



# FLOOD HAZARD ASSESSMENT FOR ZHEMGANG DZONGKHAG

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

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## Table of Contents

<b>Acknowledgement</b>	<b>i</b>
<b>Acronyms</b>	<b>ii</b>
<b>Executive Summary</b>	<b>iii</b>
<b>Introduction</b>	<b>1</b>
Background	1
Objective	3
Study Area	4
<b>Methodology</b>	<b>6</b>
<b>Data Collection and Assessment</b>	<b>7</b>
Hydrological and Meteorological Data	7
Scientific Data	8
<b>Flood Frequency Analysis</b>	<b>9</b>
Gumbel distribution	9
<b>Development of Model</b>	<b>11</b>
Hydrodynamic model	11
River geometry creation	11
Preparation of boundary condition	13
Scenario simulation	13
<b>Result Analysis and Conclusion</b>	<b>15</b>
<b>Recommendation for flood management</b>	<b>19</b>
<b>Interventions</b>	<b>20</b>
<b>Limitations of the study</b>	<b>22</b>
<b>References</b>	<b>23</b>

Figure 1: Location of the study area .....	1
Figure 2: Historic flooding events reported by the Dzongkhag and Local Government.....	3
Figure 3: Peak discharge profiles of storm flood and GLOF.....	5
Figure 4: Methodology adopted for the study.....	6
Figure 5: Hydro-Meteorological station in the study area .....	7
Figure 6: Methodology adopted for the developing the 1D Hydrodynamic Model .....	11
Figure 7: ALOS DSM of the study area .....	12
Figure 8: TIN for the study area .....	12
Figure 9: River system schematic for Mangde River .....	13
Figure 10: Sample Output of HEC-RAS for a cross-section of Mangde River.....	13
Figure 11: Plot of water surface profile of Mangde River.....	14
Figure 12: Flood Hazard Map for Tingtibi, Trong Gewog.....	15
Figure 13: Flood Hazard Map for Goling, Trong Gewog.....	15
Figure 14: Flood Hazard Map for Budashi, Gozhing Gewog.....	16
Figure 15: Flood Hazard Map for Changarzam, Pangkhar Gewog and Rebati Daling, Nangla Gewog.....	16
Figure 16: Flood Hazard Map for Pantang and Sameri, Pangkhar Gewog .....	17
Figure 17: Flood Hazard Map for Rebati, Nangla Gewog.....	17
Figure 18: Flood Hazard Map for Tangodengma, Nangla Gewog .....	18
Figure 19: Typical cross section of a gabion revetment, FEMD, DES, MoWHS .....	21

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2. Department of Hydro-met Services, Ministry of Economic Affairs, Bhutan
3. National Land Commission, Ministry of Home and Cultural Affairs, Bhutan
4. Department of Geology and Mines, Ministry of Economic Affairs, Bhutan
5. National Statistical Bureau, Bhutan

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## Acronyms

FEMD	Flood Engineering Management Division.
HEC-RAS	The Hydrologic Engineering Center, 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 Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
GIS	Gewographical Information System is a computer based method for analyzing Gewographical information and maps.
FHM	Flood Hazard Map
AoMI	Areas for Mitigation Interest
DDM	Department of Disaster Management.
GLOF	Glacial Lake Outburst Flood.

## Executive Summary

Mangde River flows in central Bhutan traversing roughly north-south of Bhutan. The Mangde River sub basin in Zhemgang district has the third highest poverty rates in Bhutan. Most of the villages are scattered and located in the flood plains and are exposed to high risk of flooding. The main objectives of the study are as follows:

- Detailed flood assessment of Mangde River sub basin in Zhemgang Dzongkhag.
- Analyze the AoMI (Areas of Mitigation Interest) assessment in Zhemgang Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Zhemgang Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

It is recommended that the areas that fall under the flood hazard zones for the following listed locations to be taken into consideration for flood intervention measures. However, it is highly recommended to visit the specific area before any flood intervention is designed.

1. Tingtibi, Trong Gewog
2. Goling, Trong Gewog
3. Budashi, Gozhing Gewog
4. Changarzam, Pangkhar Gewog and Rebati Daling, Ngangla Gewog
5. Pangtang and samseri, Pangkhar Gewog
6. Rebati, Ngangla Gewog
7. Tangodengma, Ngangla Gewog

Through the study, it was recommended to adopt gabion revetment structures at critical locations where there is erosion due to the concentration of the flow. The Dzongkhag administration is recommended to carry out the flood protection works with technical support from the Flood Engineering and Management Division, DES, MoWHS,

## Introduction

### Background

Zhemgang, is considered one of the most inaccessible Dzongkhag in the country with most of its Gewogs still situated far from road heads. Based on existing land use patterns, Zhemgang can be divided into three agro-ecological zones: Upper Kheng which is characterized by high altitudes and infertile soil on steep slopes; Middle Kheng which is characterized by high altitudes and infertile soil on steep slopes; Middle Kheng which is the most accessible part of the Dzongkhag with good irrigation facilities and where people have begun to specialize in farm production aimed at generating cash income and Lower Kheng which consists of four southern Gewogs and is characterized by relatively fertile soil but limited irrigation facilities. Its farming system is largely based on shifting or Tseri cultivation. Zhemgang has a total area of 2,411sq.km with altitude ranging from 100m to 4520m. The Dzongkhag has eight Gewogs which includes Bardo, Bjoka, Goshing, Nangkor, Nanglam, Phangkhar, Shingkhar and Trong.

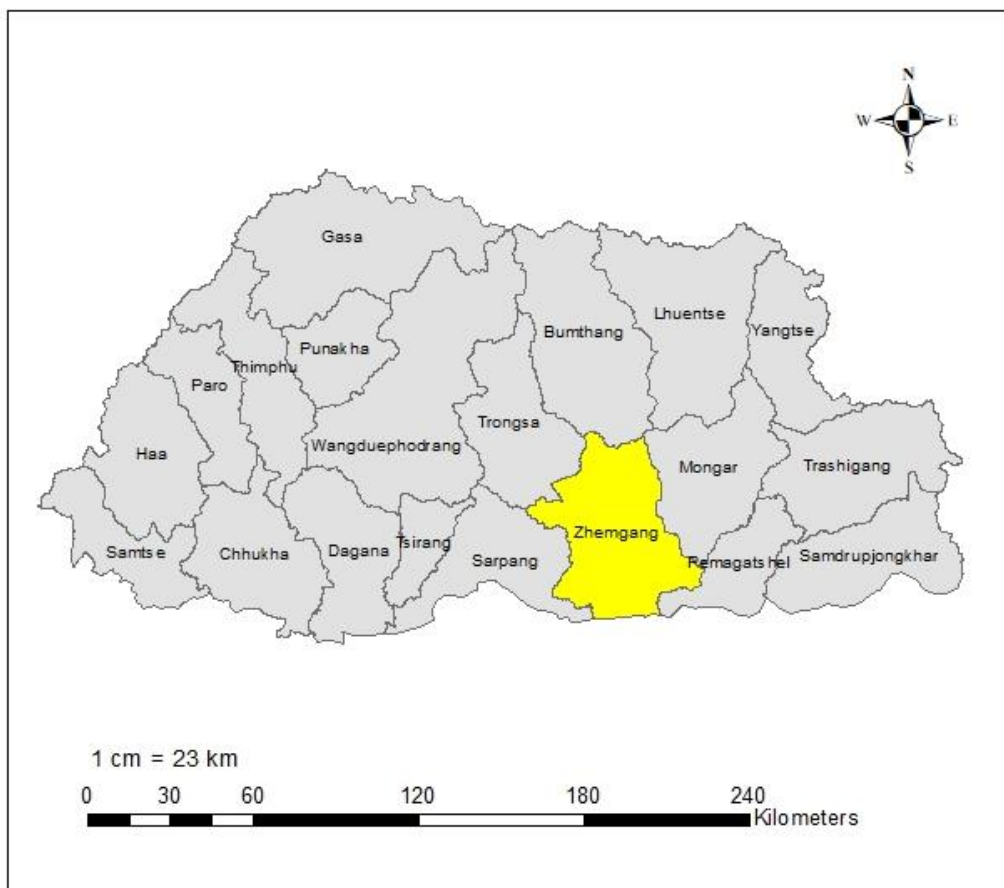


Figure 1: Location of the study area



Gewog:	8	(source: National Statistical Bureau of Bhutan)
Population:	19,636	
Hospitals:	1	
BHU:	14	
Schools:	33	
Wet Land Area: 639.6 Hectares	Wet Land Area: 639.6 Hectares	(Source: Policy and Planning Division, MoAF, Thimphu)
Dry land: 3250.7 Hectares	Dry land: 3250.7 Hectares	
Cash crop land: 211.2 Hectares	Cash crop land: 211.2 Hectares	



