FLOOD HAZARD ASSESSMENT FOR TRONGSA DZONGKHAG

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

YEAR 2019

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3. National Land Commission, Ministry of Home and Cultural Affairs, Bhutan
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Acronyms

FEMD	Flood Engineering 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 Defence, 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
FRA	Flood Risk Assessment.
AFA	Areas for Further Assessment.
MoWHS	Ministry of Works and Human Settlement
NCHM	National Centre for Hydrology and Metrology
GLOF	Glacial Lake Outburst Flood.
AoMI	Areas of Mitigation Interest

Executive Summary

This study focuses only on Mangdechu sub basin in Trongsa District along the river valley of Mangdechu. Most of the villages are scattered and located along the Mangdechu valley (from Jongthang Nubi Gewog to Yourmo under Langthel Gewog) in the flood plains which expose them to high risk of flooding.

The main objective of the study is as follows:

- Flood assessment of Trongsa Dzongkhag.
- Identify and prioritize critical flood prone areas within Trongsa Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

A hydrodynamic model of Mangdechu was developed in HEC RAS and map were generated in GIS software. ALOS DSM 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 100-year return periods discharge was used as the upstream boundary condition. Furthermore, GLOF are also considered and developed separate map. The flood hazard map was developed and the areas were identified.

The flood hazard areas along Mangdechu include schools, shops, Common Facility Centre (CFC), Temporary houses, Forest Beat Office are located at Bjezam area along the Mangdechu under Nubi Gewog. However, as per site assessment we observed Changdegangchu directly hit towards school and pose threat. As per map we also observed Mangdechu may affect Common Facility Centre if intervention is not been carrying out.

Introduction

Bhutan is exposed to climate risks, in particular floods, glacial lake outburst floods, landslide. Climate change and variability has resulted in changing rainfall and temperature patterns, thereby aggravating these disaster risks.

This study focuses only on Mangdechu sub basin in Trongsa District along the river valley of Mandechu. Most of the villages are scattered and located along the Mandechu valley (from Jongthang Nubi Gewog to Yourmo under Langthel Gewog) 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 livelihood's assets where significant portion of cultivable lands are lost to flooding and flash floods.

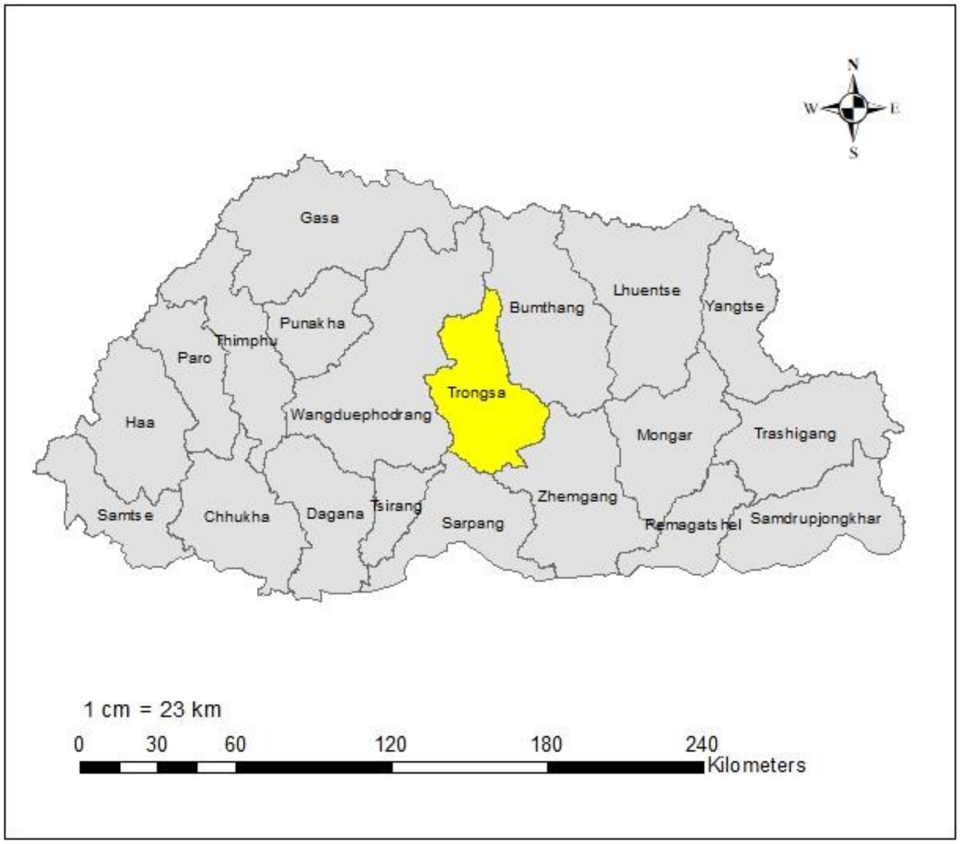

Figure 1: Study Area

Langthel Gewog

Table 1: Historic flooding in Langthel Gewog, Trongsa Dzongkhag

Sl.No	Name of village	Name of Gewog	Name of river/stream	Types of threat (agriculture/Resident	Estimated Population/Households	Past Flooding Record
1	Dangdung	Langthel	Thraschu	Highway bridge		2009
2	Balling	Langthel	kartigangchu	Highway bridge		2009
3	Yourmo	Langthel	Wogangchu	MHPA Power House		2009

Dragten Gewog

Sl.No	Name of village	Name of Gewog	Name of river/stream	Types of threat (agriculture/Resident	Estimated Population/Households	Past Flooding Record
1	Samcholing	Drakten	Narangchu	Causeway		2009
2	Bubja/Changrey	Drakten	Yeshigangchu	Irrigation Channel & Causeway		2009

Nubi Gewog

Sl.No	Name of village	Name of Gewog	Name of river/stream	Types of threat (agriculture/Resident	Estimated Population/Households	Year of past flooding record
1	Jongthang	Nubi	Mangdechu	Wetland		2009
2	Karshong	Nubi	Mangdechu	Suspension bridge		2009
3	Semji	Nubi	Mangdechu	Wetland		2009
4	Bjizam	Nubi	Mangdechu	Resident		2009
5	Bjezam/Forest Beat Office	*Nubi*	Mangdechu	Resident		2009

Objective

Objective 1: Flood assessment of Trongsa Dzongkhag.
Objective 2: Analyse the AoMI (Areas of Mitigation Interest) assessment in Trongsa Dzongkhag and identify critical flood prone areas within Trongsa Dzongkhag.
Objective 3: Recommend appropriate flood protection measures along the identified flood prone areas.

