FLOOD HAZARD ASSESSMENT FOR CHUKHA DZONGKHAG

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

YEAR 2019

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Acknowledgement

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

1. National Center for Hydrology and Meteorology, Ministry of Economic Affairs, Bhutan
2. National Statistical Bureau, Bhutan
3. Dzongkhag Administration, Chhukha Dzongkhag
4. Phuentsholing Thromde

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

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 modeling 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	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.
MoAF	Ministry of Agriculture and Forest.
DDM	Department of Disaster Management.

Executive Summary

Chhukha Dzongkhag was established in April 1987, coinciding with the beginning of the sixth plan. The Dzongkhag has one Drungkhag and 11 Gewogs Viz Sampheling, Bongo, Bjabchho, Chapchha, Darla, Dungna, Getena, Geling, Lokchina, Metakha and Phuentsholing. Chhukha is the main entry points for import and commercial hub of the country.
The main objectives of the studies are listed below.

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

Gewog level assessment was carried out to capture all the flooding risk in Dzongkhag. It has been observed that higher discharge with sediment loads due to bed erosion, bank erosion and landslides caused by higher velocity and weak geology is seen as the main problem in the area. Moreover, rivers are mostly seasonal (Runoff -fed) with no or significantly low discharge as compared to rainy seasons.
Barsa River was found to be most critical river where study is not carried out. Hence, the detailed assessment of Barsa River was carried out and hazard map is prepared using **Elevation and Euclidean distance** method.
The general recommendation on flood protection structural and typical cross-sections is provided for references only. Actual design and drawing can be carrying out only after site visit as the designed structure can be site specific.

The study recommends installation of permanent rainfall stations providing hourly data to represent the spatial rainfall pattern over the entire Barsa River catchment. Further, a proper study is to be done to select the best method for rainfall interpolation and estimation. The study also recommends that necessary equipment for acquisition of discharge data be installed along the river at suitable location for future updates of the flood hazard map.
The purpose of this study is only applicable for flood prone awareness programs and drafting the flood management plans. It is not recommended for any administrative purpose since other hazard might not been considered during the mapping.

Introduction

Background

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

In the year 2011, the Government of Bhutan expressed concern for damages caused by floods and had instructed the MoWHS to establish an institution to oversee all the flood management works in the country. So, in the following year 2012, a new Division named 'Flood Engineering and Management Division' (FEMD) under the Department of Engineering Services (DES) was created.

The mandates of Flood Engineering and Management Division are listed below, but are not limited to:

- ✓ Identification of flood prone areas
- ✓ Carry out Preliminary Flood Hazard Assessment Studies
- ✓ Design and Construction of Appropriate River Training Measures
- ✓ Fortification of towns and communities from flood
- ✓ Reclamation of land from flood plains
- ✓ Provide assistance to Local government in Implementation of Flood Alleviation Projects
- ✓ Planning and design of storm water drains.

One of the most important mandates for FEMD, DES, MoWHS is to conduct the preliminary flood hazard assessment for all the 20 Dzongkhags in Bhutan. After the assessment, necessary mitigation works are planned and implemented in the flood prone areas.

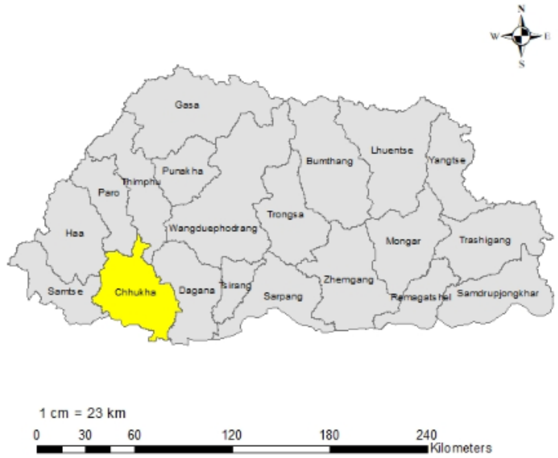

Figure 1: Map showing the Study area.

Objective

Objective 1: Detailed flood assessment of Barsa River in Chhukha Dzongkhag.

