FLOOD HAZARD ASSESSMENT FOR LHUNTSE DZONGKHAG

FLOOD ENGINEERING AND MANAGEMENT DIVISION, DEPARTMENT OF ENGINEERING SERVICES, MINISTRY OF WORKIS AND HUMAN SETTLEMENT

YEAR 2019

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Acknowledgement

Flood Engineering and Management Division under Department of Engineering Services, Ministry of Works and Human Settlement have taken immense initiative and efforts in carrying out flood hazard assessment for Lhuntshe Dzongkhag and preparation of the Flood Hazard Map for Autsho in Lhuntse Dzongkhag. The Division has successfully completed this project on time. However, it would not have been possible without the valuable support, guidance and help of many individuals and organizations. Therefore, we would like to extend our sincere thanks and appreciation to all of them:

1. Department of Hydro-met Services, Ministry of Economic Affairs, Bhutan
2. National Statistical Bureau, Bhutan
3. Dzongkhag Administration, Lhuntse Dzongkhag

The Flood Engineering and Management Division would also like to acknowledge and thank all those who have contributed and willingly helped us with their abilities towards carrying out the flood hazard assessment studies for Lhuntse Dzongkhag.

Acronyms

FEMD	Flood Engineering and Management Division.
HEC-RAS	The Hydrologic Engineering Centre, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modelling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Défense, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
GIS	Geographical Information System is a computer-based method for analysing geographical information and maps.
FHM	Flood Hazard Map.
FHA	Flood Hazard Assessment.
NCHM	National Centre for Hydrology and Metrology.
MoWHS	Ministry of Works and Human Settlement.
DHS	Department of Human Settlement.
NSB	National Statistical Bureau.
AoMI	Areas of Mitigation Interest

Executive Summary

This study focuses only on Kurichu sub basin in Lhuntse District along the river valley of Kurichu at Autsho under Tshenkhar, Gewog. Although, sum of the villages is scattered and located along the Kurichu valley (from Gangzor Gewog to Autsho under Tshenkhar Gewog) in the flood plains which expose them to high risk of flooding. But Autsho has more settlement as well as propose new Township therefore, we focus and developed hazard map.

The main objective of the study is as follows:

Objective 1: Flood hazard assessment of Kurichu and its critical tributaries in Lhuntse Dzongkhag.
Objective 2: Analyse the AoMI (Areas of Mitigation Interest) assessment in Lhuntse Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Lhuntse Dzongkhag.
Objective 3: Recommend appropriate flood protection measures along the identified flood prone areas.

A hydrodynamic model was developed for Kurichu in HEC RAS software. SRTM 30m resolution was used for creating the river geometry and a representative value of Manning's n value of 0.03 is assigned for main stream and 0.01 for overbanks. The steady flow hydrodynamic model was run with a Subcritical flow regime. Due to the unavailability of other data, critical depth was assigned as downstream boundary condition, which is computed automatically by the model.

The flood hazard areas along Kurichu include crematorium, Autsho Town, Forest Beat Office are located at Autsho area along the Kurichu. In this case we carryout site investigation of flood prone areas under lhuntse Dzongkhag for eight Gewog and found out the Autsho was most critical and identified to need to produce hazard map. We also found most of the required data are available such as discharge gauge station. Therefore, to process the discharge for modelling we took observed data from 1985 to 2011 for Kurichu at Autsho station.

The Area of interest are further prioritized for flood protection measures. Following are the prioritized areas:

1. Autsho Town, Tshenkhar Gewog
2. Crematorium, Confluence of Khomachu and Kurichu

The intervention is based on the important structure and settlement affected by the flood. The first priority area was crematorium, confluence of khomachu and kurichu. The FEMD, DES in the year 2014 (11th FYP) constructed gabion wall along the left bank of kurichu and right bank of khomachu at confluence to protect the crematorium from flooding risk. A total amount of approx. Nu. 10 million was invested for the flood protection works. Similarly, after developing flood hazard map the division found second critical area at Autsho, and invested Nu.7.3m for construction of gabion walls in FY 2016-2017.

Introduction

Background

Bhutan has a history of loss of life and damage to property due to flooding. Rivers are generally characterized by steep slopes in the upper catchment, which are subject to intense seasonal rainfall and high rates of erosion. As the rivers flow towards the southern foothills, the transition from mountainous areas to flat plains typically occurs and is accompanied by extensive flooding. On the other hand, owing to Climate Change, the rainfall pattern has become erratic with prolonged drought period followed by unusually high precipitation which causes flash floods all over the country. Climate change and variability has resulted in changing rainfall and temperature patterns, thereby aggravating these disaster risks, leading to higher risks, especially for the poor and vulnerable.

This study documents the use of flood-hazard mapping as a way of helping communities to devise plans that would help them develop warning and response systems. It allows communities to prepare a management plan that will boost their resilience to mitigate damages and salvage their livelihoods to the extent possible.

This project focuses only on Kurichu sub basin in Lhuntse District along the river valley of Autsho Town. Most of the settlement are scattered and located along the Kurichu valley. The Autsho is in the flood plains which expose them to high risk of climate change threats such as flash flood as well as climate change impacts on the livelihoods.

This publication is a summary of a study on flood-hazard mapping of the Kurichu using HEC-RAS and GIS methods. It is describing some socioeconomic characteristics of Lhuntse Dzongkhag and discusses on the frequency, and magnitude of flood in Autsho. This describes flood-hazard and details of the project area and the methodology for and results of hazard mapping. It also gives an account of the assessment carried out on past history of flooding and future hazard in Autsho. And finally, it also covers the main findings, conclusions, and recommendations.

Objective

Objective 1: Flood hazard assessment of Kurichu and its critical tributaries in Lhuntse Dzongkhag.

Objective 2: Analysed the AoMI (Areas of Mitigation Interest) assessment in Lhuntse Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Lhuntse Dzongkhag.

Objective 3: Recommend appropriate flood protection measures along the identified flood prone areas.

Study Area

Lhuntse Dzongkhag is located in the north east of the country. It covers an area of 2851 Sq. Km and consists of 2506 household with an elevation of 2034 meters above mean sea level. Lhuntse Dongkhag is divided into eight village blocks (gewogs) namely Gangzur , Jaray , Khoma, , Menbi, Metsho ,Minjay and Tsenkhar Gewog.

The Dzongkhag is approximately located at the latitude of 27˚45' 0" north and longitude of 91˚11'0" East. The Kurichu valley is main part of the Lhuntse Dzongkhag which is major river that has formed the scenic valley with high peaks and steep hills. Kurichu is a tributary of the Manas River system, which is the largest river of Bhutan and a major tributary of the Brahmaputra River that drains most of Eastern Bhutan.

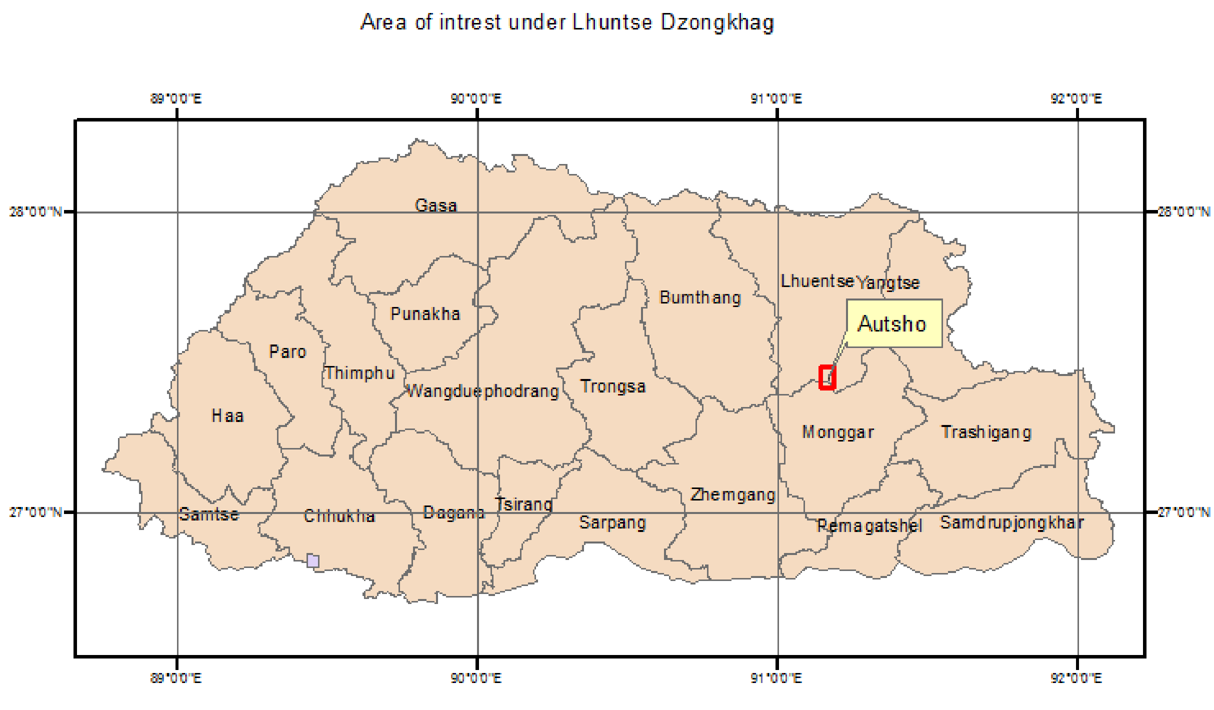


Figure 1: Area of interest under Lhaunts

Every Gewog in the Dzongkhag has a BHU, RNR centres and a School each. Agriculture Farming is the main source of income for majority of the population. Farmers grow almost all kinds of crops but in some areas, potatoes are the main source of cash income. The upcoming Rodpashong hydro power also located under Lhuntse Dzongkhag which will be future revenue for the country. The project is expected to bring in lots of economic boon to the local people of Autsho.

Sl.No	No. of Gewog	Population	Hospital	BHU	ORC	School	Wet land in (Ha)	Dry land in (Ha)	Cash Crop in (Ha)
1	8	17600	1	14	30	58	1575.6	4328.7	0.9
Total	**8**	**17600**	**1**	**14**	**30**	**58**	**1575.6**	**4328.7**	**0.9**

Table 1: Social economic data of lhuntse Dzongkhag.

