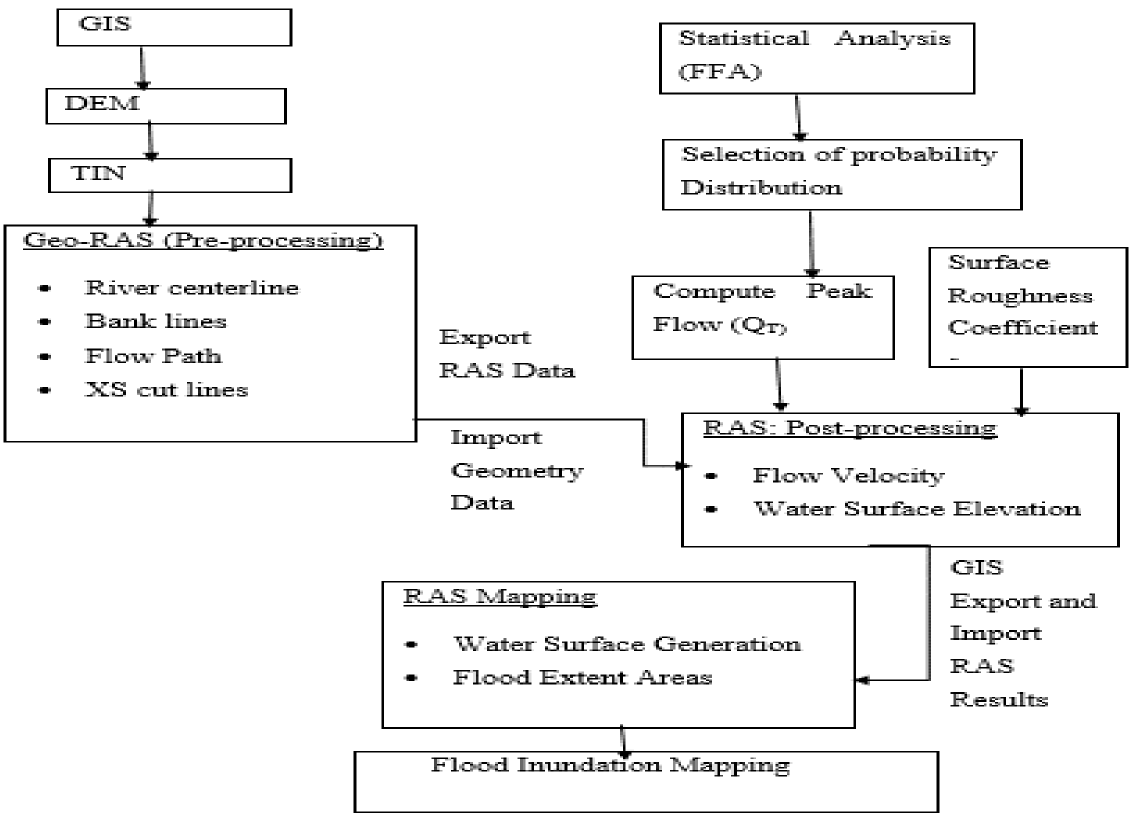


Figure 3. 17 Step-wise procedure for Flood Inundation Mapping

4. RESULTS AND DISCUSSION

4.1. Flood frequency analysis

Flood frequency analysis is done based on maximum daily annual flow recorded at Beko station from year 1990 to 2014. The probability distribution model selected are such as; Log-Logistic, Log-Logistic (3P), General Extreme Value (GEV), Pearson5 (P5), Log–Pearson3 (LP3), Pearson 6 (P6), Log-Pearson 6(LP4). For selecting best fitted distribution, goodness-of-fit test has been conducted. Using Easy-Fit, Kolmogorov-Smirnov (K-S) test is found that Log- Pearson -III (LP3) is the best distribution among the selected probability distribution.

The peak discharges for different return periods was computed using log-Pearson 3(LP3) for 10, 25, 50 and 100 years their corresponding peak flow are 67.39, 82.93, 95.06 and 107.15 m^3/s respectively. However, transposing peak discharges was employed at downstream point using Drainage Area Weighting (DAW) methods. The transposing coefficient is 2.794 (shown in Appendix B) and the peak discharges for Upper-Middle Gilo River for different return periods: 10, 25, 50 and 100 years become 255.66, 314.64, 360.66 and 406.53 m^3/s respectively. These value from log-Pearson3 (LP3) distribution methods have been used for flood inundation mapping.

4.2. Flood inundation mapping

The general procedure adopted for inundation mapping consists basically of five steps: i) Preparation of terrain (DEM or TIN) in Arc GIS, ii) HEC Geo RAS for Pre Processing to generate HEC –RAS import file, iii) Running of HEC RAS to calculate water surface profiles, IV) post-processing of HEC-RAS result, V) Flood plain mapping. Flood inundation mapping was done considered result obtain from four simulation scenarios. For illustration purpose the inundation maps of only the DEFAULT scenarios of 10, 25, 50 and 100 year flood for this section analyzed.

The preparation Triangular irregular Network (TIN) from Digital Elevation Model is very important. A Triangulated Irregular Network (TIN) is a vector-based structure that is used to model irregularly spaced sampled points across a surface. Thus, TIN allows efficient generation of terrain surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as stream banks that are critical for hydrologic and hydraulic analyses.

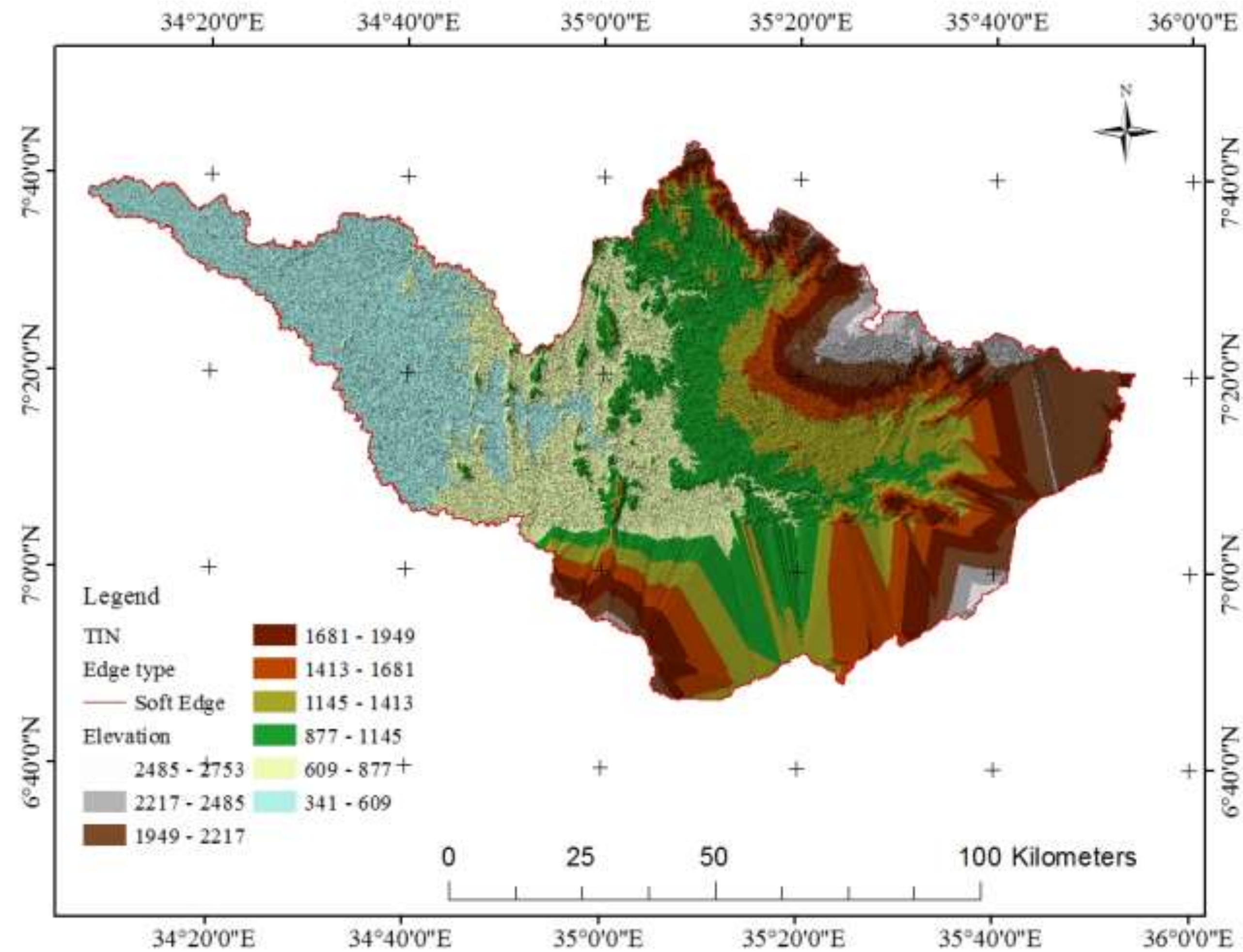
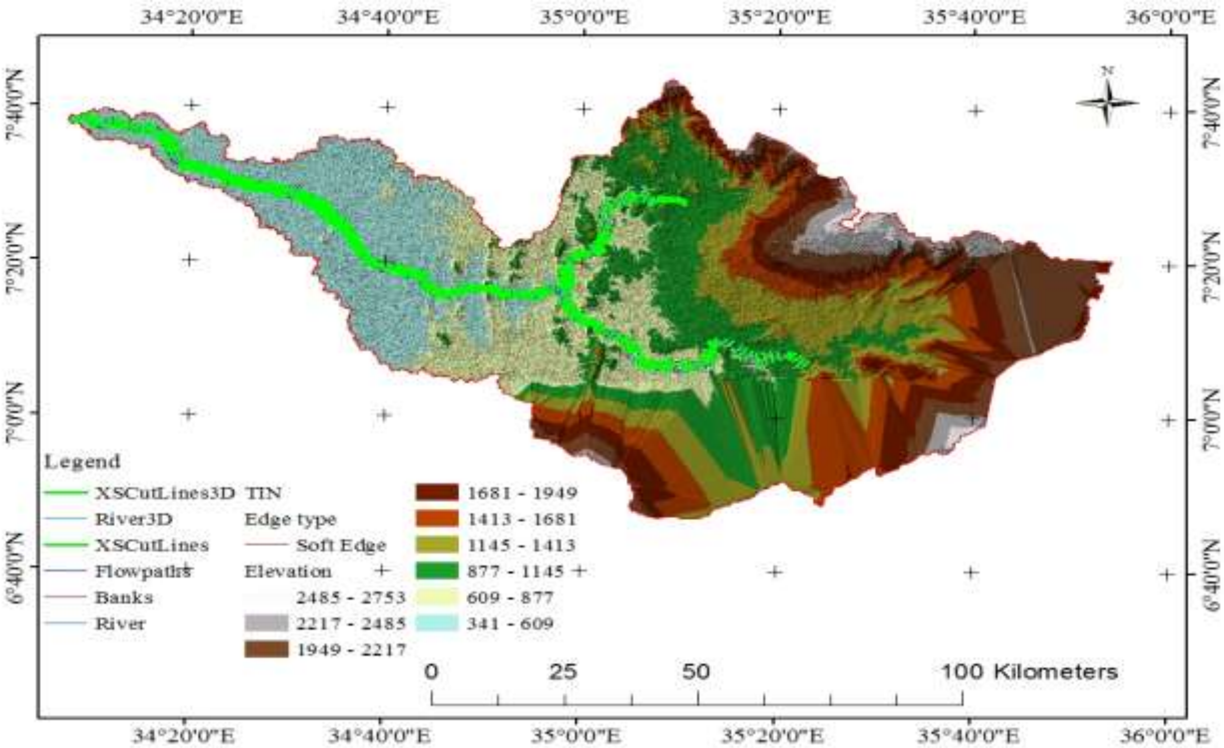


Figure 4. 1 TIN from DEM

4.2.1. River geometry

The river geometry is a very important to develop flood inundation mapping. It is the pre-processing done by using HEC Geo RAS and used for HEC-RAS hydraulic analysis. The required element includes river center line, river banks, flow path and XS Cut lines. There is about 310 XC cut line's was digitized for upper- middle Gilo river and with their detail information. The attribute table of XS Cutlines3D, river3D and XS cut lines are shown in Appendix C gives brief information such as elevation; reach name, channel length, station number, Hydro ID and other.



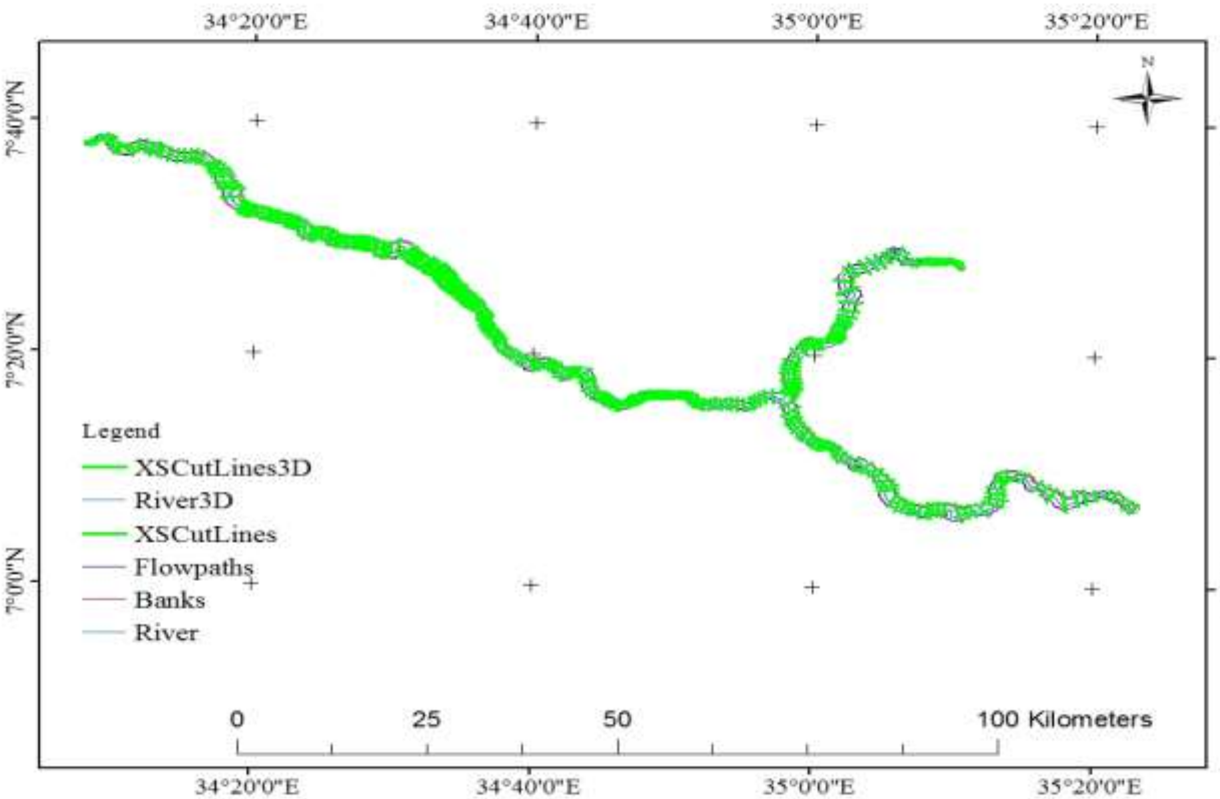


Figure 4. 2 Upper-Middle Gilo River Geometry created by HEC-Geo RAS

4.2.2. Hydraulic computation

HEC-RAS is the ability to model flood events and produce water surface profiles over the length of the stream. The water surface elevation are estimated using hydraulic model, served very important. Hydraulic simulation are executed for the design discharge at different return period (10, 25, 50 and 100 years). In addition, the detail information of hydraulic computation shown in table format found in Appendix.

The water surface elevation from HEC-RAS hydraulic model are geo-referenced (mapped) on the digital terrain model. Thus, water surface converted to Triangular Irregular Network (TIN format) for post processing.

4.2.3. Inundation mapping

The RAS Mapping tool in HEC Geo RAS was used to develop generation of water surface and flood plain delineation for different flow scenario and return period. The hydraulic simulation from HEC data is imported to Geo RAS mapping in this stage as shown in figure 4.3 below. The Inundation mapping was completed using two steps: Generation of water surface TIN and Flood plain Delineation.

Generation of water surface TIN: The water surface TIN is intersected with the digital terrain model to create flood plain polygon for different flow scenario. The TIN is converted to Raster using Raster converter in GIS and RAS results was imported HEC – Geo RAS, flood bounding polygon, XS Cut line’s, River 2D, water Surface Extents and Bank Points have to be created as shown figure below.

