FLOOD HAZARD ASSESSMENT FOR BUMTHANG DZONGKHAG

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

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Acronyms

FEMD	Flood Engineering and Management Division.
Chamkhar Chu	River flowing through Bumthang Dzongkhag
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
FHA	Flood Hazard Assessment.
NCHM	National Centre for Hydrology and Meteorology
AFA	Areas for Further Assessment.
MoWHS	Ministry of Works and Human Settlement
DDM	Department of Disaster Management.
GLOF	Glacial Lake Outburst Flood.

Executive Summary

This flood hazard assessment study focuses only for Bumthang Dzongkhag and flood hazard map have been prepared for Chamkhar Chu under Bumthang Dzongkhag. Most of the settlements, institutions, historical places, agricultural land and Chamkhar town are located along Chamkhar Chu in the flood plains which expose them to high risk of flooding.

The main objective of the study is as follows:

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

A hydrodynamic model was developed for Chamkhar Chu using HEC-RAS software. Digital Elevation Model with 10 meter resolution ALOS is used for this project. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

The reliability of the maps has been affected by the inadequate spatial rainfall data for the study area. The Kurjey hydrological station data is used in modelling since it is the nearest station. Land cover data and soil data has not been used for modelling purpose resulting in unrealistic ground condition.

This project focuses only on Chamkhar Chu sub basin in Bumthang Dzongkhag along the river valley of Chamkhar Chu. Most of the villages are scattered and located along the Chamkhar Chu valley (from Zangtherpo Primary School to Gongkhar village under Choekhor 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 livelihoods assets where significant portion of cultivable lands are lost to flooding and flash floods

Introduction

Background

Bumthang Dzongkhag, encompassing a total area of 2,708.46 Sq.Km with an altitude ranging from 2400-6000 meters above the sea level, has four Gewogs, namely Choekhor, Chumey, Tang and Ura. It is bordered by China in the north, Mongar in the east, Zhemgang in the south and Trongsa in the west. As per the PHCB 2005, Bumthang has 1,462 households and a total population of 16,116 out of which 11,913 live in the rural areas. A favorable terrain condition coupled with easy road accessibility has brought manifold changes in the socio-economic development of Bumthang. It is also considered as one of the prosperous Dzongkhags in the country. The main sources of income for the people of Bumthang are from potatoes, livestock farms and more recently tourism related activities. The sale of Cordyceps, Masutake and medicinal plants are also supplementing their income. The Dzongkhag has a total road network of 193.1 Km including 124 Km of National Highway from Yotongla to Thrumshingla. It has a total of 19 Schools, out of which 12 are Community Primary Schools, 2 Lower Secondary Schools, 3 Middle Secondary Schools and 2 Higher Secondary Schools with a total of 4,312 students and 219 teachers as of December 2010. It also has 14 NFE Centres and over 127 NFE Learners and 14 NFE Instructors. Ugyen Wangchcuk Institute for Conservation and Environment and Chumey Institute for Civil Engineering with over 198 trainees and 35 teachers as of July 2010 are also located in Bumthang. It has one hospital and five BHUs. The Dzongkhag also has a mini-hydro power plant located at Chumey Gewog supplying power to the local community. (Source: National Statistical Bureau of Bhutan)

Figure 1: Study Area

Table 1: Historic flooding events reported by the Dzongkhag and Local Government

Sl. No.	Name of Village	Name of Gewog	Name of river/stream	Type of threat(Agriculture/Resident	Estimated Population	Past flooding record
1	Zhebjethang	Choekhor	Chamkhar Chu	Choekhor Toe PS	100	26th. May 2009
2	Wangdicholing	Choekhor	Chamkhar Chu	Both	60 households	26th. May 2009
3	Chamkhar Town	Choekhor	Chamkhar Chu	Both	800	26th. May 2009
4	Chamkhar	Choekhor	Chamkhar Chu	Both	8 households	26th. May 2009
5	Chamkhar	Choekhor	Chamkhar Chu	Gangrithang PS	200	26th. May 2009
6	Gongkhar/Jalikha	Choekhor	Chamkhar Chu	Both	270	26th. May 2009
7	Gamling	Tang	Shekey Chu	Resident ,wooden bridge	15 households	26th. May 2009
8	Khangrab	Tang	Tang Chu	Wet land	11 households	26th. May 2009
9	Khangrab	Tang	Chu Karbi Chu	Wooden bridge		2014
10	Kizum	Tang	Tang Chu	Bridge, eco-tourism park		26th. May 2009 and 2014
11	Nimalung	Tang	Tang Chu	Wet land & feeder road		26th. May 2009 and 2014
12	Nimalung Zug	Tang	Tang Chu	Wet land & feeder road		26th. May 2009 and 2014
13	Wagar	Tang	Tang Chu	Wet land		26th. May 2009 and 2014
14	Nangar/Khartengthang	Chumey	Chumey Chu	Crematorium& Agricultural land		26th. May 2009
15	Phurjoen	Chumey	Sirmong Chu	Resident	3 households	No
16	Domkhar	Chumey	Degang Chu	Agricultural land	20 households	1987
17	Domkhar	Chumey	Chumey Chu	VTI, Resident & Agricultural land.	10 households	No

Table 2: Historic flooding events reported by the Media

Sl. No.	Place of incident	Name of river/stream	Types of threat	Reported Date	Flooding record	Remarks
1	Chamkhar Town	Chamkhar Chu	Residents of Chamkhar	27/07/2016	26/07/2016	Flood alarm in Chamkhar Town
2	Wangdicholing village	GLOF	Residents of Wangdicholing	5/08/2016	5/08/2016	Anxiety of lake outburst grips Wangdicholing village
3	Chokhoetoe	Heavy rainfall	Ngalhakhang, Dramphel, and Samthang flood threat	11/08/2016	9/08/2016	Heavy rains caused flash flood in Chokhor

Objective

Objective 1: Flood hazard assessment of Bumthang Dzongkhag.

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

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

Study Area

There are four Gewogs in Bumthang; three out of four Gewogs are prone to flood namely Choekhor, Tang and Chumey Gewogs. Gewog wise flood affected areas are described as follows:

Choekhor Gewog: Located in Northern part of Bumthang Dzongkhag and is the biggest of the four Gewogs in the Dzongkhag. The Gewog borders Chumey Gewog to the southwest , Ura Gewog to the southeast, Trongsa Dzongkhag to the west, Wangdue Phodrang Dzongkhag to northwest, Tibet to the north, Lhuentse Dzongkhag to the northeast, and Tang Gewog to the east. Total area coverage is approximately 1,533 square kilometres. Its altitude ranges from 2600-5800meters above sea level.Total number of population till date is approximately 8756.
In Choekhor Gewog there are 39 villages with 11 Tshogpas, about 661 households, 7 schools, 4 ORCs (Out Reach Clinics) and 5 VHW (Village Health Worker). Also there are four Dratshangs, one Gomday and one Lobdra.