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

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

Study Area

Chukha Dzongkhag was established in April 1987, coinciding with the beginning of the sixth plan. The Dzongkhag has one Drungkhag and 11 Gewogs Viz Sampheling, Bongo, Bjabchho, Chapchha, Darla, Dungna, Getena, Geling, Lokchina, Metakha and Phuentsholing. Chukha is the main entry points for import and commercial hub of the country. Major hydro power plants, which are key source of national income, are also located in Chukha Dzongkhag. Chukha Dzongkhag covers an area of about 1,802 sq.kilometers with elevations ranging from 200 to 3500m above sea level. Overall arable land forms only around 4.63% percent of the total area of the Dzongkhag with average landholding of 5.6 acres per household. Majority of the people depend on livestock and subsistence agricultural farming. Mandarin, potatoes and cardamom are the principal cash crops in the Dzongkhag. Despite favorable climatic conditions, farm productivity is low due to terrain conditions and lack of adequate farm infrastructure in particular farm roads.
The climate in Chhukha Dzongkhag is hot, humid sub-tropical climate with an elevation ranging from 200 m to 3600 m above the mean sea level from the Phibsoo Wildlife Sanctuary in the west to the Manas National Park in the east. Around three quarters of its land is under forest cover mostly consisting of the broad leaf subtropical evergreen trees. The winter season is moderately cool and comfortable whereas summer season is hot and humid. The rainfall in winter is much

lesser than in summer. In 2017, the annual average maximum temperature for Phuentsholing Station was 29.0° C and annual average minimum temperature was 19.3°C respectively. The mean monthly maximum and minimum temperature from Chhukha station and Phuentsholing station is provided in Table 1 and Table 2 respectively.

Table 1: Temperature at Chhukha "Class C" station.

Month	Mean Monthly Maximum Temperature (Degree Celsius)						Mean Monthly Minimum Temperature (Degree Celsius)					
	2009	2010	2011	2013	2016	2017	2009	2010	2011	2013	2016	2017
January	25.2	23.9	24.6	25.0	22.9	28.6	13.2	14.0	11.6	10.1	9.4	21.5
February	28.1	27.8	30.3	28.7	26.2	26.1	15.7	13.6	20.1	15.2	18.6	20.7
March	31.1	30.9	30.0	33.3	31.4	28.7	17.9	17.7	19.7	18.9	21.7	15.2
April	30.8	31.0	31.9	34.1	30.4	30.9	19.7	19.9	19.1	20.4	21.4	18.5
May	31.5	31.7	32.7	34.2	31.3	30.6	20.7	20.4	21.3	21.7	20.1	19.6
June	32.3	30.4	33.4	33.9	29.3	30.2	22.8	22.0	18.0	23.1	20.7	22.2
July	32.0	31.3	32.2	34.7	29.7	29.1	23.1	25.3	21.9	23.2	23.6	22.0
August	31.3	31.3	32.8	34.2	31.8	29.5	22.8	23.7	23.8	23.0	24.4	22.3
September	33.1	31.6	33.0	34.6	32.7	30.0	22.7	22.9	25.2	23.2	23.0	21.8
October	31.2	31.7	31.8	31.6	32.2	29.2	22.0	20.9	19.3	20.8	22.1	19.5
November	28.4	29.7	31.6	27.4	31.7	28.1	18.4	18.6	19.4	15.6	21.1	15.4
December	25.0	26.1	23.8	25.4	30.8	26.2	15.4	12.5	14.9	13.0	21.7	13.4

Table 2: Temperature at Phuentsholing "Class A" station.

Month	Mean Monthly Maximum Temperature (Degree Celsius)						Mean Monthly Minimum Temperature (Degree Celsius)					
	2009	2010	2011	2013	2016	2017	2009	2010	2011	2013	2016	2017
January	25.2	23.9	24.6	25.0	22.9	28.6	13.2	14.0	11.6	10.1	9.4	21.5
February	28.1	27.8	30.3	28.7	26.2	26.1	15.7	13.6	20.1	15.2	18.6	20.7
March	31.1	30.9	30.0	33.3	31.4	28.7	17.9	17.7	19.7	18.9	21.7	15.2
April	30.8	31.0	31.9	34.1	30.4	30.9	19.7	19.9	19.1	20.4	21.4	18.5
May	31.5	31.7	32.7	34.2	31.3	30.6	20.7	20.4	21.3	21.7	20.1	19.6
June	32.3	30.4	33.4	33.9	29.3	30.2	22.8	22.0	18.0	23.1	20.7	22.2
July	32.0	31.3	32.2	34.7	29.7	29.1	23.1	25.3	21.9	23.2	23.6	22.0
August	31.3	31.3	32.8	34.2	31.8	29.5	22.8	23.7	23.8	23.0	24.4	22.3
September	33.1	31.6	33.0	34.6	32.7	30.0	22.7	22.9	25.2	23.2	23.0	21.8
October	31.2	31.7	31.8	31.6	32.2	29.2	22.0	20.9	19.3	20.8	22.1	19.5
November	28.4	29.7	31.6	27.4	31.7	28.1	18.4	18.6	19.4	15.6	21.1	15.4
December	25.0	26.1	23.8	25.4	30.8	26.2	15.4	12.5	14.9	13.0	21.7	13.4

The daily maximum rainfall recorded for 2017 was 285.4 mm on 12th August, 2017 at Phuentsholing Station. Further, the total annual rainfall for 2017 at Phuentsholing station is 4979.4 mm. The Table 3 and Table 4 shows monthly (maximum and total) rainfall at Chhukha and Phuentsholing station respectively.