Name of Village	Name of Geog	Name of river/stream	Type of threat(Agriculture/Resident	House Affected	Population Affected	Land Affected
Redijong	Phangkha	Redijongchu	1 acre Agricultural land & residential	Bhu & 5h/h	30 popl.	50 deci. Land
Pantang & Sangsari		Shengshanglachu	25 acres agricultu	RNR-C & 10h/h	200 popl.	washed away only crops
Panabi		Panibichu	20 acres	8h/h	80 popl.	1.5 acres dry land
Changarzam		Mangdechu	3 acres	9h/h	100 popl.	1.5
Tashibi		Tashibichu	10 acres	5h/h	80 popl.	50 deci.
Salapong		Badangchu	5 acres	2h/h	30 popl.	
Phulabi	Bardho	Laundigangchu	10 acres	17 h/h	245 popl.	
Khomshar		Chamkharchu		2h/h	25 popl.	
Jongar		Pertigangchu	15 acres	5h/h	50 popl.	
Langdorbi		Bortigangchu	30 acres	61h/h	900 popl.	
Marangdut	Ngangla	Drangmechu&Rodgangc hu		2h/h	70 popl.	3 acres dryland
Misergang/PV		Rodgangchu		5h/h	50 popl.	3 acres dryland
Jirang		Maangdichu&Lunjong		8h/h	70	5 acres dryland
Sonamthang		Drangmechu		4h/h	30	2 acres dryland
Thinleygang		Ratpagang		4h/h	30	8 acres
Kagtong		Darangchu	5 acres dry land		School & few household	
Goling	Nangkor	Mangdechu	Orchard			

Figure 2: Historic flooding events reported by the Dzongkhag and Local Government

## Objective

**Objective 1:** Detailed flood assessment of Mangde River sub basin in Zhemgang Dzongkhag.

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

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

## Study Area

This project focuses only on Mangde River sub basin in Zhemgang district, which has the third highest poverty rates. Most of the villages are scattered and located in the flood plains which expose them to high risk of climate change threats such as floods and flash flood as well as climate change impacts on the livelihoods assets where significant portion of cultivable lands are lost to flooding and flash floods.

Mangde River flows in central Bhutan traversing roughly north-south. The river rises in Wangdue Phodrang district, near Gangkhar Phuensum (Bhutan's highest peak at 7546 m). Bhutan's main east-west highway crosses the Mangde River approximately 8 km west of Trongsa. South of Trongsa, the river drains the eastern slopes of the Black Mountains and forms the eastern boundaries of Jigme Singye Wangchuck National Park and Royal Manas National Park. Another highway follows the river south from Trongsa to Zhemgang. The highway leaves the river at Tingtibi and eventually reaches the Indian border at Gelephug. South of Tingtibi, the Mangde River is joined by the Bumthang River from the east and is known as the Tongasa. Shortly before entering India in Assam, the Manas River flows into the river from the east and river exits Bhutan near Manas.

### Basic Hydrology of Zhemgang

- Basin area of Zhemgang= 2,411km<sup>2</sup>
- Mean annual rainfall of Zhemgang recorded= 1805. 8 mm
- Maximum Daily rainfall recorded : 152.8 mm

A study on the Glacial lake outburst floods in the Bhutan Himalaya carried out by K.Fujita, K.Nishimura, J. Komori, S. Iwata, J. Ukita, T. Tadono, T.Koike from the Graduate School of Environmental Studies, Nagoya University in 2012 has done GLOF inundation maps in Bjizam and Tingtibi villages in Zhemgang.

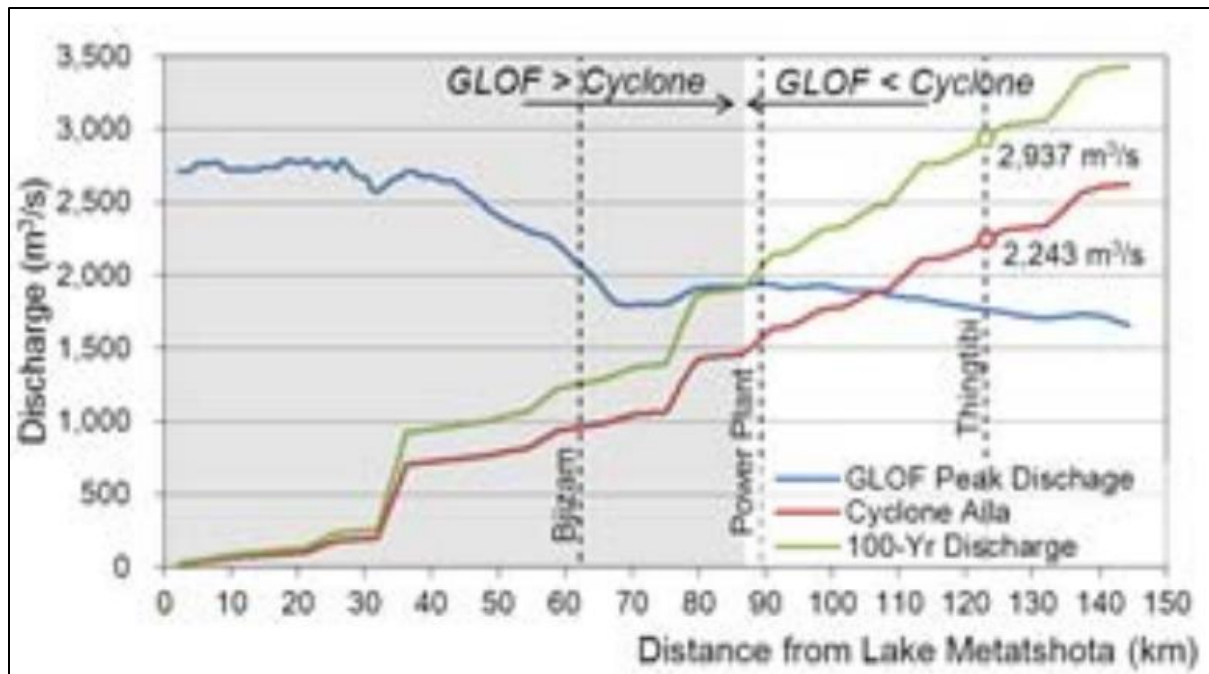


Figure 3: Peak discharge profiles of storm flood and GLOF

The peak discharge profiles of Storm Floods and GLOF in Bjizam and Tingtibi is shown in Figure 3 as per their study. The Figure signifies the differences between the peak discharge profiles of storm flood (Cyclone Aila in 2009 and 100-years probable flood) and the GLOF estimated in this study. In storm flood, the peak discharge is increasing accordingly from upstream toward downstream by merging with lateral inflows from tributaries. In contrast, the GLOF event produces huge discharge at breaching point of most upstream, and is gradually going to decay toward downstream. In GLOF event, considering its nature of only rarely occurrence, the rapid rising discharge flows down involving huge amount of drift trees uprooted from the river bank slope especially in the upstream where storm flood discharge is comparatively smaller than that of GLOF.