Study Area

The total projected population for the Dzongkhag in 2009 was 14,448 with an annual growth rate of 1.4 percent. This Dzongkhag is bordered by Bumthang Dzongkhag in the northeast, Wangdue Dzongkhag in the west and Zhemgang Dzongkhag in the south. Trongsa Dzongkhag has five Gewogs viz; Drakteng, Korphu, Nubi, Langthil and Tangsibji. Among the five, Nubi Gewog is one of the most densely populated and furthermore, the Mandechu sub basin also fall in this Gewog.

Trongsa Dzongkhag has connecting almost all the Gewogs in the by motorable roads. Every Gewog has a BHU, RNR canters 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 Mangdechu hydro power of 720 megawatt and Tangsibi hydro power also located under this Dzongkhag.

Table 2: Dzongkhag information

Sl.No	Gewog	Pop.	Hospital	BHU	ORC	TU	School	Wet Land (Ha)	Dry Land (Ha)
1	5	14448	1	6	21	3	25	1,082.3	1,204.9
Total	**5**	**14448**	**1**	**6**	**21**	**3**	**25**	**2,287.2**	

Mangdechu

Mangdechu flows in central Bhutan traversing roughly north-south. The river flow from Gangkhar Phuensum (Bhutan's highest peak at 7546 m) down to Trongsa Dzongkhag and joined chamkhar from the east before entering Assam in India.

Methodology

The methodology adopted for the study is as shown in Figure 2. A thorough desktop study was done before going to site for assessment. Than followed by data collation from different agencies and detailed site assessment was conducted in the flood prone gewogs and analysed. A hydrodynamic model was developed for Mangdechu and the flood hazard maps were developed. After analysing the results, Areas of Mitigation Interest (AoMI) were identified.

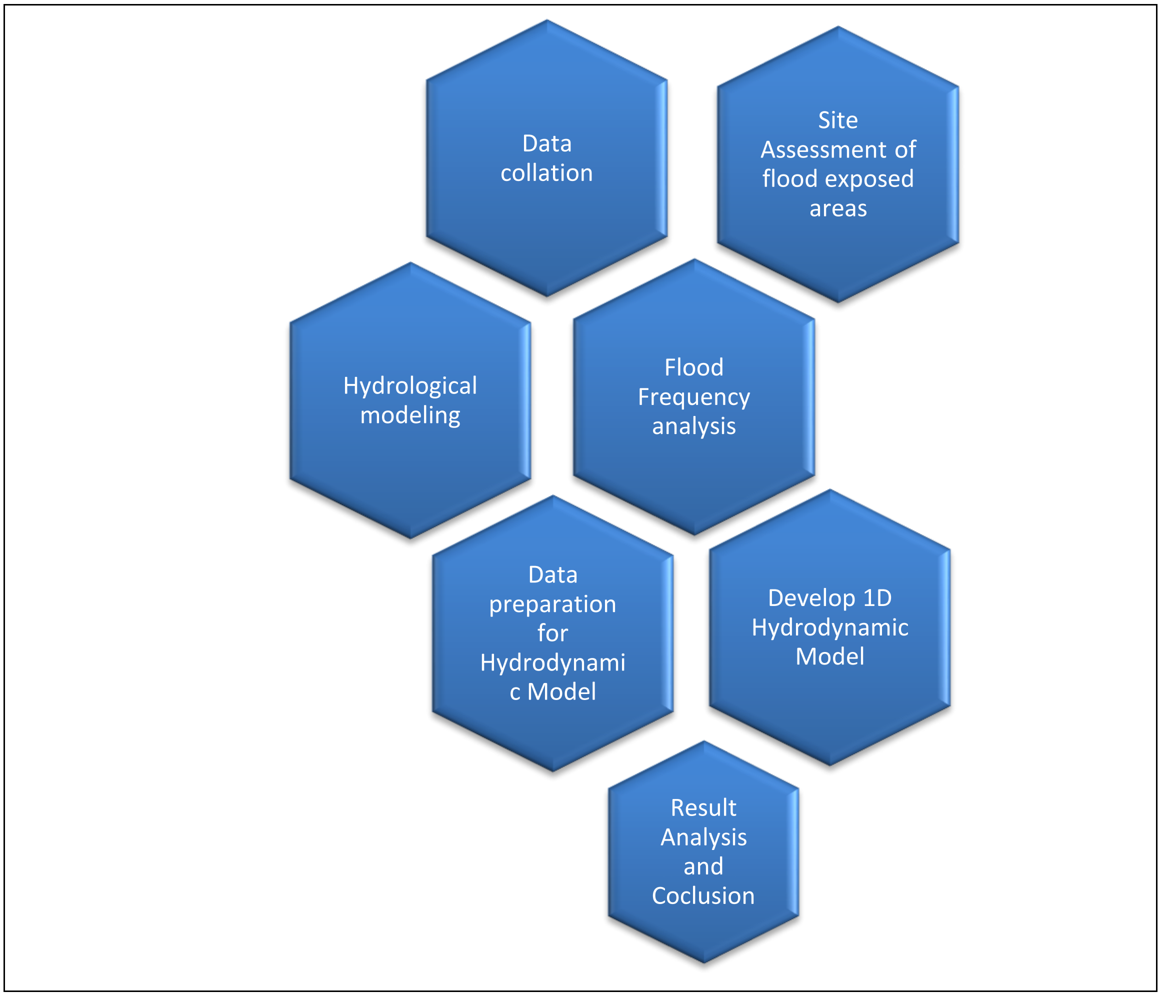

Figure 2 : Methodology adopted for the study

Data Collection and Assessment

Hydrological and Meteorological Data

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

- Basin area of Trongsa: 2470 km^2
- Mean annual rainfall of Trongsa recorded: 1088±142mm
- Maximum Daily rainfall recorded: 95 mm