The schools include four community schools namely Zangtherpo Community Primary School, Dhur Community Primary School, Kharsat Community Primary School, Choekortoe Community

Primary School, one Primary School namely Gangrithang Primary School, one Lower Secondary School called Wangdicholing Lower Secondary School and one Higher Secondary School called Jakar Higher Secondary School. There are 7 Non Formal Education centers. The Gewogs primary socio economic activities are farming and livestock rearing.

Tang Gewog: located in the eastern part of Bumthang Dzongkhag and has an area of about 511 square kilometres. It is bordered by Lhuentse Dzongkhag to the north and east, Ura Gewog to the south, and Choekhor Gewog to the west. The altitudes of the Gewog ranges from approximately 2800-500 meters above sea level. Total number of population till date is approximately 1816.
In Tang Gewog there are 32 villages with 10 Tshogpas, about 300 households, 3 schools, one BHU(Basic Health Unit), 4 ORCs() and 11 VHW(Village Health Worker). Also there is one Anim Dratshang, 2 Gomday and one Drubdey.

The schools include 2 community schools namely Khangrab Community Primary School, Jigmeling Community Primary School, and one lower secondary school, Mesithang Lower Secondary School. There are 4 Non Formal Education center.

The livelihood of the people of Tang Gewog is mainly Agriculture and livestock rearing. The food crops produced in Tang Gewog are Wheat, Barley, Buckwheat and sweet buckwheat. The cash crops produced are potatoes and apples.

Chumey Gewog: located in South-western part of Bumthang Dzongkhag bordered by Choekhor Gewog to North, Ura Gewog to the East, Trongsa Dzongkhag to West and Zhemgang Dzongkhag to South. Total area coverage is approximately 404 square kilometers. Its altitude ranges from 2200-4485 meters above sea level. Total number of population till date is approximately 2900.

In Chummy Gewog there are 21 villages with 13 Tshogpas, about 291 households, 5 schools, one BHU and 3 ORCs (Out Reach Clinics).

The schools include three community schools namely Gaytsa Community Primary School, Chungphel Community Primary School, Zungye Community Primary School, one Middle Secondary School namely Chumey Middle Secondary School and one Private School, Sonam Kuenphen Higher Secondary School.

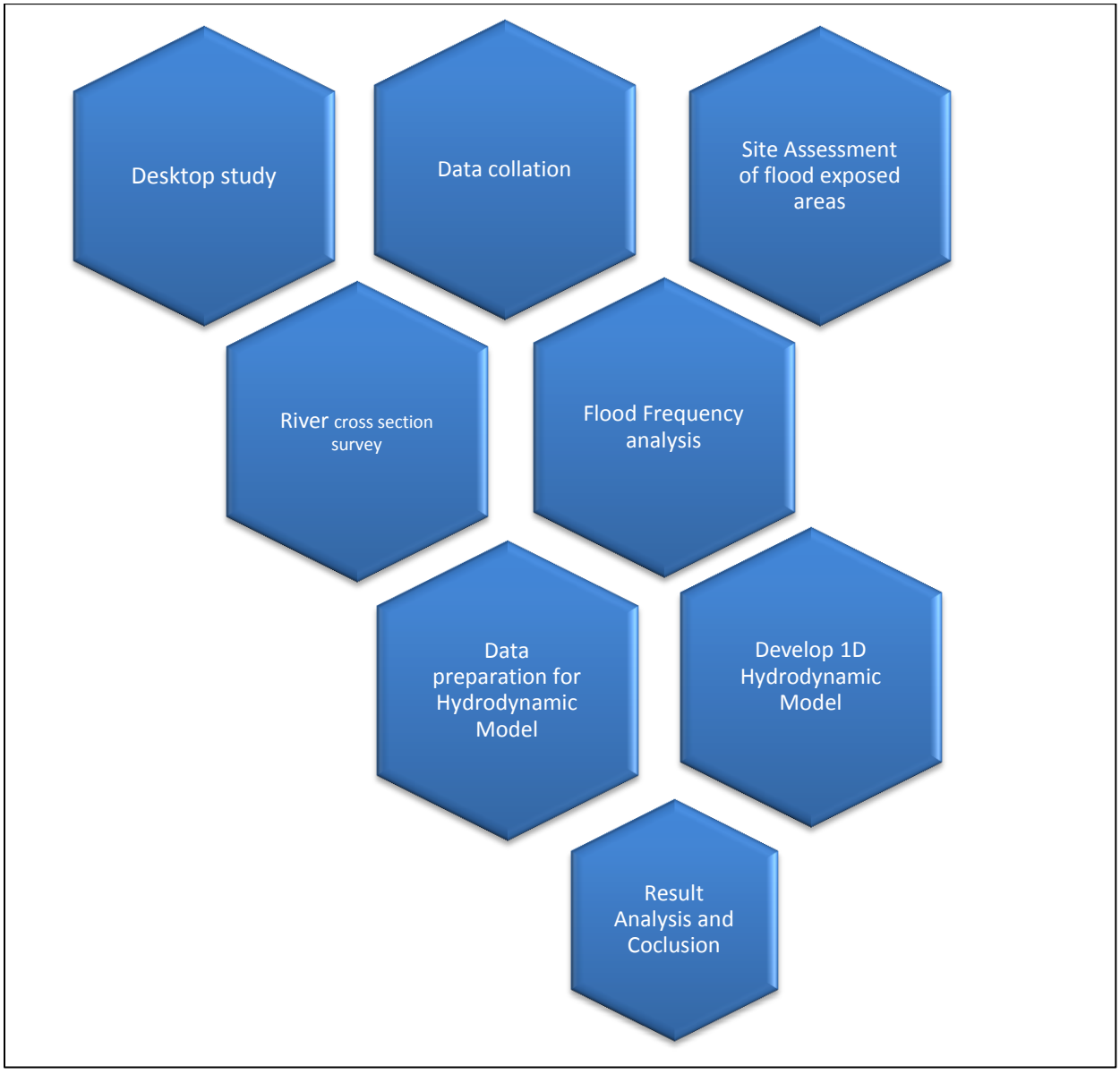
There are 4 Non Formal Education center and one Vocational Training Institute.