These differences between storm flood and GLOF suggests that the GLOF risk is higher at the upstream, whereas storm flood risk is higher at the downstream comparatively. Assuming 100-years probable flood in the Mangde River, for example, the level of inundation risks of GLOF and storm flood may be equivalent at around the site of hydroelectric power plant as shown in Figure 3. (K, June 2012).

It is helpful for understanding GLOF risk to compare its hydrographical characteristics with that of storm flood. The study shows that the storm flood risk is higher at the downstream comparatively.

## Methodology

The methodology adopted for the study is as shown in Figure 4. A thorough desktop study was followed by data collation from different agencies. A hydrodynamic model was developed for Mangde River and the flood hazard maps were developed. After analysing the results, areas of Mitigation Interest (AoMI) were identified and prioritized.

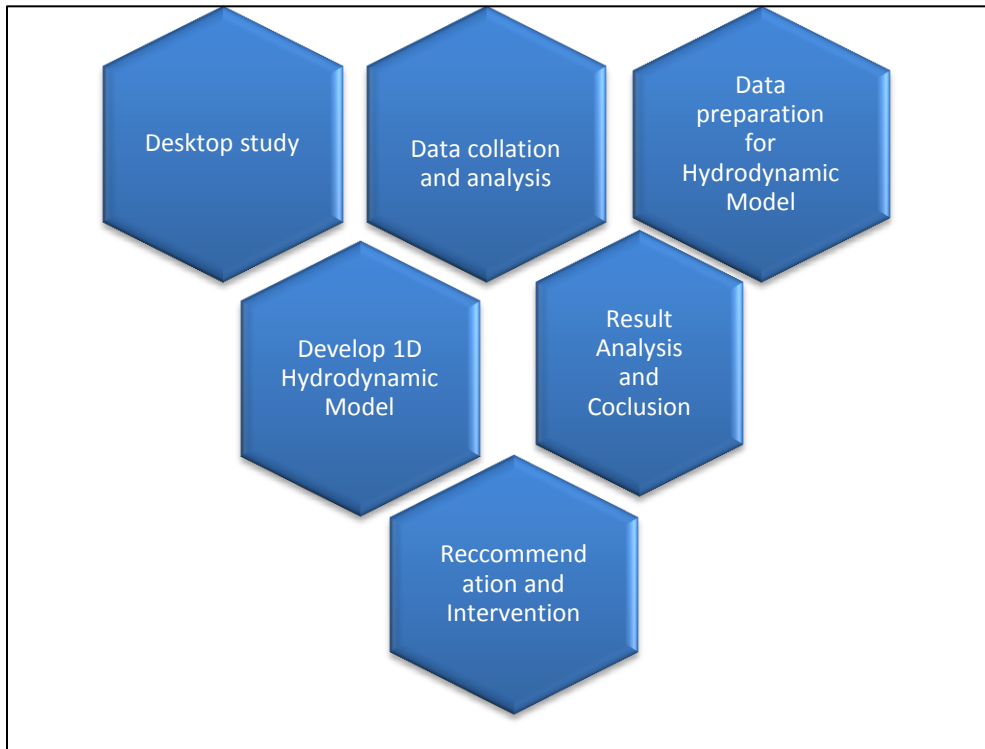


Figure 4: Methodology adopted for the study

## Data Collection and Assessment

### Hydrological and Meteorological Data

The hydro-meteorological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). As per the data from NCHM, there is only one meteorological station and one hydrological station as shown in Figure 5.

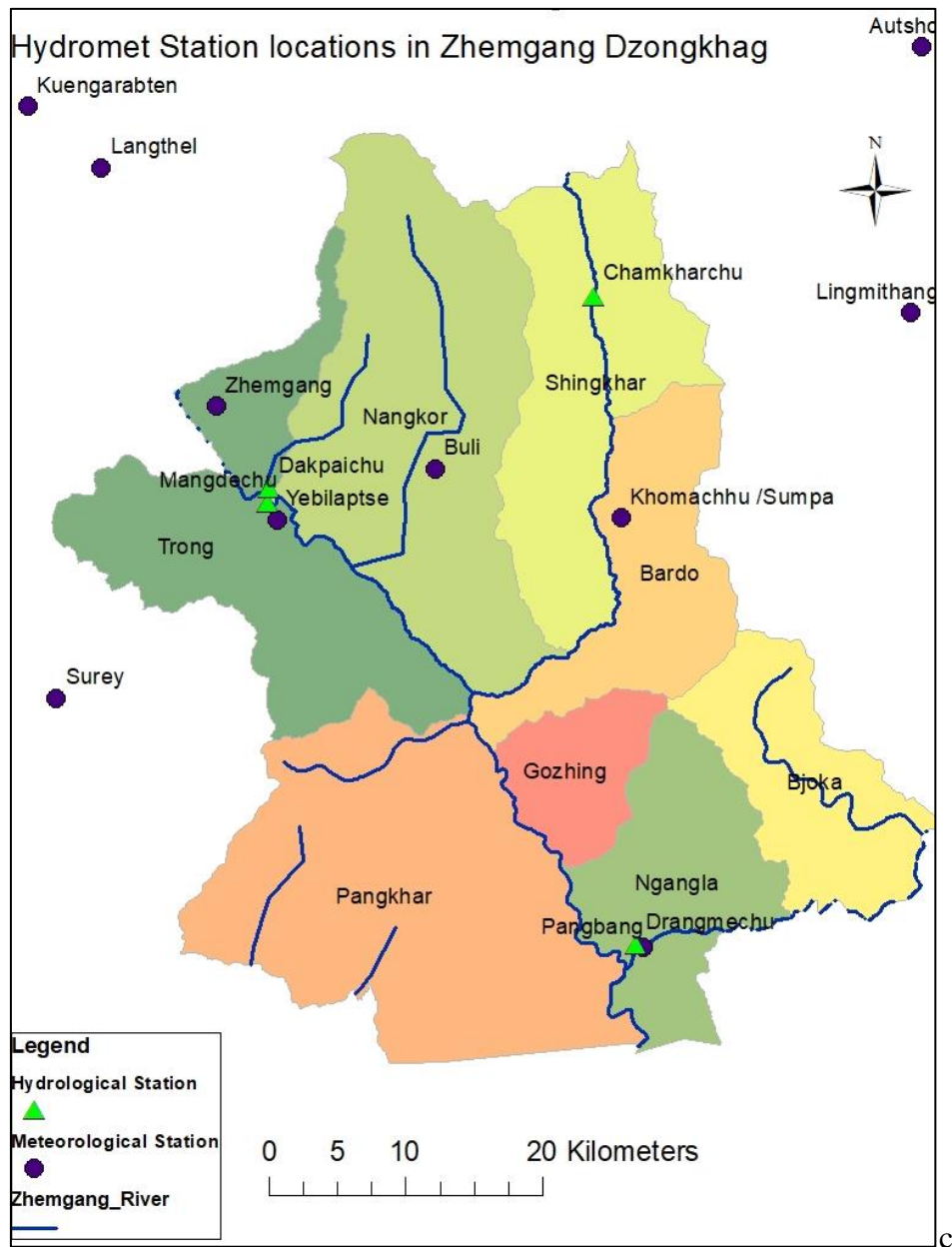


Figure 5: Hydro-Meteorological station in the study area

## Scientific Data

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

1. ALOS DSM : 10 meter resolution (courtesy: SATREPSE PROJECT, Nagoya University, Japan)
2. Project site image: 10 meter resolution (courtesy: SATREPSE PROJECT, Nagoya University, Japan)
3. Hydro-metrological data (courtesy: National Centre for Hydrology and Meteorology)
4. Climate Change Model (Climate Change Knowledge Portal, The World Bank Group).
5. Settlement Data of Zhemgang Dzongkhag (courtesy: National Land Commission, Ministry of Home and Cultural Affairs, Bhutan)

## Flood Frequency Analysis

### Gumbel distribution

Gumbel is an Extreme Value distribution (EV Type I) (Emil Julius Gumbel, 1941) used to analyse extreme maximum or minimum of a number of sample of distribution. The parameters for the distribution are as follows. The mean ( $\mu$ ) and the standard deviation ( $\sigma$ ) 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.