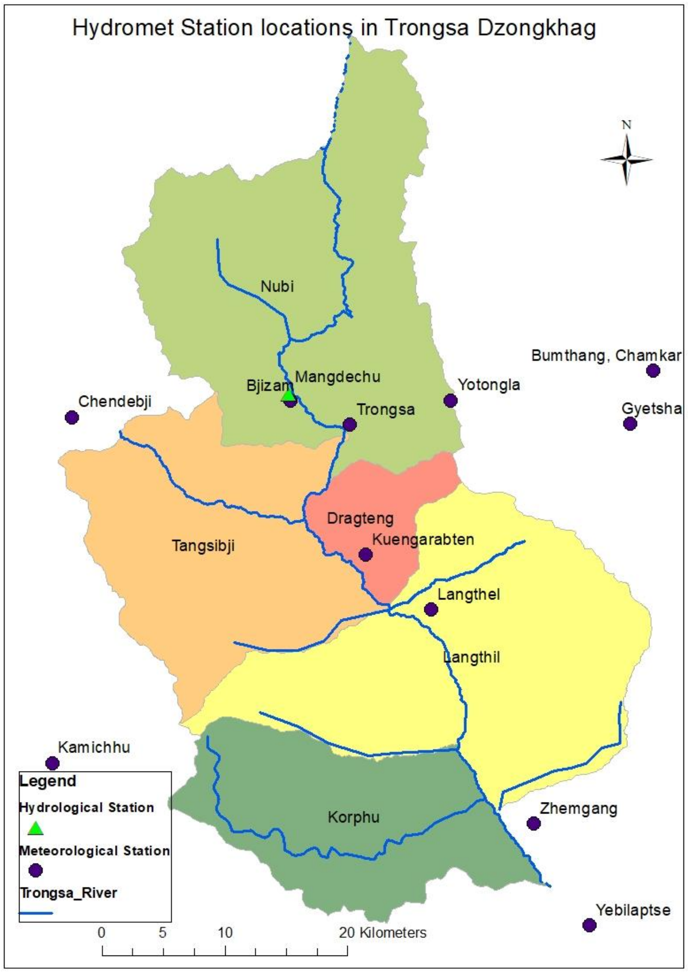

Figure 3: The location of the Hydro-met station in the study area

Hydrology of Trongsa

The river discharging gaging station were found within our study area. Therefore, we used Bjezam station discharge.

Meteorological Data

There are two meteorological stations available in the watershed (study area). One station was located in Bjezam but other one was located at Laoshong, Trongsa. So, we used Bjezam met station has data.

Scientific Data

DEM (Digital Elevation Model)

1. ALOS DSM: 10-meter resolution (courtesy: (SATREPSE) DGM, DHS)
2. Project site image: 10-meter resolution (courtesy: (SATREPSE) DGM, DHS)
3. Hydrological data: (courtesy: Department of Hydro met Services, Ministry of Economic Affairs, Bhutan)

ALOS DSM with 10-meter resolution is used for this project. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings. However, we could not get better resolution than ALOS and we suggested to use in our project.

Site Assessment at Gewog Level

Desk study of Trongsa Dzongkhag was carried out before going to site. As per the desk study Trongsa Dzongkhag has five Gewog, however, we found out mostly three Gewog were affected by flood. The team (FEMD) visited site on May, 2015 and consulted with Local leaders regarding past flood. As per their view they informed us that out of five Gewog three were affected at few areas and rest two Gewog were mostly landslide due to blockage of side drain firm road. Therefore, team decided to assess affected three Gewogs.

Consulting with the community people and Local Government leaders the pre-hazard areas were mapped. The local authorities have also provided information on past flood areas and future risk areas. As per their information the assessment was carry out and following areas were identified.

Langthel Gewog

Sl. #	Name of the Villages (Rivers)	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Dangdung (Thraschu)	Langthel	27° 29' 35.2"	90° 40' 19.5"	1047	
2	Balling (kartigangchu)	Langthel	27° 22' 00.8"	90° 32' 05.8"	1070	
3	Yourmo (Wogangchu)	Langthel	27° 22' 10.0"	90° 32' 01.3"	1071	

Thraschu, Kartigangchu and Wogangchu affects the bridges under Langthel Gewog. In 2009 cyclone Aila, water level of above river almost reached to the bridge and caused damage on bridge abutments and weakend the bridge foundation.Since both bridges are located in the national highway,department of roads have immediately restored and made it functional.

Figure 2. Langthel Gewog

Figure 3. Dangdung Bridge.

Figure 4. Balling Bridge

Figure 5. Wogangchu joining Mangdechu.

Figure 6. Location of MHPA powerhouse.

Wogangchu joins in Mangdechu just below the MHPA powerhouse. In 2009, it caused damage to the highway and it took about two months to clear the highway. PWD labour colony was completely washed away in 2009. River protection structures are not provided as of now below the powerhouse. There is threat to highway and powerhouse.