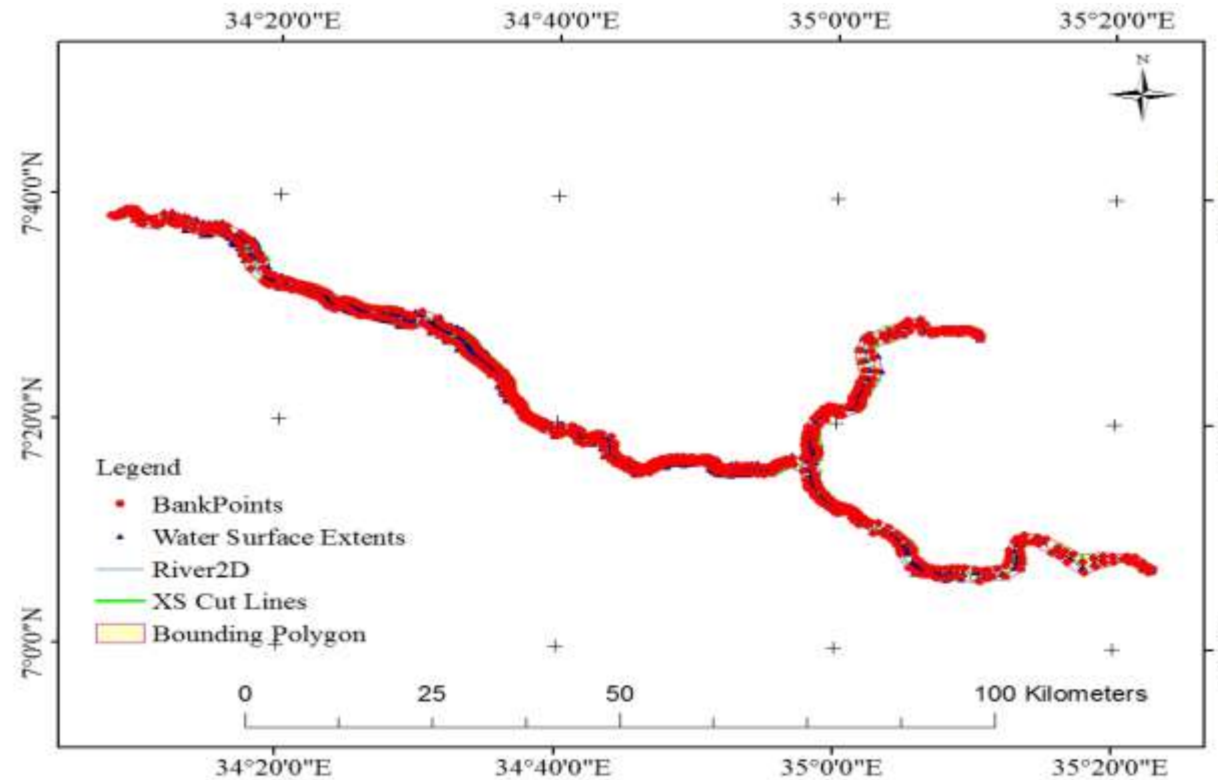


Figure 4. 3 100-year Flooding RAS results

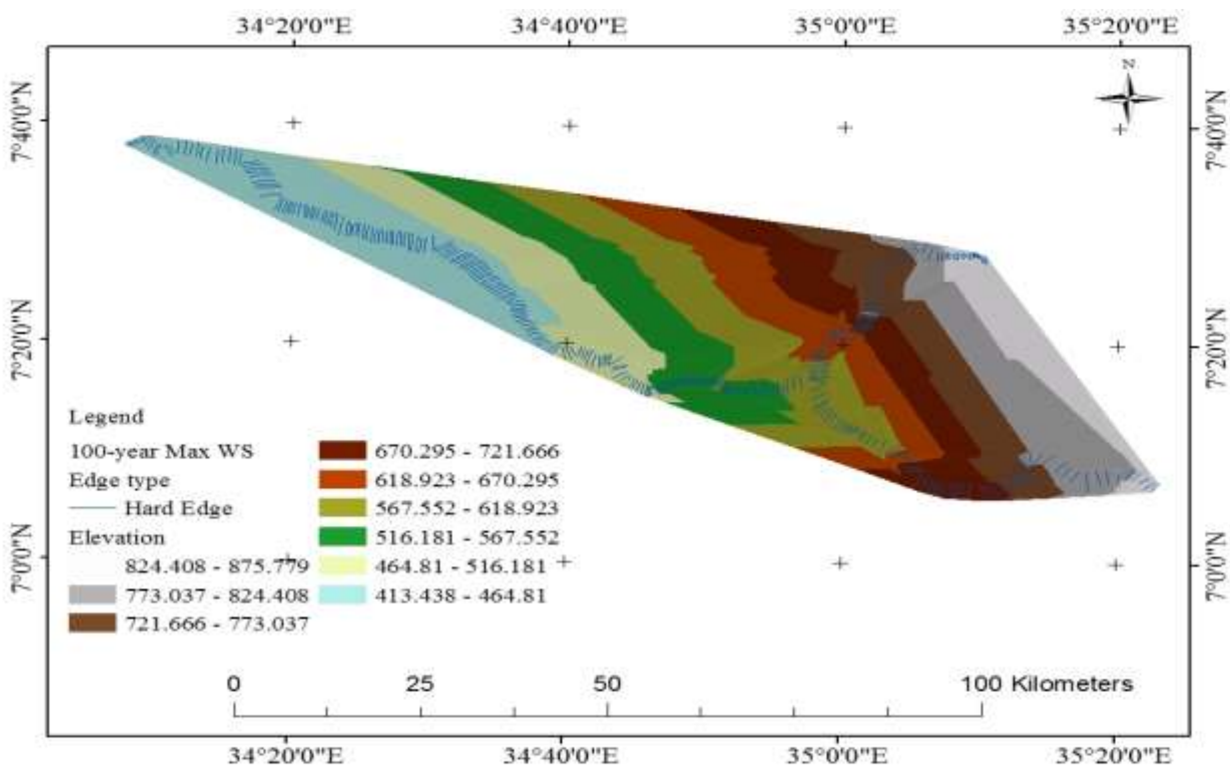
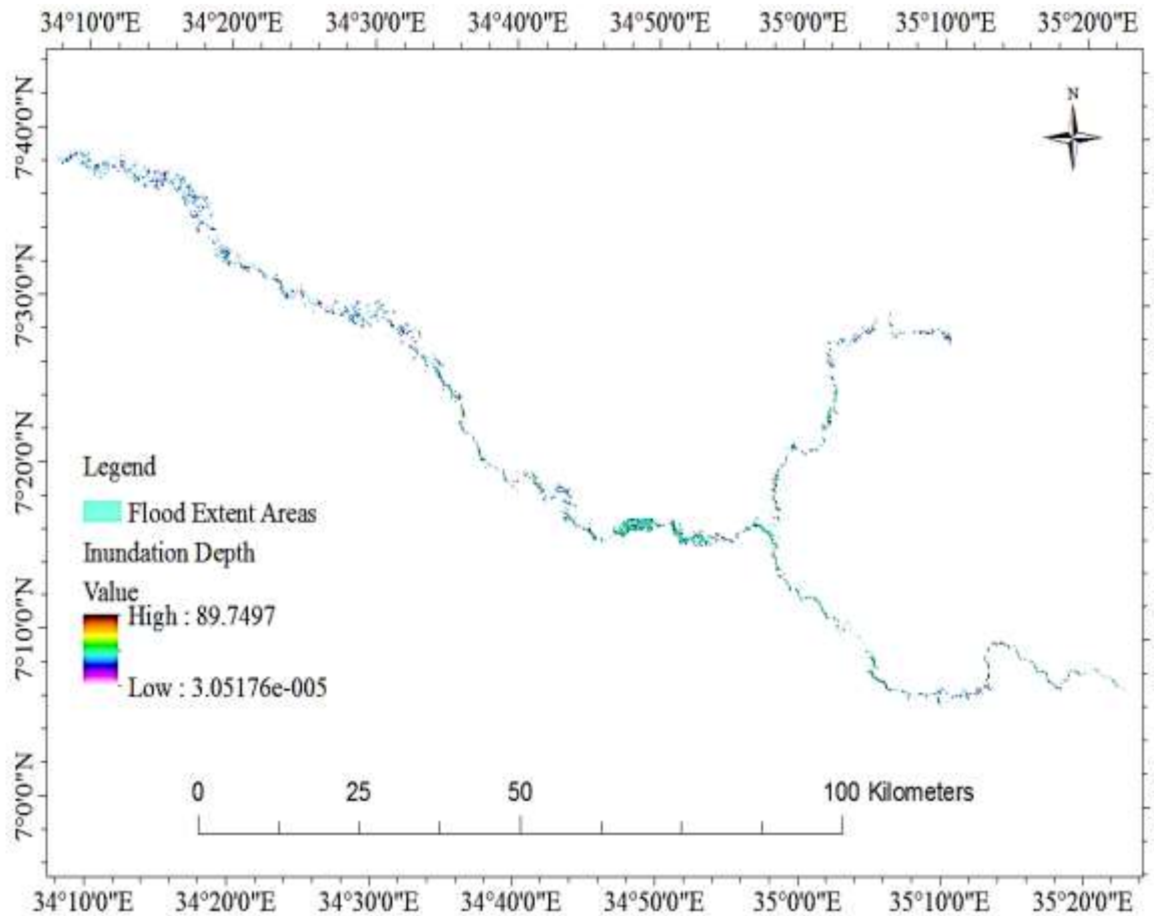
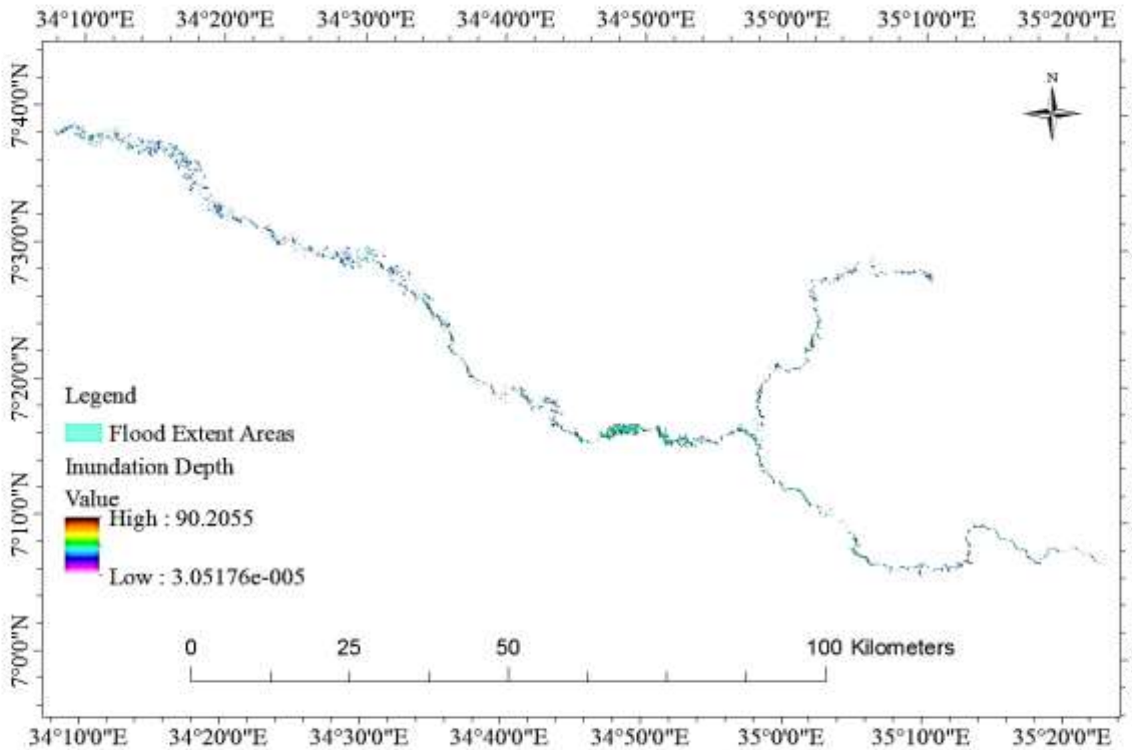


Figure 4. 4 100-yaer Flooding water surface TIN

Flood plain Delineation: HEC-Geo RAS can post-process the HEC-RAS data in to bounding polygon shape files that define the extents of flooding for a given flood event. The water surface TIN was converted to GRID and subtract the terrain GRID from water surface GRID. Thus, water depth GRID is created and used to map for a different water surface profile. Finally, a floodplain feature, inundation depth, extent area of flood inundation map was developed along upper-middle Gilo River. The inundation maps of the DEFAULT scenarios of 10, 25 , 50 and 100 year are shown below with their flood extents area and inundation depths for both steady and unsteady flow flood simulation.



a.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34°30'0"E
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7°40'0"N
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7°20'0"N
7°10'0"N
7°0'0"N
N
Legend
Flood Extent Areas
Inundation Depth
Value
High : 90.2055
Low : 3.05176e-005
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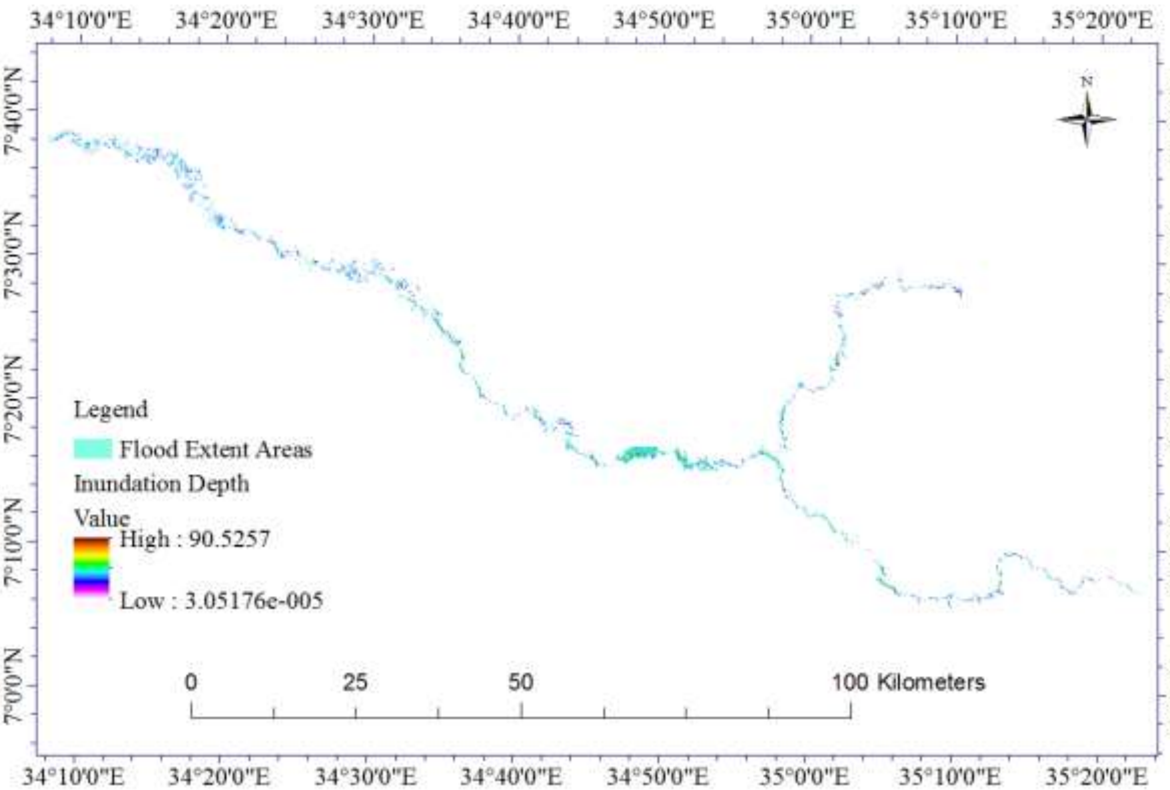
25
50
100 Kilometers

b.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35°20'0"E
7°40'0"N
7°30'0"N
7°20'0"N
7°10'0"N
7°0'0"N
N
Legend
Flood Extent Areas
Inundation Depth
Value
High : 90.5257
Low : 3.05176e-005
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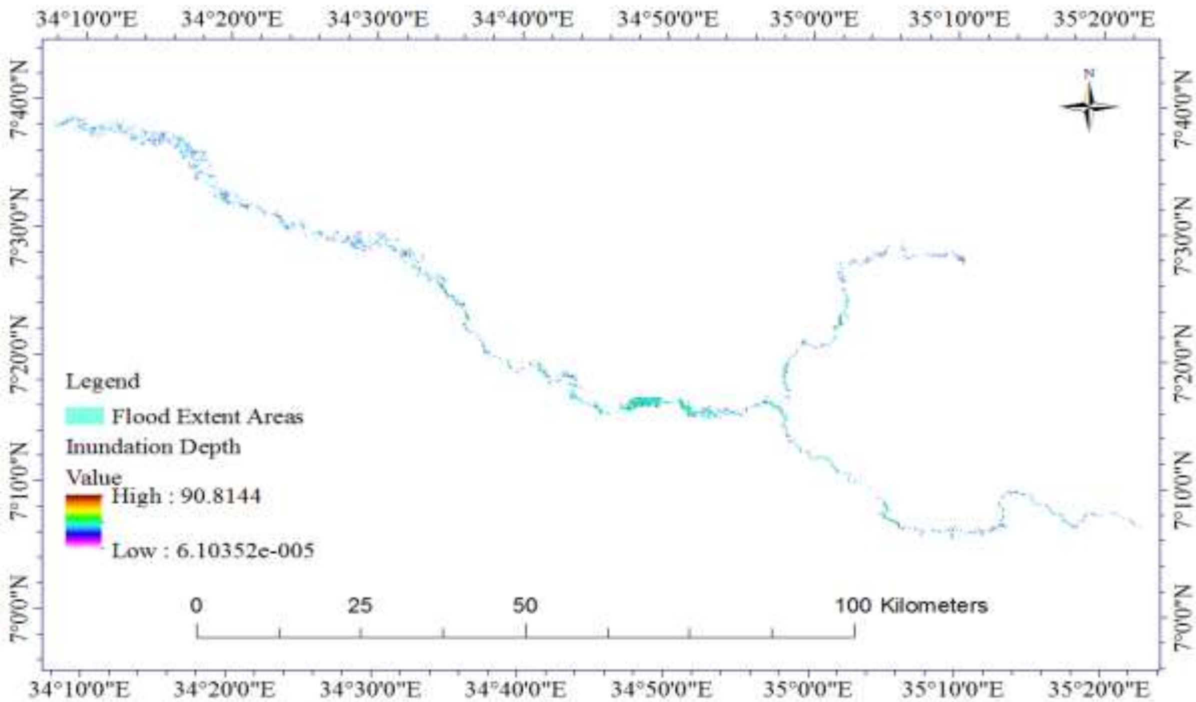
100 Kilometers