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

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

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.

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

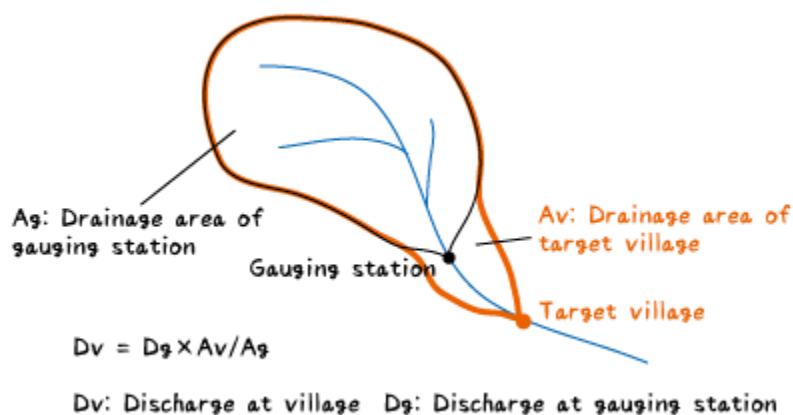
$$Q_T = c + Y_T a \quad \text{Equation 4}$$

The results from the Gumbel distribution for the study area is as follows:

Discharge for Tingtibi=3178.8cumecs

Discharge for Kurjey=572cumecs

The sum total discharge for Tingtibi and Kurjey = 3750.8 cumecs (Dg, Drainage area of Gauging station)



The specific discharge for gauged catchment area can be used to compute the discharge of un-gauged catchment area using the formula:  $D_v = D_g * A_v / A_g$

Where

$A_v$  = Area of target village measured Arc GIS



$A_g$  = Area of gauging station measured using Arc GIS

Since this discharge is only for gauged catchment area so to get the total discharge of the entire catchment area we have to multiply by certain factor, Factor=1.591383

Total discharge  $D_v = 5968.96 \text{ cumecs}$

## Development of Model

### Hydrodynamic model

A 1D hydrodynamic model was developed for Mangde River in freely available hydraulic mode HEC-RAS. The methodology followed for developing the model is shown in Figure 6.

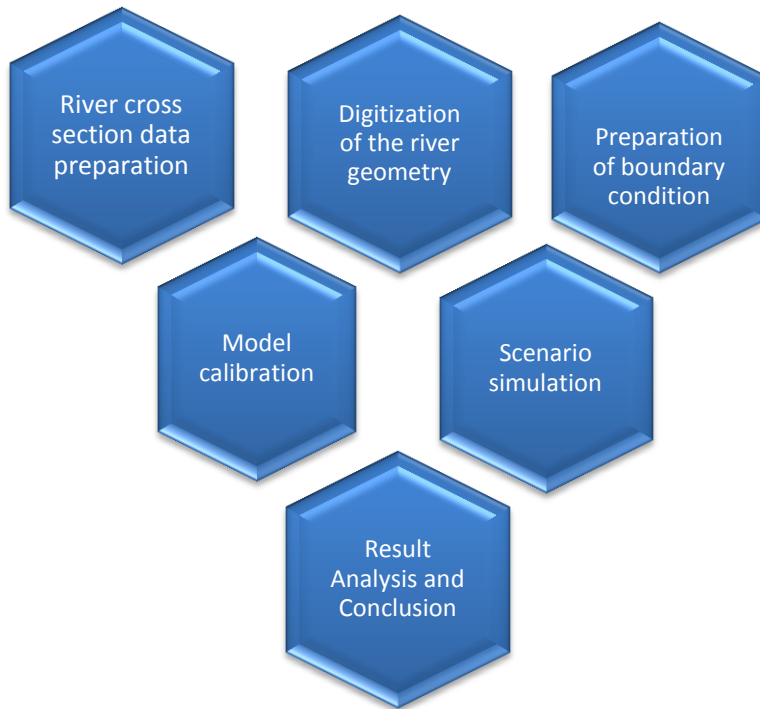


Figure 6: Methodology adopted for the developing the 1D Hydrodynamic Model

### River geometry creation

ALOS DSM (Digital Surface Model) used in this project was prepared through the ‘SATREPSE PROJECT’ titled “Study of Glacial Lake Outburst Floods in the Bhutan Himalaya” in June 2012 by the Graduates School of Environmental Studies, Nagoya University. The DSM is clipped for the study area. The Geographic projection is transformed into UTM 46N. The final DSM is shown in Figure 2 for Zhemgang Basin. DSM in TIN format is required for HEC-RAS model. Raster DSM converted to TIN with the study stretch of river is shown in Figure 3 for the basin.

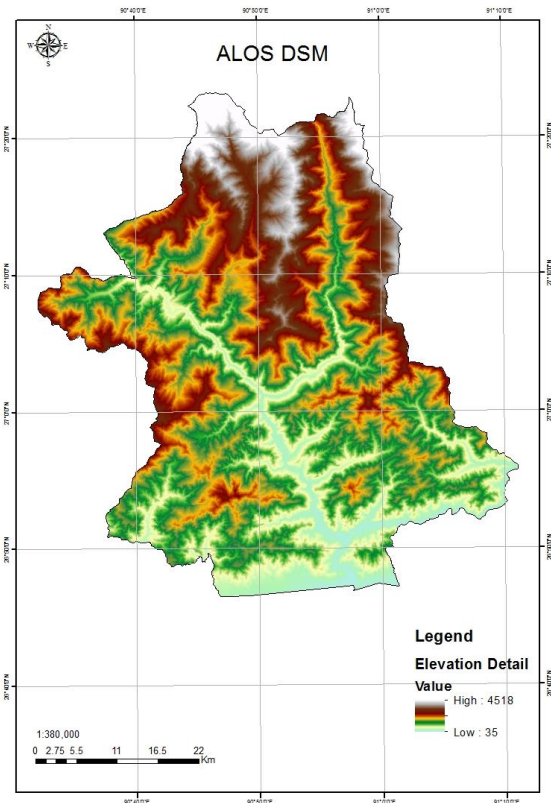


Figure 7: ALOS DSM of the study area

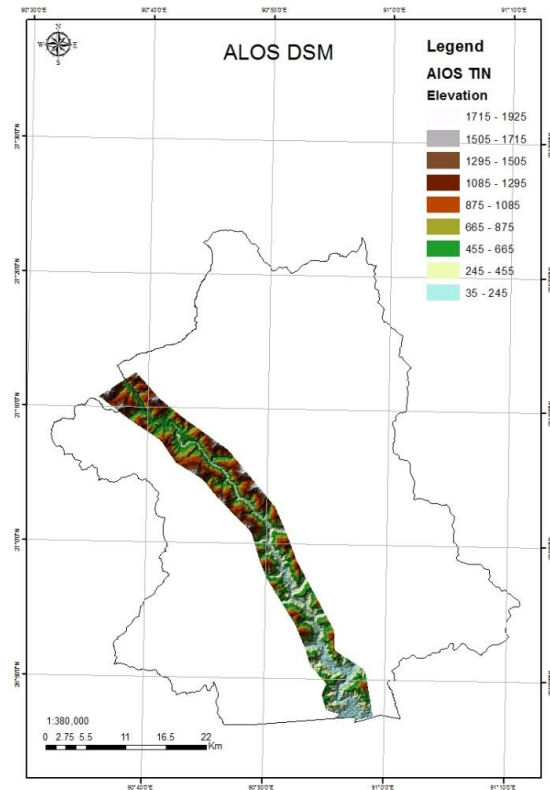


Figure 8: TIN for the study area

River centreline is sketched with the help of given river network. The river cross-section data used in modelling are obtained from ALOS DSM. The river terrace was more visible in ALOS DSM as compared with other satellite data such as ASTER DEM or SRTM. Though at some locations, elevation data was corrected in ALOS DSM with reference to ASTER DEM and SRTM elevation data.