Drakten Gewog

Sl. #	Name of the Villages (Rivers)	Gewog	Coordinates		Elevations in m
			Northing	Easting	
1	Samcholing (Narang chu)	Drakten	27° 24' 46.2"	90° 32' 03.3"	1871
2	Bubja (Yeshigangchu)	Drakten	27° 25'03.8 "	90° 29' 48.8"	1791

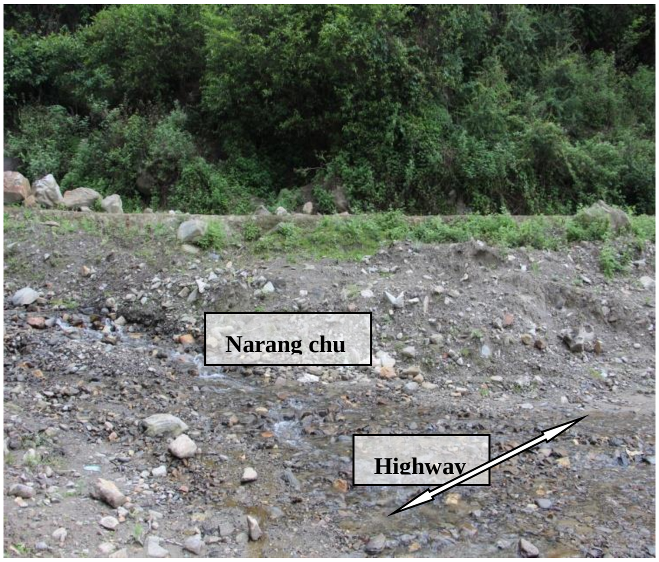

Figure 7 Samcholing

Figure 8. Bubja irrigation channel

In Samcholing village, Narangchu flows through national highway.It is a small stream as shown above in fi g 7.During monsoon season,it carries large quantity of debris and deposits on the road which causes road block. Stream caused threat to causeway during the flooding. Figure 8 represents Yesheygangchu in Bubja. Some portion of water from waterfall is collected and used for irrigation purposes and remaining water flows from causeway. Incase of heavy rainfall, there is a risk that waterfall might damage the highway. As of now,it has not caused damages.

Nubi Gewog

Under Nubi Gewog there are four places which are having threat by Mangdechu namely Jongthang,Karshong,Semji and Bjizam.

Sl. #	Name of the Villages (Rivers)	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Jongthang (Mandechu)	Nubi	27° 35' 17.43"	90° 30' 46"	2052	
2	Karshong (Mangdechu)	Nubi	27° 34' 09.67"	90° 28' 20.77"	1985	Suspension bridge (Restored)
3	Semji (Mandechu)	Nubi	27° 31' 02.89"	90° 27' 43.72"	1835	
4	Bjizam (Mandechu)	Nubi	27° 31'21.5 "	90° 27' 28.1"	1889	Bjizam
5	Bjizam (Mandechu)	Nubi	27° 31' 08.4"	90° 27' 38.1"	1878	Forest Beat Office

Jongthang village:

In Jongthang village,wet land is mostly affected by 2009 flood. About five acres of wet land and irrigation channel was affected. There is also threat to livestock (grazing area) which is located at 1.5 km above from river however, there is no threat to settlement.

Figure 9. Jongthang wet land.

Karshong village:

In Karshong village is located higher elevation and has no threat to settlement, however, there is threat to wet land and suspension bridge. During 2009 flood, suspension bridge was washed away. Dzongkhag Administration have constructed new suspension bridge and it is in good condition at present.

Semji village:

Semji village is located at upstream of Bjizam.There is no threat to the settlement.Wet land is located at downstream of Bjizam.There is athreat to about three acres of wet land but as of now it has not affected.

Bjizam:

Fig.11 represents the Chendigang chu which is flowing through Bji village and finally joins Mangdechu right bank at Bjizam as shown in fig 12.During 2009, Cyclone Aila flood alomost reached to bridge level. So far, no damage to bridge.

Figure 10. Bjizam village.

Figure11. Chendigang chu at Bjezam

Figure 12. Chendigangchu joining to Mangdechu

Figure 13. Common facility centre at Bjezam Figure 14. Forest Beat Office below Bjezam

Figure 45.Temporary houses in Biezam at Right bank of Mangdechu

There are threat to common facility centre,four temporary houses, PWD camp, shops and police camp above Bjezam. Presently Dzongkhag Administration have constructed common facility centre for farmers at right bank of Mangdechu. Elevation difference between river and ground is only 1.50m. There is high risk that, water level might reach plint level and affect the common facility centre. Below Bjezam forest beat office is located, however, there is a threat to this office since intervention were carry out.

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 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.

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

$$c = \mu - 0.5772a$$ 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.

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

$$Q_T = c + Y_T a$$ Equation 4

The result from the Gumbel distribution for Mangdechu is detailed in Table 3.

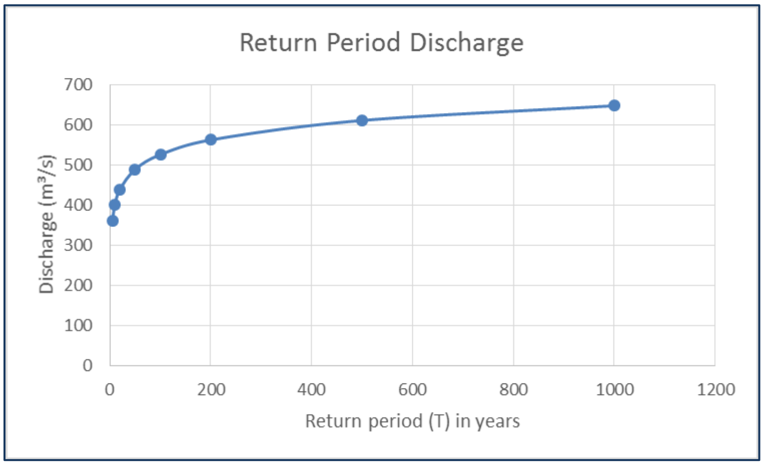

Figure 5: Return period discharge for Mangdechu using Gumbel method

Table 3: Return period discharge for Mangdechu using Gumbel method

Return Period (T)	Discharge (m^3/s)
5	362
10	401
20	440
50	489
100	526
200	562
500	611
1000	648

Hydrological Modelling

To simulate flood process, IFAS uses the theoretical of tank model and Manning's law, Darcy's law and kinematic wave method. When the horizontal and vertical flows are formed, IFAS divides them into 4 types of model: Surface tank, Subsurface tank, Aquifer tank, River tank.

Input data of IFAS are base map and satellite rainfall data, which are available on the Internet.