(Source: National Statistical Bureau of Bhutan, 2015)

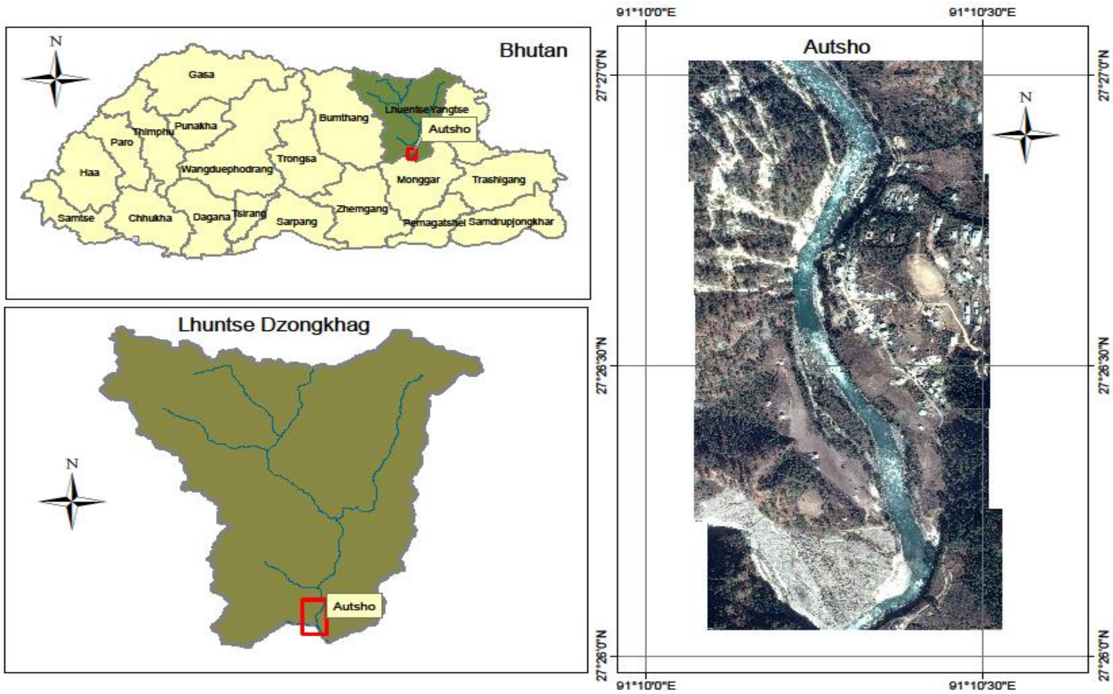


Figure 2: Autsho Study area

Kurichu, also known as the major river of eastern Bhutan, that has formed a scenic valley with high peaks and steep hills. Kurichu is a tributary of the Manas River system, which is the largest river of Bhutan and a major tributary of the Brahmaputra River that drains most of eastern Bhutan. It crosses into Bhutan at a relatively low elevation of 1,200 meters, flowing in a southerly direction up to Nye and changes its course to south-easterly until it reaches Lhuentse Dzong. Further downstream the Kurichu flows in a south-westerly direction and joins the Manas River.

Methodology

The methodology adopted for the study is as shown in Figure 2. A thorough desktop study was followed by data collection from different agencies. A detailed site assessment was conducted in the flood prone Gewogs and analysed. A hydrodynamic model was developed for Kurichu and the flood hazard maps were developed. After analysing the results, areas of Mitigation Interest (AoMI) were identified and prioritized.

Flow chart 1: Procedure for analysis flood hazard area

Data Collection and Assessment

Desk study

Desk study are carried out for analysed quantitatively and qualitatively in order to understand the nature of flooding to before visiting to the site for assessment:

1. Identity the probability of a flood occurring
2. Identify the specific future time period
3. Identify the area and intensity of impact

The desk study has been done in various ways before going for specific site assessment and modelling. Assessment is based on the 'detailed observation of natural systems' and considers the impact of the hazard on the physical environment. A flood hazard assessment derives a number of aspects relating to flooding that pose a threat to people and property. The method to carry out the assessment depends on the information, technology and resources available.

Hydrological and Meteorological Data

The hydro-meteorological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). The location of the hydro-met stations is depicted in Figure 3**Error! Reference source not found.**.

Figure 3: Location of the Hydro-met station in the study area

There are four meteorological stations available in the Dzongkhag. This river is gauged and have enough data of discharge therefore we have not used rail fall data.

Hydro-Met Data

In Bhutan, most of the rivers are un gauged and hence it poses a challenge while undertaking such kind of assessment. But in case of this river we have two gauging station at khomachu confluence and other at Autsho. Therefore, we directly used for modeling.

Scientific Data

The following the list of globally available scientific data that were used in the study:

Item	Data Source	Original Cell-size	Model
DEM	SRTM	30m grid square	Hydrodynamic

Table 2: 30 m SRTM DEM

Site Assessment at Gewog Level

Floods are naturally occurring phenomena that can and do happen almost anywhere. In its most basic form, a flood is an accumulation of water over normally dry areas. Floods become hazardous to people and property when they inundate an area where development has occurred, causing losses. Mild flood losses may have little impact on people or property, such as damage to landscaping or the generation of unwanted debris. Severe flood losses can destroy buildings, crops, and cause severe injuries or death.

FEMD, DES, MoWHS mandated to prepare flood hazard map for twenty Dzongkhag, therefore Division forecasted to visited the flood prone areas in Lhuntse Dzongkhag to carry out the Flood Hazard Assessment in Lhuntse Dzongkhag. The team from FEMD met with District Engineer, Municipal engineer, Mangi of Tshankhar gewog and some official from Lhuntse Dzongkhag. The team briefed the Dzongkhag and gewog officials on the importance of carrying out flood hazard assessment and subsequently identification of most critical river for preparation of flood hazard mapping in Lhuntse. The team also conveyed that flood prone areas were identified by the Dzongkhag initially and list given to FEMD for record and therefore, the validation of the flood prone areas will also be carried out during the site visit.

Assessment of hazard in the Autsho along the Kurichu was based on primary data collected from the field December 2015. Primary data, basically on past hazards, socioeconomic conditions and efforts made by local people to mitigate floods and other water induced disasters in the recent past, were collected during field work. Information on the magnitude, recurrence intervals, and damage from different types of disaster was collected through group discussions with the help of structured checklists. Local elders people were consulted to collect data from the past. The individual households, information on the perception of local people about flood hazards and efforts made to mitigate hazards at household level was collected through household surveys.

The flood hazard assessment is carried out to find out the area which is at the risk of flooding and prioritize the area needing immediate attention. Based on the priority as per the flood hazard assessment, the appropriate flood protection structures to reduce the impacts of floods on the vulnerable population, infrastructure etc. is recommended. During the assessment, the most flood risk river to the settlement is identified and cross section survey of the river is conducted to prepare flood hazard map. The team visited Tshankhar, Minje, Khoma and Gangzur Gewog as per the inventory of flood prone available with FEMD and interactions with Gewog officials.

As per the desk study done by the visiting engineers, the most critical river along the settlements in Lhuntse was found out to be Kurichu along Autsho in Tshenkhargewog. Therefore, the site visit was also conducted to validate the findings from the deskstudy.It was found out the Kurichu along Autsho posed more risk of flooding to the settlements, therefore cross-sectional survey of the Kurichu along Autsho has been conducted for preparation of flood hazard map.
The cross-section survey of Kurichu river at Autsho was conducted for around 2 kms starting from confluence of Shagma chu and kurichu in Autsho till workshop area in Autsho. The survey interval was about 100-150 meters. The survey data will be used for flood modelling and preparation of flood hazard map for Autsho upcoming town. Flood hazard map will show the risky area where flooding can take place and depth of inundation in different places, which will help to identified the site for mitigation works. The modelling will also give the water level and velocity for the given discharge, which will be used during the design of flood protection works along Kurichu in Autsho.
During the visit to Gangzor Gewog, the District Engineer emphasized the need for rectification of the flood protection works upstream of culvert, which was damaged by the flood in midsummer, 2015. In addition to the rectification works, some more flood protection structure is required along Lakpagang chu upstream of culvert as per the Dzongkhag Engineer. The Drasha (hostel for the monk), road, archery ground, proposed parking etc. will be affected by the flood if no flood protection works are done. In addition to the requirement of flood protection works along lekpagangchu, the District Engineer had also pointed out some prioritize areas where flood protection work required, such as along left bank of Lekpagang chu in Dzong areas and along Kurichu in Autsho near cremation ground.

Tshenkhar Gewog

There are Eight Gewogs under Lhuntse Dzongkhag, three out of eight Gewogs are prone to flood namely Tshenkhar, Gangzor, and Khoma Gewogs. Gewog wise flood affected areas are described.

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Confluence (near chorten)	Tshenkhar	27° 21' 48.1"	91° 39' 52.3"	848	Left bank
2	Suspension bridge (downstream of Autsho)	Tshenkhar	27°26' 14.2"	91° 10' 24.2"	843	Right bank
3	Suspension bridge (upstream of Autsho)	Tshenkhar	27°26'37.9"	91° 10' 16.2"	860	Right bank
4	Above cremation ground	Tshenkhar	27°26' 59.1"	91° 10' 17.8"	868	Left bank

Table 3: Location under tshenkhar Gewog .

Autsho is under Tshankhar gewog and it is located at 27°26'37.9" northing and 91° 10' 16.2" easting having elevation 860 m. Around 80 shops and approximately 300 people are residing in Autsho town, and it is the main commercial hub of lhuntse. Apart from town, agricultural land is also having threat from flood along the right bank Kurichu and is opposite to Autsho town.The ground profile is flat and quite vulnerable to flood.Autsho town is located at left bank of the Kurichu. Realising the importance of upcoming town and existing infrastructure, FEMD intervened and initiated to conduct the river cross section for developing flood hazard map.

Figure 4: Autsho main study area.

Existing 60 m length and 2 m height of gabion were found in front of cremation ground which was constructed by Dzongkhag Administration.

During monsoon season high flood level almost reaches to the crematorium ground from the upstream and downstream of existing gabion wall.