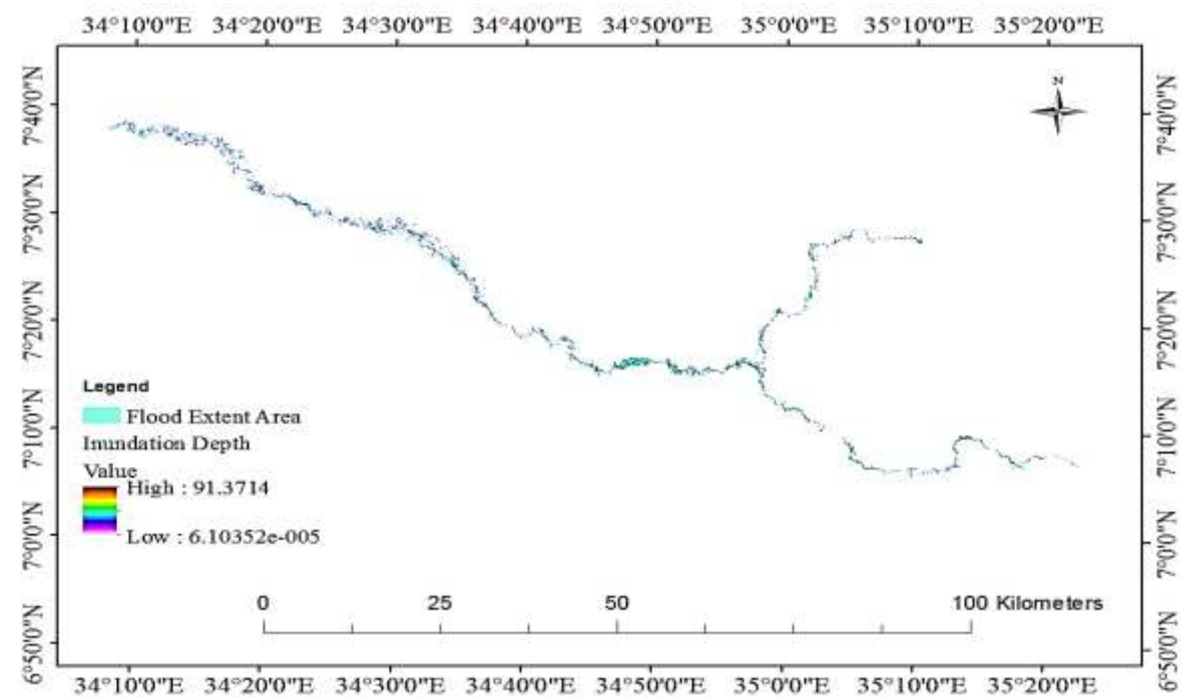
c.



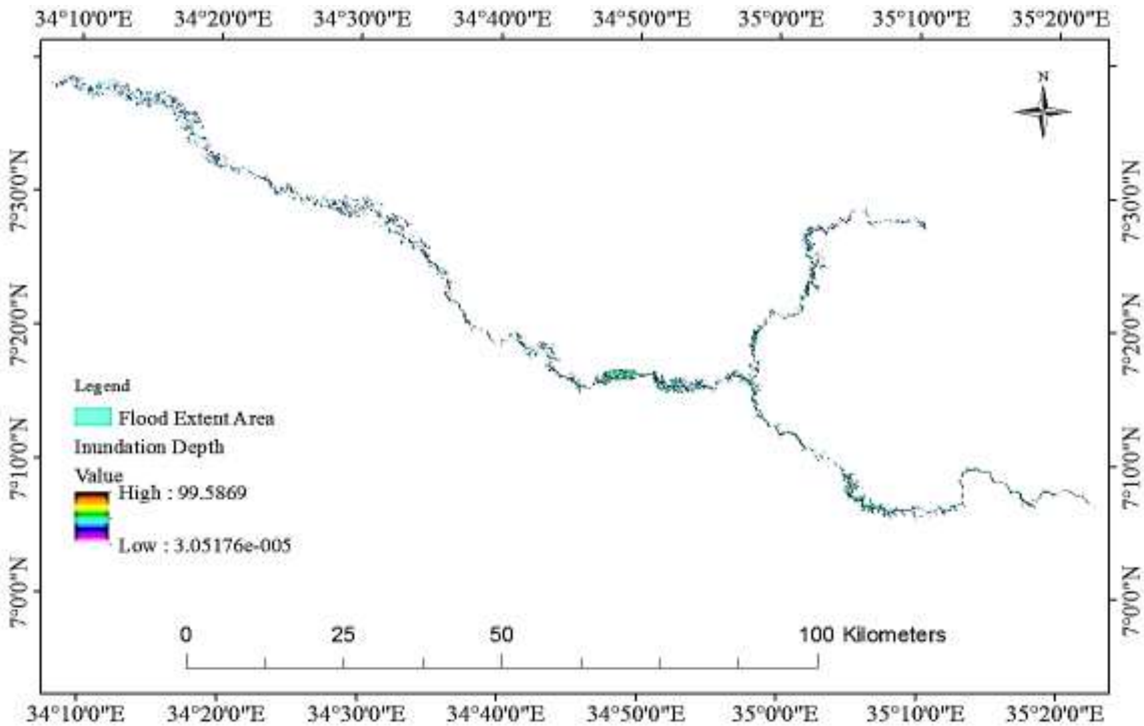
d.

Figure 4. 5 Flood Inundation Mapping for Upper-Middle Gilo River

(a, b, c and d are steady 10, 25, 50 and 100 year flooding respectively)



a.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35°10'0"E
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7°30'0"N
7°20'0"N
7°10'0"N
7°0'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 99.5869
Low : 3.05176e-005
0
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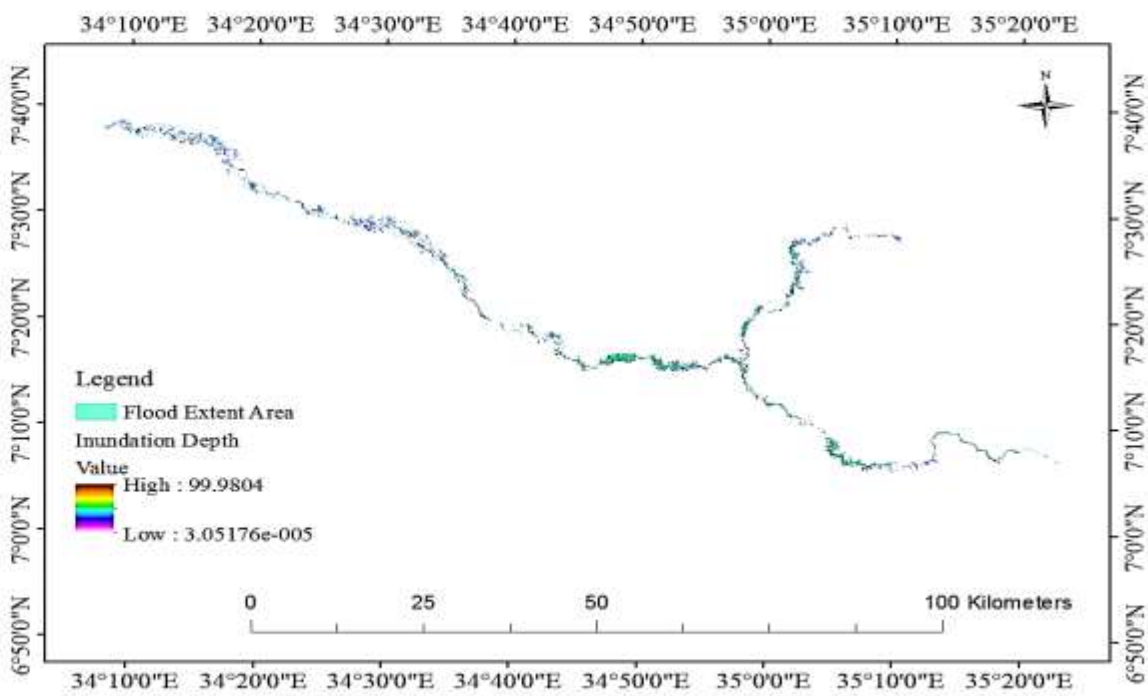
100 Kilometers

b.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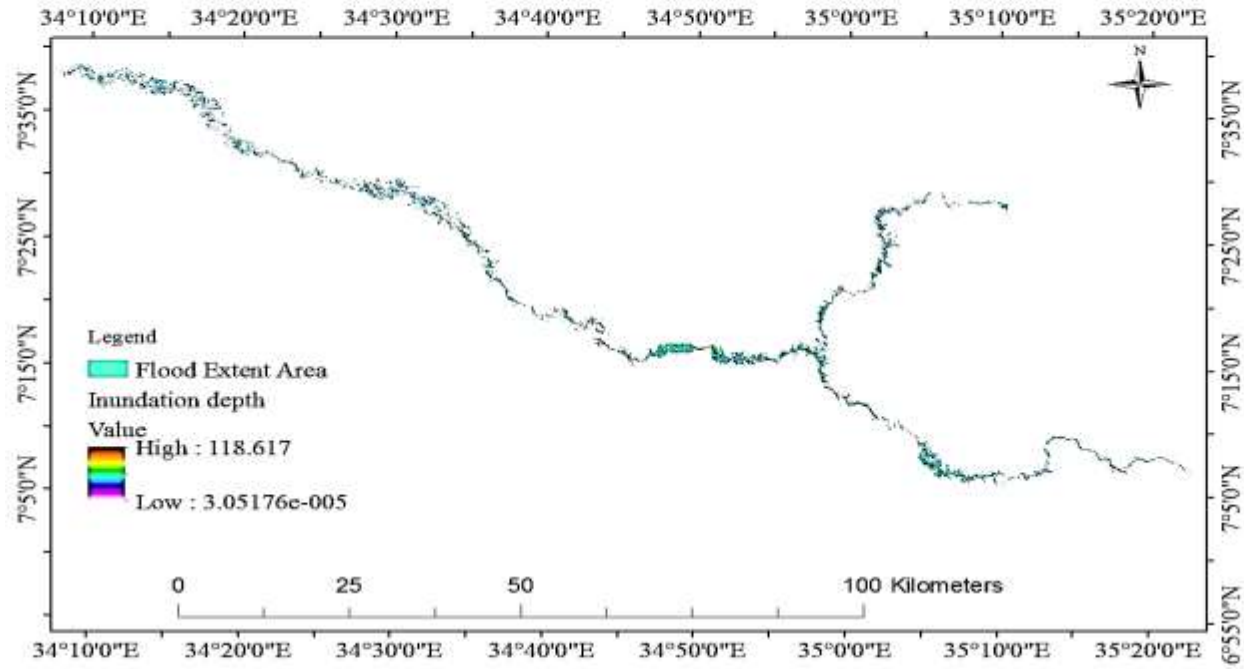
34°30'0"E
34°40'0"E
34°50'0"E
35°0'0"E
35°10'0"E
35°20'0"E
7°40'0"N
7°30'0"N
7°20'0"N
7°10'0"N
7°0'0"N
6°50'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 99.9804
Low : 3.05176e-005
0
25
50
100 Kilometers

c.



d.

Figure 4. 6 Unsteady Flow Flood Inundation Mapping for Upper-Middle Gilo River

(a, b, c and d are unsteady 10, 25, 50 and 100 year flooding respectively)

The flood inundation areas and Percentage Inundation (%) of steady and unsteady flood simulation for upper –middle Gilo River are shown in table below. The total area of flood bounding polygon is estimated about 455.365km^2 using GIS software. The maximum and minimum inundation area is estimated about 60.51, 88.12km^2 for 100 years and 54.72, 71.76km^2 for 10 years for steady and unsteady flow simulation respectively.

Table 4. 1 Flood Inundation Extent Areas For upper-middle Gilo River

Return period(years)		10	25	50	100
Peak Q(m^3/s)		255.66	314.63	360.66	406.53
WSE(m)	Steady	413-871.53	413-871.86	414-872	414-872.32
	unsteady	413-877	413-873.42	416-873.77	413-875

Inundation areas(km^2)	Steady	54.72	57.13	58.88	60.51
	Unsteady	71.76	83.49	85.98	88.12
Percentage Inundation (%)	steady	12.02	12.55	12.93	13.288
	Unsteady	15.75	18.33	18.88	19.35
	% diff	3.73	5.78	5.95	6.06
Inundation Depth(m)	Steady	89.85	90.20	90.52	90.811
	Unsteady	91.37	99.58	99.98	118.617
velocity(m/s)	Steady	6.84	7.21	7.385	7.66

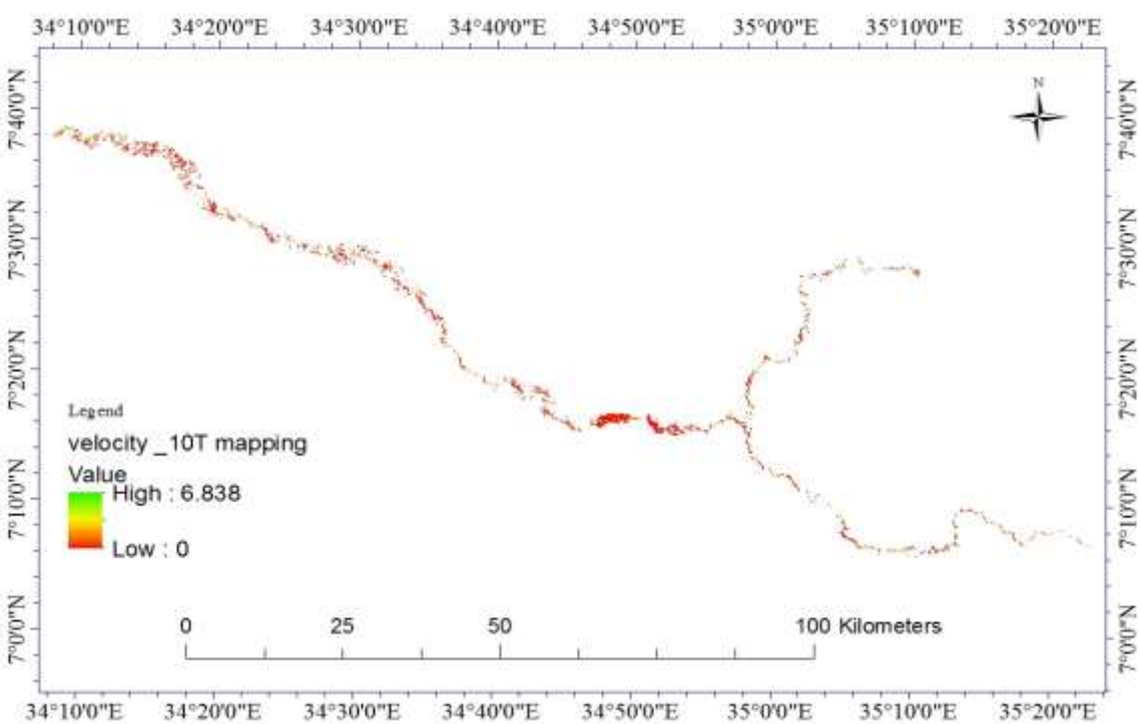


Figure 4. 7 Steady 10-Year Velocity Mapping

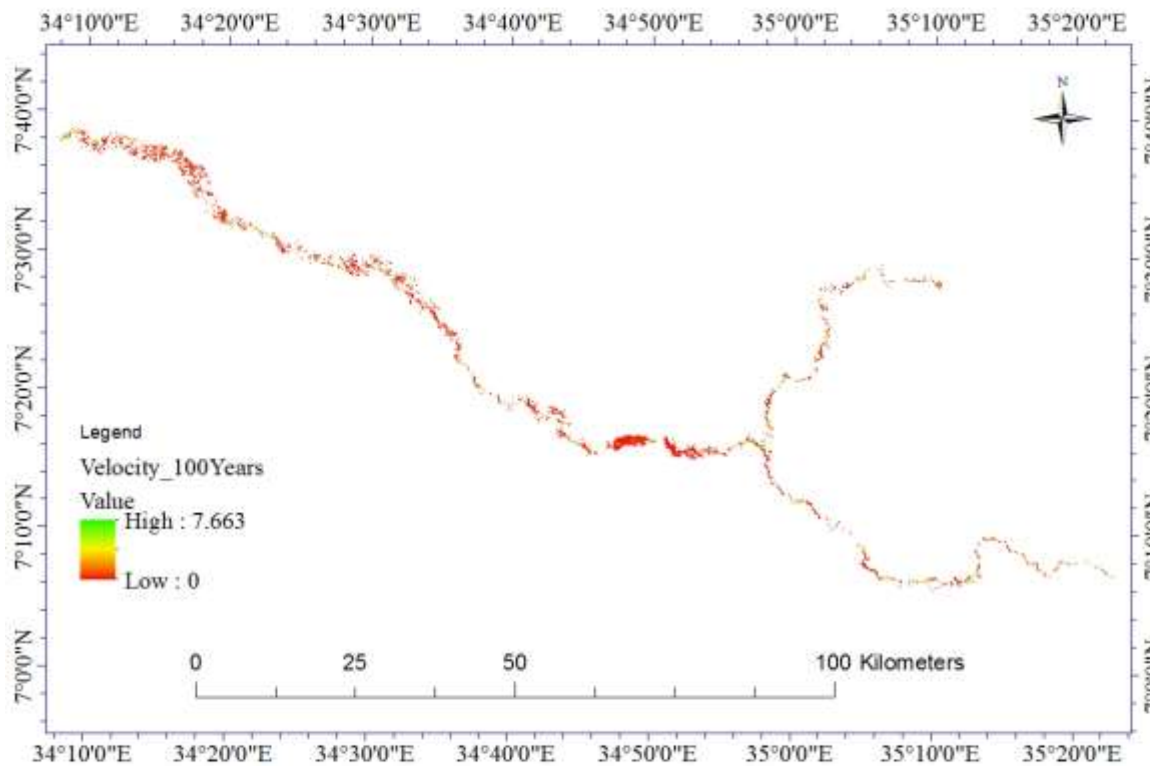


Figure 4. 8 Steady 100- year Velocity Mapping

4.3. Flood hazard mapping

Flood Hazard Mapping was developed using Arc GIS software. Based on the catchment-Response Approach to flood susceptibility, the flood prone areas was identified. The flood generating factors varies from study to study. For this study, the selected flood generating factors are Elevation, Slope, Rainfall, Drainage Density, Flow accumulation, land use land cover and soil.