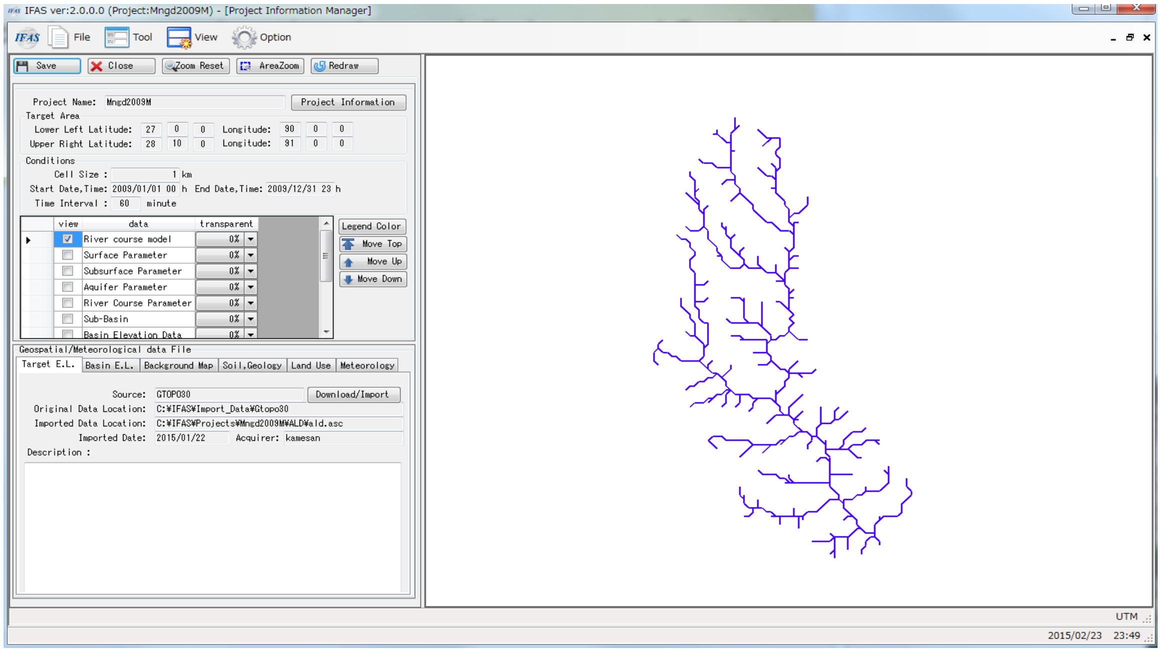

Figure 6: Drainage pattern of Mangdechu

Background map are derived from Global Map 4 - Digital Geographic information in 1 km resolution covering the earth's surface with standardized specification and available to everyone at marginal cost. Global Map data have 8 layers: Boundaries, Drainage, Transportation, Population Centers, Elevation, Land use, Land Use, and Vegetation. Two layers which are used in IFAS, are Elevation and Land use.

Global rainfall information observed by satellite is free for downloading on the Internet. The products called 3B42RT (provided by satellites TRMM/TMI, SSMI, IR of NASA) and GSMaP (provided by satellites TRMM/TMI, Aqua/AMSR E, ADEOS II/AMSR, DMSP/SSMI) are such rainfall data set.

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 25 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.

An alternative approach is to extend the period of record through the incorporation of historical flood data can be also used. In our assessment report we took the 2009 cyclone Aila peak discharge for the analysis. The peak discharge during the 2009 Aila were found maximum with compared to probable peak discharge calculated by Gumbel method for success return period of 20, 50 and 100 years. The peak discharge simulation by IFAS found 690 m³/s which is higher with compared to the100 years Gumbel peak discharge as shown in Table 4. The model input was used cyclone Aila probable peak discharge.

Table 4: Flood frequency result using Gumbel and IFAS for Mangdechu

Bjizam	**Probable Rainfall**		**Probable Discharge (m^3/s)**		
	(mm/day)	(mm/3days)	observed	IFAS	+GCC
Aila	95.0	203.4	642	690	-
20yr	75.2	96.3	466	440	419
50yr	87.4	106.9	524	489	539
100yr	96.5	114.9	568	526	633
200yr	105.6	122.8	611	562	738
500yr	117.6	133.2	669	611	883
1000yr	126.6	141.1	712	648	1002

Hydrodynamic model

The freely available global DEM such as SRTM 30m and SRTM 90m and the ALOS 10m DSM were explored to find the most suitable DEM for the study area. As per our study area it was found that ALOS 10m DSM represented better than other globally available DEM. Thus, for this study, ALOS 10m DSM was used.

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.

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 equ-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.