Table 3: Monthly rainfall at Chhukha “Class C” station.

Month	Maximum Monthly Rainfall (mm)						Total Monthly Rainfall (mm)					
	2010	2011	2014	2015	2016	2017	2010	2011	2014	2015	2016	2017
January	0.0	4.6	3.4	12.8	8.0	2.8	0.0	8.6	3.4	17.0	18.0	5.0
February	8.0	30.0	19.8	8.2	18.8	10.4	10.8	33.8	27.2	13.2	19.8	17.2
March	14.4	20.2	6.0	27.2	8.0	30.4	53.6	37.2	15.0	56.4	50.5	105.5
April	21.8	12.2	25.2	68.4	20.5	37.4	122.9	77.2	51.6	257.8	80.1	113.4
May	66.4	19.8	120.4	78.0	31.0	28.6	214.1	120.8	228.2	182.7	152.5	170.8
June	59.9	35.4	48.6	41.1	22.6	24.0	389.8	208.4	267.2	223.1	189.8	154.5
July	136.4	34.6	30.0	65.8	121.3	96.2	519.0	195.7	170.4	249.2	571.8	278.6
August	26.0	16.6	152.2	74.0	10.6	112.4	193.3	115.5	485.0	306.2	54.7	325.2
September	22.6	40.6	44.6	59.4	45.1	29.6	155.3	184.3	187.3	202.4	296.4	198.6
October	18.0	12.2	4.6	5.4	68.2	0.0	66.1	20.6	5.4	13.6	137.9	0.0
November	1.4	7.0	0.4	3.0	0.00	20.0	3.4	20.2	0.6	4.4	0.0	47.0
December	0.0	0.2	0.0	3.4	-	0.0	0.0	0.2	0.0	3.9	-	0.0

Table 4: Monthly rainfall at Phuentsholing “Class A” station.

Month	Maximum Monthly Rainfall (mm)						Total Monthly Rainfall (mm)					
	2009	2010	2011	2013	2016	2017	2009	2010	2011	2013	2016	2017
January	0.0	0.0	0.0	2.8	9.0	4.7	0.0	0.0	0.0	2.8	20.9	4.7
February	70.0	25.0	26.2	3.0	0.0	5.5	70.0	25.0	37.9	3.0	0.0	9.0
March	25.0	79.0	26.2	48.5	22.0	18.2	81.0	210.7	42.2	79.8	137.9	92.4
April	86.0	112.0	60.1	41.8	33.0	118.4	221.7	423.3	208.8	115.2	66.4	325.4
May	94.0	80.0	110.0	70.0	22.0	86.2	275.0	394.4	245.5	270.3	130.6	450.9
June	74.0	130.0	82.0	84.0	22.0	81.0	544.4	894.3	848.2	574.9	140.9	488.6
July	110.0	155.0	97.5	162.5	165.4	280.0	708.3	926.0	706.2	934.5	1456.0	1317.7
August	100.0	75.2	104.0	125.0	51.0	285.4	828.9	610.5	524.4	641.1	144.2	1506.9
September	47.0	96.2	130.1	69.2	90.0	117.3	225.7	629.5	424.7	278.9	773.6	653.0
October	120.8	22.0	0.0	59.5	130.0	30.6	201.2	67.5	0.0	113.0	356.0	129.8
November	0.0	0.6	10.1	10.9	0.0	0.6	0.0	0.6	12.0	14.5	0.0	1.0
December	5.6	0.0	0.0	13.5	0.0	0.0	19.6	0.0	0.0	13.5	0.0	0.0

Chhukha Dzongkhag experiences frequent flooding causing extensive damages to the agricultural fields, infrastructures etc. This is due to the fact that most of the rivers in the Dzongkhag passes through the settlement. The Dhoti Khola(River) and Toorsa Khola(River) passing through Phuentsholing Thromde created havoc in 2016 causing extensive damages as given in Figure 2, Figure 3 and Figure 4.