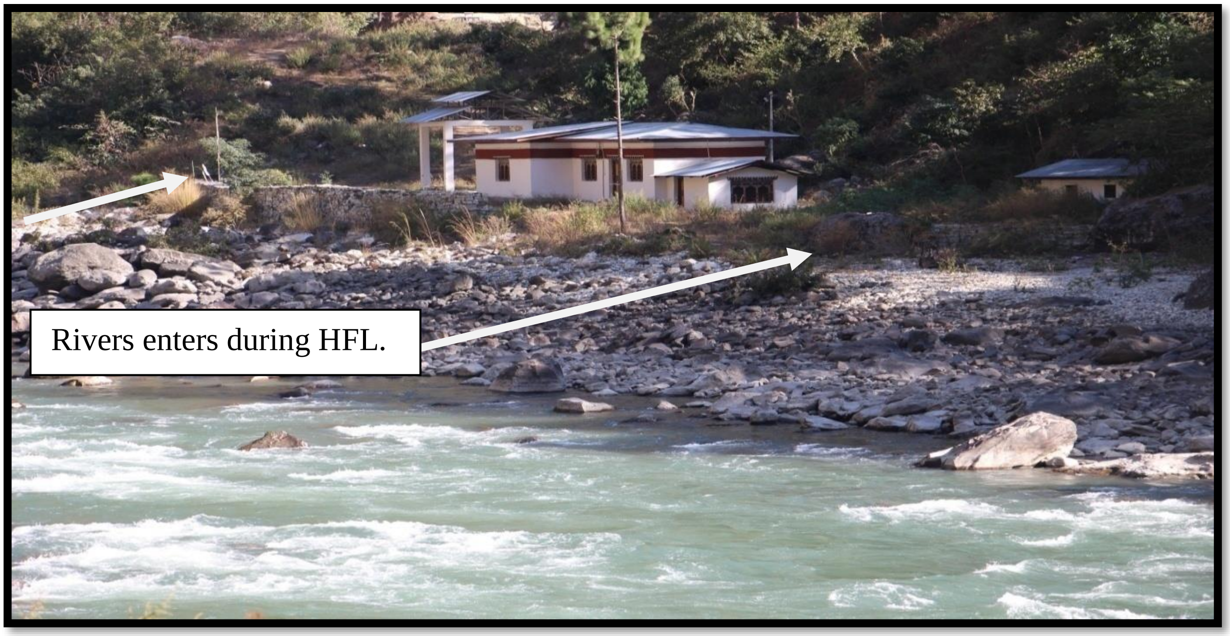


Figure 5: Near crematorium.

Scouring at the left bank of Kurichu was also observed which is a threat wing wall, Forest and agriculture office.

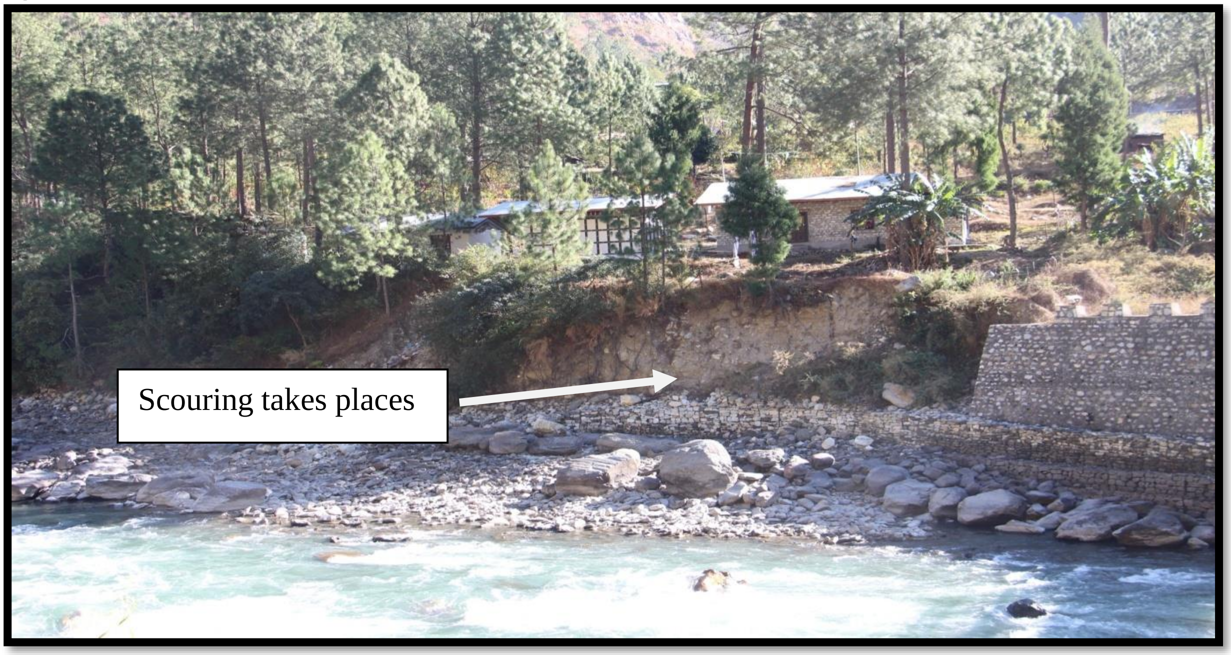


Figure 6: Scouring takes place above bridge point and creates threat to settlements.

Right bank of Kurichu below the motorable bridge, during high flood level river create new flood way and was observed to be threat to agricultural land.

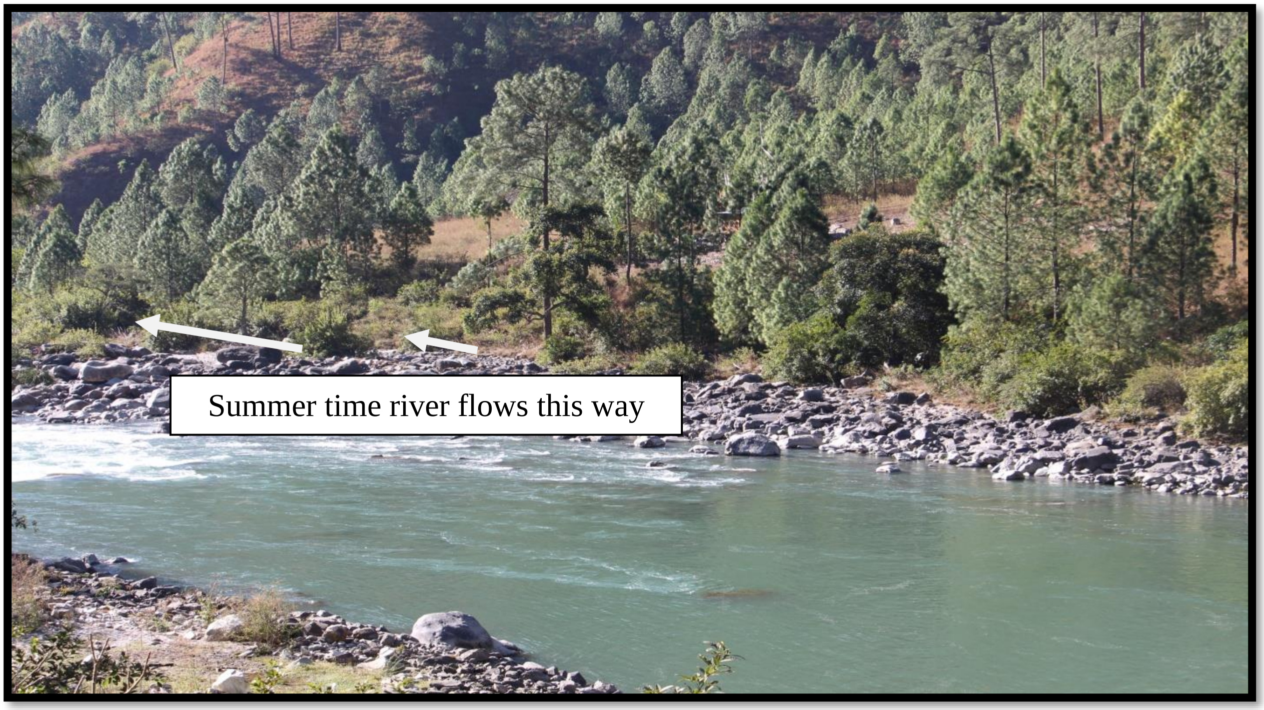


Figure 7: Opposite to town below suspension bridge.

Left bank towards to Autsho town, risk of entering river during the heavy rainy season and when river gets swollen. Downstream of this right bank settlement were seen and we found height deferent is 2 to 3 meters. There are chances of inundation the downstream settlement.

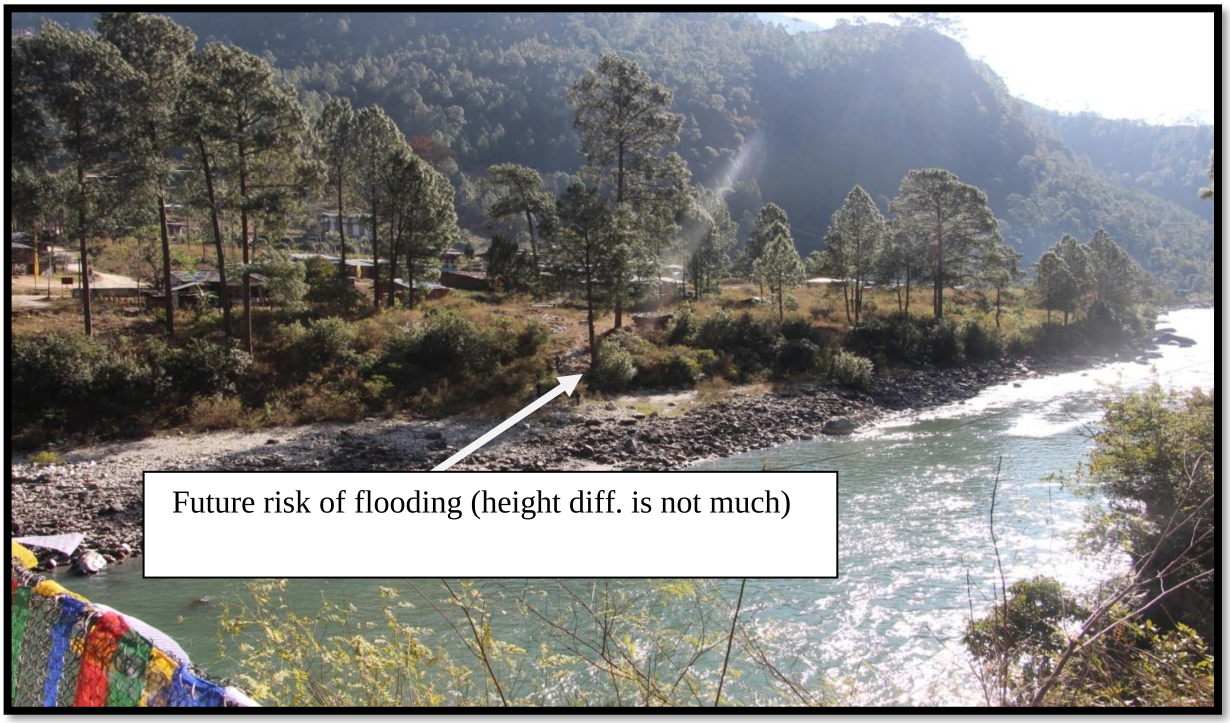


Figure 8: Autsho Town below suspended bridge.

Gangzor Gewog

The Gangzor gewog lies on the latitude of 27° 26' 59" north and longitude 91° 10' 17.4" east with the elevation of 1443 meter. The maximum people depend on agriculture product. The Dzongkhag administration and small town of lhuntse Dzongkhag is also under this gewog. Under this gewog we find the affected areas is below Dzong. The Lakpaigang chu crates flooding in so many years which affect the people living nearby that vicinity.