There are two Yathra factories in Chumey Gewog at Nanger village. Yathras are hand woven cloth piece made out of wool and are mainly used for making bags, jackets, seat covers, table clothes, scarfs and etc.

There are three sawmills, one in Domkhar village and two in Hurjey.

Main livelihood of the people living in Upper Chumey is Agriculture and for the people of Lower Chumey, it is Yathra weaving. Other livelihood includes livestock rearing. The food crops produced in Chumey Gewog are wheat; barley, sweet buckwheat and the cash crop produced are mainly potatoes.

Methodology



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 Figure 2.

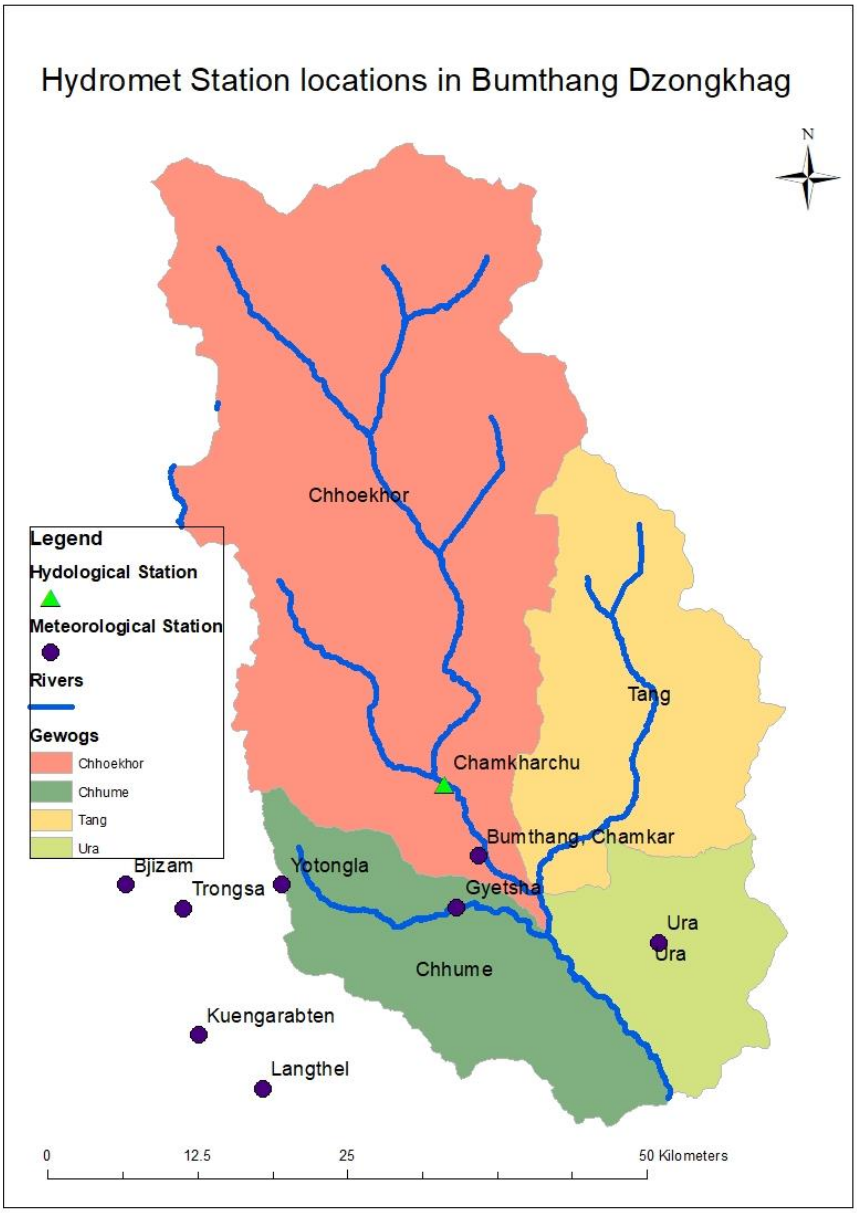


Figure 2: The location of the Hydro-met station in the study area

Meteorological Data

There are 4 meteorological stations available in the watershed study area. Chumey met station has temporal daily data from 1996 to 2012.

Scientific Data

DEM (Digital Elevation Model)
Digital Elevation Model with 10 meter resolution ALOS is used for this project. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

Site Assessment at Gewog Level

Choekhor Gewog:
Zhebjithang: located at 27° 40' 32.2" northing and 90° 44' 06.3" easting having elevation 2763m. Chamkhar Chu is flowing below Choekhor Toe PS.Before 2009 Chamkhar Chu was flowing from its original course and it has not affected school and residential areas.When cyclone aila happened in 2009,Chamkhar Chu has been divided into two rivers creating small island in between.Newly divided river carried lots of heavy boulders and deposited on the Choekhor Toe school ground which is still lying on the ground.There are around 100 population including school which will be affected in case if heavy flood occurs in future.There is no river protection structures constructed as of now.This area falls on the right bank of Chamkhar Chu.

Figure 3: 1 River divided from original course after 2009


Figure 4: Boulders deposited at Choekhor Toe PS ground by 2009 flood.

Wangdicholing: located at 27°35'33.6"northing and 90°43'43.9"easting having elevation 2580m.Airport located on the left bank and Wangdicholing is located at the right bank of the Chamkhar Chu.There are threat to around 60 households and agricultural land in Wangdicholing area.Department of civil aviation have constructed gabion wall throughout the length of airport at left bank and some portion at right bank as well.Some portion of gabion wall has bulged and already failed.Till now gabion wall along airport is in good condition.

Figure 5: Chamkhar Chu right bank below Wangdicholing

Figure 6: Bulged gabion wall below Wangdicholing

Chamkhar town: located at 27°33'01.7" northing and 90° 45' 26.4" easting having elevation 2568m.Around 200 shops and approximately 800 people are residing in Chamkhar town, and it is the main commercial hub of Bumthang. Apart from town, agricultural land is also having threat from flood along the Chamkhar Chu which is above and below the Chamkhar town.The ground profile is flat and quite vulnerable to flood.Chamkhar town is located at right bank of the Chamkhar Chu.Realising the importance of town and infrastructure, FEMD kept budget to construct river training works along the right bank of Chamkhar Chu.Highest flood level observed at the bridge area is 3m.