Figure 2: Damages caused by Dhoti Khola.

Figure 3: Damaged caused to the properties at the confluence of Dhoti Khola.

Figure 4: Damages caused by Amochu.

Similarly, Barsa River also caused erosion along the river banks due to increase in the river discharge during the southern flooding in July, 2016 as depicted in Figure 5 and Figure 6. However, the flood protection structures along the river banks protected the settlements from the flood as seen from Figure 6 during the 2016 flood. The electric power station located on the right bank of Barsa River is on the risk of flooding as it is situated very near to the river.

Another extreme flood event caused by Barsa River was in August 2000, it caused major damage including the deaths of 5 people and also affected the habitat and industry. The buildings near the bridge on the right bank of Barsa River were flooded and partially destroyed. The flood was considered to be severe by the people experiencing it.

Figure 5: River bank erosion during the flooding.

Figure 6: Barsa chhu during the high discharge.

Figure 7: The flood protection structure protecting the housing colony.

The Bhalujhora River also caused damaged to the temporary road/ bypass connecting Phuentsholing to Pasakha. The Figure 8 shows the vehicles and people stranded due to increase in river discharge during the July, 2016 flood. The Bhalujhora Bridge as seen in Figure 9 at present can only be used by people and light vehicles during low flow and dry season as it was damaged by the flood in 2012. The heavy vehicles use bypass located on the upstream of the bridge to go to Pasakha industrial area. The river meanders and changes its course very season.

Figure 8: The vehicles stranded during the July, 2016 flood.

Figure 9: The Bhalujhora Bridge.

Methodology

Data Collection and Assessment

Hydrological and Meteorological Data

The hydro-meterological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). The location of the hydro-met stations is depicted in Figure 10.

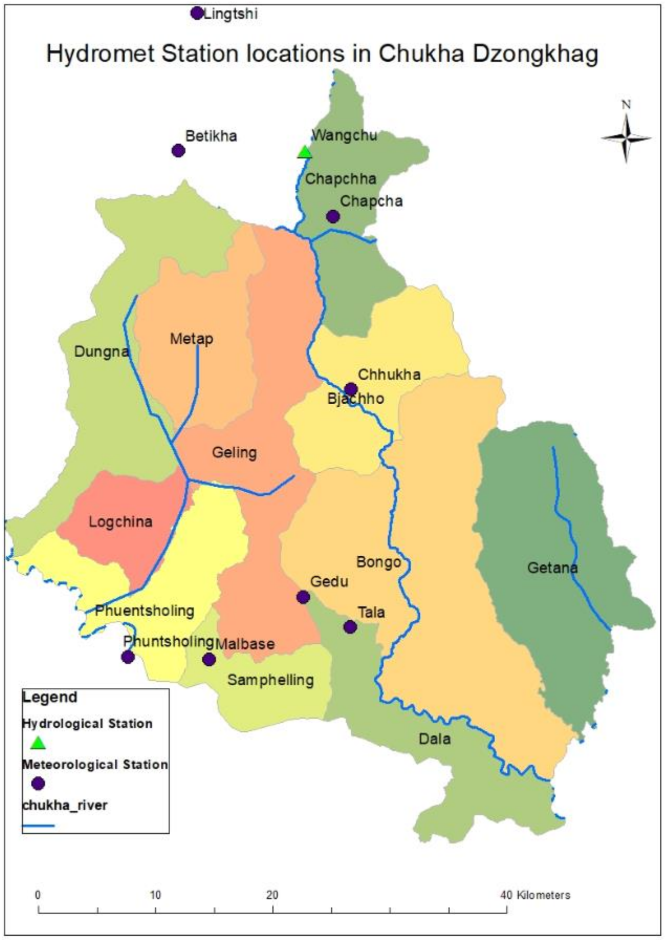

Figure 10: The location of the Hydro-met station in the study area

Meteorological Data

There are 5 meteorological stations available in the watershed study area. All the data have a temporal scale of daily data interval and the data availability varies from each station. The details of the met station are shown in Table 5.

Table 5: Meteorological station in the study area

Sl.No	Met station name	Temporal data available
1	Bjachho	1996/01/01 to 2017/12/31
2	Gedu	1996/01/01 to 2017/12/31
3	Tala	1996/01/01 to 2017/12/31
4	Malbase	1996/01/01 to 2017/12/31
5	Phuentsholing	1996/01/01 to 2017/12/31

Scientific Data

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

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

Sub-basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width are derived from the DEM.
Collected about 0.1km resolution Digital Elevation Model (SRTM30) has been used to create a basin model. SRTM30 is a global DEM covering the full extent of latitude from 90 degrees South to 90 degrees North, and the full extent of longitude from 180 degrees West to 180 degrees East, which freely available and has been contributed by organizations contributed by funding or source data: the National Aeronautics and Space Administration (NASA) and other. The horizontal coordinate system is decimal degrees of latitude and longitude and referenced to WGS84. The vertical units represent elevation in meters above mean sea level.