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Lhuntse HS School	Gangzor	27° 26' 59"	91° 10' 17.4"	1443	landslide
2	Lakpagangchu	Gangzor	27° 35' 51.9"	91° 14' 22.2"	1476	Upstream

Table 4: Location under Gangzor Gewog.

Existing gabion wall around 30 m at upstream or front of Drasha and 30 m downstream has been partially washed away/damage.

Figure 9: Partially washed away gabion wall at upstream

Scouring has been observed at base of the foundation of another the 70 m gabion wall. The foundation of wall needs to restore by constructing additional structure like apron.

Figure 10: RRM wall in front of Drasha

In front of Drasha 12 m RRM wall is on the verge of collapse due to scouring of the base of the wall and need to protect immediately for further damage.
Bottle neck created by the culvert and not able to carry whole discharge during flooding and this will allow water to over top and flow towards to the chorten. Monsoon flood created few places scoring along the Lakpagangchu and needs to be protected.

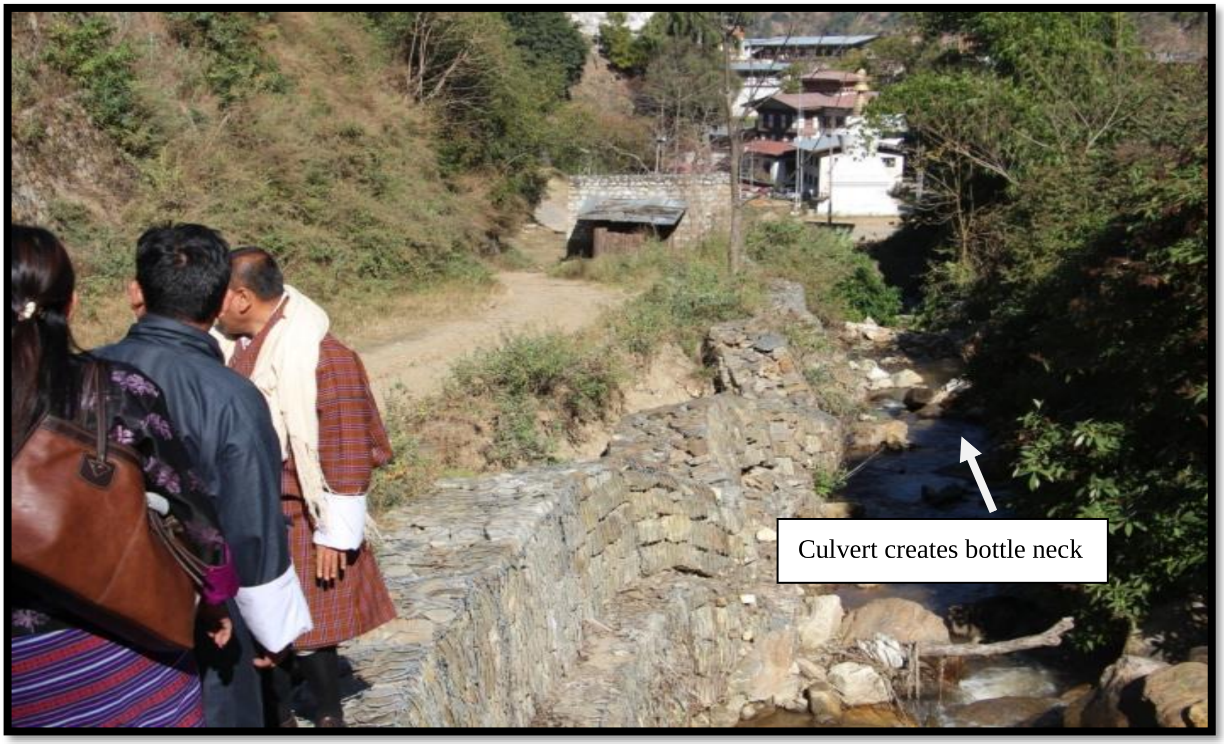


Figure 11: Culvert create bottle neck during heavy monsoon season and not able to accumulate whole discharge.

Khoma Gewog

The Khoma Gewog lies on the latitude of 27° 41' 10.8 " north and longitude 91° 13' 11.5" east and with the elevation of 1308 m. The maximum people depend on agriculture product. Few people cultivate cash crop for their incomes. Under this gewog we identified flood affected areas by past history

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Khomachu	Khoma	27° 41' 10.8"	91° 13' 11.5"	1308	Left bank

Table 5: Location under Khoma Gewog.

Scouring at the left bank of Khoma River triggers the base of hill lock and creates threat to Khoma LS school. Gewog Administration, Khoma had carried out dredging work at scouring area, diverted the river and also constructed rip-rap at based of the landslide area. The area improved and found some vegetation had grown.

Figure 12: Souring creates landslide below the khoma L.S School.

Minje Gewog

The Tshenkhar Gewog lies on the latitude of 27° 35' 52" north and longitude of 91° 14' 22.3"east with the elevation of 2029 meters. The maximum people depend on agriculture product.
Few people cultivate cash crop for their incomes. Under this gewog we identified flood affected areas by past history.

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Minje MS School	Minje	27° 35' 52"	91° 14' 22.3"	2029	Sinking area

Table 6: Location under Minje Gewog.

Below the Minje Middle Secondary School the mass movement of earth/landslide creates threat to school. This landslide will pull down the school play field and some of structure in future.
The road to village which passes below the school had wash away by landslide. This is caused by the unmanaged outlet discharge water from school and irrigation channel. Sinking area below the football ground had affected both the school and community.

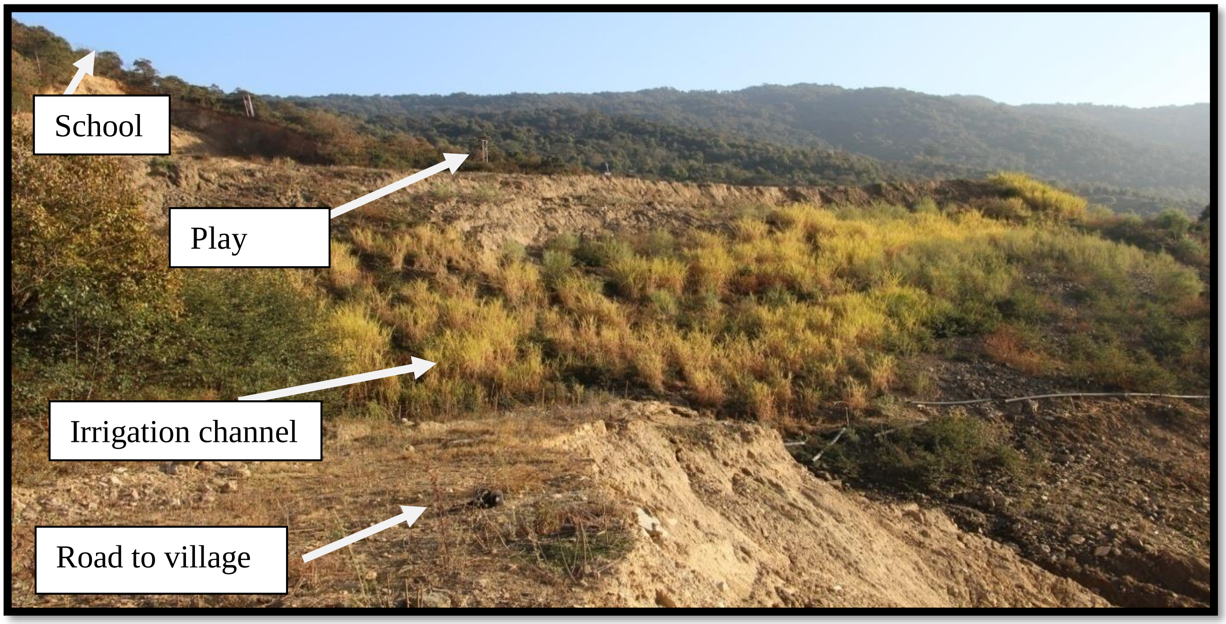


Figure 13: Below Minje MS School (landslide pull down village road and ply field).

Development of Model

Hydrodynamic model

The freely available global DEM such as SRTM 90m, SRTM 30m and the ALOS 10m DSM were explored to find the most suitable DEM for the study area. All the DEMS were corrected as per the site location and resample to create a terrain for the 1D hydrodynamic model. However, as per site condition SRTM found most suitable. Thus, for this study, SRTM, 30m resolution was used.

HEC-RAS 1D Model setup

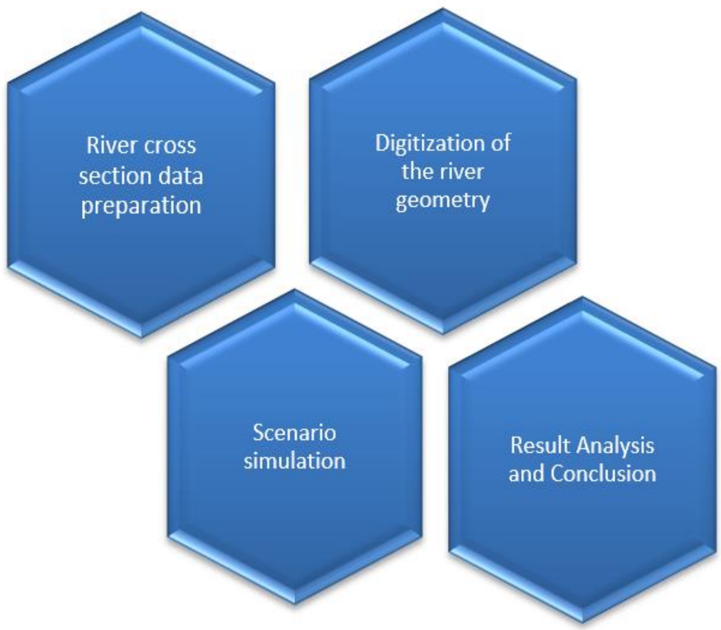


Figure 14: Methodology adopted for the developing the 1D Hydrodynamic Model

River cross section data preparation

Taking cross-section survey along the river study area is important for flood modelling and river analysis. Modelling of river helps to find out velocity, river profile etc. Cross-sections are required to represent channel geometry in a river hydraulic model. The accuracy of the simulated water levels and the floodplain delineation largely depends on the shape as well as extent of these cross-sections. For the assessment, the cross-section data was derived from DEM and also surveying using total station. The cross-section survey of Kurichu was carried out by FEMD, DES, MoWHS in December, 2015. About 20 numbers of cross-section data along Kurichu were collected.