The spatial Analyst Tool (SAT) proceed the raster format and re-classify them based on degree to flooding. The re-classification of these factors to four hazard level (very low hazard level, low flood hazard, moderate flood hazard and high flood hazard), based on susceptibility to flood each parameter rate to different flood hazard category. Hereby, the personal judgment, local information, professional knowledge and information from previous study help to identify the degree of flood generating factors causing flooding.

4.3.1. Watershed delineation

A common task in hydrology is to delineate watershed from topographic map. The DEM store topographic data in the form of grid cells. Using DEM within geographic information system (GIS) the spatial information can be performed like slope, flow length, flow accumulation and stream network. At this stage the flow accumulation and the pour point (interested point or outlet) can perform to give the watershed and boundary. The coordinate of pour point for watershed delineation for this study was taken at Longitude 34° 2' 42.88"E and latitude 7° 2' 42.88"N. Care should be taken that the pour point lies in the line of flow accumulation.

The size of watershed depends on the choosing of pour point along the drainage path (flow accumulation line). For this study, the pour point selected at the middle point of the river. The catchment area for upper-middle Gilo River was estimated about 9100km^2 using GIS.

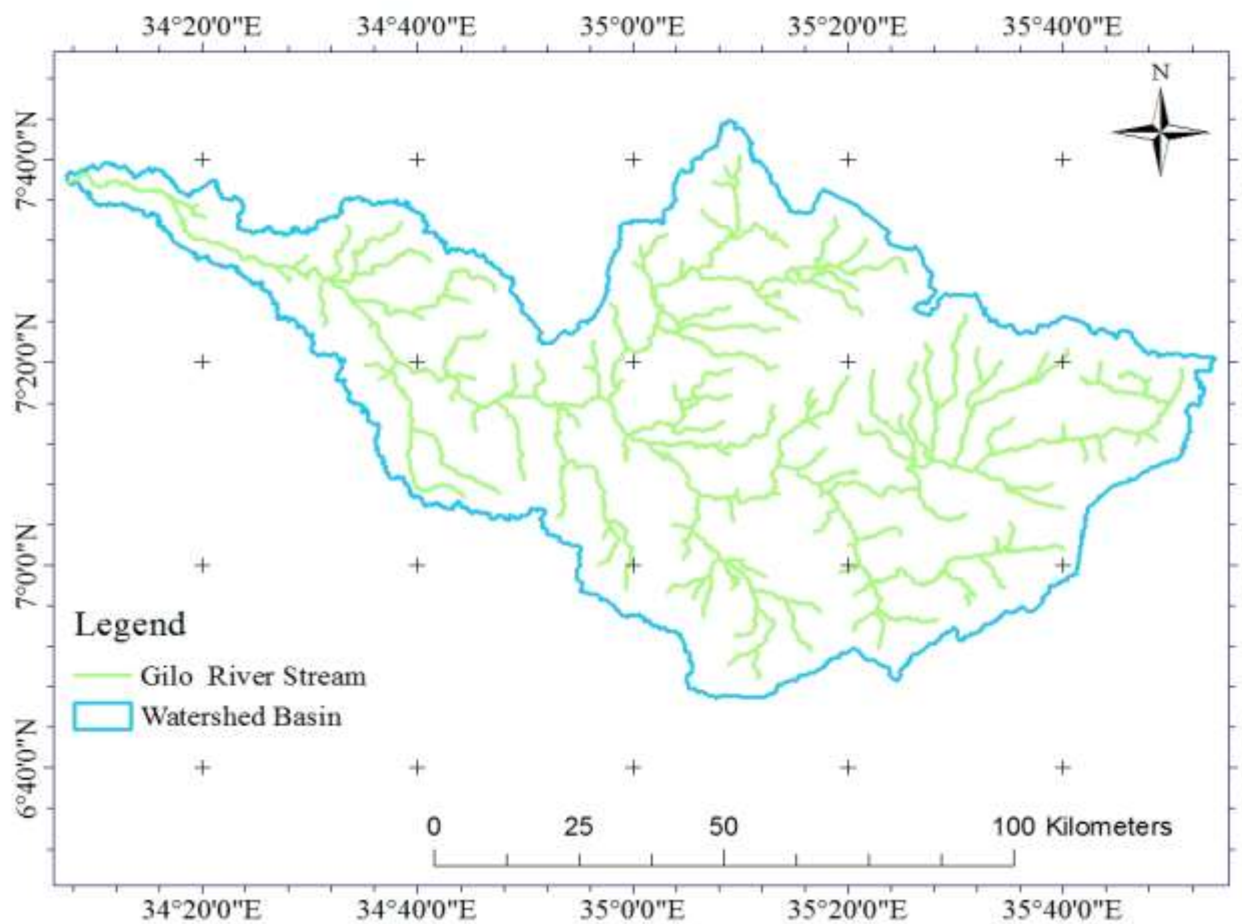


Figure 4. 9 Catchment and Stream Network for upper –Middle Gilo River

4.3.2. Weighting coefficients

The flood generating factors used for this study, their pair wise comparison to calculate priorities to flood hazard and computed using the Analytical Hierarch process (AHP). The pair-wise comparison of one factor to other, following repetition iteration until acceptable consistency ratio becomes less than 10% or 0.1. For this study, the consistency ratio computed as 4.1% or 0.041 which is less than 10% or 0.1, so that acceptable. The decision matrix gives the resulting weight based on the principal eigenvector.

Table 4. 2 The decision matrix for resulting weight Upper-Middle Gilo River

1	2	3	4	5	6	7
1	9	3	7	9	3	2
0.11	1	0.33	2	3	1	0.5
0.33	3	1	3	5	1	0.5
0.14	0.5	0.33	1	1	0.5	0.2
0.11	0.33	0.2	1	1	0.5	0.11
0.33	1	1	2	2	1	1
0.5	5	2	5	9	1	1

Table 4. 3 The resulting weight of priority for Upper-Middle Gilo River

These are the resulting weights for the criteria based on your pair wise comparisons.

category	priority	rank
Re-class_ Rainfall	38.10%	1
Re-class_ Elevation	6.80%	5
Re class slope	13.50%	3
Re class _LULC	4.30%	6
Re-class _Soil	3.40%	7
Re- class Flow Accumulation	11.20%	4
Re class Drainage Density	22.70%	2

4.3.3. Weighted overlay

The weighting methods are used to prioritize the relative importance of each factor relative to another factor. The larger the weight, the more important factor in weighted overlay relative to the other factors. The final flood hazard map produced by overlapping the above seven flood generating with their respective coefficients for upper – middle Gilo River.

Flood Hazard = 0.068 * Elevation + 0.227 * River Density + 0.112 * Flow Accumulation + 0.135 * slope + 0.381* Rainfall + 0.043 * land Use + 0.034 * Soil.

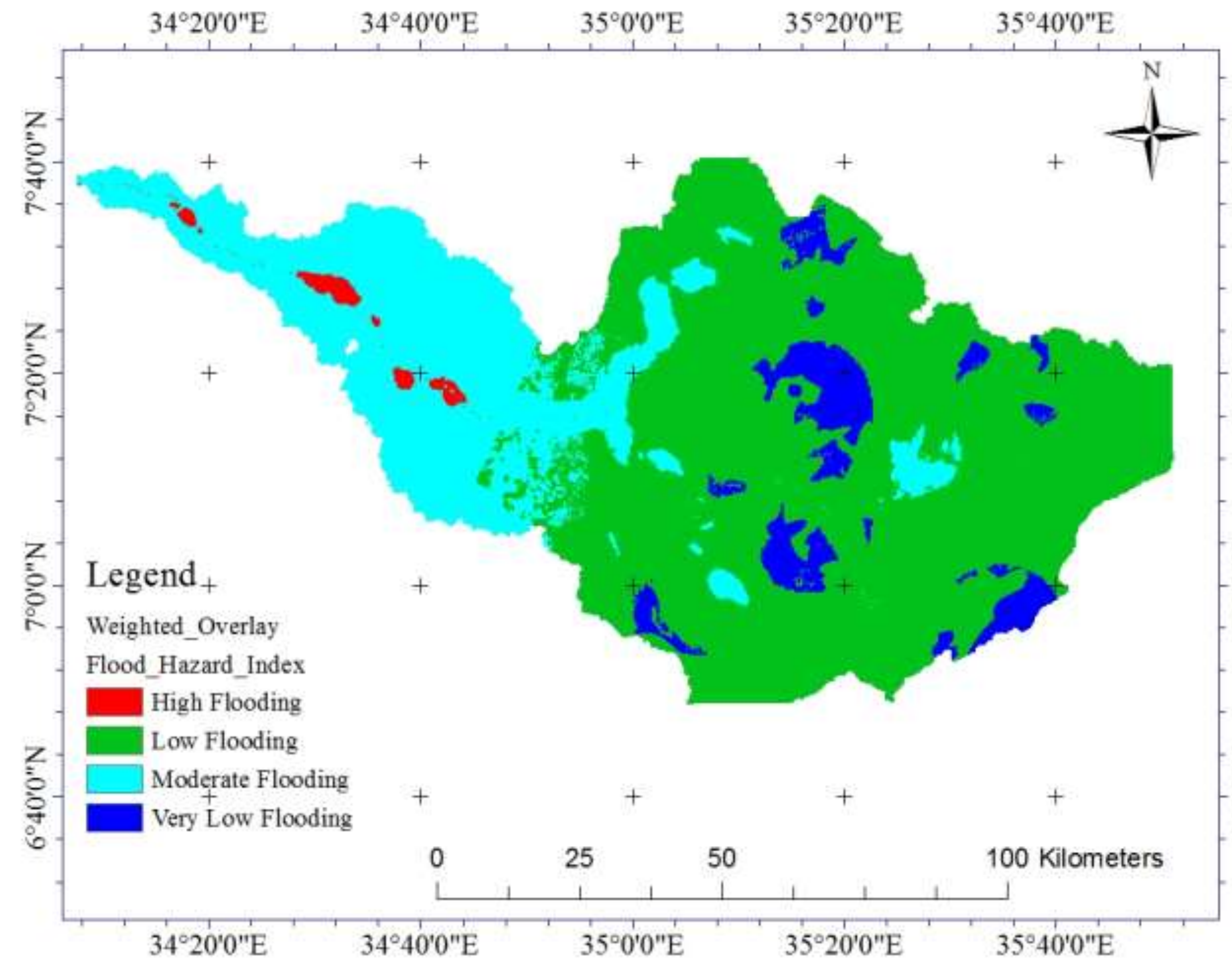


Figure 4. 10 Flood Hazard Map for Upper-Middle Gilo River catchement

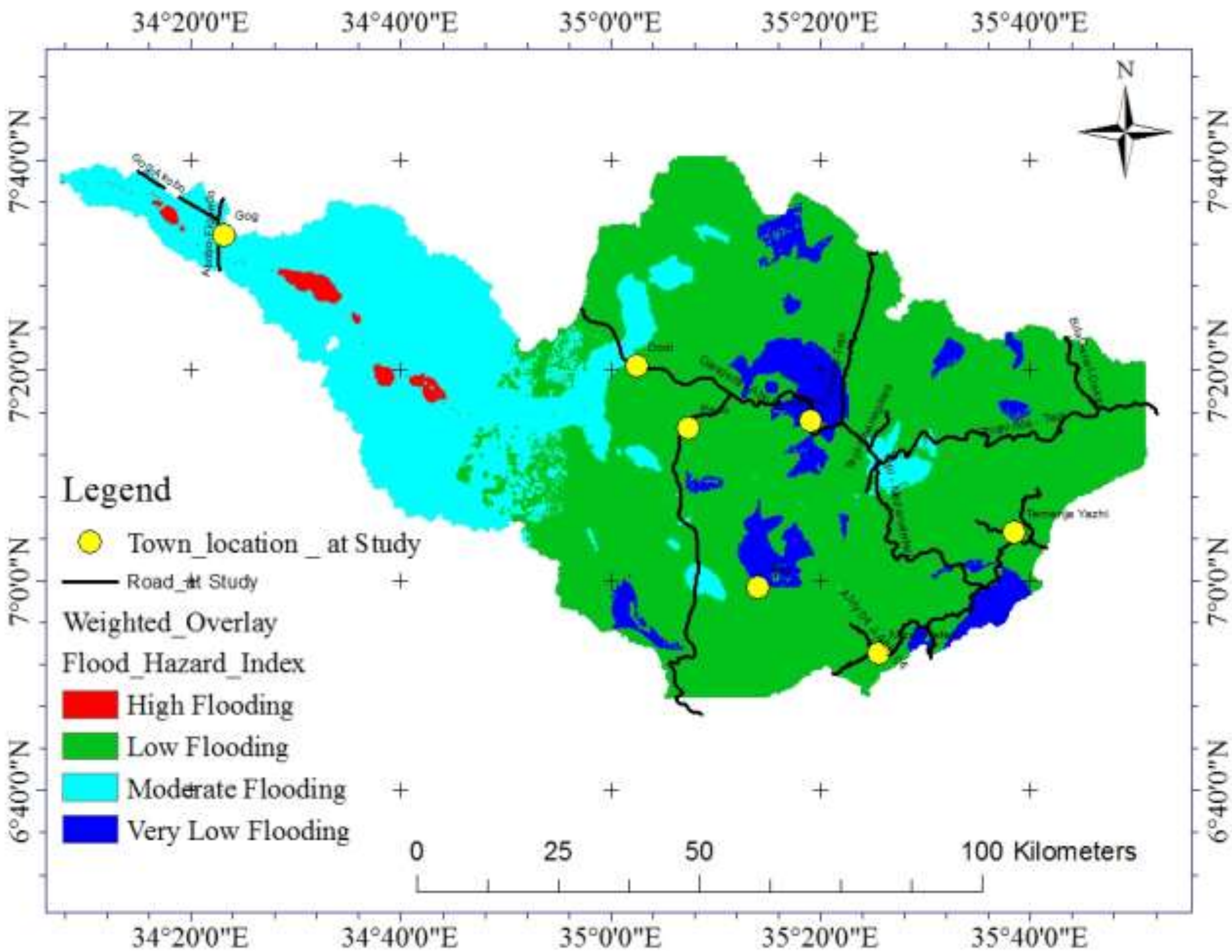


Figure 4. 11 Town and Road Infrastructure location at flood

Table 4. 4 Areas of Flood Prone Areas for Gilo River catchment

Flood Hazard category	Area of flood prone (km^2)	Percentage(%) area of flood prone
Very low Flooding	598.06	6.72
Low Flooding	5817.44	65.35
Moderate Flooding	2410.29	27.07
High Flooding	76.26	0.85

4.4. Mitigation Measurement

Mitigating flood effects requires information on the flooding characteristics and how such characteristics propagate. Information about flood characteristic could be obtained through flood hazard assessment, forecasting, modeling and mapping. Flood inundation mapping are able to simulate flood extents, depths, levels, velocities and timing over distributed model and over the time dimension. Hereby, the flood hazard map developed for upper–middle Gilo River at catchment scale indicate the flood prone areas by categorizing in to different flood hazard level from low to high flooding. The map shows the middle Gilo River has high flooding rate and care should have necessary to prevent flooding up to possible. Also information from flood inundation map shows the extent area of flooding from river course.