Site Assessment at Gewog Level

Site investigation is required to gather the information on the ground reality (e.g. settlements along the rivers, existing flood protection structures, river hydraulics, hazards it pose on the community etc.). The whole site is walked thoroughly to see any particular points of interest while carrying out the preliminary flood hazard assessment studies.
Though, there are 11 Gewog under Chhukha Dzongkhag, the team could only visit 8 Gewogs. The remaining three Gewogs of Dungna, Getena and Metakha couldnot be visited due to inadequate road connectivity and its distance. However, as per discussion with District Engineer, the team was informed that flooding is not the issue in the three Gewog as they are located on higher elevation. Furthermore, through telephonic conversation with the Gewog administration officer and the Gups, the information on the risk pose by river (flood) under their jurisdiction has been documented. The Gups informed that there are just few landslides posing threat to the Gewog road but it doesn’t affect the human settlements and agriculture land.

Bjacho Gewog center is located 10 kilometers away from Tsemasham town at global reference of 89°34’8.64” E and 27°3’22” N. The Gewog has a total population of 2300 with 212 households. Most of the people under this Gewog depend on agriculture farming and only few people rear livestock. Their main source of income is potato. Every year they grow potato in 350 acres of land and harvest about 10,000kg per acre. Since the place is located at a higher elevation with gentle slope, the settlements are not vulnerable to flood. However, the Gewog Administration pointed out some low-lying areas near Wang Chhu (River) as flood prone area. It was informed that the river has affected about 25 acres of agricultural land owned by 6 households as depicted in Figure 11and Figure 12.

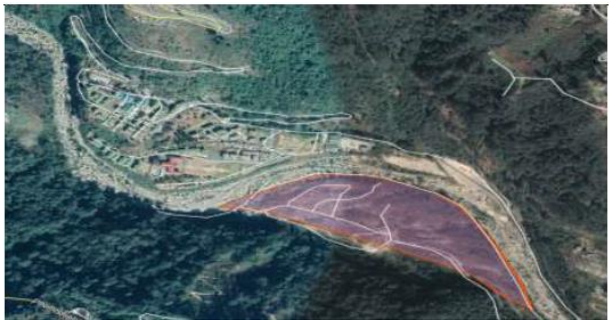

Figure 11: Location of the affected agricultural land.

Figure 12: Ground reality of the affected agricultural land.

Bongo Gewog center is located 10 kilometers away from Gedu town towards Pakshikha Central School and it has a total population of about 7000. Most of the people under this Gewog depend on agriculture farming for their livelihood and only few people rear livestock. Their main source of income is potato, cardamom, beans and oranges. Every year they harvest about 19.5MT of cardamom, 3 MT of oranges, 7 MT of beans and 1 MT of potato. Since most of the settlements are located at higher elevation with gentle slope, there is not much threat from flooding however, the Gewog administration informed the team that settlements in the low-lying areas near Wang Chu namely Peeping (also known as Jigme Chu), which is about 50 KM from Gedu are flood prone as shown in Figure 13. The Wang Chu has affected about 20 acres of agricultural fields owned by 7 households of about 40 people. This settlement is located at 89°43’52” E, 26°45’59” N with elevation of 169 m above the mean sea level.

The Figure 14 shows that the fertile agricultural land is empty and there are about 9 household on the left bank of Wang Chhu and therefore, flood protection structure of about 1500 m length is required to protect the settlements.

Figure 13: Settlements at the confluence of Wang Chhu and Jigme Chu.

Figure 14: Picture of Peeping (Jigme Chhu) under Bongo Gewog.

Chapcha Gewog center is located few meters away from Chhukha to Thimphu National Highway way towards Chapcha Middle Secondary School. The Gewog is divided into 6 Chiwogs and has a population of about 3000 with 400 households. The people mostly depend on agricultural farming for livelihoods and few people rear livestock. Their main source of income is potato and chilies. Every year they grow potatoes in about 900 acres of land and harvest about 35000kgs of potatoes in addition to 30000kgs chilies per acre respectively. The villages own about 200 cattle only. The villages in this Gewog are not prone to flood as they are located at a higher elevation as shown in Figure 15.