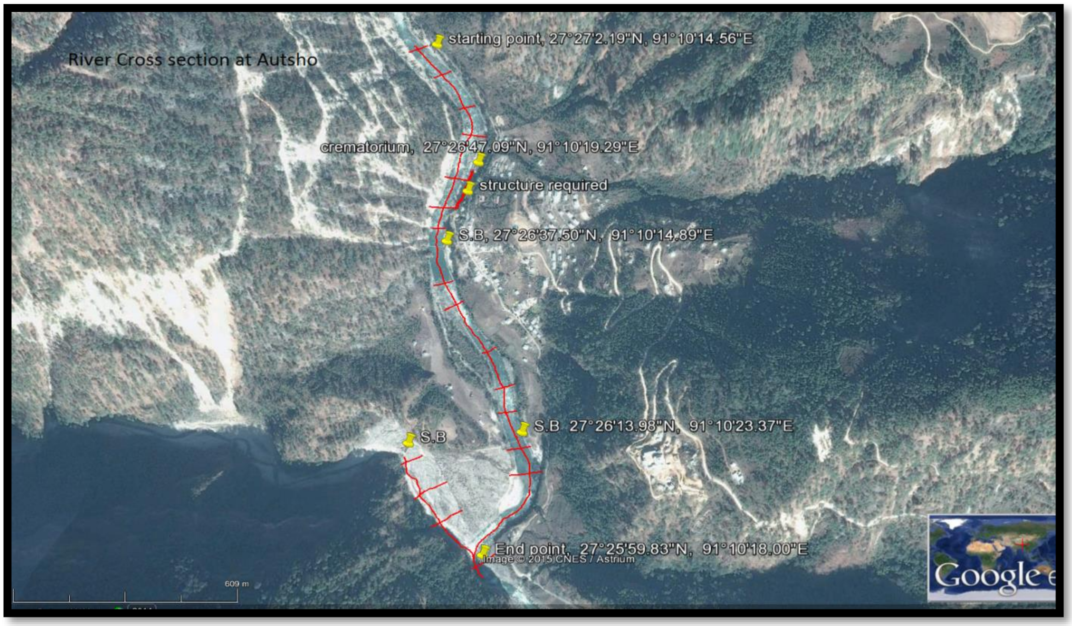


Figure 15:Digitize river cross section at Kurichu

Digitize the River geometry

First digitize river centreline (upstream to downstream), left bank and then right bank, after that the left flow path and the cross sections. The cross-section line can be digitized in the same line as the survey point. The digitization was done in HEC-Geo RAS to define the river geometry in google image.

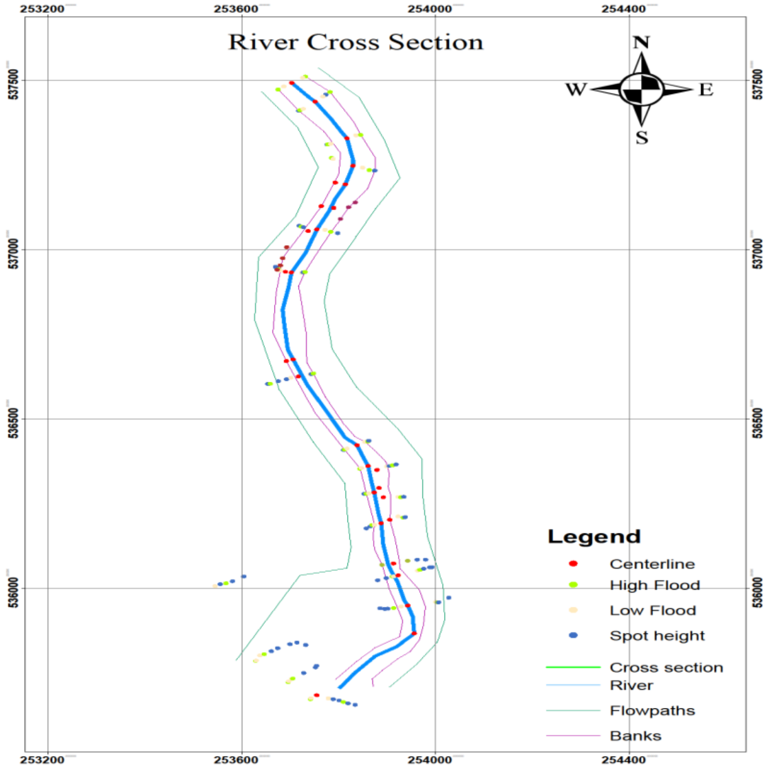


Figure 16: River geometry.

DEM (Digital Elevation Model)

SRTM (Shuttle Rader Topography Mission) DEM with 30-meter resolution is used for this project. When the river model simulates the design flows in the river channel and the flow is too large for the channel, the water comes out of bank and onto the floodplain. The model will then need elevation data that defines the terrain (topography) in order to simulate where this flood water will go and how deep it will be. For this, we use a Digital Elevation Model (DEM) and it is clipped for the study area using the ARC-GIS. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

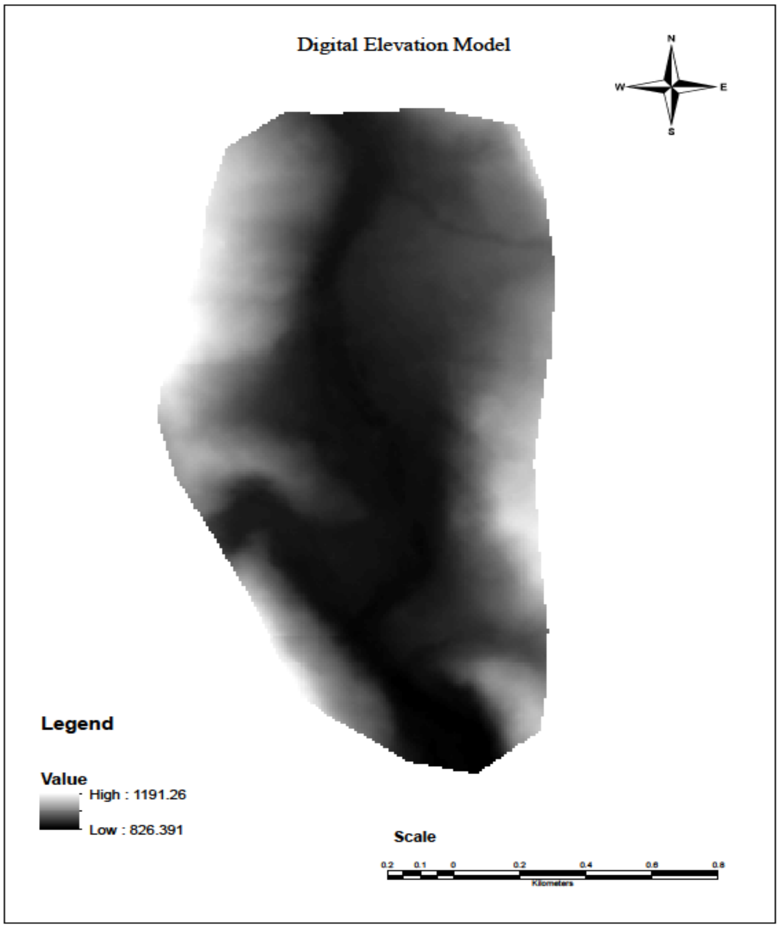


Figure 17:DEM of study area.

TIN preparation

A triangulated irregular network data model (TIN) is an efficient way for representing continuous surfaces as a series of linked triangles. Although both grids and tins can be used for surface representation, tins are especially useful for representing surface elevation, subsurface elevation and terrain modeling, especially when the represented surfaces are highly variable and contain discontinuities and break lines.

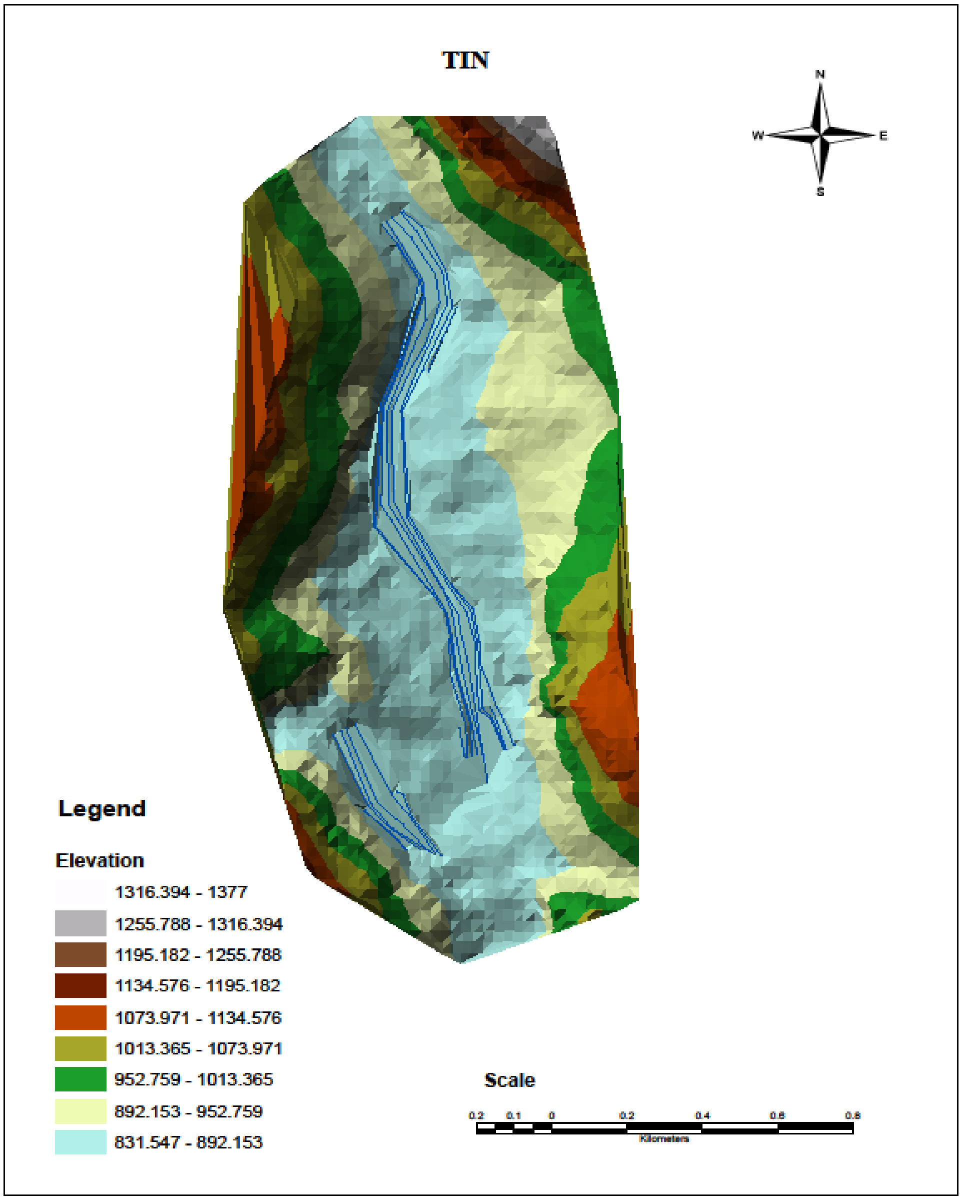


Figure 18: TIN for study area.