There are three areas below Chamkhar Chu bridge which can be affected in case of flood viz.Chamkhar village at Right bank, Gangrithang PS at Left bank,Gongkhar and Jalikha at left bank.There is only one metre elevation difference between Gangrithang PS and river bed level.Presently,there is no river training structures provided near by school area.It is found that Gongrithang PS is very prone to flood.During 2009 year flood,water from Chamkhar Chu entered the Gangrithang PS but did not cause any damage to the school.

Gongkhar and Jalikha village is located at left bank of Chamkhar Chu just below Gangrithang PS.There are about 270 population residing in Gongkhar and Jalikha village.Before 2009 year cyclone aila,Chamkhar Chu had not threathened resident and agricultural land.After occurance of

cyclone aila, water from Chamkhar Chu had deposited large quantities of heavy boulders and reached almost equal height of wet land area.Some portion below the Gongkhar village still having water logged areas which is not cultivable at present.

Figure 7: Gabion wall construction in progress along Chamkhar Chu

Tang Gewog:

Gamling: Shekay Chu is small tributary which runs through Gamling village under Tang Gewog and joins Tang Chu.There are about 15 housekols residing in Gamling Village.During monsoon season,discharge becomes large and reaches almost equivalent to the ground level.There are two bridges located next to this village,Baa-Zam and RCC motorable bridge.Baa-Zam was washed away completely in 2009 and it was again rebuilt.There is only one metre height difference between river bed level and ground level.This Shekay Chu causes threat to resident,bridges and irrigation channel.In 2009,due to flood,river reached the ground level and deposited large quantities of debris.How ever,Gewog Administration immediately deployed excavator and cleared the debris and also carried out dredging works in river.Thereafter,there is no record of flood.

Figure 8:Shekay Chu along Gamling village

Khangrab: There is a threat to only Agricultural land by the Tang Chu.There are around 11 house holders land which are under threat in case of flood.There is only 0.5m elevation diff in this area.As shown in fig 8 above,during 2009 flood Tang Chu entered into the agricultural land and deposited large quantities of boulders and sand.There is a temporary wooden bridge located at this place which needs to be replace every year.Wet land areas are mostly located at left bank.

Figure 9: Tang Chu along Khangrab village.

Chu Karbi Chu is located at upper Khangrab village.Water from Chu Karbi Chu joins the TangChu at downstream.Gewog Administration have constructed gabion wall at upperstream of wooden bridge at both banks to control the flow towards wet land.As per the Gewog,there is more threat to motorable wooden bridge in case of flooding.

Figure 10: Chu Karbi Chu at Khangrab.

Nimalung: Mainly consists of wet land and farm road which has been threatened by flood in 2009 and 2014.As per the information from Gewog office, 0.48 acre of wet land have been completely covered by sand during 2009 flood.Farm road is located along the right bank of Tang Chu.In this area, width of the river is wide and the river have tendency to often change its course easily.Affected area lies mostly in right bank.Tang Chu mostly scoured along the road.Therefore,Department of road have constructed gabion wall measuring 40m length and 4m height. In Nimlung Ju they have also constructed gabion wall measuring 50m span and 3m height. Besides constructing gabion wall, Gewog Administration have also carried out dredging works along the right bank.There are around 18 households located at this affected area.

Figure 11: Dredging works at Nimalung Ju

Wagar Village: Wet land in Wagar village is located in left bank of Tang river.Wet land was threatened by flood in 2009 and 2014.However,there was no loss of land by the flood as per the Gewog Administration.There is only 1.5m elevation difference between river bed level and cultivable land surface.Wet land lying on left bank is very prone to flood which would cause huge loss to the land owners.

Chumey Gewog:

Nangar,Khartengthang: In Khartengthang,elevation difference between river bed level and ground surface is only one metre.There is a crematorium and dry lands belonging to Nangar village on the left bank . After 2009 flood, river is divided in two halves and one half is flowing few metres away from crematorium.There is a concern for the Gewog Administration that in case of flood,crematorium would be washed out.Till now there is no flood protection structures provided.

Figure 12: Chumey Chu in Khartengthang before and after 2009

Phurjoen: Sirmong Chu flows through Phurjon and Chetenpang village.There are threat to three households, proposed new town and public land at downstream.In case of flooding,there is high risk that river might flow through left bank and cause damage to properties.As per the Gewog Administration sources, there is no record of flood event as of now.

Domkhar: In Domkhar,there is threat to agricultural land belonging to around 20 households.There was flood in 1987 caused by Domkhar Chu but did not cause excessive damage.Other than 1987,there is no record of flooding.

There is a threat to VTI, agricultural land and around 10 households by Chumey Chu.There is no record of flood caused by Chumey Chu in this area as of now.

River cross section survey

The JICA consultant and an engineer from the Hydrology Division from Department of Hydro met Services (DHMS) under the Ministry of Economic Affairs had planned a site visit and a cross-section survey of the Chamkharchu in Bumthang. The survey was proposed on many locations starting from Kurjey in the north till the last settlement at the end of Bumthang Dzongkhag. With FEMD closely working with Hydro met Division in comprehending the information of the rivers in Bhutan, the officials from the Division were asked for the participation. Besides, the FEMD have a major task of identifying high flood risk area along Chamkharchu and to come up with an appropriate flood protection structures. The Division has a budget provision for flood protection works along Chamkharchu in the coming fiscal year 2014-2015.

The team comprised of Mr. Wada, JICA Consultant and Mr. Bikash, Engineer from the Hydrology Division and Mrs. Thinley Choden, Executive Engineer and Mr. Tashi Phuntsho, Dy. Exe. Engineer from the FEMD. The Cross-Section Survey of the river was planned to be conducted with the help of the GPS instrument (GNSS receiver + promark120) at sections wherein crossing of the river is possible and with total station when impossible to do so. The JICA Consultant was also generous enough to train the team on the use of GPS instrument for the survey which was very convenient and applicable when rivers are crossable and the river basin is wide.

Figure 13: Setting out Total Station

Figure 14: Conducting Cross Section Survey.

The team first conducted the site visit along the bank of the Chamkharchu from Kurjey till the bridge in Chamkhar town. Accordingly, the survey started from Kurjey using both the GPS and total station, the GPS was also used in knowing the details of first station (reference point). Where the depth of river was too deep for the engineers to cross, the survey was conducted at the highest point outside the river bank which we call terrace level, then high flood level shown by the mark on the boulders on the river bank (identified from the stone colour at the bank), then the maximum water level at present, then inside the river when possible to go in the river and then

on the opposite bank respectively. The survey was conducted with the two instruments throughout the sections. The team completed at least 5 to 6 cross-sections a day and could have carried out more if not for the forceful currents and depth of the river. Where the river was not too deep, the team crossed the river and took the cross-sections of the river.