Figure 15: Flood prone area near Damchu River in Chapcha Gewog.

Figure 16: Damchu River in Chapcha.

However, a hotel at Damchu is vulnerable to flood from Damchu River as depicted in Figure 16. This hotel is located at 89°21'21" E, 27°14'10" N with elevation of about 2026 m above the mean sea level (msl). Damchu River flows directly towards the hotel. During the lean season, the river discharge is low posing no risk to the hotel. However, there is a threat to the hotel during the rainy season in future and therefore, the team proposes a flood protection structure of about 100m length along the left bank. Furthermore, there is a stone crasher above the hotel near the river leading to widening of the river flow path posing more threat to the hotel.

Dala Gewog center is located about 7 kilometers away from Gedu town towards Dala Hydro Power Plant. The Gewog has a total household of about 882 with a population of about 8000. Majority of the people in the Gewog depend on agriculture farming for their livelihood. Their main source of income is cardamom and oranges and every year, they harvest about 8,814 kgs of cardamom.

Most of the villages in the Gewog are located at a higher elevation and therefore, there is no threat of flooding. However, the team observed few landslides in Gangu Village due to poor geological condition of the soil in the area as shown in Figure 17 . Further, low lying areas near the Wang Chhu called Lamey are flood prone as shown in Figure 18.It has been observed that about 30 acres of agricultural land owned by 7 households of 40 people has been affected by Wang Chhu. This settlement is located at 89◦ 43'52" E longitude and 26◦ 45'59" N Latitude with elevation of 169 m above the mean sea level.

In Lamay Village under Darla Gewog, the team observed vacant agricultural fields near the river. This land is owned by 12 household. According to the shopkeeper from Lamay, his kitchen was washed away by Wang Chu (River) during 1990s flood. In order to protect the settlements on the right bank of the river, there is a requirement of 150 m length of flood protection structures.

Figure 17: Lamay (aka peeping) under Darla Gewog

Figure 18: Landslide in Gangu Village in Darla Gewog.

Logchina Gewog located 15 kilometers away from Phuentsholing town at global reference of 89◦21’8.47” E and 26◦53’49” N. The Gewog has a total population of about 3013 people with 397 households. The total agricultural land in the Gewog is around 1786 acres. Most of the people under this Gewog depend on agriculture farming and also rear livestock numbering about 1500. Their main source of income is ginger, cardamom and orange. Every year they cultivate around 40 acres of land for ginger only and harvest about 1000kgs per acre. This Gewog is usually inaccessible from Phuentsholing in summer due to swollen Ammochu. Most villages in this Gewog have no flooding threat as it is situated at a higher elevation. However, as per Gup, the Chimti Khola has eroded base of Chimti village and also affected 8 acres of agricultural land owned by 8 households as depicted in Figure 19 and Figure 20.

Figure 19: Flood prone area in Chimti village at Lokchina Gewog.

Figure 20: Location of Pa Chu, Chimti Chhu and Landslide at Lokchina.

As per the Gewog official, the Pa Chhu has also affected 3 household and 22 acres of agricultural land at Gewog boundary between Lokchina and Dungna.

Geling Gewog has a total population of about 1300 people with 180 households. The total agriculture land owned by this Gewog is about 1712 acres. Most of the people under this Gewog depend on agriculture farming for livelihood. Additionally, another main source of income is from livestock. They grow cardamom in 100 acres of land and harvest about 200kgs per acre. Since, the Gewog boundary lies along the Chukha-Phuntsholing highway, the farmers own about 50 numbers of vehicles. Most of the villages in the Gewog are located at a higher elevation and therefore, there is not so much flooding threat to the community as per the site investigation.

Phuentsholing Gewog is located 7 kilometers away from Phuentsholing town towards Lokchina Gewog at a global reference of 89°22'29" E, 26°53'52" N with elevation of 646 m. The Gewog has a total population of about 7000 people with 700 households. Majority of the population under this Gewog depend on agriculture farming for their day to day livelihood and only few people rear livestock. The main source of income in the Gewog is ginger and cardamom. Every year they grow ginger in about 150 acres and cardamom in 100 acres of land.
In the past, due to landslide at Dogona village, the entire village comprising of 21 households was relocated to other safer area. About 30 acres of land were damage by the heavy rainfall at Dogona village. Since the Gewog is situated at a higher elevation with gentle slope, there is not so much threat of flooding in the area. However, during heavy monsoon, all runoff drains towards the city boundary as depicted in Figure 21 causing flash flood and creating havoc in the downstream portion of catchment.