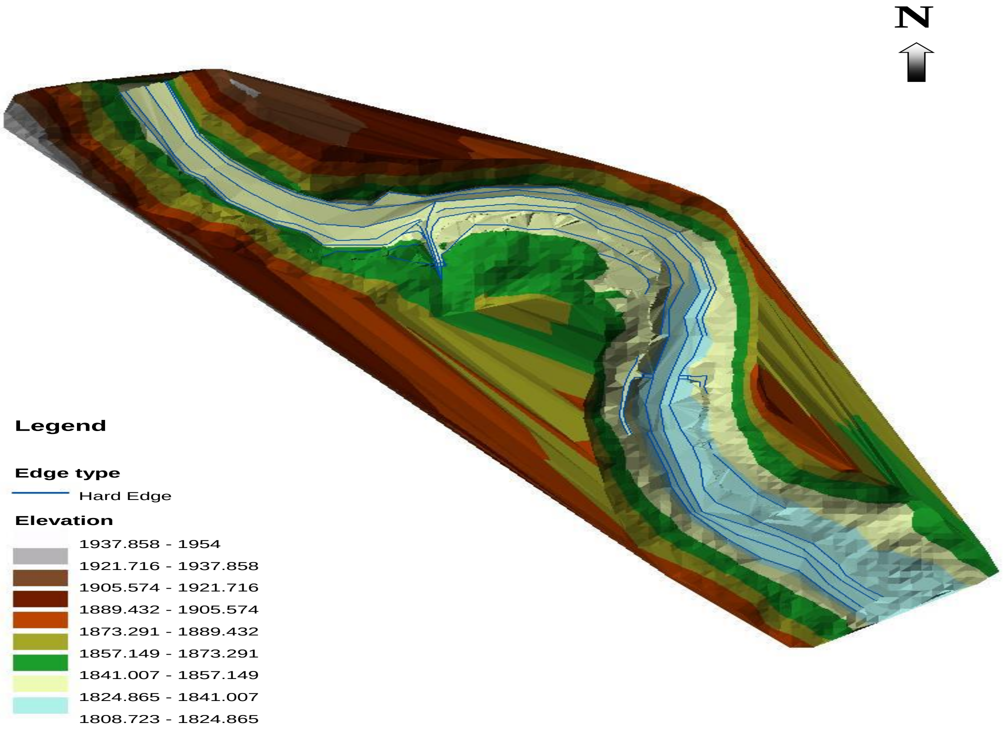

Figure 7: TIN for Mangdechu

HEC-RAS 1D Model setup

River centerline is sketched with the help of given river network. The river cross-section data used in modeling 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 Mandechu are shown in

Figure 8 .The cross-section consists of three parts: main channel, left bank and right bank.

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.

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 cyclone Aila 2009. (690m3/s)

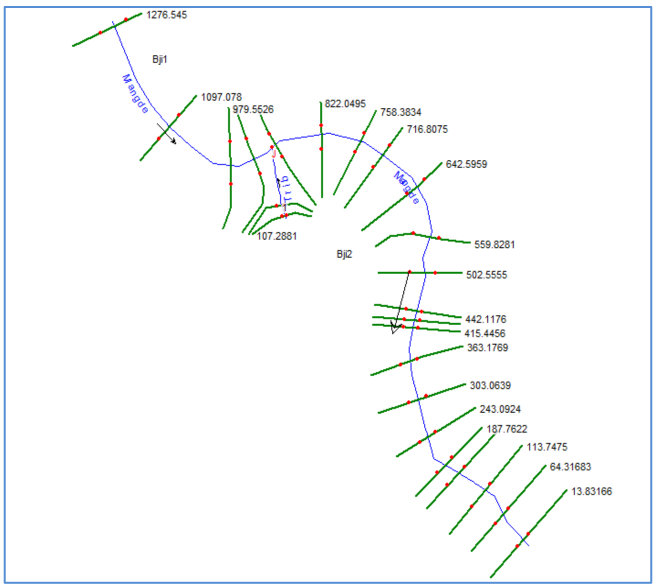

Figure 8: Geometry of Mangdechu

HEC-RAS output

HEC-RAS gives cross-section wise output. Sample of output is shown in Figure 9. The plot shows the cross-section along with the water level for cyclone Aila maximum discharge.

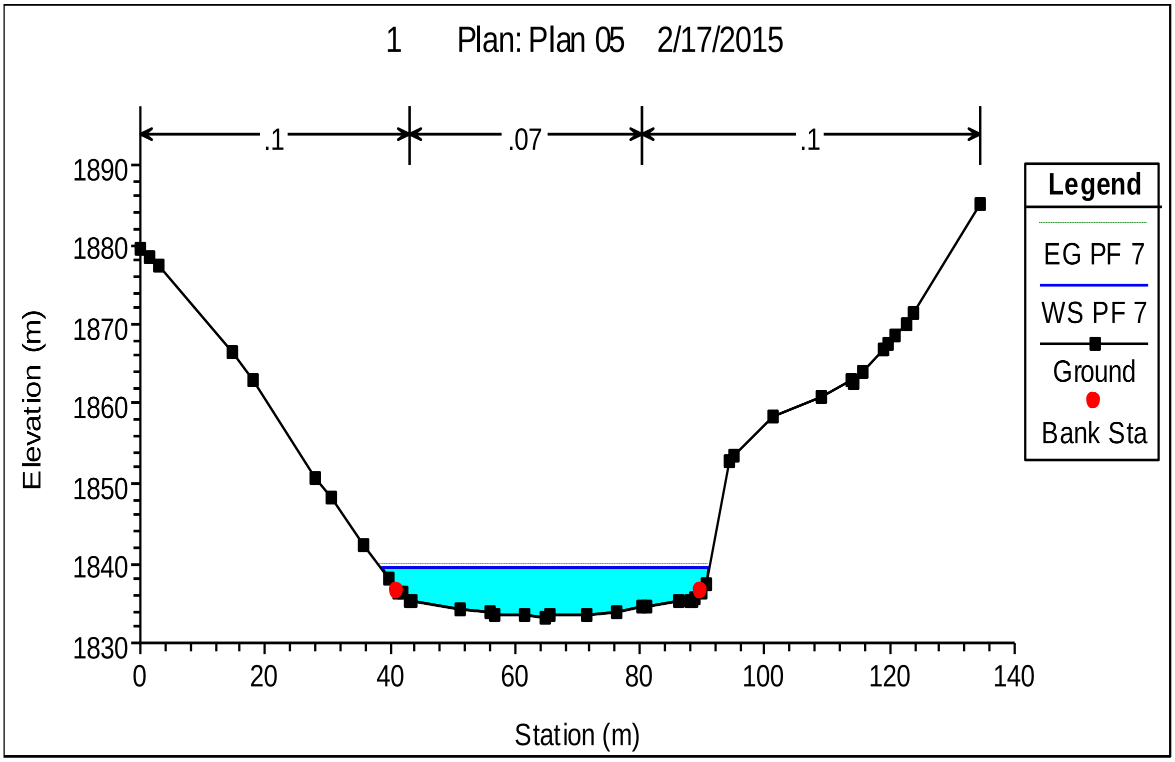

Figure 9: Sample output of HEC RAS for a cross section at Mangdechu, Bjizam

Result Analysis and Conclusion

The flood hazard area along Mangdechu is shown in the two hazard maps as shown in Figure 10: Cyclone Aila Flood Hazard map of Bjezam.Figure 11: Glacial Lake Outburst Flood (GLOF) Hazard Map of Bjezam however, it is required for further validation .