The FEMD as mandated concentrated mostly on the stretch of the bank where the river was a threat to the settlement along the Chamkharchu. Of many, the settlements on the stretch of the bank opposite to the Badpalathang airport , Chamkhar town, Gangrithang Primary School (the school below the Chamkhar bridge) and the national highway from Bumthang to Trongsa (near the Wangdicholing resort) were found out to be of greater risk to flooding. The Badpalathang airport has a long stretch of flood protection structures (Gabion wall) on their side of the bank. The gabion wall with apron ranging from height of 2.5 metres on the upstream to 3.0 m on the downstream section of the bank has been constructed for airport protection. However, the gabion wall on some part of the bank has been deterioted over time due to poor quality construction and also due to fast flowing Chamkharchu in summer. As per the site visit, the Chamkharchu seems to be bringing in lots of sediment deposits during summer rainy seasons. The river bed is also covered with lot of sediments at present and the width of the river bed is also quite wide on the downstream side.

Figure 15: Gabion wall for flood protection on the upstream of airport.

Figure 16: Gabion wall for flood protection on the downstream of airport.

At present, on the right bank of the river opposite to Badpalathang Airport, dredging works is been done creating an artificial embankment of height about 3 metres besides constructing a gabion wall at the back. The construction of gabion wall is also ongoing along with the dredging work on the right bank. The gabion wall constructed on the right bank is of height 2.45 m to 3.00 m on the site but the quality of construction is still poor. The wire mesh and the stones used for gabion wall are also of poor quality.

A lot of erosion and scouring of the terraces and useful lands (agricultural land, private lands etc.) could be seen on the portion of the banks without proper protection works both at the upstream and downstream of Chamkhar bridge. The height of the terrace top from the maximum water level (MWL) at present ranges from 0.7 m to 1.0 m at places where there are no protection walls on the right bank opposite of airport.

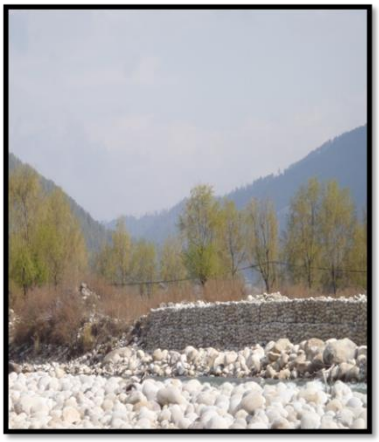


Figure 17: Gabion wall construction of the right bank of Chamkharchu opposite to airport.

Figure 18: Scouring and terrace level on the right bank of Chamkharchu opposite to Airport.

The velocity of river in the upstream of airport is 1.1 m/s and the velocity of river in the downstream of the airport is about 1.7 m/s to 2.0 m/s. The increased velocity must be triggered by the constriction of river cross-section as we move downstream. The points (cross-section) had been picked wherever necessary to give us the actual river cross-section profile. The surveyors did everything to get the points required for river cross-sections by crossing the river, walking through dense shrubs and thorny plants.

Following are some of the observations made from the site visit:

- The inhabitants on the right bank of the Chamkhar chu (Chamkhar town, Wangdicholing etc.) are more prone to risk of flooding. The gabion walls are constructed on some part and it is still ongoing. Depending on the availability of budget, we would like to recommend gabion wall with apron in areas where there are high risk of flooding. The stones and wire mesh used for gabion walls should also have proper specifications. The

Dzongkhag should also be requested to check the quality of construction more often as the quality of construction is poor at present on the site.

- In the downstream of Chamkhar Bridge near the school, the boundary fence of the school is near the river bed and therefore, the school is also more floods prone. There are no flood protection structures in front of the school. The responsible agencies should keep budget provision for the flood protection structures on that side.
- Further down the school, the river width widens as we move down and it is affecting the land as well as infrastructures like road. There are lots of erosion and scouring taking place in both side of the bank. There is not so much difference between the water level and the terrace level on that area. Therefore, there should also be appropriate flood protections structures on that side.
- Since the engineers have to cross the river when taking river cross-sections, waders and life jackets are very necessary. A total of 3 people are required to go in the river with reflector in case of deep rivers for taking points. Therefore, we would like to recommend a minimum of 2 surveyors who knows total station and 2 survey attendants for our Division.