The schematic of geometry in HEC-RAS for Mangde River are shown in Figure 9. The cross-section consists of three parts: main channel, left bank and right bank.

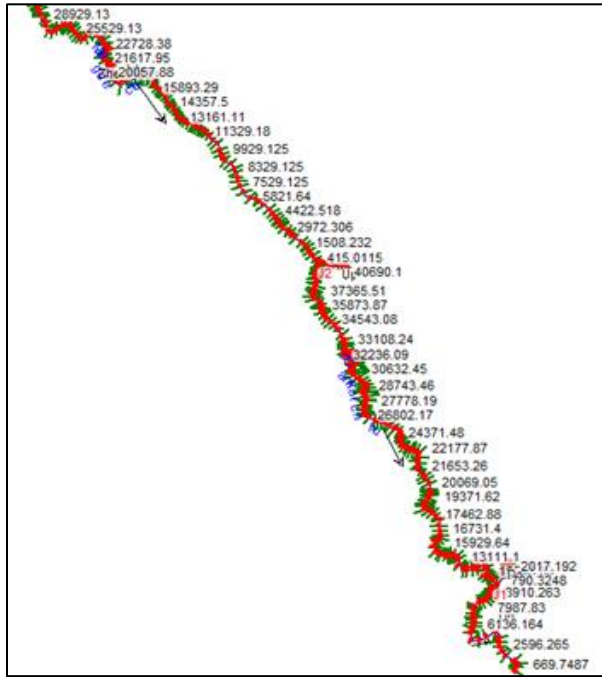


Figure 9: River system schematic for Mangde River

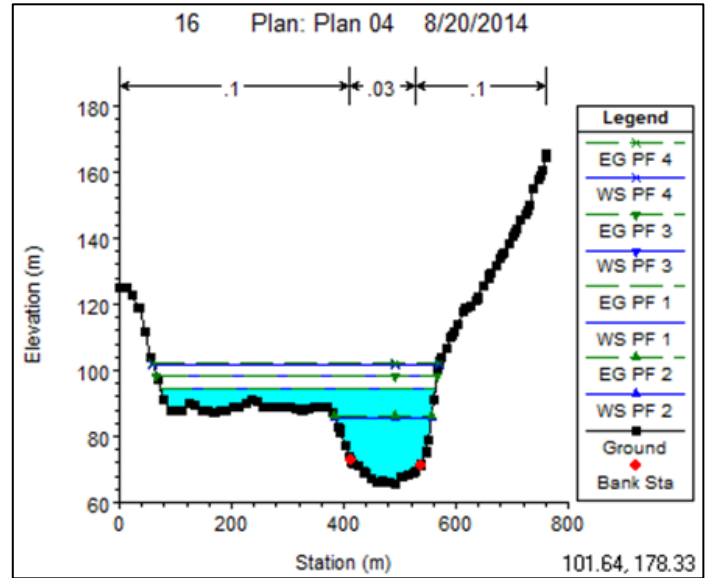


Figure 10: Sample Output of HEC-RAS for a cross-section of Mangde River

Manning's value at main stream channel and overbank is assigned for each cross-section. A representative value of 0.03 is assigned for main stream and 0.01 for overbanks.

### Preparation of boundary condition

As the discharge for certain return period is fixed, steady flow option is selected. Subcritical flow regime is chosen. Due to the unavailability of other data, critical depth is assigned as downstream boundary condition, which is computed automatically by the model. The flow data assigned is the discharge of 100 year return periods.

### Scenario simulation

HEC-RAS gives cross-section wise output. Sample of output is shown in Figure 10. The plot shows the cross-section along with the water level for 100 years return periods. The water surface profile obtained from HEC-RAS for Mangde River is given in Figure 11.

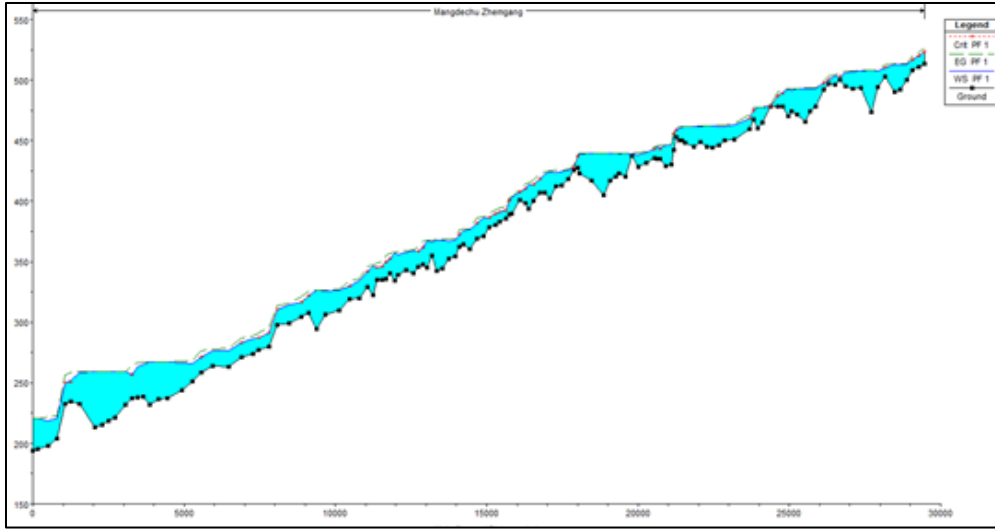


Figure 11: Plot of water surface profile of Mangde River

## Result Analysis and Conclusion

The flood hazard maps with 100 year return period for the flood prone areas along Mange River in Zhemgang Dzongkhag is as shown in Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, Figure 17, Figure 18.