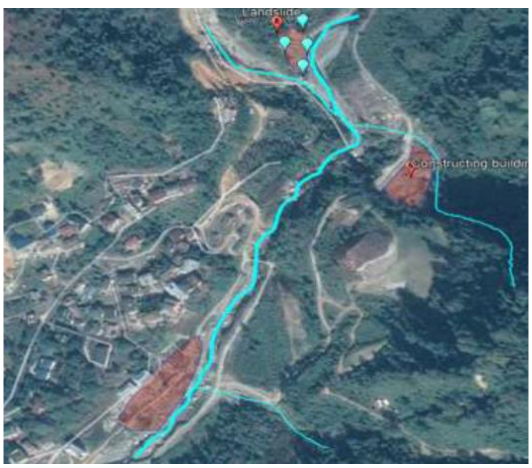

Figure 21: Tributaries of Om chu (River) in Phuentsholing.

Figure 22: Construction on the left bank of a tributary of Dhoti Chhu (River).

During the site visit, it has been observed that the people are constructing houses within the flood plains as given in Figure 22 and thus, their vulnerability to the flooding is increased.

Sampheling Gewog is located 15 kilometers away from Phuentsholing town at an elevation of about 332 m above the mean sea level. The Gewog has a total population of 6000 with 550 households. Their main source of income is livestock and betel nut. The people grow betel nut in about 6 acres of land. Most of the industries are located in this Gewog, therefore the farmers own about 600 vehicles. There are three Rivers in this Gewog as given in Figure 23. In this Gewog, Balujora River does not pose threat to the settlements within the Gewog boundary. Similarly, the Barsa River poses minor threat to the communities within the Gewog boundary. The swollen Barsa River only poses threat to the village road during the rainy season as given in Figure 24. According to Gup, more than 40 vehicles ply the village road every week to transport milk from Gurung Dara to dairy farm. The team recommends construction of 200 m long wall to protect road erosion by the river at the base.

Figure 23: Location of three Rivers (Bhalujora, Barsa and Singye River).

Figure 24: Erosion at the road base by Barsa chu above BPC sub-station at Pasakha.

However, as the Bhalojora and Barsa Rivers passes through the Thromde boundary, the threat to flooding increases. On the other hand, Singye River doesnot pose threat to the settlements both within the Gewog and Thromde boundary.

Dungna Gewog is located about 70 kilometers away from Phuntsholing-Chukha highway. The Gewog has 5 Chiwogs and its total population is about 1024 people with 167 households. The Gewog shares its boundary with Haa and Samtse Dzongkhag. The main source of income in this Gewog is livestock and cardamom. Cardamoms are grown in about 157 acres of land and the people harvest about 160kgs per acre every year. The Gewog is connected with Gewog road and people owned about 9 vehicles.

This Gewog faces problem due to heavy monsoon rain at Dagchulum Chu and has requested flood protection walls at both banks. In 2016, the river affected 12 acres of agriculture lands. There are two more streams in the Gewog such as Chuilum Chu (Irrigation channel) and Chukti Chu. The bridge across Chukti Chu was washed away in 2016.

Metakha Gewog is located about 80 kilometers away from Phuntsholing-Chukha highway. The Gewog consists of 5 Chiwog and its total population is 960 people with 108 households. The Gewog depends on agriculture farming for livelihood. They grow all sorts of grains (maize, wheat, burly and rice) in 720 acres of land. The Gewog is connected with Gewog road.

Regarding the threat from flooding, Menlam Chu doesn't pose threat to the settlement as per the Gewog official.

Getana Gewog is located about 81 kilometers away from Gedu. The Gewog boundary shares its boundary with Dagana Dzongkhag. This Gewog is the farthest from Dzongkhag center. It has 5 Chiwogs and the total population is about 1550 people with 152 households. Their main source of income is cardamom. Cardamoms are grown in 100 acres of land and people harvest about 200kgs per acre every year. This Gewog has about 200 cattles and people own about 23 vehicles as it is connected with Gewog road. It has no threat of flooding.

Phuentsholing Thromde has following rivers cause havoc rainy seasons:

- ✓ Amochu (Toorsa River)
- ✓ Om Chhu (River)
- ✓ Barsa Chhu(River)
- ✓ Balujora Chhu(River)
- ✓ Singye Chhu(River)

Ammo Chhu (Toorsa) and Om Chu are the two main rivers passing through the settlements in Phuentsholing Municipality as given in Figure 25. The rivers in summer bring lots of sediments and it is deposited within the city leading to change in the flow path of the river.

Figure 25: Satellite image of Amochhu and Om chu at phuntsholing.