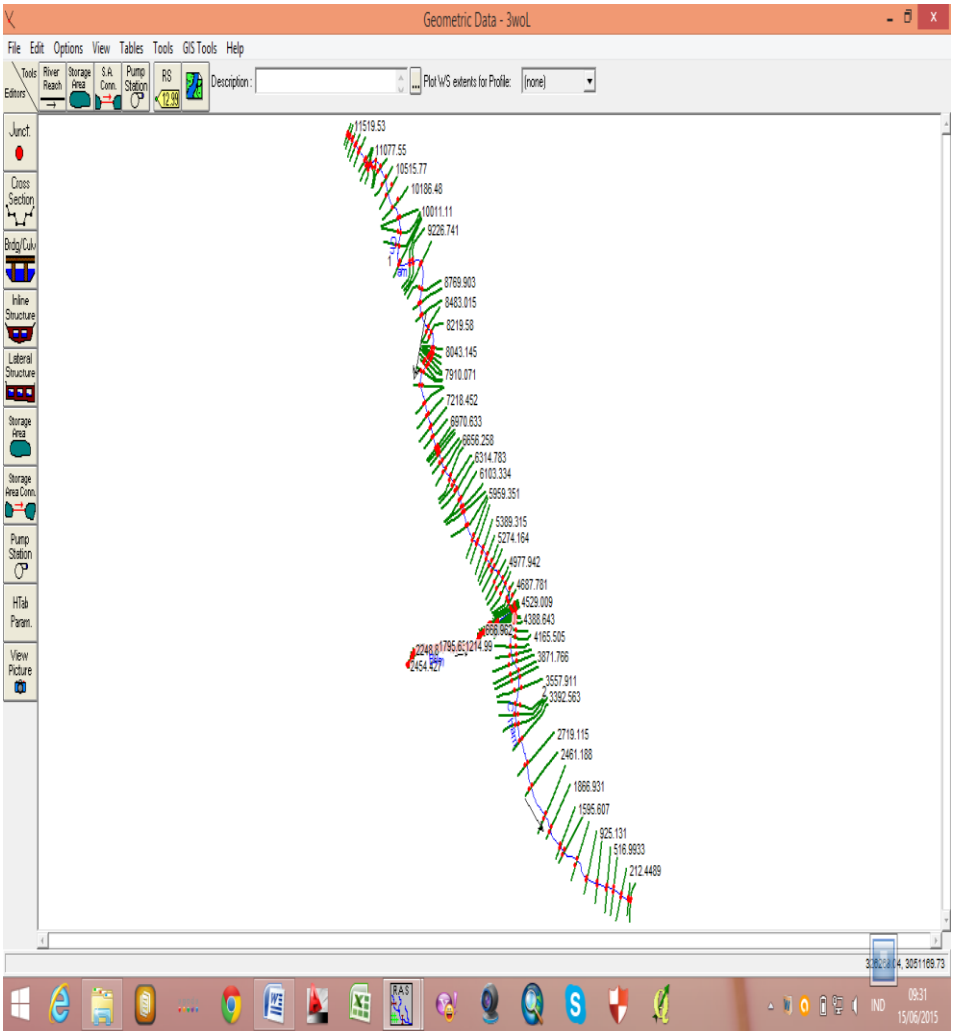


Figure 19: Cross section schematic of Chamkhar Chu

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 (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 Chamkhar Chu is detailed in Table 3

Table 3: Flood frequency result using Gumbel probability method for Chamkhar Chu.

Return Period	Return Period Discharge (Peak Method)
2	224.6
5	261.2
10	285.4
25	308.6
50	338.7
100	361.2
500	383.6
1000	413.2

Run off simulation by IFAS

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.

• Background map are derived from Global Map4 - 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.

Table 4: Probable discharge results using IFAS

Kurjey (Bumthang)	Probable Rainfall		Probable Discharge (m3/s)	
	(mm/day)	(mm/3days)	observed	IFAS
Aila(2009)	90.0	138.5	586	612
20 year	64.8	120.1	309	298
50 year	75.6	141.6	339	365
100 year	83.7	157.8	361	423
200 year	91.8	173.9	384	475
500 year	102.5	195.1	413	545
1000 year	110.5	211.2	436	610

Development of Model

Hydrodynamic model

ALOS DEM (10 m resolution) was used to prepare flood hazard map.

DEM Preparation

Freely available ALOS DEM (10m resolution) covered study area is downloaded. The downloaded DEM is clipped for the study area. The Geographic projection is transformed into UTM. The DEM in TIN format is required for HEC-RAS model.

TIN Preparation

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 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.

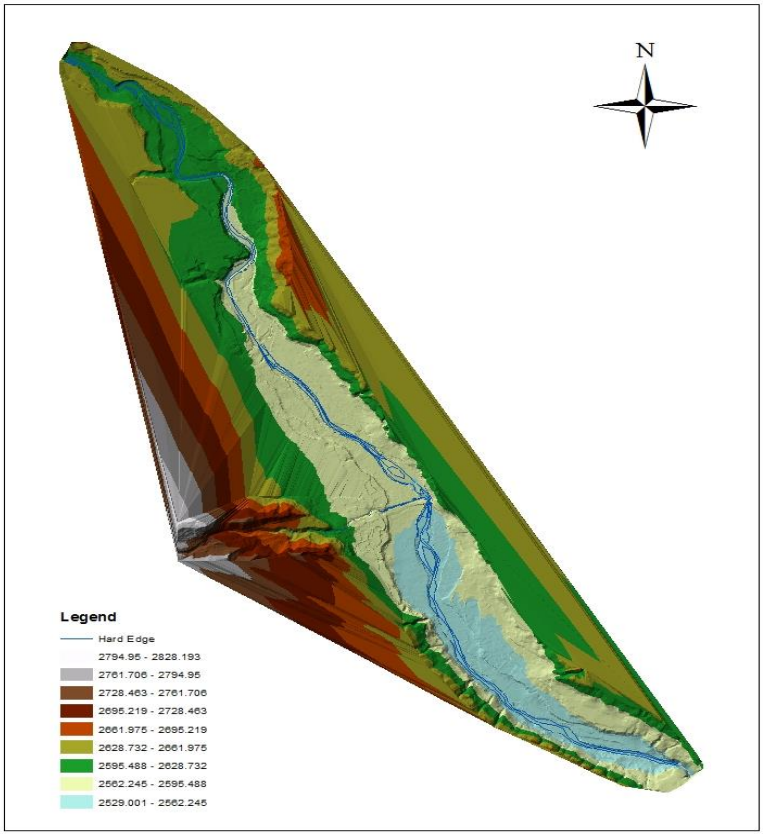


Figure 20: TIN for Chamkhar Chu

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 DEM. (10m resolution).

The schematic of geometry in HEC-RAS for Chamkhar Chu are shown in Figure 19. 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 100 year return periods.

Result Analysis and Conclusion

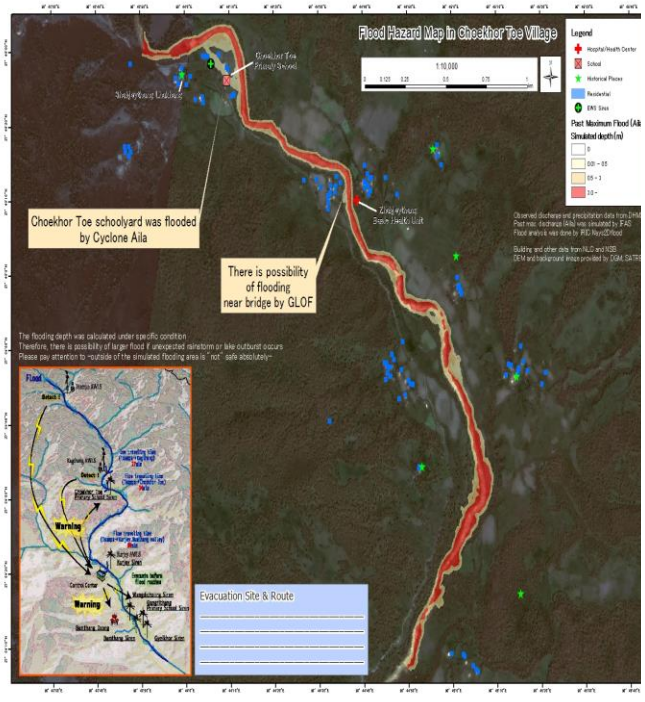


Figure 21: Cyclone Aila Flood Hazard map of Choekhor Toe.