Traditional approach to floods was dominated by physical flood protection works such as levees and erosion protection consisting of stone rip rap. It is clear that traditional approach towards flood did no longer hold. This study illustrated that the most flood prone areas at a catchment and river scale, as result flood management strategy is very vital in flood protection mechanism. It is better to plan and manage flooding through three approach that, before flooding (preparedness, land use management, community awareness, flood free peoples settlement), during flooding (emergency flood alert) and after flooding (training damaged river course, construct engineering structures on the river, resettlement). Information from flood hazard map gives the flood prone areas at catchment scale and inundation mapping gives flood extent areas along Gilo River, so public should have given awareness for community live in flooding zone. Also, weather forecasting Agency provide information about climatology through the time, while peoples are ready for preparedness.

An integrated approach in flood management is necessary that, most important measure to reduce flood damage in the future is to improve land use planning in flood prone areas. In flood hazard and risk management, local municipalities are responsible for taking natural hazards in to account in land use planning, and could be liable if damage occurs.

Flood based previous study in Gambela region state that, engineering structures are not practiced along the river to prevent flood hazard consequence. Because, the region was faced by others problem like HIV, Poverty and Drought as result of this, considering responsible office may not pay attention at flood damage. But, the problem of flooding (through overflow of river in the region (Baro, Akobo, Alwero and Gilo)) increasing as it a damage property throughout the year. So, flood embankment structures are better for control water level from overflow of river banks.

As flooding is natural hazard and its frequency is a probability, the response during and after flooding is very essential. This can be improved by ensuring food security, health security, and economy security. Also, the recovery activity have to be done at flood damage areas through resettlement, recover damaged water course and others. The responsible flood insurance organization and management and government give attention in controlling flooding, because its consequence is very high, that cause drought and poverty, economic degradation of the country.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The main contribution of this study is flood inundation mapping and hazard assessment of upper-middle Gilo River, Ethiopia. The overflow of the Gilo River cause series flood problem in Gambella, Ethiopia especially, during summer season. An intensive flood control and mitigation system is required for such flood problem.

By using GIS, HEC-Geo RAS and HEC-RAS flood inundation mapping and hazard assessment was developed. Using GIS and AHP, the selected flood generating factors like elevation, slope, rainfall, land use land cover, soil, drainage density and flow accumulation was classified in to four flood hazard category based on degree to flooding. The four flood hazard categories are very low flooding, low flood, moderate flood and high flooding. The catchments flood generating parameters susceptibility to flooding the flood prone areas are identified for Gilo River, Ethiopia.

Using Spatial Analyst Tool (SAT) in GIS, the weighting methods overlay the ranked flood generating factors to prepare the final flood hazard map. The coefficients of weighting factors are determined by using multi criteria analysis methods done by Analytical Hierarch Process (AHP). The consistency ratio should be less than 10% for pair wise comparisons of criteria acceptable. For this study, the consistency ratio was 4.1% which was less than 10% made iteration terminate. Based on this study, the final flood hazard map gives most of the areas of upper-middle Gilo river show very low and low flooding. Some part of the areas was middle flood hazard level and high flood rate was very small.

Also, based on probabilistic modeling and hydraulic modeling the flood inundation map gives the extent areas of flood from river. This can be done first by computing the peak flow for different return period (10, 25, 50 and 100 years) by using probability distribution model. Among the selected probability distribution model for flood frequency analysis, goodness fit test techniques was proceed by Easy Fit software. For this study, log-Pearson type III was used to compute the peak flow. However, the interested point at the downstream there is limited data records so transposing Peak Discharge using Weighting Area ratio was used for upper-middle Gilo River.

The transposing coefficient was estimated about 2.794 (Appendix B). So, that the final peak Discharges for 10, 25, 50 and 100 years was estimated 255.66, 314.64, 360.60 and 406.53m^3/s respectively.

Additionally, the river geometry (river center, river bank, flow path and XS cross section) was done using HEC Geo RAS. The hydraulic computation was analyzed using HEC RAS software. The final floodplains delineation to develop flood inundation mapping was done using HEC Geo RAS software (RAS mapping tool) with GIS. The area of inundation for unsteady flow of 10, 25, 50 and 100 years are estimated about 71.76, 83.49, 85.98 and 88.12km^2 respectively.

5.2. Recommendations

Flood hazard based study is very important and critical, because as flood damage and its consequence is high. This study was deal with flood inundation mapping and hazard assessment for upper-middle Gilo River, Ethiopia. Ongoing study the following recommendations are made for further studies in the future.

The resolution cell size of Digital Elevation Model (DEM) used for this study was 30m by 30m. However, the during catchment delineation process for Gilo River sub basin, the downstream stream network doesn’t extracted or created. As result of this, study was focused on upper-middle Gilo River. Therefore, High Advanced technology which Extract River with high resolution by choosing small cell size of DEM will be preferable.

There is no recorded historical flood record information for this study. So, ground truth of flood event is very important like flood level or water surface elevation and existing historical flood map (either inundation or flood prone areas). This can be used for comparison for scenario simulation for flood water surface and prepared flood map. Therefore, historical existing flood events and map will be preferable for comparison prepared flood map from simulation.

Watershed management practices in the uplands of the catchment are crucial in alleviating future flood disasters in the study area. Land use planning can play very important role to reduce the adverse effects of flooding. It is recommended to adopt an appropriate land use planning in flood prone area.

Usually, the value of roughness parameters is estimated through having the geological image of river bed. However, due to limited observed value, empirical equation was employed to estimate manning roughness coefficients. So, having observed value of roughness from a river geological survey or aerial river geological photo, it will be better to develop flood inundation mapping.

When using HEC Geo RAS software (in RAS Mapping tool) for floodplain delineation, the map unit or resolution cell size used by DEFAULT is 20 units. For this study 10 units map was used for analysis flood inundation mapping, because of a computer hardware limitation used by author. However, the smallest cell size will be preferable about 1 or 2 map unit to increase inundation map visualization.

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ANNEX and APPENDIX

Annex A. Frequency Factors K for Gamma and log-Pearson Type III Distributions (Haan, 1977, Table 7.7) Recurrence Interval In Years

Weighted	1.0101	2	5	10	25	50	100	200
Skew coefficient	Percent Chance (>=) = 1-F							
	99	50	20	10	4	2	1	0.5
3	-0.667	-0.396	0.42	1.18	2.278	3.152	4.051	4.97
2.9	-0.69	-0.39	0.44	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.46	1.21	2.275	3.114	3.973	4.847
2.7	-0.74	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.36	0.518	1.25	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.8	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.33	0.574	1.284	2.24	2.97	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.23	2.942	3.656	4.372
2	-0.99	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.31	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.14	-0.268	0.66	1.324	2.179	2.815	3.444	4.069

1.6	-1.197	-0.254	0.675	1.329	2.163	2.78	3.388	3.99
1.5	-1.256	-0.24	0.69	1.333	2.146	2.743	3.33	3.91
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.21	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.34	2.087	2.626	3.149	3.661
1.1	-1.518	-0.18	0.745	1.341	2.066	2.585	3.087	3.575
1	-1.588	-0.164	0.758	1.34	2.043	2.542	3.022	3.489
0.9	-1.66	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.78	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.79	1.333	1.967	2.407	2.824	3.223
0.6	-1.88	-0.099	0.8	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.91	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.88	2.261	2.615	2.949
0.3	-2.104	-0.05	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.83	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.4	2.67
0	-2.326	0	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2	2.252	2.482
-0.2	-2.472	0.033	0.85	1.258	1.68	1.945	2.178	2.388
-0.3	-2.544	0.05	0.853	1.245	1.643	1.89	2.104	2.294

-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.2	1.528	1.72	1.88	2.016
-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.66	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.18	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.21	0.838	1.064	1.24	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.27	1.318	1.351
-1.5	-3.33	0.24	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.88	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.97	1.075	1.116	1.14	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.92	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.98	0.99	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869

-2.4	-3.8	0.351	0.725	0.795	0.823	0.83	0.832	0.833
-2.5	-3.845	0.36	0.711	0.711	0.793	0.798	0.799	0.8
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.74	0.74	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.39	0.651	0.681	0.683	0.689	0.69	0.69
-3	-4.051	0.396	0.636	0.66	0.666	0.666	0.667	0.667

Source: U.S. Interagency Advisory Committee on Water Data, Hydrology Subcommittee (1983). “Guide-lines for Determining Flood Flow Frequency, “Bulletin No.17B, issued 1981, revised 1983.

Appendix B. Peak Discharge computations using **Log-Pearson Type-3**

		Log	Pearson	Type-III			(LP-III)		
Year	Qpeak	Rank	Year-Max	Q(m^3/s)_max	LOGQ	(LogQ-avr(LogQ))^2	(log Q – avg(logQ))^3	Return period (Tr) = n+1/m	Excedence pro= 1/Tr
1990	59.9	1.00	1998.00	85.42	1.93	0.11376	0.038	26.00	0.0385
1991	64.1	2.00	1996.00	81.32	1.91	0.0998	0.032	13.00	0.0769
1992	36.9	3.00	1997.00	65.23	1.81	0.04847	0.011	8.67	0.1154
1993	44.2	4.00	1991.00	64.14	1.81	0.0453	0.01	6.50	0.1538
1994	38.4	5.00	1995.00	63.71	1.80	0.04407	0.009	5.20	0.1923
1995	63.7	6.00	1990.00	59.90	1.78	0.03354	0.006	4.33	0.2308
1996	81.3	7.00	2013.00	51.94	1.72	0.01469	0.002	3.71	0.2692
1997	65.2	8.00	2007.00	48.28	1.68	0.00801	7E-04	3.25	0.3077

1998	85.4	9.00	2010.00	45.40	1.66	0.00394	2E-04	2.89	0.3462
1999	27.2	10.00	1993.00	44.19	1.65	0.00261	1E-04	2.60	0.3846
2000	20.9	11.00	2006.00	39.93	1.60	4.9E-05	3E-07	2.36	0.4231
2001	19.5	12.00	1994.00	38.37	1.58	0.00011	-1E-06	2.17	0.4615
2002	25.2	13.00	1992.00	36.88	1.57	0.00076	-2E-05	2.00	0.5
2003	36.3	14.00	2003.00	36.25	1.56	0.00122	-4E-05	1.86	0.5385
2004	34.1	15.00	2011.00	35.29	1.55	0.00217	-1E-04	1.73	0.5769
2005	26.8	16.00	2004.00	34.11	1.53	0.00377	-2E-04	1.63	0.6154
2006	39.9	17.00	2008.00	33.23	1.52	0.00529	-4E-04	1.53	0.6538
2007	48.3	18.00	2014.00	32.91	1.52	0.00592	-5E-04	1.44	0.6923
2008	33.2	19.00	2012.00	32.18	1.51	0.00752	-7E-04	1.37	0.7308
2009	19.9	20.00	1999.00	27.20	1.43	0.02551	-0.004	1.30	0.7692

2010	45.4	21.00	2005.00	26.78	1.43	0.02771	-0.005	1.24	0.8077
2011	35.3	22.00	2002.00	25.17	1.40	0.0374	-0.007	1.18	0.8462
2012	32.2	23.00	2000.00	20.87	1.32	0.07549	-0.021	1.13	0.8846
2013	51.9	24.00	2009.00	19.93	1.30	0.08689	-0.026	1.08	0.9231
2014	32.9	25.00	2001.00	19.49	1.29	0.0927	-0.028	1.04	0.9615
			Average	42.72	1.59	0.78671	0.016		
	N is number of sample data e.g. 25					St Dev. = Sqroot(0.786708999/sqr(n-1) =			
	m is number of rank						Skewnes coefficient(Cs)		
						0.18105	0.1228		

	Transpose	Q peak			
LP3	Kt	1.29	1.79	2.12	2.42
	Tr	10.00	25.00	50.00	100.00
	LogQpeak	1.83	1.92	1.98	2.03
	Gauged Qpeak	67.39	82.93	95.06	107.15
	Ratio	2.794	2.794	2.794	2.794
	Total QUngauged	188.27	231.71	265.60	299.38
	Total Qpeak in (m^3/s)	255.66	314.64	360.66	406.53

Transpose coefficients (Using weighting Area –Ratio Methods)

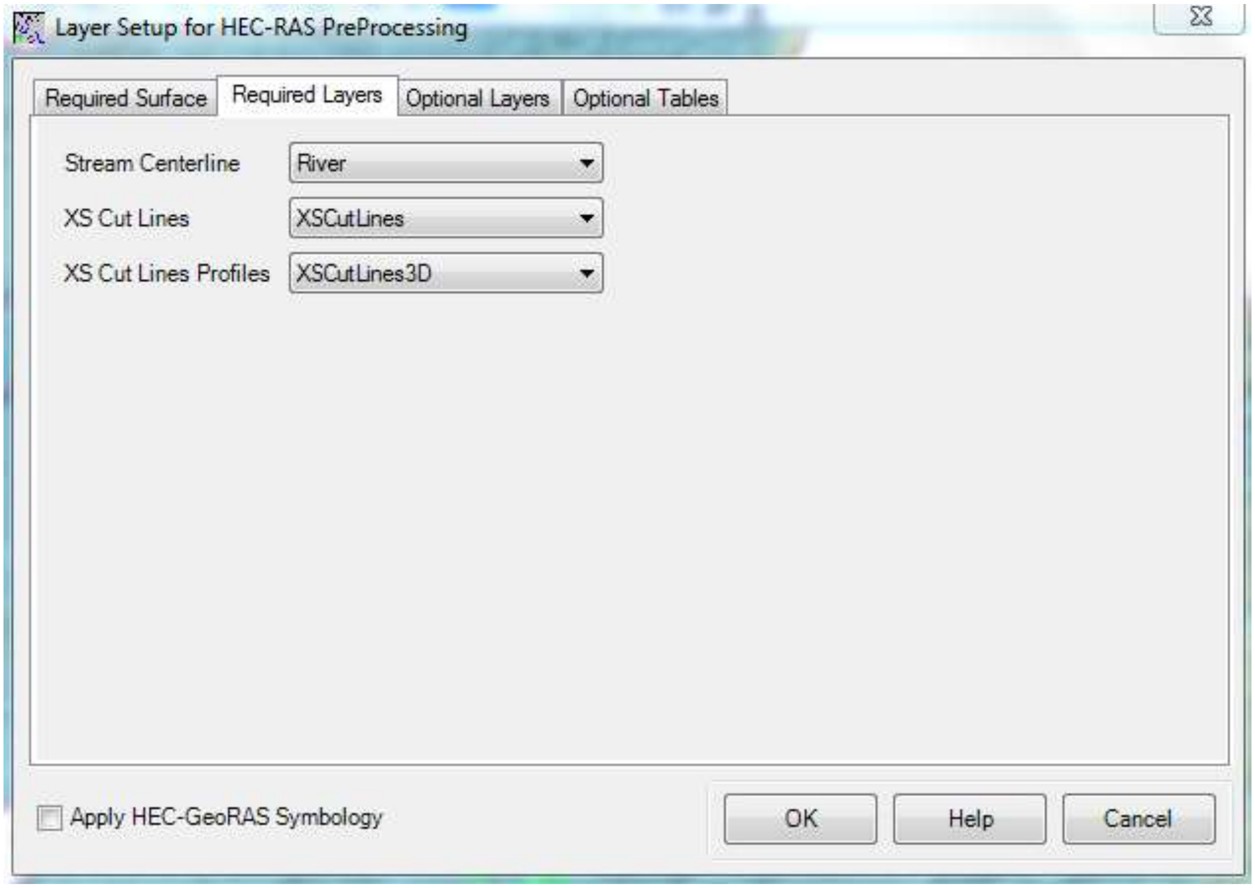
S.No	Reach	Gauged Area	Ungauged Area	%Difference	<25%	Ratio	(Au/Ag)^0.7
1	Right _Tributary	2942	1848	10.94	yes	0.628144	0.72217343
2	Reach_1	2942	1614	13.28	yes	0.548606	0.6568748
3	D/S _ Reach	2942	1595	13.47	yes	0.542148	0.65145229
4	D/s -End	2942	1121	18.21	yes	0.381033	0.50894876
						total	2.794