A tin is formed by nodes, triangles and edges. Nodes are locations defined by x, y and z values from which a tin is constructed. Triangles are formed by connecting each node with its neighbors according to the Delaunay criterion: all sample points are connected with their two nearest neighbors to form triangles (by using this method the triangles are as equi-angular as possible, any point on the surface is as close as possible to a node, and the triangulation results independent of the order the points are processed). Edges are the sides of triangles.

Land cover Data

Land cover data from Department of Forest and Park Services has been collected. However, it could not be used for modeling purpose since, the soil data collected from National Soil Service Centre is not enough to derive the curve number. Therefore, we have not used land cover data for this modeling.

Observed Discharge

The flood studies regularly required the estimation of the peak discharge for annual maximum discharge from 1985 to 2011 at Autsho gauging station.

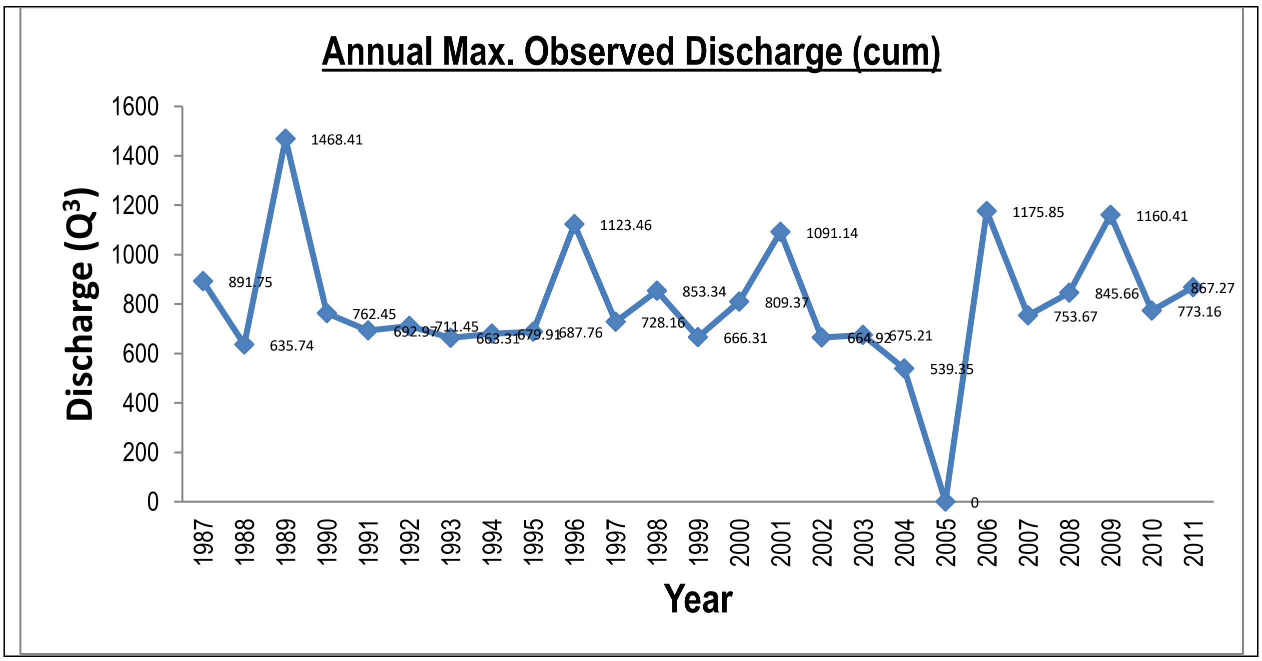


Figure 19: Observed discharge (Q^3)

Flood studies regularly require the estimation of the peak discharge for a specified return period that is substantially longer than the available gauged record. Typically, the estimation of the peak for the 100-year return period event is based on a gauged annual maximum series less than 20 years in length. The formally gauged record represents a relatively small sample of a much larger population of flood events, and may be unrepresentative, particularly if it comprises a ‘flood-free’ or ‘flood-rich’ period. The Flood Estimation Handbook gives guidance on how to effectively extend these relatively short records by pooling data from catchments that are hydro logically similar.

Gumbel Distribution

Gumbel is an Extreme Value distribution (EV Type I) (Emil Julius Grumble, 1941) used to analyse extreme maximum or minimum of a number of samples of distribution. The parameters for the distribution are as follows. The mean (μ) and the standard deviation (σ) of the annual maximum time series is computed along with values of 'a' and 'c' which is given by Eqn.5.1 and Eqn.5.2.

$$a = \sqrt{\frac{6\sigma^2}{\pi^2}} = 0.7797\sigma \qquad \text{Equation 1}$$

$$c = \mu - 0.5772a \qquad \text{Equation 2}$$

And for each return period of (T), the standard variate is computed using Eqn.3 and the return period discharge is computed using Eqn.4.

$$Y_T = -\ln\left[-\ln\left(1 - \frac{1}{T}\right)\right] \qquad \text{Equation 3}$$

$$Q_T = c + Y_T a \qquad \text{Equation 4}$$

Gumbel method for success return period of 20, 50 and 100 years. The peak discharge observed to be 1502.0 Cumic and Gumbel peak discharge of 50-year return period, therefore we took 50 years return period discharge as given below:

	Autsho	Probable Discharge (m^3/s)
Year	Return Period	Observed /Calc Value
	20yr	1316.3
	50yr	1502.0
	100yr	1641.1

Table 7: The results from the Gumbel distribution for Kurichu at Autsho.

Result and conclusion (HEC-RAS)

HEC-RAS model were developed with input data from Gumbel distribution analysis result. Using HEC-RAS (Hydrologic Engineering Center's River Analysis System), softwere the model were developed.

This model is chosen for the study because it is available freely and easy to use. The model is applied to perform 1D analysis of steady flow water surface profile for preparing water surface profiles. The model performs 1D channel flow analysis and floodplain determination using discharge data, landcover data, DEM and river cross-section data.Bernoulli’s energy equation is applied for the flow profile calculation in the steady flow. For unsteady non-uniform flow, 1D St. Venant equations are used, which represent the principle of conservation of mass and principle of conservation of momentum.

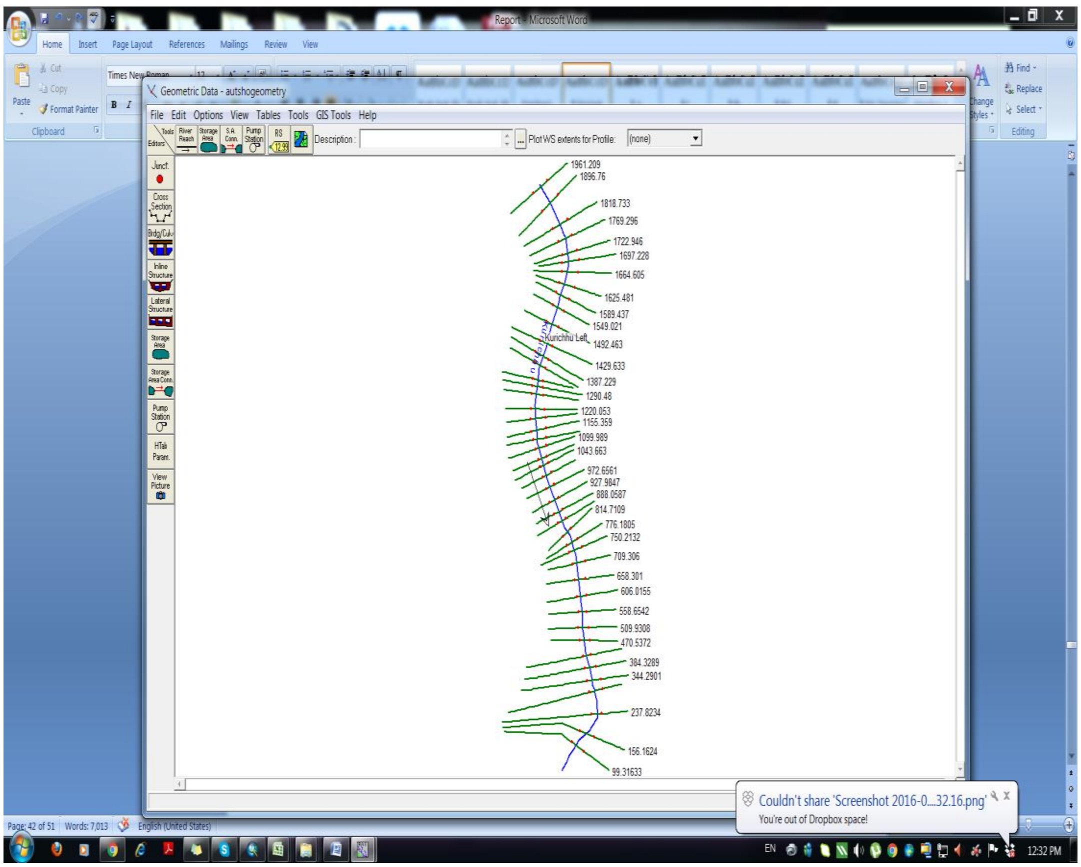


Figure 20: Geometric data used in the River Analysis of Kurichu.

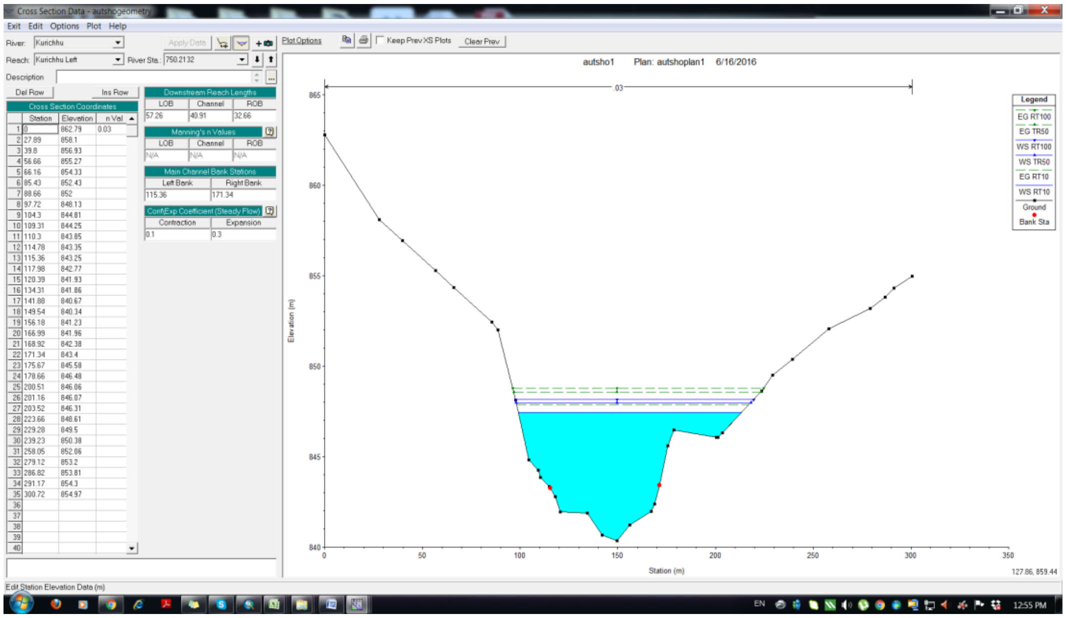


Figure 21: River cross-section showing the water level.