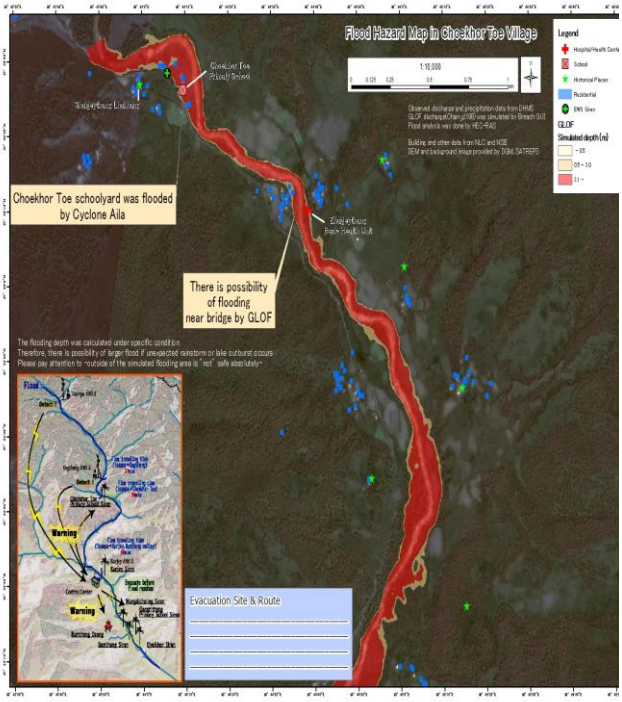


Figure 22: Glacial Lake Outburst Flood (GLOF) Hazard map of Choekhor Toe.

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

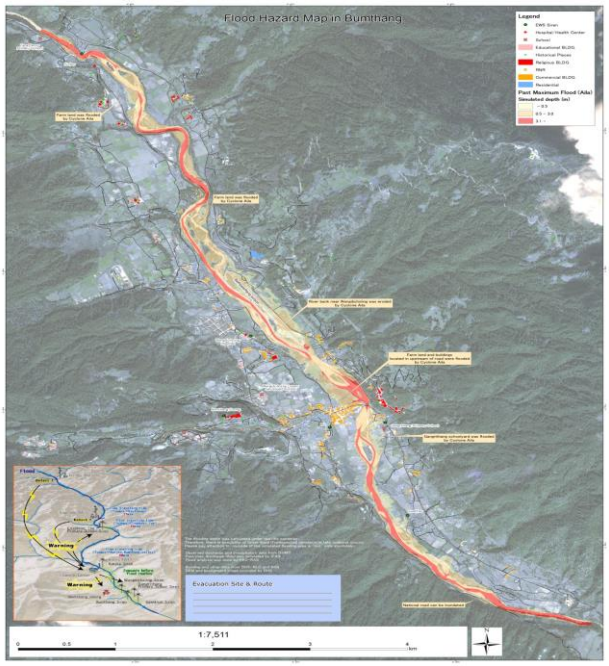


Figure 23: Cyclone Aila Flood Hazard Map of Bumthang

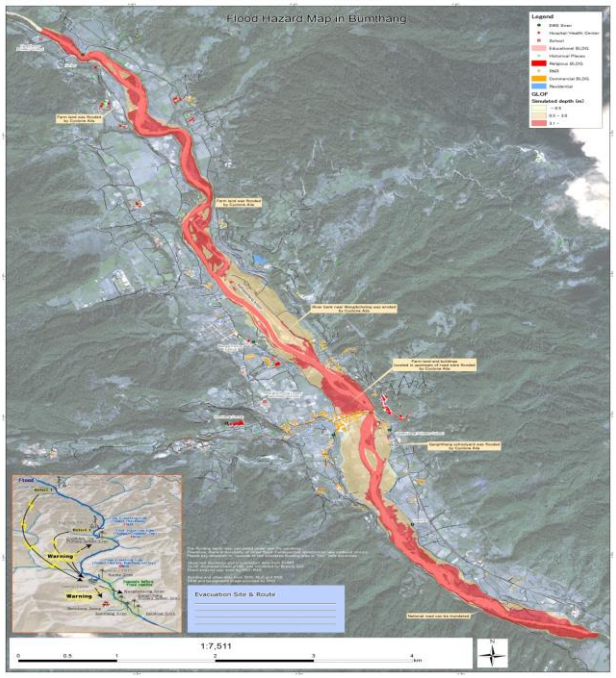


Figure 24: Glacial Lake Outburst Flood(GLOF) of Bumthang

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

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 Department of Engineering Services, MoWHS, Royal Government of Bhutan have invested Nu.15.264M in financial year 2014-2015 and Nu.4.655M in financial year 2017-18 respectively in the 11th FYP for Bumthang Dzongkhag. Gabion wall along Chamkhar Chu was designed by FEMD, DES and implemented by Bumthang Dzongkhag.

Gabion Wall: The gabion walls are retaining walls made of stacked stones filled in gabion boxes which are either hand woven or mechanically woven by using wire meshes such as galvanized steel wire and stainless steel as given in Figure 25 and 26. The stone fill should be of hard and durable material. To reinforce the structure, all the mesh panel edges are selvedge with a wire of greater diameter than the wire mesh. The mesh panel is divided into cells by providing diaphragm at every 1 meter interval.