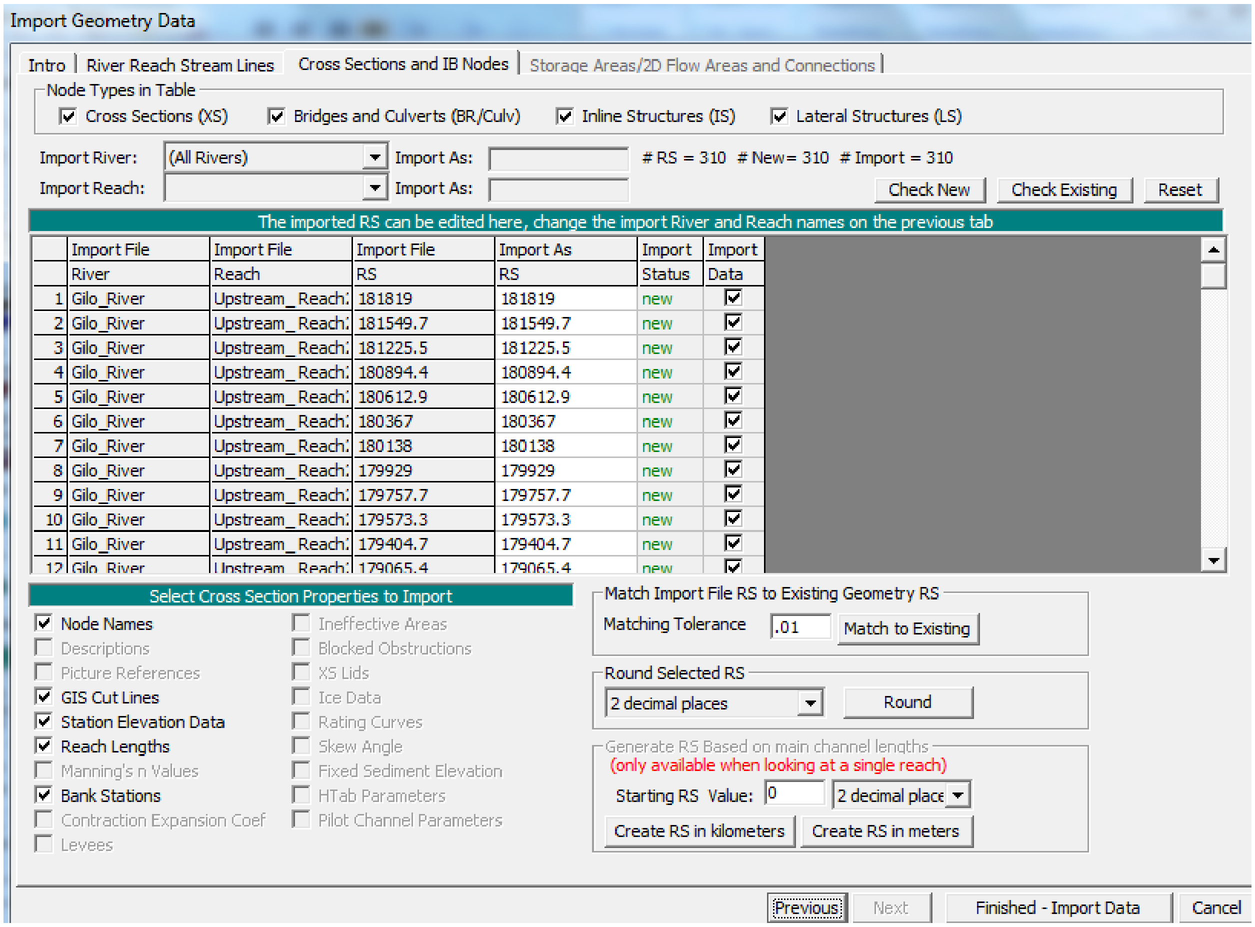
General Extreme Value (GEV)

location parameter (ξ)	33.733	shape parameter(k)	0.07238					
alpha (scale parameter)	13.749	General	Extreme	value(GEV)	QT = ξ +	alpha/k*	1-(-Log(T-1/T))k	
Return period(T)	T-1	(T-1)/T	Log(T-1/T)	(-Log(T-1/T))k	1-(-Log(T-1/T))k	alpha/k	alpha/k *1-(-Log(T-1/T))k	QT= ξ + alpha/k*1-(-Log(T-1/T))k
10	9	0.9	0.045757491	0.799915761	0.200084239	189.9557889	38.00715945	71.74015945

25	24	0.96	0.017728767	0.746860261	0.253139739	189.9557889	48.08535881	81.81835881
50	49	0.98	0.008773924	0.709787543	0.290212457	189.9557889	55.12753615	88.86053615
100	99	0.99	0.004364805	0.674808677	0.325191323	189.9557889	61.77197426	95.50497426

Appendix C: Sample information for Upper-Middle Gilo River geometry by HEC-Geo RAS





XSCutLines3D

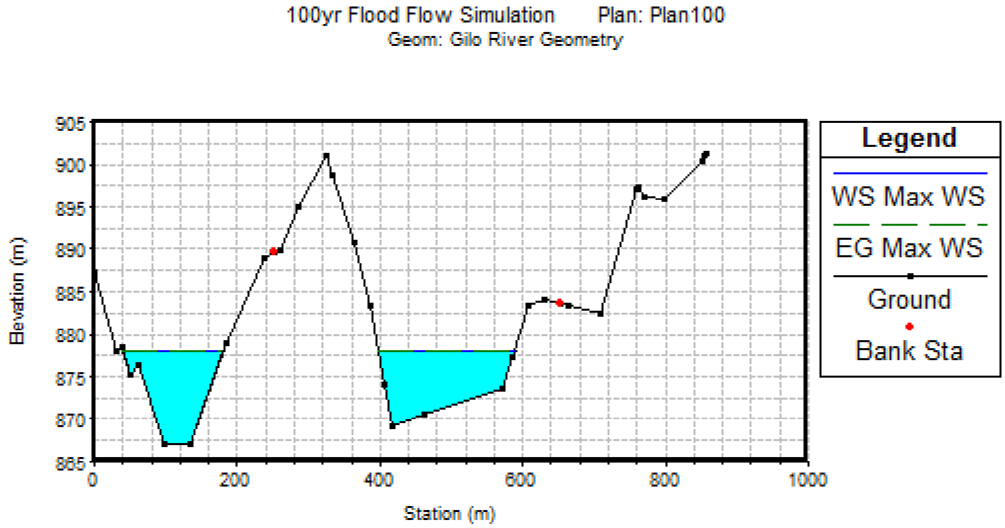
	Shape *	OID *	Shape_Len	XS2DI	HydroID	Station	River	Reach	LeftBank	RightBank	LLength	ChLength	RLength
	Polyline Z	942	1868.11131	17	1274	67471.5	Gilo _River	Upstream _Reach1	0.245848	0.681424	1650.555	1521.594	1386.947
	Polyline Z	943	2357.36371	18	1275	65949.91	Gilo _River	Upstream _Reach1	0.235293	0.738499	2104.697	1755.765	1600.366
	Polyline Z	944	2634.23768	19	1276	64194.14	Gilo _River	Upstream _Reach1	0.12858	0.707342	1857.653	1997.983	1620.205
	Polyline Z	945	3363.28661	20	1277	62196.16	Gilo _River	Upstream _Reach1	0.147444	0.665742	3023.51	2655.988	1657.57
	Polyline Z	946	2542.79404	21	1278	59540.17	Gilo _River	Upstream _Reach1	0.222878	0.776239	1380.202	1400.236	1198.813
	Polyline Z	947	2107.41343	22	1279	58139.93	Gilo _River	Upstream _Reach1	0.225975	0.672252	1436.753	1282.094	1204.119
	Polyline Z	948	2346.08468	23	1280	56857.84	Gilo _River	Upstream _Reach1	0.240445	0.713785	2787.322	2423.35	2555.009
	Polyline Z	949	2026.09745	24	1281	54434.49	Gilo _River	Upstream _Reach1	0.197796	0.769117	1136.976	1250.547	1375.464
	Polyline Z	950	2067.86297	25	1282	53183.94	Gilo _River	Upstream _Reach1	0.200432	0.757777	643.0593	1035.271	1863.972
	Polyline Z	951	1878.82485	26	1283	52148.67	Gilo _River	Upstream _Reach1	0.225954	0.788492	579.8647	817.9681	1219.308
	Polyline Z	952	2110.46067	27	1284	51330.7	Gilo _River	Upstream _Reach1	0.263662	0.799029	512.9061	496.9373	569.1171
	Polyline Z	953	2151.48336	28	1285	50833.77	Gilo _River	Upstream _Reach1	0.197178	0.746636	778.7451	1482.327	1822.819
	Polyline Z	954	2501.19228	29	1286	49351.44	Gilo _River	Upstream _Reach1	0.179526	0.828561	874.743	1102.859	951.0526
	Polyline Z	955	2740.87045	30	1287	48248.58	Gilo _River	Upstream _Reach1	0.164151	0.819397	919.3806	940.285	812.2184
	Polyline Z	956	3025.17836	31	1288	47308.3	Gilo _River	Upstream _Reach1	0.175286	0.743104	987.5426	982.7382	979.1928
	Polyline Z	957	2997.07655	32	1289	46325.56	Gilo _River	Upstream _Reach1	0.143849	0.78569	2589.956	2590.966	1123.117
	Polyline Z	958	2746.48365	33	1290	43734.59	Gilo _River	Upstream _Reach1	0.199178	0.803102	1805.954	1892.796	1235.518
	Polyline Z	959	2273.15105	34	1291	41841.8	Gilo _River	Upstream _Reach1	0.23814	0.800692	837.1021	895.9829	778.7437
	Polyline Z	960	2360.95696	35	1292	40945.81	Gilo _River	Upstream _Reach1	0.189067	0.797981	1147.476	1055.641	979.6348
	Polyline Z	961	3072.87707	36	1293	39890.17	Gilo _River	Upstream _Reach1	0.146852	0.829501	3259.483	3462.56	1353.319
	Polyline Z	962	2403.23869	37	1294	36427.61	Gilo _River	Upstream _Reach1	0.240793	0.840728	822.7154	859.9071	884.1071
	Polyline Z	963	2392.18055	38	1295	35567.7	Gilo _River	Upstream _Reach1	0.173384	0.811492	797.5981	770.0634	789.3101
	Polyline Z	964	2560.76314	39	1296	34797.64	Gilo _River	Upstream _Reach1	0.164674	0.788766	527.3096	717.1232	793.3761
	Polyline Z	965	2504.54866	40	1297	34080.52	Gilo _River	Upstream _Reach1	0.16734	0.761426	1109.225	1692.761	1038.752
	Polyline Z	966	2399.74067	41	1298	32387.76	Gilo _River	Upstream _Reach1	0.150625	0.814964	1125.879	863.8934	838.6945
	Polyline Z	967	2158.95408	42	1299	31523.86	Gilo _River	Upstream _Reach1	0.230578	0.759104	616.2273	582.5375	522.9406
	Polyline Z	968	2215.94321	43	1300	30941.33	Gilo _River	Upstream _Reach1	0.194059	0.719648	884.4036	801.8137	758.579

River3D

Shape *	OID *	Shape_Length	Riv2DID	HydroID	River	Reach	FromNo	ToNo	ArcLength	FromSta	ToSta
Polyline Z	7	51026.636239	3	1266	Gilo_River	Upstream_Reach2	1	2	51026.64	131034.6	182061.2
Polyline Z	8	74292.696268	4	1267	Gilo _River	Upstream _Reach1	3	2	74292.7	0	74292.7
Polyline Z	9	131034.562469	7	1268	Gilo_River	Downstream_Reach	2	4	131034.6	0	131034.6

XSCutLines

Shape *	OID *	Shape_Len	HydroID	Station	River	Reach	LeftBank	RightBank	LLength	ChLength	RLength
Polyline	1	1883.74785	12	73579.63	Gilo _River	Upstream _Reach1	0.30417	0.71053	1111.619	1062.529	870.575
Polyline	2	1971.01299	13	72517.11	Gilo _River	Upstream _Reach1	0.23054	0.7209	1311.214	1158.314	935.725
Polyline	3	1679.15175	14	71358.79	Gilo _River	Upstream _Reach1	0.22324	0.77788	1109.776	1395.608	1359.383
Polyline	4	1964.46705	15	69963.19	Gilo _River	Upstream _Reach1	0.17605	0.7231	894.048	928.803	1108.65
Polyline	5	1689.18098	16	69034.38	Gilo _River	Upstream _Reach1	0.19934	0.62953	1244.601	1562.882	2102.312
Polyline	6	1868.11131	17	67471.5	Gilo _River	Upstream _Reach1	0.24585	0.68142	1650.555	1521.594	1386.947
Polyline	7	2357.36371	18	65949.91	Gilo _River	Upstream _Reach1	0.23529	0.7385	2104.697	1755.765	1600.366
Polyline	8	2634.23768	19	64194.14	Gilo _River	Upstream _Reach1	0.12858	0.70734	1857.653	1997.983	1620.205
Polyline	9	3363.28661	20	62196.16	Gilo _River	Upstream _Reach1	0.14744	0.66574	3023.51	2655.988	1657.57
Polyline	10	2542.79404	21	59540.17	Gilo _River	Upstream _Reach1	0.22288	0.77624	1380.202	1400.236	1198.813
Polyline	11	2107.41343	22	58139.93	Gilo _River	Upstream _Reach1	0.22597	0.67225	1436.753	1282.094	1204.119
Polyline	12	2346.08468	23	56857.84	Gilo _River	Upstream _Reach1	0.24045	0.71378	2787.322	2423.35	2555.009
Polyline	13	2026.09745	24	54434.49	Gilo _River	Upstream _Reach1	0.1978	0.76912	1136.976	1250.547	1375.464
Polyline	14	2067.86297	25	53183.94	Gilo _River	Upstream _Reach1	0.20043	0.75778	643.059	1035.271	1863.972
Polyline	15	1878.82485	26	52148.67	Gilo _River	Upstream _Reach1	0.22595	0.78849	579.865	817.968	1219.308
Polyline	16	2110.46067	27	51330.7	Gilo _River	Upstream _Reach1	0.26366	0.79903	512.906	496.937	569.117
Polyline	17	2151.48336	28	50833.77	Gilo _River	Upstream _Reach1	0.19718	0.74664	778.745	1482.327	1822.819
Polyline	18	2501.19228	29	49351.44	Gilo _River	Upstream _Reach1	0.17953	0.82856	874.743	1102.859	951.053
Polyline	19	2740.87045	30	48248.58	Gilo _River	Upstream _Reach1	0.16415	0.8194	919.381	940.285	812.218
Polyline	20	3025.17836	31	47308.3	Gilo _River	Upstream _Reach1	0.17529	0.7431	987.543	982.738	979.193
Polyline	21	2997.07655	32	46325.56	Gilo _River	Upstream _Reach1	0.14385	0.78569	2589.956	2590.966	1123.117
Polyline	22	2746.48365	33	43734.59	Gilo _River	Upstream _Reach1	0.19918	0.8031	1805.954	1892.796	1235.518
Polyline	23	2273.15105	34	41841.8	Gilo _River	Upstream _Reach1	0.23814	0.80069	837.102	895.983	778.744
Polyline	24	2360.95696	35	40945.81	Gilo _River	Upstream _Reach1	0.18907	0.79798	1147.476	1055.641	979.635
Polyline	25	3072.87707	36	39890.17	Gilo _River	Upstream _Reach1	0.14685	0.8295	3259.483	3462.56	1353.319
Polyline	26	2403.23869	37	36427.61	Gilo _River	Upstream _Reach1	0.24079	0.84073	822.715	859.907	884.107
Polyline	27	2392.18055	38	35567.7	Gilo _River	Upstream _Reach1	0.17338	0.81149	797.598	770.063	789.31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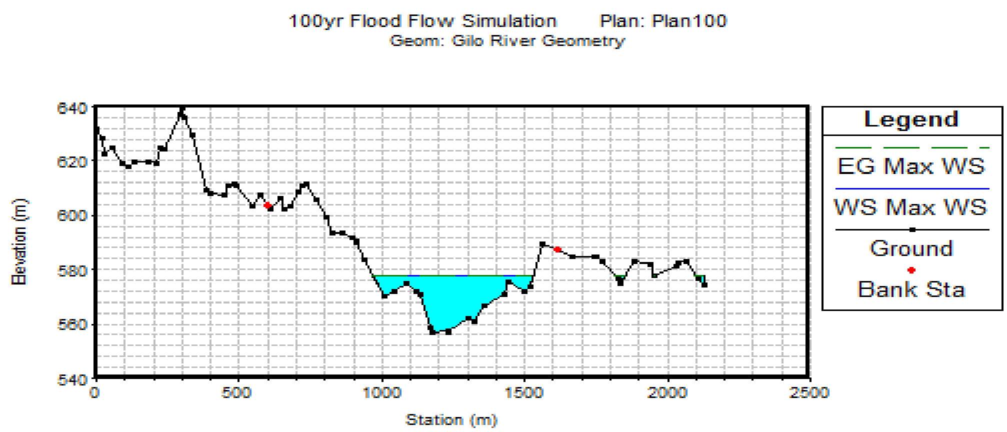
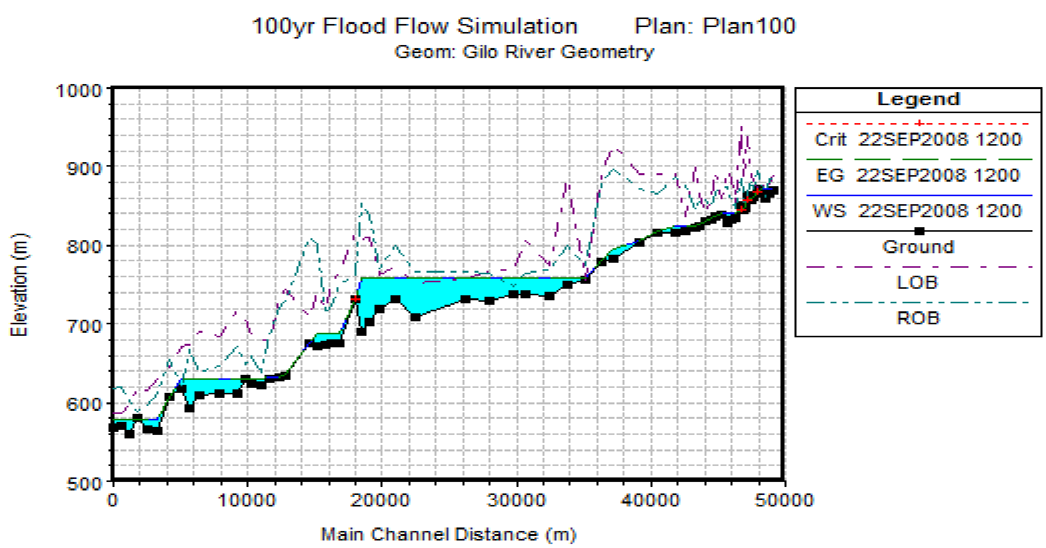
Geom: Gilo River Geometry
Elevation (m)
Station (m)
Legend
WS Max WS
EG Max WS
Ground
Bank Sta