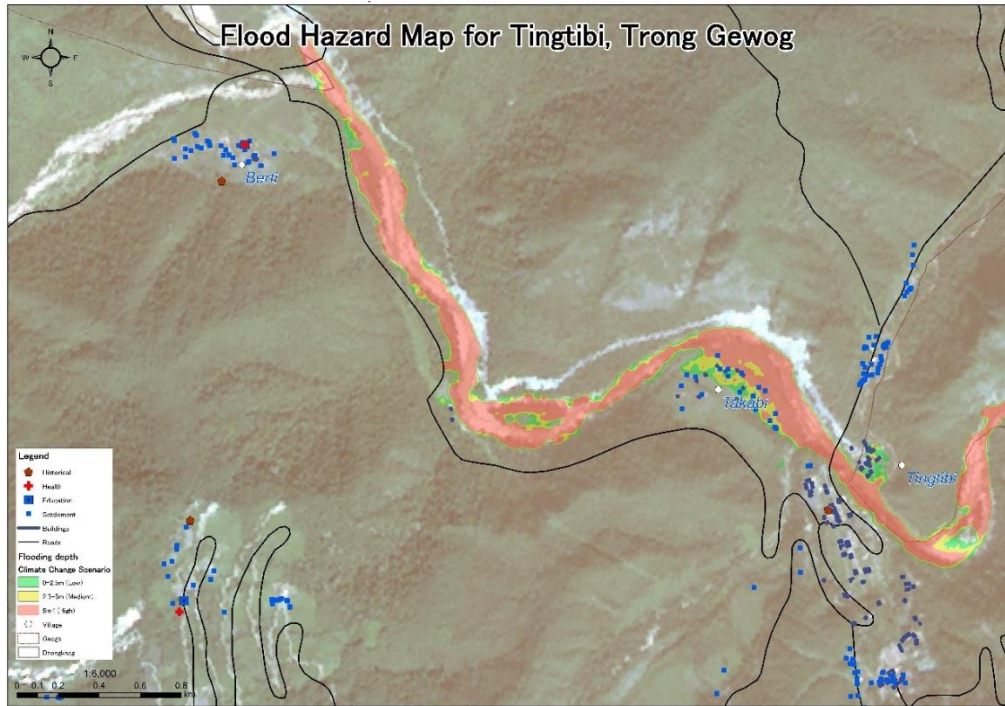


Figure 12: Flood Hazard Map for Tingtibi, Trong Gewog

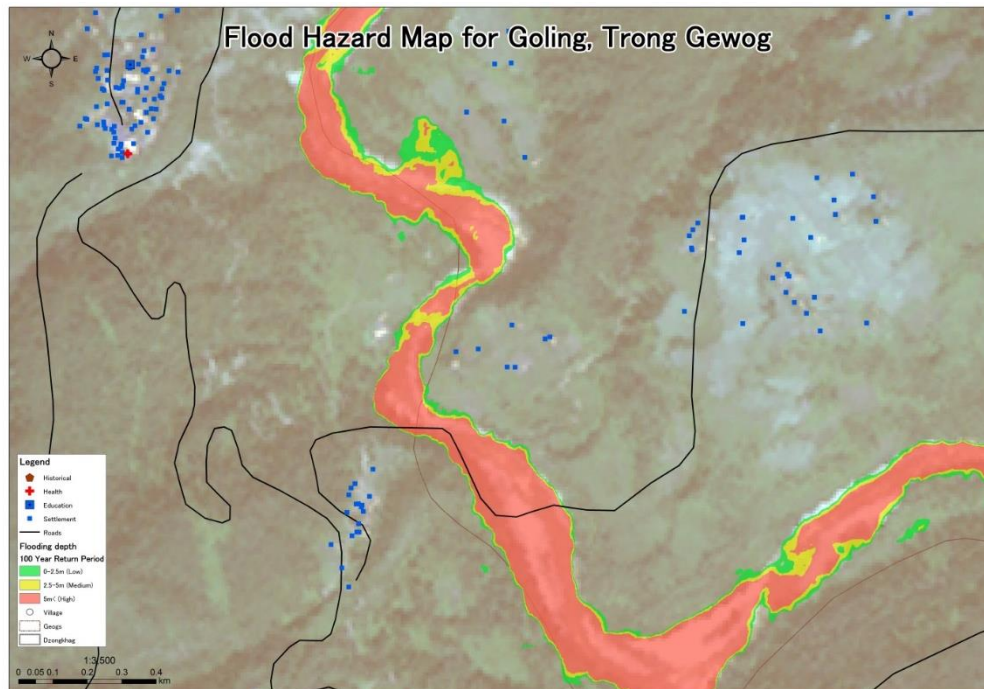


Figure 13: Flood Hazard Map for Goling, Trong Gewog



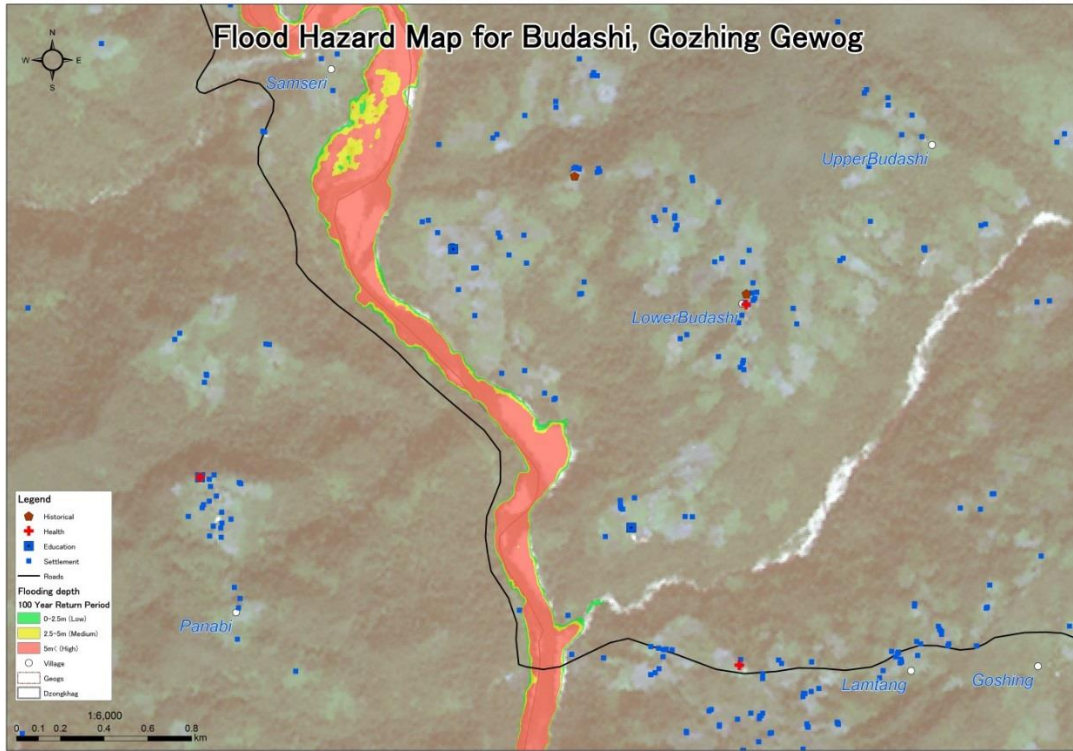


Figure 14: Flood Hazard Map for Budashi, Gozhing Gewog

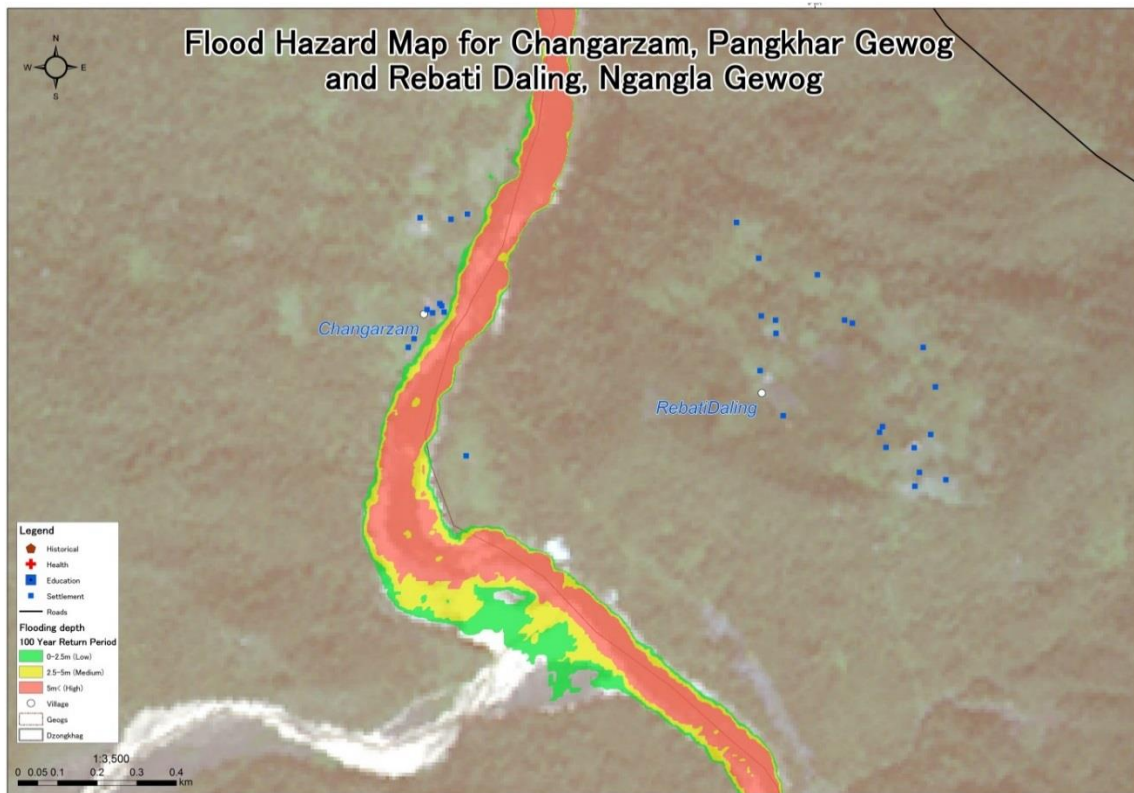


Figure 15: Flood Hazard Map for Changarzam, Pangkhar Gewog and Rebatidaling, Ngangla Gewog