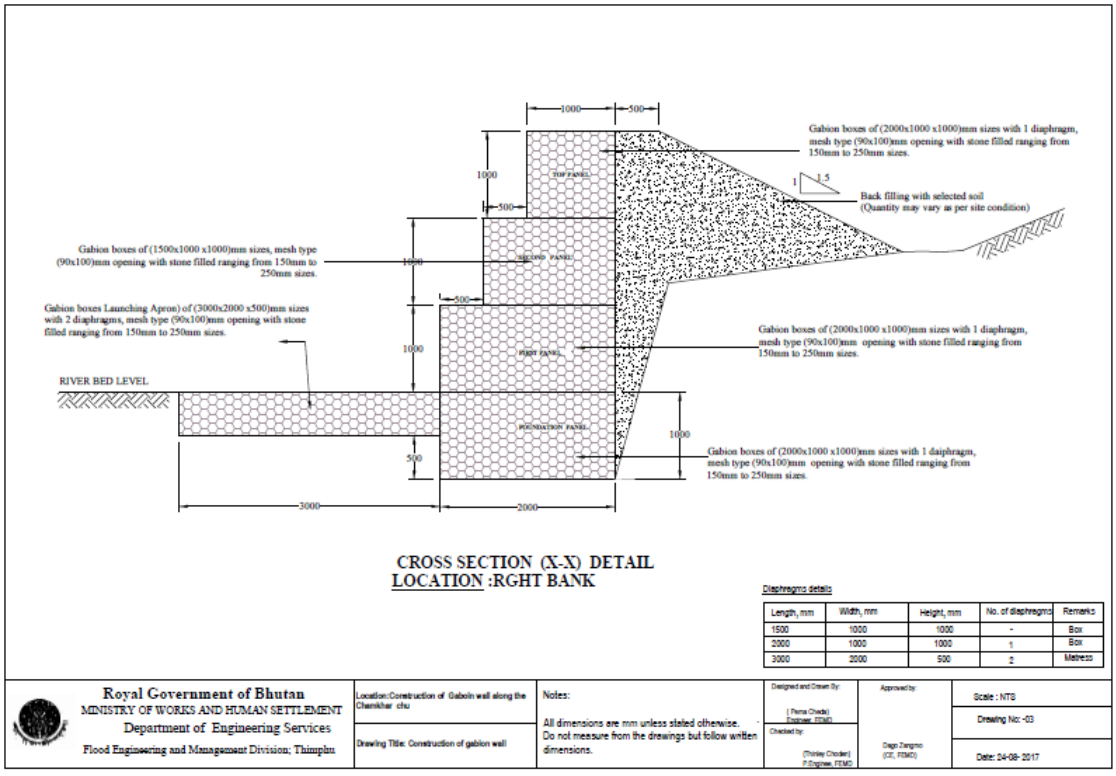


Figure 25: Cross section of gabion wall along Chamkhar Chu

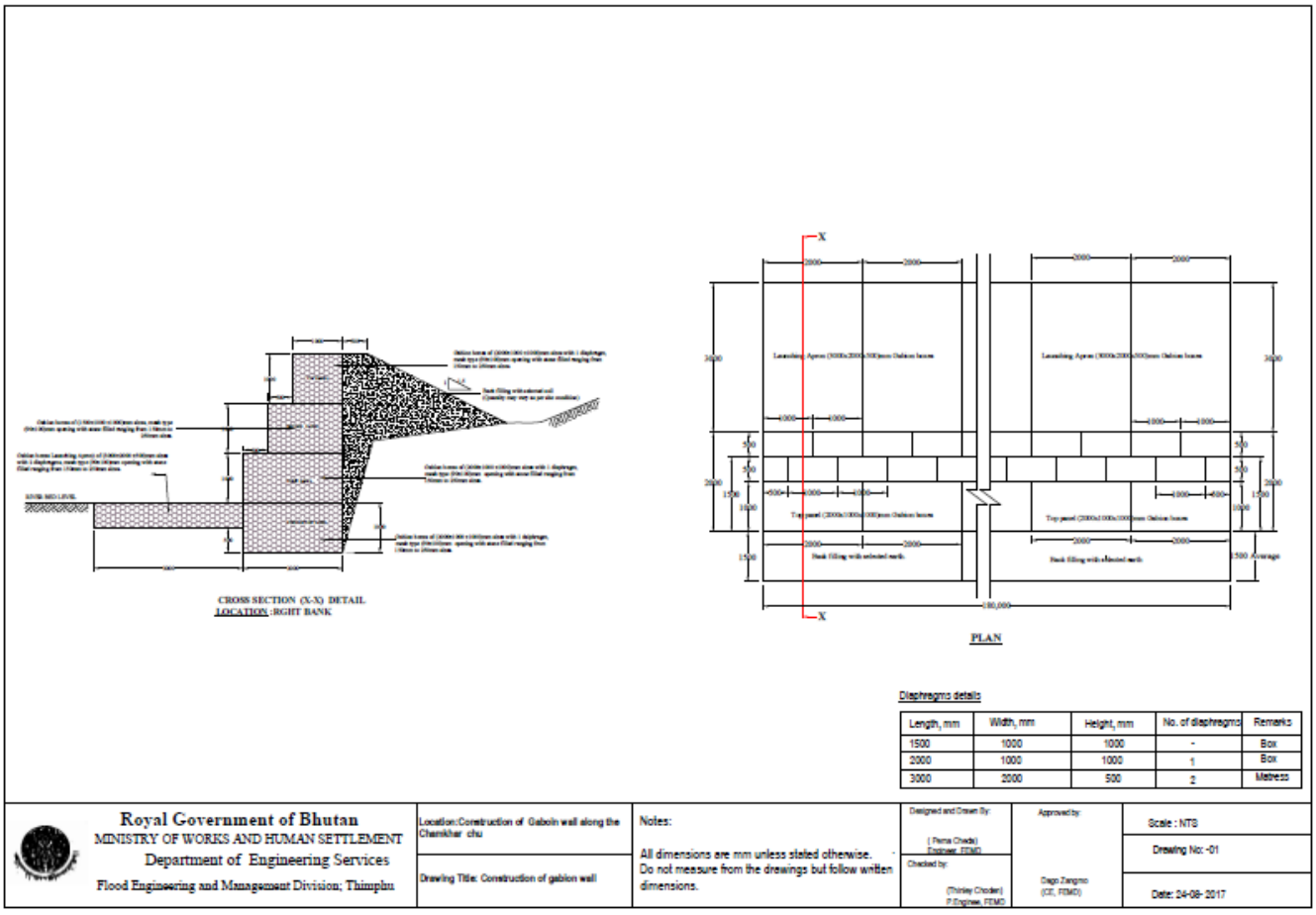


Figure 26: Plan and cross section of gabion wall along Chamkhar Chu.

Recommendation for flood management

Along the Chamkhar Chu, the following areas are identified as flood prone areas from the flood hazard map.

1. Choekhor Toe
2. Kurjey
3. Wangdicholing
4. Chamkhar

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

As per the flood hazard map shown in Figure 24, the settlements under red zone should be given the 1st priority, brown zone as the 2nd priority and white zone as the 3rd priority. The areas that do not fall under any of the three zones can be identified as evacuation centres. There is possibility of larger flood if unexpected rainstorm or Lake Outburst will occur.

Limitations of the 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.

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 ALOS DEM with 10 meter resolution. 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.

References

1. Preliminary flood hazard assessment of Bumthang Dzongkhag
2. Flood inundation mapping using global datasets, Kuenzang Choden, FEMD, DES.
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4. National Preliminary Flood Risk Assessment (PFRA), Ireland, Engineering Service, Office of Public Works.
5. 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.
6. Flood control measures for effective flood management, FEMD, DES, MoWHS