100yr Flood Flow Simulation Plan: Plan100
Geom: Gilo River Geometry
Elevation (m)
Station (m)
Legend
EG Max WS
WS Max WS
Ground
Bank Sta


100yr Flood Flow Simulation Plan: Plan100
Geom: Gilo River Geometry
Elevation (m)
Main Channel Distance (m)
Legend
Crit 22SEP2008 1200
EG 22SEP2008 1200
WS 22SEP2008 1200
Ground
LOB
ROB

Appendix D: Theoretical Estimated manning roughness coefficient

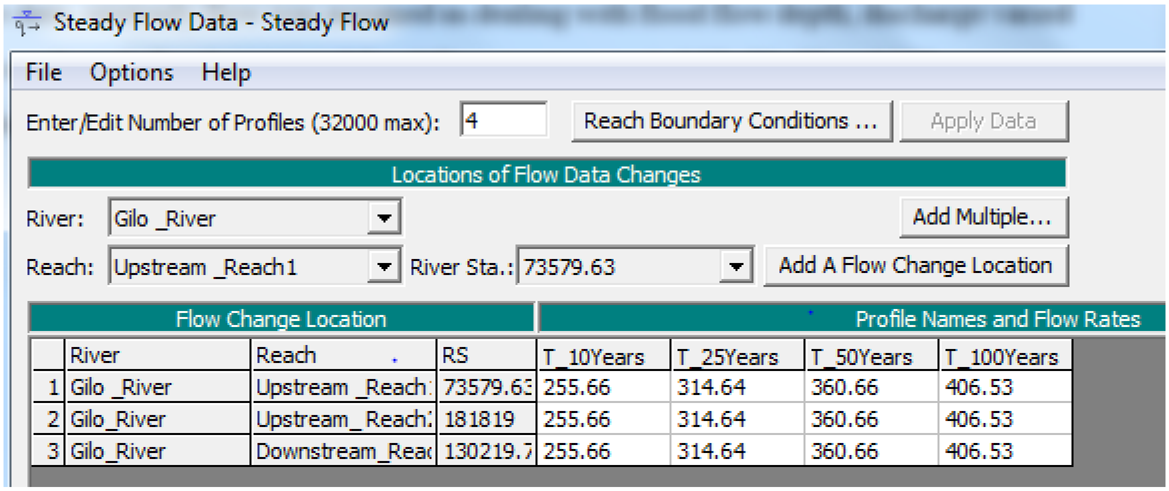
S.No	Irregularity(n1)	Variation in channel cross-section(n2)	Obstruction(n3)	base (nb)	Vegetation(n4)	Total _n	Left Banks	Right banks
1	0.02	0.003	0.005	0.02	0.005	0.053	0.035	0.04
2	0.02	0.003	0.005	0.02	0.005	0.053	0.035	0.04
3	0.02	0.003	0.005	0.02	0.005	0.053	0.035	0.04
4	0.02	0.003	0.005	0.02	0.025	0.073	0.035	0.04
5	0.02	0.003	0.005	0.02	0.025	0.073	0.035	0.04
6	0.02	0.003	0.005	0.02	0.025	0.073	0.035	0.04
7	0.02	0.003	0.005	0.02	0.025	0.073	0.035	0.04
8	0.02	0.003	0.03	0.02	0.025	0.098	0.035	0.04
9	0.02	0.003	0.03	0.02	0.025	0.098	0.035	0.04
10	0.02	0.003	0.03	0.02	0.025	0.098	0.035	0.04
11	0.04	0.003	0.004	0.02	0.025	0.092	0.035	0.04
12	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04
13	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04
14	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04

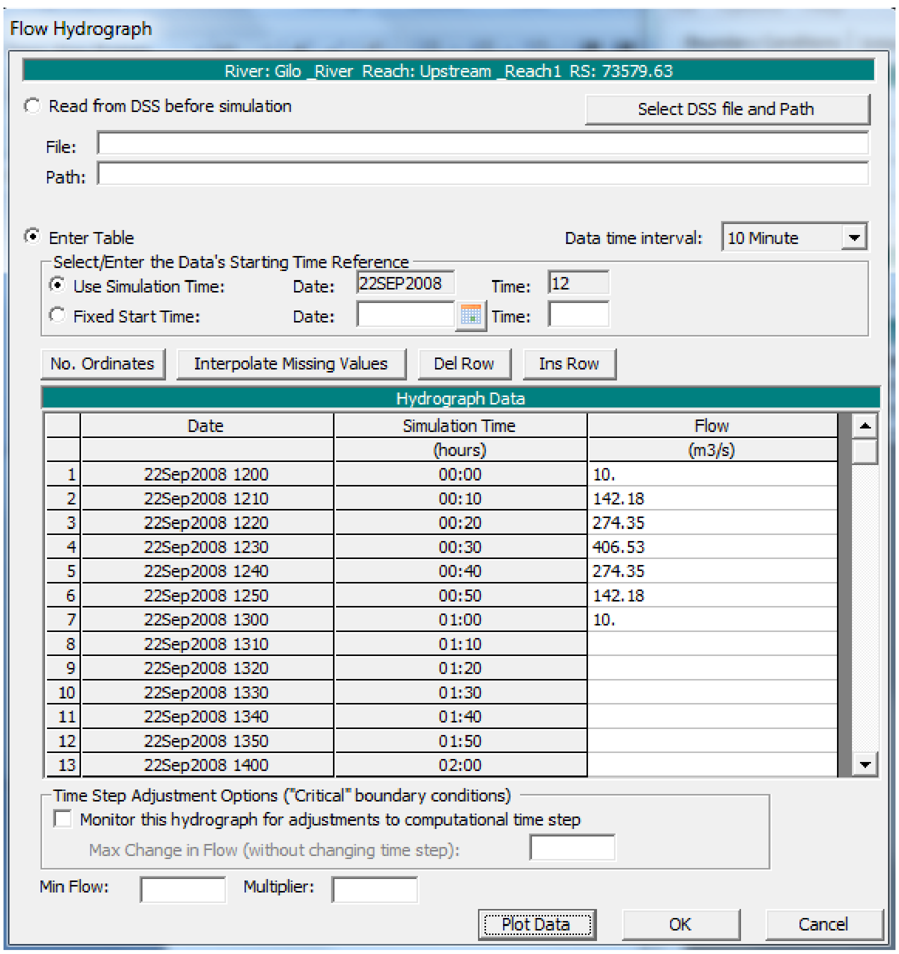
15	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04
16	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04
17	0.02	0.003	0.004	0.02	0.025	0.072	0.035	0.04
18	0.04	0.003	0.03	0.025	0.04	0.138	0.035	0.04
19	0.04	0.003	0.03	0.025	0.04	0.138	0.035	0.04
20	0.04	0.003	0.03	0.025	0.04	0.138	0.035	0.04
21	0.04	0.003	0.03	0.025	0.04	0.138	0.035	0.04
22	0.04	0.003	0.03	0.025	0.04	0.138	0.035	0.04
23	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04
24	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04
25	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04
26	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04

27	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
28	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
29	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
30	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
31	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
32	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
33	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
34	0.006	0.003	0.004	0.02	0.025	0.058	0.035	0.04
35	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
36	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
37	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
38	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
39	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
40	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04

41	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
42	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
43	0.006	0.003	0.03	0.02	0.025	0.084	0.035	0.04
44	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04
45	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04
46	0.006	0.003	0.03	0.025	0.04	0.104	0.035	0.04

Appendix E. HEC-RAS Hydraulic computation





HEC-RAS Plan: Plan100 Profile: Max WS													
River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Gilo_River	Upstream_Reach2	181819	Max WS	15.51	869.28	878.10		878.10	0.000000	0.00	2076.42	331.99	0.00
Gilo_River	Upstream_Reach2	181549.7	Max WS	-19848.27	865.99	874.01	874.94	878.51	0.040530	-9.41	2113.49	344.85	1.19
Gilo_River	Upstream_Reach2	181225.5	Max WS	10.00	860.23	871.28		871.28	0.000000	0.00	3556.30	602.05	0.00
Gilo_River	Upstream_Reach2	180894.4	Max WS	10.00	864.91	871.28		871.28	0.000000	0.02	653.05	249.76	0.00
Gilo_River	Upstream_Reach2	180612.9	Max WS	59670.93	872.35	872.94	892.27	4836.99	26.342670	27.77	215.04	85.48	17.43
Gilo_River	Upstream_Reach2	180367	Max WS	3499.05	860.65	868.44		869.02	0.008713	3.37	1039.15	241.69	0.52
Gilo_River	Upstream_Reach2	180138	Max WS	10.00	857.00	860.05		860.05	0.000001	0.03	374.80	152.90	0.01
Gilo_River	Upstream_Reach2	179929	Max WS	5414.11	863.23	859.26	865.53	1294.08	17.910360		58.63	71.57	0.00
Gilo_River	Upstream_Reach2	179757.7	Max WS	1013.28	848.00	851.30	852.19	854.20	0.082632	6.59	137.66	80.19	1.42
Gilo_River	Upstream_Reach2	179573.3	Max WS	-4.18	845.97	854.15		854.15	0.000000	-0.01	345.30	139.80	0.00
Gilo_River	Upstream_Reach2	179404.7	Max WS	-65.04	851.72	847.50		847.56	0.001030		63.44	43.46	0.00
Gilo_River	Upstream_Reach2	179065.4	Max WS	-267.05	834.00	842.15		842.16	0.000128	-0.47	573.35	110.02	0.06
Gilo_River	Upstream_Reach2	178747.3	Max WS	-2404.72	832.36	842.87		843.68	0.015663	-3.44	640.35	162.83	0.52
Gilo_River	Upstream_Reach2	178327.2	Max WS	36.09	827.67	841.65		841.65	0.000000	0.02	1972.65	204.89	0.00
Gilo_River	Upstream_Reach2	177901	Max WS	7930.89	838.88	841.93	850.21	2040.43	31.758300	153.32	51.73	33.92	39.65
Gilo_River	Upstream_Reach2	177471.2	Max WS	118.44	836.00	839.77		839.81	0.005347	0.92	129.29	94.49	0.25
Gilo_River	Upstream_Reach2	177161.9	Max WS	10.00	833.42	835.51		835.51	0.000157	0.14	71.91	62.83	0.04
Gilo_River	Upstream_Reach2	176743.2	Max WS	106.55	830.04	835.89		835.90	0.000827	0.53	200.24	80.40	0.11
Gilo_River	Upstream_Reach2	176367.6	Max WS	-8749.40	824.67	828.94	835.34	977.67	8.658679	-54.01	162.00	66.34	11.04
Gilo_River	Upstream_Reach2	175993.4	Max WS	270.17	821.86	824.21		824.76	0.059770	3.28	82.30	54.19	0.85
Gilo_River	Upstream_Reach2	175200	Max WS	-981.30	818.56	823.73		824.49	0.037283	-3.86	254.37	92.16	0.74
Gilo_River	Upstream_Reach2	174553.5	Max WS	10.00	816.60	823.37		823.37	0.000000	0.02	502.94	105.17	0.00
Gilo_River	Upstream_Reach2	173195.5	Max WS	24505.80	817.00	821.12	843.57	10417.19	33.308200	-433.83	286.99	137.25	95.80
Gilo_River	Upstream_Reach2	171843	Max WS	253.97	804.70	807.86		808.32	0.042480	3.00	84.69	49.20	0.73
Gilo_River	Upstream_Reach2	169886.3	Max WS	10.00	783.53	796.32		796.32	0.000000	0.01	836.47	107.51	0.00
Gilo_River	Upstream_Reach2	169067.3	Max WS	-1.83	779.62	781.61		781.61	0.000135	-0.12	15.82	15.92	0.04
Gilo_River	Upstream_Reach2	167791.8	Max WS	-6257.71	757.01	761.12	764.01	776.40	0.150583	-6.27	600.57	274.70	1.41
Gilo_River	Upstream_Reach2	166435.3	Max WS	10.00	750.50	758.26		758.26	0.000003	0.03	331.63	134.94	0.01
Gilo_River	Upstream_Reach2	165139.2	Max WS	-930.28	736.06	760.37		760.37	0.000014	-0.17	5523.23	587.87	0.02
Gilo_River	Upstream_Reach2	163388.2	Max WS	24353.19	736.76	760.65		760.96	0.001598	2.48	9879.86	771.15	0.21
Gilo_River	Upstream_Reach2	162540.3	Max WS	13232.02	738.51	759.20		759.28	0.000108	0.60	13447.91	1070.92	0.05
Gilo_River	Upstream_Reach2	160630.9	Max WS	17641.26	729.49	759.17		759.21	0.000191	0.91	19402.65	1284.46	0.07
Gilo_River	Upstream_Reach2	158848.7	Max WS	6826.92	730.82	758.90		758.95	0.000267	0.79	7620.09	969.28	0.08
Gilo_River	Upstream_Reach2	155177.1	Max WS	13422.35	709.03	761.67		761.69	0.000066	0.60	21025.27	1671.46	0.04

HEC-RAS Plan: Plan100 Profile: Max WS													
River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Gilo_River	Upstream_Reach2	153738	Max WS	9132.72	731.43	758.76		758.86	0.000723	1.41	6465.21	595.75	0.14
Gilo_River	Upstream_Reach2	152500.3	Max WS	-1730.97	719.91	758.53		758.53	0.000002	-0.11	16389.27	917.08	0.01
Gilo_River	Upstream_Reach2	151690.8	Max WS	-3064.85	702.01	759.03		759.03	0.000004	-0.19	15791.78	581.47	0.01
Gilo_River	Upstream_Reach2	151131	Max WS	830.18	690.78	767.48		767.48	0.000000	0.03	23951.09	660.42	0.00
Gilo_River	Upstream_Reach2	150692.2	Max WS	12466.42	730.97	743.06	743.12	745.96	0.051111	7.54	1653.13	297.08	1.02
Gilo_River	Upstream_Reach2	149581.2	Max WS	99987.80	675.00	699.98	731.90	1370.27	3.791390	114.66	1744.21	124.71	9.79
Gilo_River	Upstream_Reach2	148933.6	Max WS	10.00	675.98	687.73		687.73	0.000000	0.01	839.53	137.34	0.00
Gilo_River	Upstream_Reach2	148428.1	Max WS	·26737.98	672.57	691.83	691.53	697.19	0.036474	-10.25	2608.10	228.64	0.97
Gilo_River	Upstream_Reach2	147841.2	Max WS	10.00	671.61	687.73		687.73	0.000000	0.00	2687.01	376.66	0.00
Gilo_River	Upstream_Reach2	147259.1	Max WS	·73505.41	675.29	681.99	701.60	4015.05	)0.183700	-255.68	287.49	78.47	42.66
Gilo_River	Upstream_Reach2	145575.9	Max WS	71.11	634.71	639.04		639.04	0.000389	0.36	196.51	88.85	0.08
Gilo_River	Upstream_Reach2	145006.5	Max WS	61248.46	631.41	638.14	659.73	1099.04	9.474385	95.08	644.20	131.16	13.70
Gilo_River	Upstream_Reach2	144310.5	Max WS	-626.99	630.02	633.52	634.07	635.15	0.201941	-5.66	110.81	88.11	1.61
Gilo_River	Upstream_Reach2	143693.5	Max WS	10.00	621.34	630.77		630.77	0.000000	0.00	2995.52	547.39	0.00
Gilo_River	Upstream_Reach2	142963.6	Max WS	-1585.71	623.83	638.00		638.06	0.001048	-1.10	1441.34	254.27	0.15
Gilo_River	Upstream_Reach2	142595.3	Max WS	-7500.68	629.64	639.00		639.37	0.007999	-2.68	2800.15	607.95	0.40
Gilo_River	Upstream_Reach2	141938.5	Max WS	52835.30	610.62	631.62	655.20	816.56	1.313342	-60.23	2537.65	232.94	5.83
Gilo_River	Upstream_Reach2	140631.1	Max WS	3595.48	610.64	631.05		631.07	0.000089	0.54	6640.13	542.16	0.05
Gilo_River	Upstream_Reach2	139169.4	Max WS	83168.50	609.00	631.09	646.06	692.86	0.335186	-34.81	8135.73	619.16	3.07
Gilo_River	Upstream_Reach2	138404.5	Max WS	2281.52	592.65	631.26		631.27	0.000022	0.35	6468.97	335.54	0.03
Gilo_River	Upstream_Reach2	137721.9	Max WS	10.00	616.81	630.56		630.56	0.000000	0.00	4974.09	696.92	0.00
Gilo_River	Upstream_Reach2	136948.5	Max WS	918.91	606.93	617.65		617.72	0.001012	1.13	816.48	197.15	0.18
Gilo_River	Upstream_Reach2	135956.2	Max WS	-545.30	563.11	590.03		590.03	0.000003	-0.12	4408.33	350.23	0.01
Gilo_River	Upstream_Reach2	135194.4	Max WS	19392.91	565.60	581.22		583.89	0.022229	-7.23	2681.80	403.57	0.90
Gilo_River	Upstream_Reach2	134435.9	Max WS	76528.03	581.09	585.14	598.92	1297.41	4.133813	-41.73	785.33	279.37	9.92
Gilo_River	Upstream_Reach2	133849.3	Max WS	1202.16	559.46	578.22		578.23	0.000071	0.43	2780.89	384.02	0.05
Gilo_River	Upstream_Reach2	133260.7	Max WS	11893.69	570.04	580.90	582.77	586.17	0.071197	10.17	1169.47	255.25	1.52
Gilo_River	Upstream_Reach2	132712.9	Max WS	28.25	569.18	578.07		578.07	0.000010	0.06	506.71	171.78	0.01
Gilo_River	Downstream_Reach	130219.7	Max WS	205.92	556.86	578.07		578.07	0.000001	0.03	6065.19	645.98	0.00
Gilo_River	Downstream_Reach	129106.5	Max WS	25362.43	567.15	573.12	579.26	626.01	3.702420	32.21	787.49	281.19	6.15
Gilo_River	Downstream_Reach	128197.6	Max WS	:71254.40	550.78	565.05	610.77	2861.99	45.145250	212.25	1277.99	173.93	25.00
Gilo_River	Downstream_Reach	127439.8	Max WS	884.16	555.33	563.52		563.59	0.002485	1.09	811.97	193.76	0.17
Gilo_River	Downstream_Reach	126564.5	Max WS	-7163.54	556.63	563.56	564.26	566.47	0.147341	-7.55	948.40	265.46	1.28
Gilo_River	Downstream_Reach	125377.3	Max WS	20.00	539.00	555.47		555.47	0.000000	0.01	2960.91	402.14	0.00