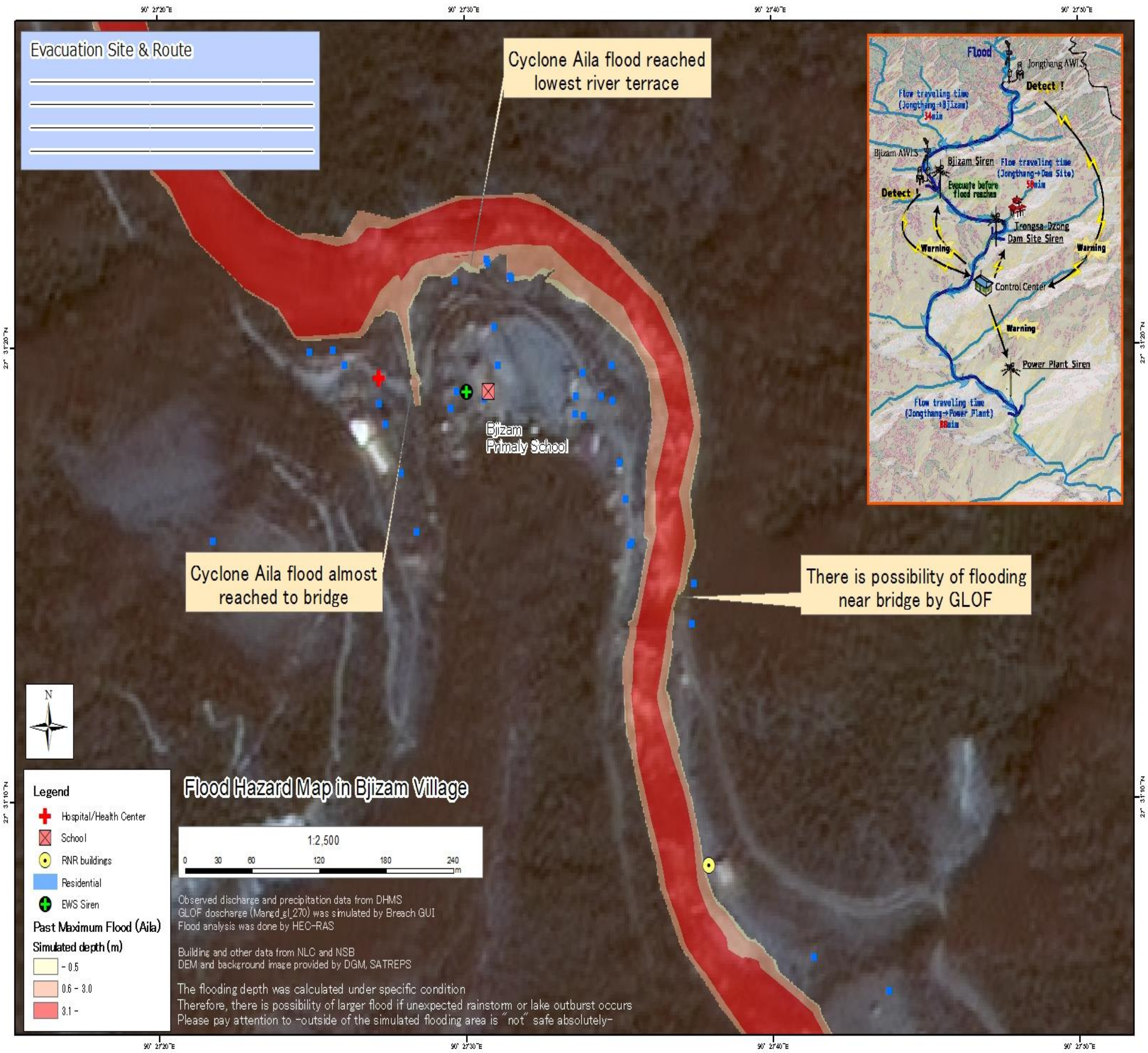

Figure 10: Cyclone Aila Flood Hazard map of Bjezam.

Source: JICA Project for Capacity Development of GLOF and Rainstorm Flood Forecasting and Early Warning in the Kingdom of Bhutan (Prepared by Mr. Tomoyuki Wada, Hydrologist)