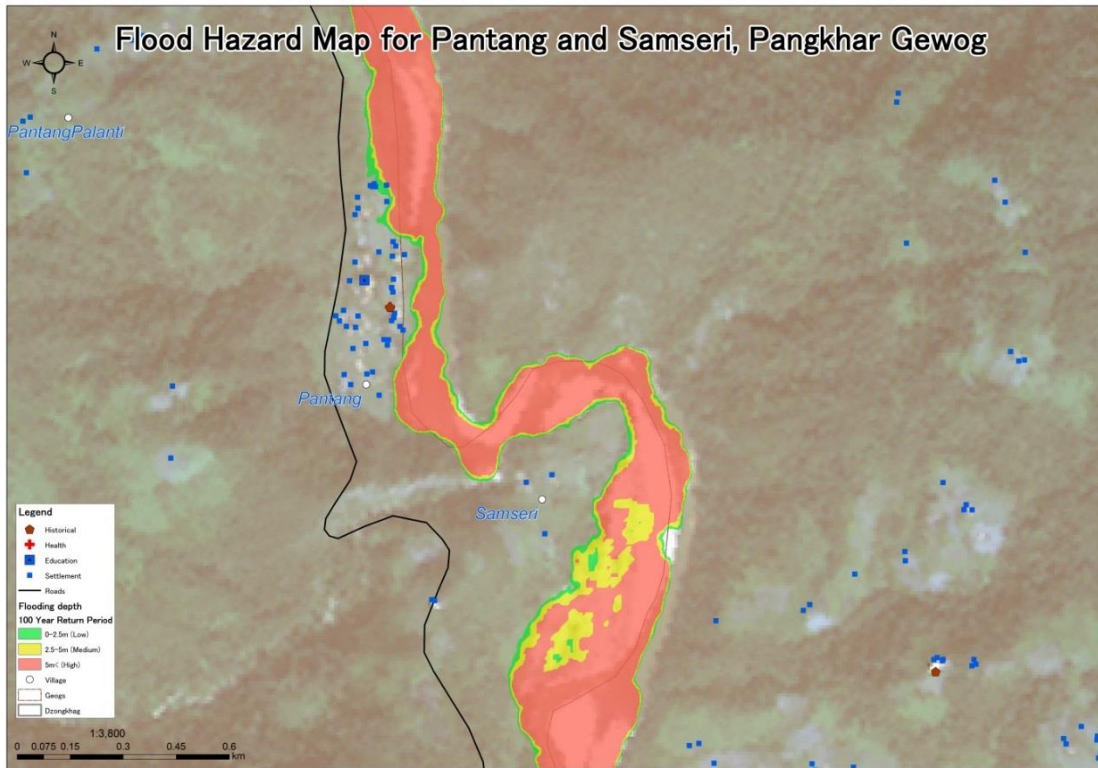


Figure 16: Flood Hazard Map for Pantang and Sameri, Pangkhar Gewog

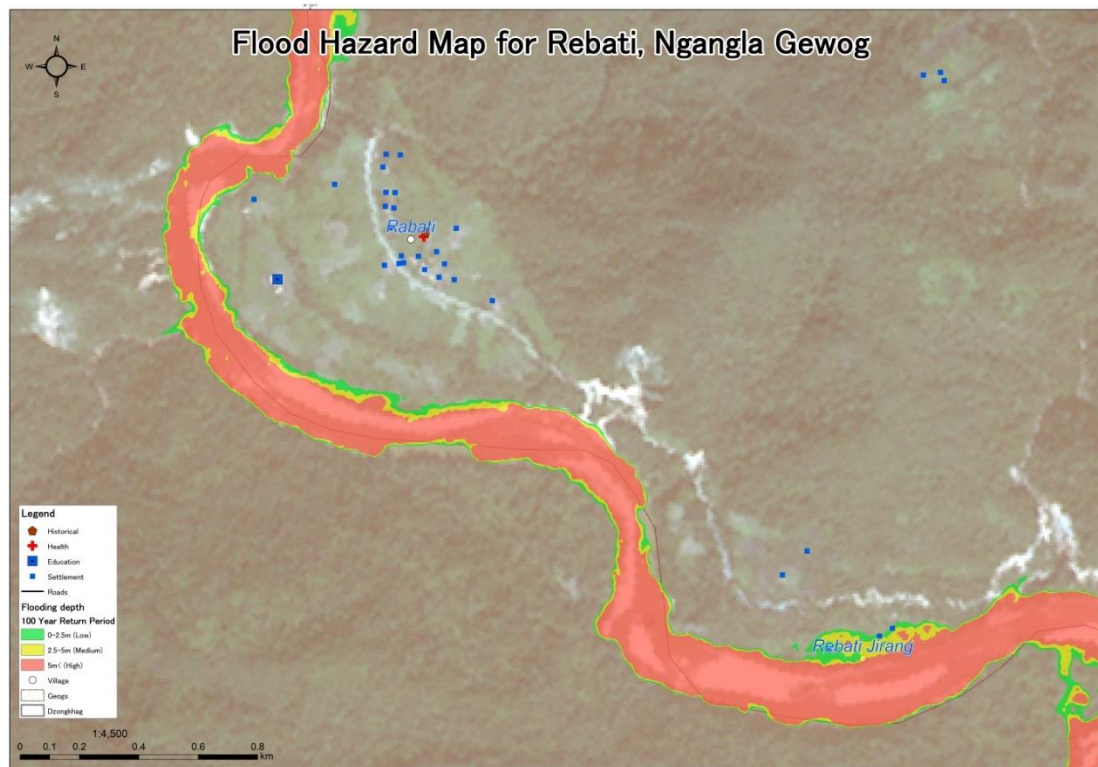


Figure 17: Flood Hazard Map for Rebati, Nangla Gewog

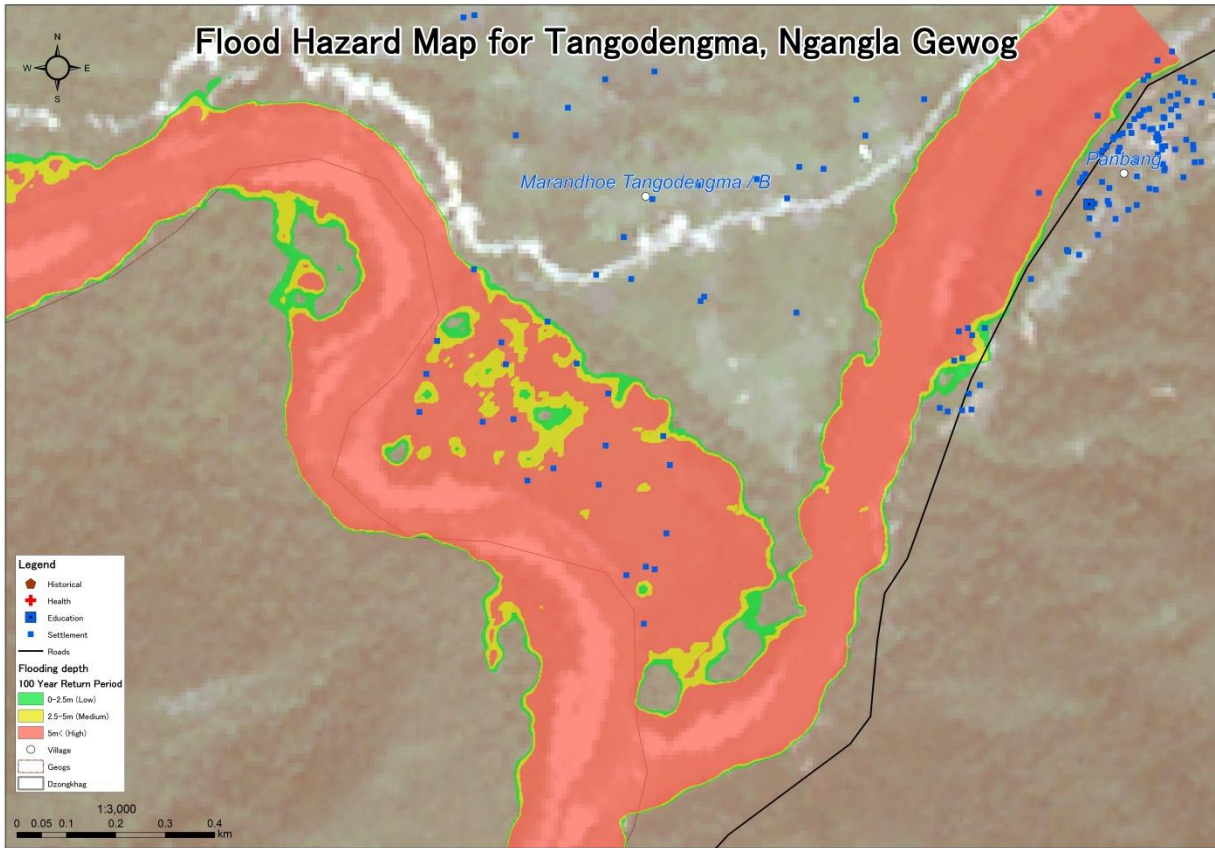


Figure 18: Flood Hazard Map for Tangodengma, Nangla Gewog

## Recommendation for flood management

It is recommended that the areas that fall under the flood hazard zones for the following listed locations to be taken into consideration for flood intervention measures. However, it is highly recommended to visit the specific area before any flood intervention is designed.

8. Tingtibi, Trong Gewog
9. Goling, Trong Gewog
10. Budashi, Gozhing Gewog
11. Changarzam, Pangkhar Gewog and Rebati Daling, Ngangla Gewog
12. Pangtang and samseri, Pangkhar Gewog
13. Rebati, Ngangla Gewog
14. Tangodengma, Ngangla Gewog

The flood interventions for the prioritised area are detailed in the next chapter of intervention. The Dzongkhag administration is recommended to carry out the flood protection works with technical support from the Flood Engineering and Management Division, DES, MoWHS,

The Department of Disaster Management, Ministry of Home and Cultural Affairs, is recommended to carry out the pre-disaster activities in the identified flood prone areas. The DDM can work in collaboration with the Local Government to locate the exact settlements from the FHM and plan the flood disaster awareness campaign in the areas. The settlements under red zone should be given the 1st priority, yellow zone as the 2nd priority and green zone as the 3rd priority. The areas that do not fall under any of the three zones can be identified by DDM as evacuation centres.

## 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).

Gabion revetments are recommended for prioritized areas in Zhemgang that lies at a gentle or flat terrain. It is recommended to visit the prioritized area before the design of the gabion revetment is finalized for implementation.

### Gabion revetment

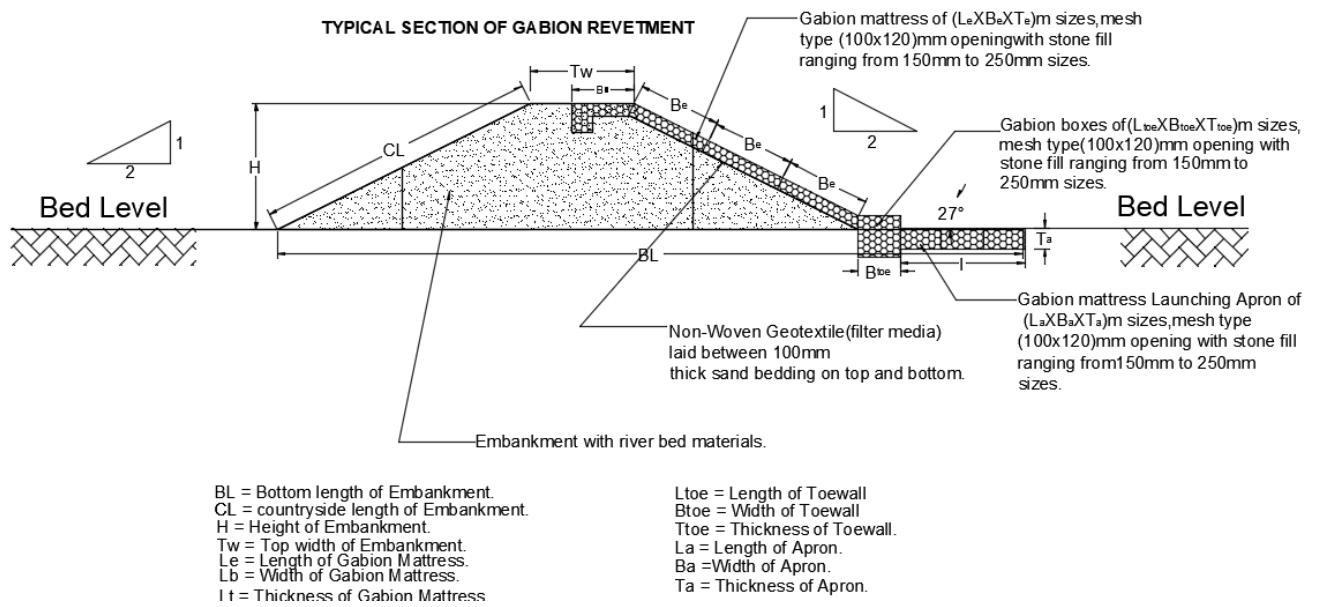