HEC-RAS Plan: Plan100 Profile: Max WS

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Gilo_River	Downstream_Reach	124526	Max WS	7844.91	536.58	556.84		556.97	0.001678	1.61	4892.68	566.31	0.16
Gilo_River	Downstream_Reach	123612.9	Max WS	3321.94	538.43	555.87		555.88	0.000155	0.42	7652.13	1046.44	0.05
Gilo_River	Downstream_Reach	122962.4	Max WS	6508.91	541.14	555.95		556.02	0.000132	0.36	8256.85	1048.35	0.04
Gilo_River	Downstream_Reach	121700.8	Max WS	83946.54	528.67	563.70		566.35	0.012177	5.63	13579.02	1073.44	0.47
Gilo_River	Downstream_Reach	121049.5	Max WS	3653.72	527.35	555.60		555.60	0.000001	0.05	28866.08	1831.17	0.00
Gilo_River	Downstream_Reach	119876.8	Max WS	40095.38	507.18	564.85		564.98	0.000376	1.36	26680.03	1416.43	0.09
Gilo_River	Downstream_Reach	119019.3	Max WS	1214.45	523.18	555.65		555.65	0.000007	0.13	9078.96	602.47	0.01
Gilo_River	Downstream_Reach	118647	Max WS	28665.00	529.98	561.58		561.68	0.000480	-1.32	20943.18	1392.51	0.10
Gilo_River	Downstream_Reach	118143.1	Max WS	1133.26	530.85	555.54		555.54	0.000001	0.05	17208.64	1496.70	0.00
Gilo_River	Downstream_Reach	117565.2	Max WS	18562.60	514.81	560.41		561.55	0.001652	2.27	36433.64	1918.64	0.16
Gilo_River	Downstream_Reach	116870.7	Max WS	57912.40	474.33	574.32		574.68	0.000819	2.63	59405.05	1457.51	0.12
Gilo_River	Downstream_Reach	116554	Max WS	44361.74	496.68	566.32		566.44	0.000509	1.52	29177.73	993.82	0.09
Gilo_River	Downstream_Reach	116081.7	Max WS	23364.40	527.37	562.99		564.19	0.001843	2.30	6488.26	326.56	0.16
Gilo_River	Downstream_Reach	115827.6	Max WS	11678.39	542.39	560.01		562.59	0.035446	7.10	1644.75	129.95	0.64
Gilo_River	Downstream_Reach	115433.6	Max WS	19904.50	541.46	560.66	591.44	854.90	4.030603	75.97	1578.37	123.73	6.79
Gilo_River	Downstream_Reach	115190.1	Max WS	7851.72	527.00	552.14		552.31	0.001497	1.81	4349.05	256.44	0.14
Gilo_River	Downstream_Reach	114917.3	Max WS	-125.38	531.60	547.03		547.04	0.000002	-0.05	2731.63	237.38	0.00
Gilo_River	Downstream_Reach	114593	Max WS	2501.06	510.38	535.93		535.98	0.000592	1.02	2458.75	166.11	0.08
Gilo_River	Downstream_Reach	114299.2	Max WS	10417.64	504.02	538.21		538.47	0.001684	2.27	4589.99	201.57	0.15
Gilo_River	Downstream_Reach	113969.1	Max WS	17223.92	508.70	537.44		537.89	0.002778	2.96	5822.05	258.99	0.20
Gilo_River	Downstream_Reach	113641.9	Max WS	39242.05	506.00	535.38		536.17	0.001998	-2.05	14336.45	1064.49	0.16
Gilo_River	Downstream_Reach	113359.4	Max WS	63892.71	500.05	538.08		539.25	0.001644	-2.04	19987.12	1165.02	0.15
Gilo_River	Downstream_Reach	112961.6	Max WS	20464.42	504.04	536.02		536.14	0.000146	0.54	20303.85	1393.94	0.04
Gilo_River	Downstream_Reach	112527.7	Max WS	20985.98	497.05	536.03		536.16	0.000510	-1.13	15706.67	1102.82	0.08
Gilo_River	Downstream_Reach	112130	Max WS	10310.46	512.72	535.35		535.43	0.000050	0.26	15146.78	1216.17	0.02
Gilo_River	Downstream_Reach	111764.1	Max WS	4363.89	483.41	536.29		536.29	0.000011	0.17	16490.17	1071.27	0.01
Gilo_River	Downstream_Reach	111464.1	Max WS	49881.90	484.11	552.33		553.28	0.000300	-1.46	53988.22	1359.47	0.07
Gilo_River	Downstream_Reach	111126.5	Max WS	1647.44	498.00	534.92		534.92	0.000002	0.07	16384.76	1120.11	0.01
Gilo_River	Downstream_Reach	110827.9	Max WS	1381.69	501.96	534.88		534.88	0.000001	0.04	20101.10	1314.68	0.00
Gilo_River	Downstream_Reach	110195.2	Max WS	-1218.53	504.91	535.04		535.04	0.000000	-0.02	24475.06	1306.56	0.00
Gilo_River	Downstream_Reach	109790.7	Max WS	71990.30	516.48	542.07	543.93	552.43	0.004244	2.31	20712.23	1473.54	0.22
Gilo_River	Downstream_Reach	109443.5	Max WS	10163.23	514.73	535.71		535.76	0.000024	-0.17	16178.96	1112.83	0.02
Gilo_River	Downstream_Reach	108907.9	Max WS	-5895.60	492.47	536.75		536.77	0.000199	-0.74	7966.34	392.44	0.05
Gilo_River	Downstream_Reach	108347.2	Max WS	-4284.54	527.21	535.88		536.28	0.022590	-2.77	1544.27	376.06	0.44

River	Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
				(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
Gilo _River	Upstream _Reach1	73579.63	Max WS	139.98	858.14	866.62		866.65	0.000275	0.77	182.52	43.04	0.12
Gilo _River	Upstream _Reach1	72517.11	Max WS	876.83	844.87	851.62		851.96	0.003217	2.57	341.10	89.84	0.42
Gilo _River	Upstream _Reach1	71358.79	Max WS	37.12	838.54	841.97		841.98	0.000211	0.39	95.82	55.86	0.09
Gilo _River	Upstream _Reach1	69963.19	Max WS	-34.77	825.26	826.45		826.61	0.015479	-1.72	20.17	31.84	0.69
Gilo _River	Upstream _Reach1	69034.38	Max WS	10.00	811.12	819.89		819.89	0.000000	0.01	720.28	117.89	0.00
Gilo _River	Upstream _Reach1	67471.5	Max WS	10.00	812.68	819.89		819.89	0.000001	0.04	240.19	61.30	0.01
Gilo _River	Upstream _Reach1	65949.91	Max WS	10.00	793.95	819.89		819.89	0.000000	0.00	4809.55	244.09	0.00
Gilo _River	Upstream _Reach1	64194.14	Max WS	93764.44	802.64	809.50	833.84	2406.78	17.565320	-177.00	529.75	155.85	30.66
Gilo _River	Upstream _Reach1	62196.16	Max WS	10.00	776.98	784.61		784.61	0.000000	0.01	856.10	221.59	0.00
Gilo _River	Upstream _Reach1	59540.17	Max WS	39802.20	780.71	784.06	842.77	07907.50	22.355000	-2015.53	168.59	100.17	496.11
Gilo _River	Upstream _Reach1	58139.93	Max WS	10.00	754.86	780.29		780.29	0.000000	0.00	2558.21	148.28	0.00
Gilo _River	Upstream _Reach1	56857.84	Max WS	10.00	768.15	780.29		780.29	0.000000	0.01	930.09	124.33	0.00
Gilo _River	Upstream _Reach1	54434.49	Max WS	10.00	760.96	780.29		780.29	0.000000	0.00	2368.70	197.14	0.00
Gilo _River	Upstream _Reach1	53183.94	Max WS	10.00	751.36	780.29		780.29	0.000000	0.00	4073.98	199.13	0.00
Gilo _River	Upstream _Reach1	52148.67	Max WS	11533.81	748.68	786.12		786.32	0.000163	2.00	5765.96	219.04	0.12
Gilo _River	Upstream _Reach1	51330.7	Max WS	10.00	763.17	780.29		780.29	0.000000	0.01	1787.66	189.77	0.00
Gilo _River	Upstream _Reach1	50833.77	Max WS	10.00	754.35	780.29		780.29	0.000000	0.00	3430.07	267.09	0.00
Gilo _River	Upstream _Reach1	49351.44	Max WS	576.92	752.00	772.71		772.71	0.000013	0.32	1815.86	170.16	0.03
Gilo _River	Upstream _Reach1	48248.58	Max WS	10.00	726.00	738.06		738.06	0.000000	0.01	937.74	106.89	0.00
Gilo _River	Upstream _Reach1	47308.3	Max WS	10.00	710.56	738.06		738.06	0.000000	0.00	2870.15	158.56	0.00
Gilo _River	Upstream _Reach1	46325.56	Max WS	80491.52	733.56	746.94	757.58	847.20	0.588478	-44.14	1815.56	373.34	6.07
Gilo _River	Upstream _Reach1	43734.59	Max WS	10.00	719.74	738.05		738.05	0.000000	0.00	4837.11	504.52	0.00
Gilo _River	Upstream _Reach1	41841.8	Max WS	21795.96	701.78	741.05		741.12	0.000071	-1.20	18718.13	1173.40	0.08
Gilo _River	Upstream _Reach1	40945.81	Max WS	10.00	709.04	738.05		738.05	0.000000	0.00	14117.26	1350.24	0.00
Gilo _River	Upstream _Reach1	39890.17	Max WS	2055.11	709.98	712.66	712.86	713.70	0.035446	4.51	455.47	317.17	1.20
Gilo _River	Upstream _Reach1	36427.61	Max WS	83168.50	683.00	694.00	726.35	3897.66	12.232490	-250.49	1129.66	168.89	29.05
Gilo _River	Upstream _Reach1	35567.7	Max WS	33645.63	680.24	685.71	700.79	1272.57	8.095169	107.29	313.61	110.05	20.29
Gilo _River	Upstream _Reach1	34797.64	Max WS	10.00	677.82	684.55		684.55	0.000000	0.02	475.45	124.66	0.00
Gilo _River	Upstream _Reach1	34080.52	Max WS	10.00	671.00	684.55		684.55	0.000000	0.01	977.94	179.84	0.00
Gilo _River	Upstream _Reach1	32387.76	Max WS	10.00	663.91	684.55		684.55	0.000000	0.00	2169.58	154.18	0.00
Gilo _River	Upstream _Reach1	31523.86	Max WS	10.00	665.96	684.55		684.55	0.000000	0.01	1817.17	201.93	0.00
Gilo _River	Upstream _Reach1	30941.33	Max WS	-6734.85	666.32	702.58		702.60	0.000046	-0.67	10229.62	1009.24	0.06
Gilo _River	Upstream _Reach1	30139.51	Max WS	32499.87	664.73	688.71		690.50	0.003379	5.93	5480.31	428.64	0.53
Gilo _River	Upstream _Reach1	29068.54	Max WS	38097.23	634.98	688.24		688.76	0.000588	3.19	11926.19	623.77	0.23
Gilo _River	Upstream _Reach1	28119.11	Max WS	10174.64	649.26	686.93		686.98	0.000059	-1.00	10205.27	556.49	0.07
Gilo _River	Upstream _Reach1	25676.72	Max WS	21198.88	630.57	688.10		688.23	0.000105	1.59	13373.55	540.92	0.10
Gilo _River	Upstream _Reach1	24869.74	Max WS	-4711.90	668.44	674.03	674.71	676.32	0.060535	-6.71	702.59	402.04	1.62
Gilo _River	Upstream _Reach1	23704.1	Max WS	682.28	629.57	633.77	634.18	635.81	0.030851	6.33	107.79	39.14	1.22
Gilo _River	Upstream _Reach1	22666.41	Max WS	10.00	609.22	629.68		629.68	0.000000	0.01	1554.78	116.10	0.00
Gilo _River	Upstream _Reach1	21598.04	Max WS	39620.80	613.36	618.38	667.67	44371.32	34.657000	926.36	150.72	51.84	173.48
Gilo _River	Upstream _Reach1	20451.6	Max WS	-448.49	594.53	600.65		600.79	0.002468	-1.63	275.50	72.34	0.27
Gilo _River	Upstream _Reach1	17688.09	Max WS	10.00	581.83	590.82		590.82	0.000000	0.02	585.53	132.70	0.00
Gilo _River	Upstream _Reach1	15887.99	Max WS	-835.60	571.13	592.49		592.50	0.000022	-0.33	2513.68	209.59	0.03
Gilo _River	Upstream _Reach1	14666.5	Max WS	-6610.23	567.05	595.06		595.18	0.000305	-1.52	4357.63	263.57	0.12
Gilo _River	Upstream _Reach1	13758.59	Max WS	10.00	561.39	590.82		590.82	0.000000	0.00	3898.69	217.67	0.00
Gilo _River	Upstream _Reach1	13071.59	Max WS	10477.51	570.12	594.47		594.94	0.001117	3.04	3449.50	190.18	0.23
Gilo _River	Upstream _Reach1	12437.29	Max WS	5490.89	564.22	596.18		596.22	0.000071	0.89	6186.44	275.54	0.06
Gilo _River	Upstream _Reach1	11889.01	Max WS	5735.43	570.03	591.63		591.74	0.000321	1.42	4049.57	286.74	0.12
Gilo _River	Upstream _Reach1	11402.25	Max WS	-2101.58	580.00	598.93		598.97	0.000321	-0.93	2258.68	301.00	0.11
Gilo _River	Upstream _Reach1	10934.43	Max WS	587.74	581.48	595.08		595.08	0.000043	0.29	2028.62	350.40	0.04
Gilo _River	Upstream _Reach1	10363.77	Max WS	-4649.88	584.27	592.71		593.00	0.005321	-2.40	1934.11	513.39	0.40
Gilo _River	Upstream _Reach1	9675.505	Max WS	1515.38	563.84	578.31		578.36	0.000326	1.02	1481.60	172.71	0.11
Gilo _River	Upstream _Reach1	8913.275	Max WS	2046.72	563.72	578.94		579.01	0.000378	1.18	1732.92	182.38	0.12
Gilo _River	Upstream _Reach1	7777.84	Max WS	2759.87	545.18	579.12		579.14	0.000043	0.66	4150.23	192.45	0.05
Gilo _River	Upstream _Reach1	7070.81	Max WS	2039.56	555.16	582.58		582.59	0.000031	0.51	4032.88	224.19	0.04
Gilo _River	Upstream _Reach1	6010.209	Max WS	1131.04	558.16	579.33		579.35	0.000080	0.62	1835.73	156.99	0.06
Gilo _River	Upstream _Reach1	5106.09	Max WS	-5168.62	550.99	579.69		579.73	0.000076	-0.88	5888.26	282.37	0.06
Gilo _River	Upstream _Reach1	4515.831	Max WS	28708.44	542.28	582.51		583.07	0.001781	3.32	8634.68	606.08	0.28
Gilo _River	Upstream _Reach1	3970.373	Max WS	5130.01	526.38	582.30		582.31	0.000026	0.56	9240.12	374.51	0.04
Gilo _River	Upstream _Reach1	2929.077	Max WS	21418.35	558.51	579.58		580.01	0.002013	-2.93	7373.78	754.06	0.29
Gilo _River	Upstream _Reach1	1477.1	Max WS	177.67	549.70	578.07		578.07	0.000000	0.03	6693.00	843.03	0.00