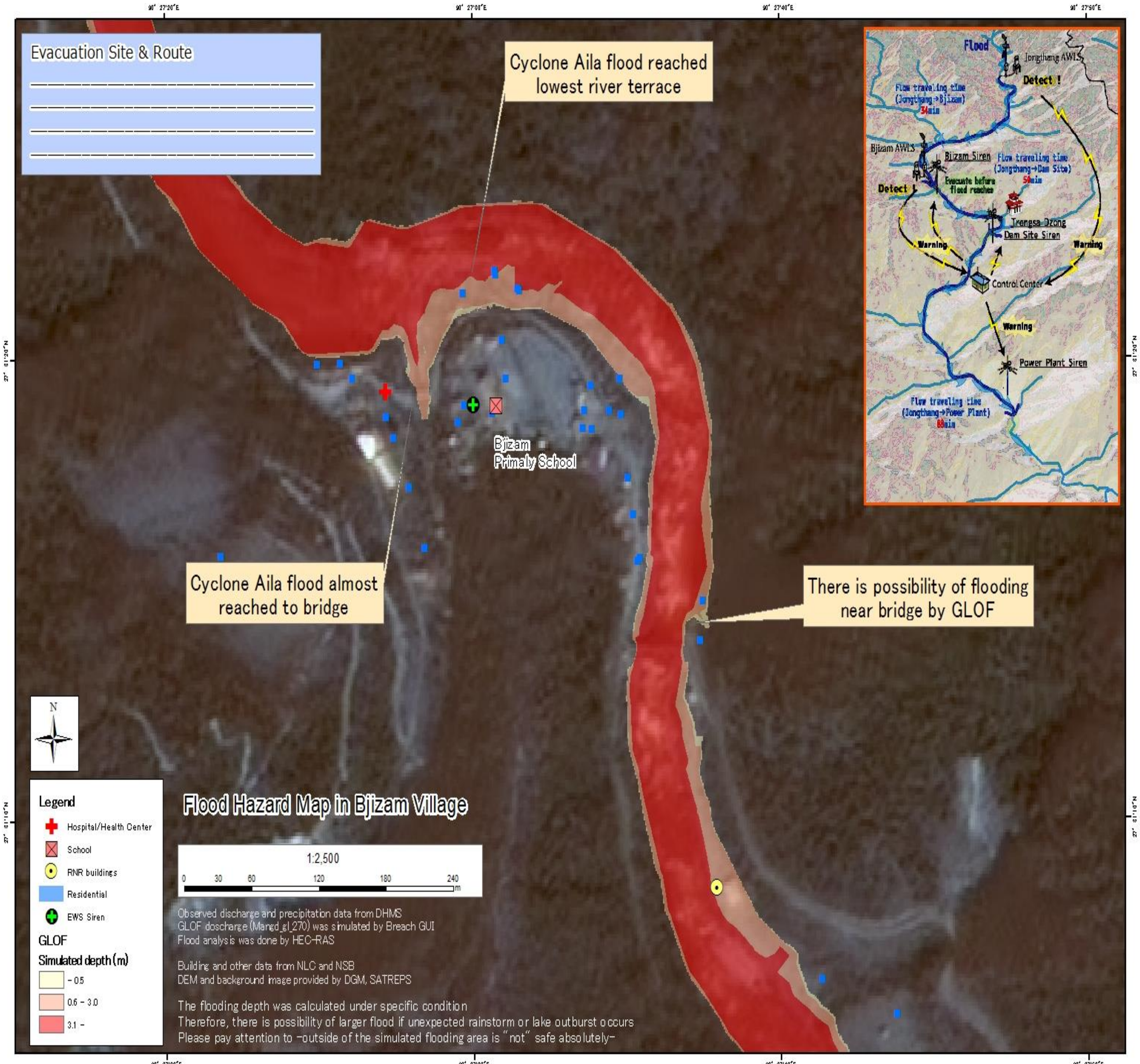

Figure 11: Glacial Lake Outburst Flood (GLOF) Hazard Map of Bjezam

Source: JICA Project for Capacity Development of GLOF and Rainstorm Flood Forecasting and Early Warning in the Bhutan (Prepared by Mr. Tomoyuki Wada, Hydrologist)

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).

As of now division has not constructed flood protection structure along this river, since this river doesn't much pose threat to human settlement while comparing to other Dzongkhag.

Table 5: Flood mitigation work information

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		√									Bjzam (Near forest office)
2	Dzo		√									Thripang Stream (Near Royal Palace)

Note:

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

Gabion wall

Construction of gabion wall is suitable at right bank of changdigangchu (stream), since stream directly hits right bank and pose threat to Bjezam school. To prevent the erosion of the bank, it is further protected by constructing gabion walls on the riverside. This type of structure may be feasible along the right bank of mangdechu, however, it is important to design as per site condition before carrying out construction works.

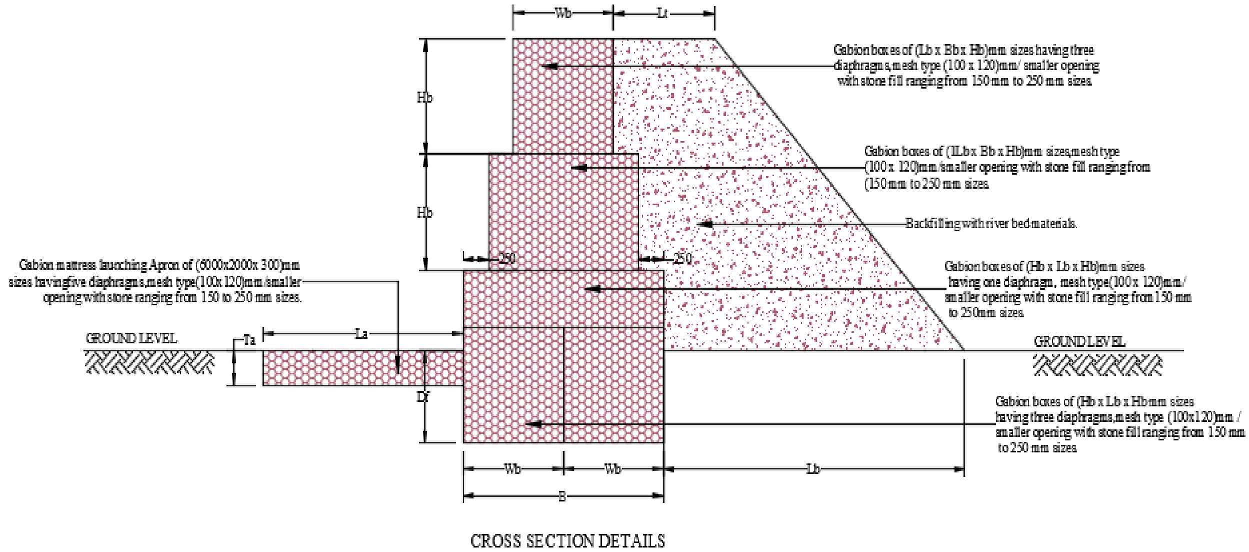

Figure 12:Typical cross section of gabion wall

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 requires to put in place in order to protect from future flooding. However, during the site visit in 2015 no intervention was found depicted below image:

Figure 13:Location require structure intervention

Recommendation for flood management

The FHM for the Bjezam village was identified through site investigation and produced with the Report.

Each identified area is mapped with two different scenarios; 1st FHM with a cyclone Aila discharge which was more than100 year return period and the 2nd FHM with GLOF model. It is recommended to take both the maps under consideration while undertaking any social or developmental activities in the areas.

Limitations of the study

The Digital Elevation Model used in this study was ALOS with 10-meter resolution which is provided by JICA project. 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 Project, it is highly recommended to procure it in the future and update the Flood Hazard Map.

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 agencies cannot be resolved within this study

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 Hazard Assessment for Trongsa Dzongkhag
2. Trongsa Dzongkhag website
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6. Flood control measures for effective flood management, FEMD, DES, MoWHS.