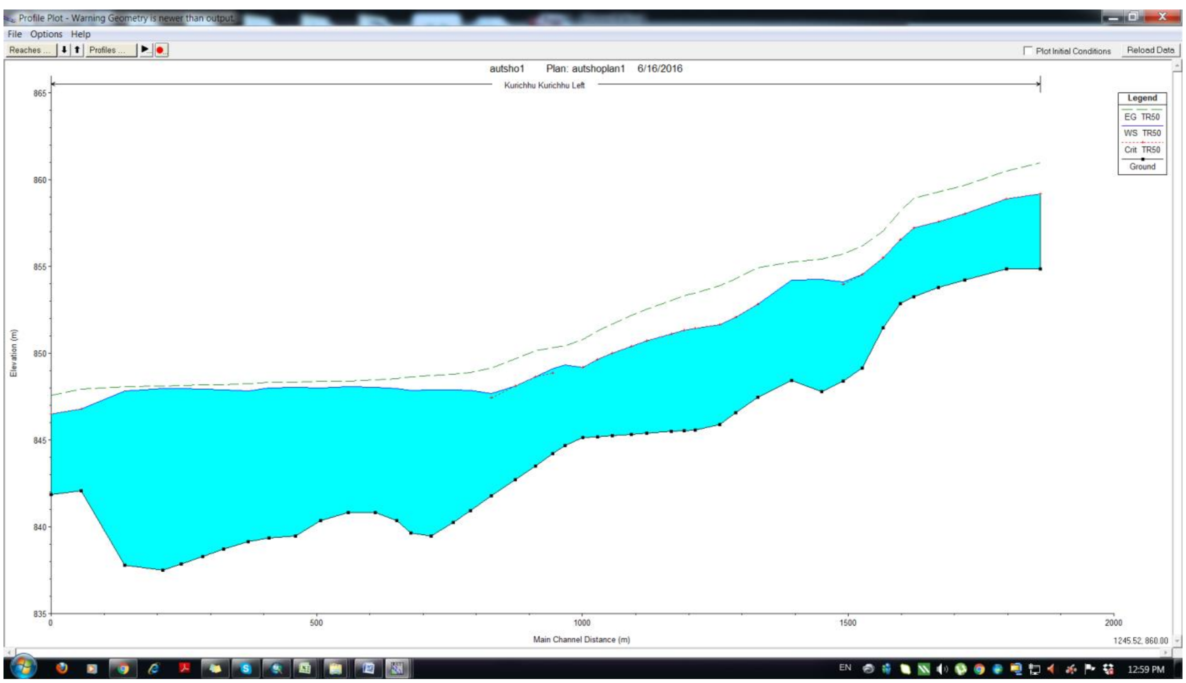


Figure 22: Plot of water surface profile of Kurichu, Autsho.

Flood hazard maps

A flood-hazard map was prepared based on the enhanced topographic information along with estimated flood peaks discharge of 20, 50- and 100-year return period of Kurichu using Gumbel distribution method for modelling. While modelling some insufficient data, we could not better result and some possibility of inundation area were shown. It required for field verification in order to get accurate result. The results of the assessment of flood hazards are presented below.

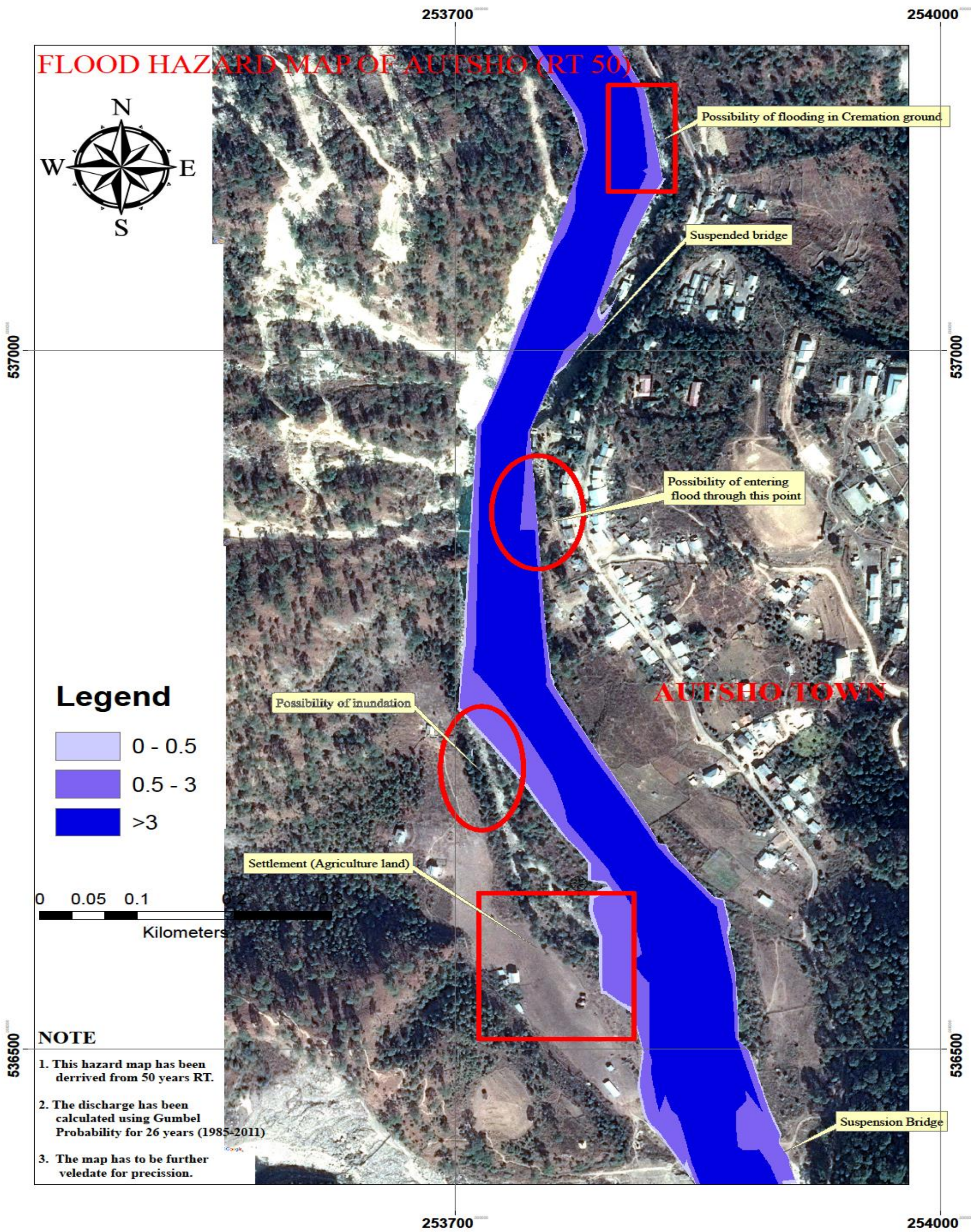


Figure 23: Flood hazard Map of kurichu river.

The flood maps show a clear snap shot of the flooding visualization along the river with elevation levels and areas susceptible to flooding for different scenarios. Generally, high water depth occurs along the main channel and spreads gradually to the flood plains. The preliminary flood hazard map only identifies the likely areas to be flooded due to extreme rainfall events and give a mean depth of floodwaters within each region.

Interventions

Design of the structures are required for effective and sustainable flood mitigation and bank protection of River to protect the lands, properties, human lives and infrastructures along the bank of the rivers. Sustainability of the flood and bank protection works in the river bed depends on sound design of the protection works. The protection will establish equilibrium flow regime and prevent the banks from eroding and overtopping. The design process is as follows:

- Interpreting the results of the mathematical model studies and field assessment studies.
- Design of river training works according to the type of flooding problem (erosion, overflow or sediment related problems).
- The types of mitigation works were carrying out by different agency as below:

Sl. No	Past intervention		Types of structures					Non-Structures		Year of const.	Expenditure	Location
	Different Agency		GW	ER	RCC	RRM	Length	DW	BEW	FY	Nu.(m)	
1	Dzo		√		√	√						Lakpagang stream
2		FEMD	√				445m			2014-2015	Nu.10m	Confluence of Khomachu and Kurichu
3		FEMD	√				390m			2016-2017	Nu.7.3 m	At Autsho
4	DOR		√									At Autsho

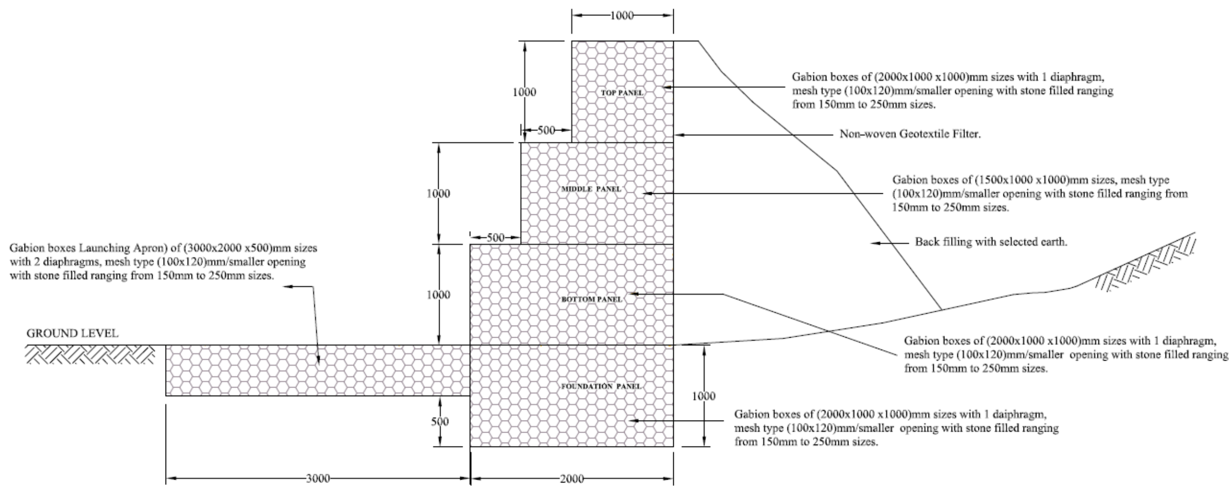
Table 8:Metigation works taken up information.