The earthen embankments are constructed along the river banks within the flood plains of a river. The embankments are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection 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 19.

### Advantages of gabion revetment

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

### Disadvantages of gabion revetment

- 1) Aesthetically not pleasing to sight.
- 2) 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.
- 3) The gabion baskets are at risk of being damaged by corrosion if high quality gabion baskets are not used
- 5) Upon failure of the gabion revetment, the earthen embankment can be easily eroded.



**Figure 19: Typical cross section of a gabion revetment, FEMD, DES, MoWHS**



## Limitations of the study

All meteorological and hydrological analysis has been performed on the basis of collected available observed data from NCHM. And if any error remains in the primary data collection of respective agency cannot be resolved within this study.

The Digital Elevation Model used in this study was SRTM DEM with 30 meter resolution which is freely available. A more accurate Flood Hazard Map could have been produced if a high resolution DEM was used. Since a higher resolution DEM was not procured for this study, it is highly recommended to procure it in the future and update the Flood Hazard Map.

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 of Zhemgang Dzongkhag
2. Flood inundation mapping using global datasets, Kuenzang Choden, FEMD, DES, MoWHS
3. Zhemgang Dzongkhag website
4. National Statistics Bureau
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6. Final Report of SATREPSE PROJECT, “Study of Glacial Lake Outburst Floods in the Bhutan Himalayas”, Graduate School of Environmental Studies, Nagoya University, Japan.
7. National Preliminary Flood Risk Assessment (PFRA), Ireland, Engineering Service, Office of Public Works.
8. Coursework book for Training in ‘Flood Risk Assessment and Planning of Mitigation Measures’ conducted by ADPC (Asian Disaster Preparedness Centre for FEMD staff and funded by UNDP- Climate Risk Management Project.
9. Flood control measures for effective flood management, FEMD, DES, MoWHS.