Note:

GW:- Gabion Wall
ER:- Embankment with revetment
RCC:- RCC Wall
RMM:- RMM Wall
DW:- Dredging Work
BE:- Bio-Engineering Work
FY:- Financial Year
Dzo:- Dzongkhag

Gabion wall

The Gabion walls are constructed along the river banks within the flood plains of a river. The walls are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection against flooding has been provided in some flood prone rivers with low banks in Bhutan. To prevent the erosion of the bank, it is further protected by constructing gabion walls on the riverside.



SECTION - XX

Figure 24:Typical cross section of gabion wall

Advantages of gabion wall

- Can be used as path by the pedestrian beside river.
- The construction materials for this type of flood protection structure are easy to transport and use at site. (Stones, soils and gabion mesh)
- Their permeability allows the gabion baskets to drain water easily reducing the pore pressure.
- They are environmentally friendly (green alternative) and requires no special masonry or skilled labour to construct it.
- With less space

Disadvantages of gabion revetment

- Aesthetically not pleasing to sight.
- When the velocity of the streams and rivers are high, the gabion mesh baskets are at risk of getting torn by the transported boulders or debris.
- The gabion baskets are at risk of being damaged by corrosion if high quality gabion baskets are not used
- Upon failure of the gabion mesh, the bank can be easily eroded.

Proposed Intervention

As shown above in flood hazard map, the location of structures is proposed in order to protect from future flooding. However, most of intervention were carried out and some stretches may require intervention as depicted below:

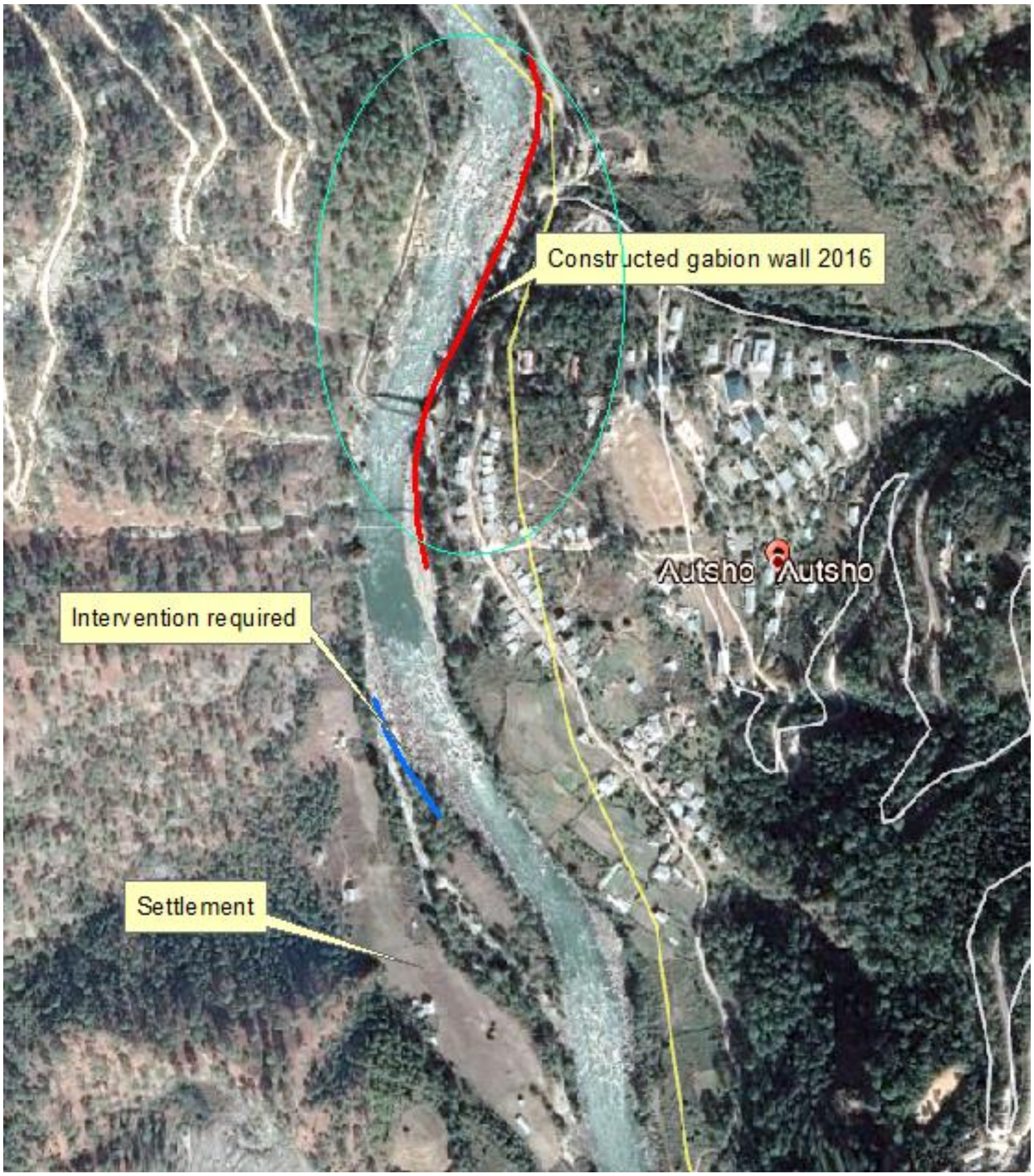


Figure 25: Location of structure intervention

Gabion revetment

The embankments are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection against flooding has been provided in some flood prone rivers with low banks in Bhutan. To prevent the erosion of the earthen embankments, it is further protected by constructing revetments on the riverside of the embankment. When the revetment is constructed with gabion mattress filled in with stones, it is called gabion revetment. A typical cross section of a gabion revetment is shown in Figure 26.

Advantages of gabion revetment

- Can be used as path by the pedestrian beside river.
- The construction materials for this type of flood protection structure are easy to transport and use at site. (Stones, soils and gabion mattresses)
- It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.
- Their permeability allows the gabion baskets to drain water easily reducing the pore pressure.
- They are environmentally friendly (green alternative) and requires no special masonry or skilled labour to construct it.

Disadvantages of gabion revetment

- Aesthetically not pleasing to sight.
- When the velocity of the streams and rivers are high, the gabion mesh baskets are at risk of getting torn by the transported boulders or debris.
- The gabion baskets/mesh are at risk of being damaged by corrosion if high quality gabion baskets are not used
- Upon failure of the gabion revetment, the earthen embankment can be easily eroded.

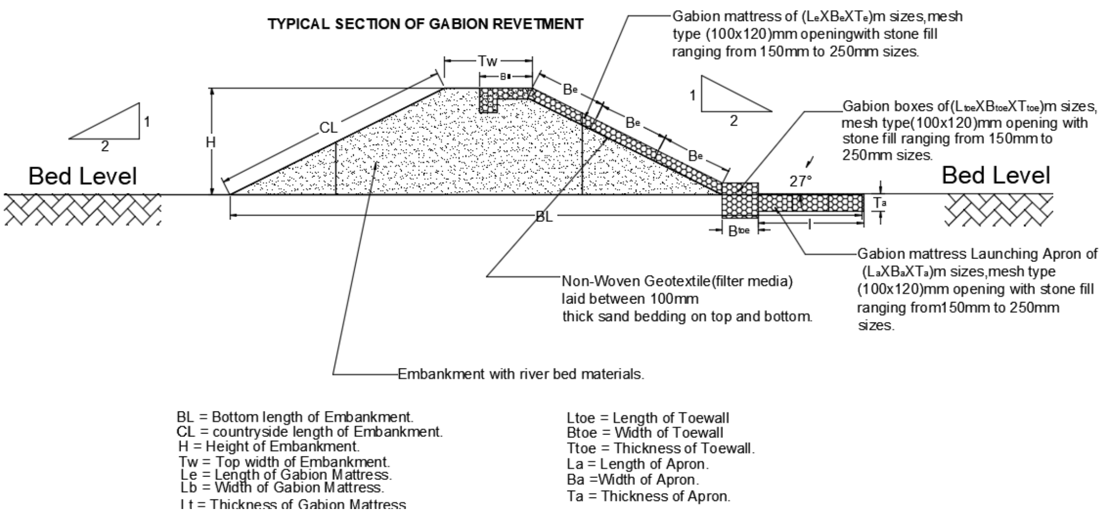


Figure 26: Typical cross section of embankment with revetment

Recommendation for flood management

- ✓ To improve the quality of flood hazard map, it is recommended that SRTM DEM be corrected after validating from the site before modeling. Further, more topographical survey is to be conducted for the areas near the rivers.

- ✓ To produce more accurate Flood Hazard Map, it is recommended to use a high-resolution DEM for modeling purpose.

- ✓ The study strongly recommends that necessary equipment for acquisition of discharge data be installed along the river at suitable location for future updates of the flood hazard map.
- ✓ During the study, the Manning's roughness is considered constant. It is therefore, necessary to calibrate these parameters at least at one small and one extreme flood event to improve the quality of the map.

- ✓ The maps should be updated by using land cover data and soil data for the region.

- ✓ Flood hazard maps are dynamic in nature and need to be updated on a regular basis. The change in any of the following conditions might require updates of the flood hazard maps:

    a. Changes in the physical characteristics of the watershed, such as land cover, construction of dams, flood protection works etc., which could alter the flow regime.
    b. Changes in rainfall pattern.
    c. Opportunity to produce more accurate maps (Easy access to more sophisticated procedures for performing the hydrologic/hydraulic analysis, availability of a more current spatial data layer and availability of spatial data of a higher resolution).

Limitations of the study

Although the preliminary flood hazard map has been prepared for Kurichu, there are some unavoidable limitations such as:

- ✓ The elevation data required for the map was extracted from STRM. A major problem with using SRTM data for hydrodynamic modelling of a floodplain is that it is not "bare-earth" and contains information about vegetation and urban areas that block the water movement in the model.
- ✓ The reliability of the maps has been affected by the inadequate spatial data for the study area.
- ✓ During the study, the Manning's roughness is considered constant.
- ✓ One of the basic assumptions of the rational method is that the rainfall intensity must be constant for an interval at least equal to the time of concentration. For long duration of rainfall, this assumption may not hold true.
- ✓ Land cover data and soil data has not been used for modelling purpose resulting in unrealistic ground condition.
- ✓ The purpose of the flood hazard maps produced in this study is only applicable for flood prone awareness programs and drafting the flood management plans. It is not recommended for any sort of administrative zonation purposes since other hazards have not been considered during the mapping.

References

1. Preliminary Flood Hazard Assessment for Lhuntse Dzongkhag
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