Figure 26: Settlement along Torsa river at Phuntsholing.

During the site investigation, it has been conveyed by the local residents that there is no difference in elevation between the river bed level and the settlements along Toorsa River as depicted in Figure 26. This is due to the deposition of the sediments by Amo Chu (Toorsa) River. However, there is an upcoming land reclamation project for Amochu and the LG officials are confident that the project is going to take care of flooding risk from Toorsa Chhu.

On the other hand, Omchu (Doti khola) was found to be a critical river as it poses threat to lower part of the Phuntsholing town and the RICB colony. The Thromde has been investing huge amount of money for construction of flood protection structures along Doti Khola and there are also lots of existing flood protection structures along Om Chhu. Further, a study to assess the risk of flooding from Dhoti Khola has been outsourced to a consultancy firm under UNDP funding. This study will focus on providing an appropriate mitigation measure for Dhoti Khola to reduce the vulnerability of the communities to flooding.

The Pasakha Industrial state is within the Thromde Boundary, therefore the three rivers such as Balajhola (seasonal), Barsa (perennial) and Singye Chu (perennial) as depicted in Figure 27 also is considered during the flood hazard assessment.

Figure 27: Image of Balujora, Barsa and Singye chu.

Figure 28: Balujora river posing threat to the BBPL factory at Pasakha.

During the site investigation, it has been observed that the stream Balujora and Barsa affects the local communities and industries during rainy season. The rate of erosion on these two streams is quite high due to poor geology of the area. There is lots of sediment deposit in the river causing meandering of rivers every season.

The Balujora River causes flooding risks to factories, restaurant, roads and shops as depicted in Figure 28 and the river bed level has risen. This has increased the risk of flooding along the River and therefore, there is a requirement of 1 km flood protection structure on the left bank of the river to reduce the risk of flooding.

Similarly, the Barsa River also poses threat to the Bhutan Power Corporation (BPC) sub-station located opposite to BCCL factory. Further, there is possibility of the river affecting the BCCL and BFAL's lower colony and school area in future. As per the local community, these rivers have caused flooding in the year 2000, 2009 and 2016. The Figure 29 and Figure 30 shows newly constructed flood protection structures near the colony and factory under NAPA-II project respectively.

Figure 29: Flood Protection Works along Barsa chu.

Figure 30: Flood Protection Works along Barsa chu.

It has also been observed that due to excessive siltation, the river flow path is constricted and this might lead to river breaching the bank along Barsa Chhu. Therefore, it is recommended that the sediments be dredged after every rainy season to ensure that the river have enough flow path. The collected sediments after quality assurance can be marketed to recover the cost of maintenance of the stream. The third stream, Singye Chhu hasn’t affected the communities as of date because there are flood protection structures in place. However, there are chances of the stream affecting the factories and agricultural fields in future.

River cross section survey

Taking cross-section survey of a river channel is important while conducting river analysis to find the river discharge, velocity, river profile etc. Cross-sections are required to represent channel geometry in a river hydraulic model. The accuracy of the simulated water levels and the floodplain delineation largely depends on the shape as well as extent of these cross-sections. For the assessment, survey was done using total station to get the cross-section data. The crosssection survey of Barsa Chhu was carried out by FEMD, DES, MoWHS in March, 2018. About 36 numbers of cross-section data were collected along Barsa Chhu.

Development of Model

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. All the DEMS were corrected as per the site location and resampled to create a terrain for the 2D hydrodynamic model. The results of the models were compared and it was found that ALOS 10m DSM represented the study area better than other globally available DEM. Thus for this study, ALOS 10m DSM was used.

Model setup

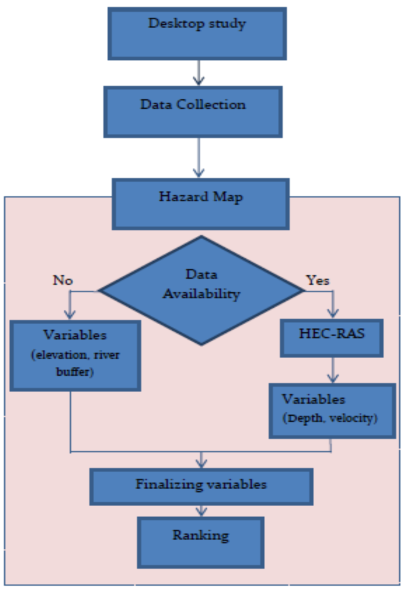

Figure 31: Methodology adopted for the developing the Hydrodynamic Model.

The flood hazard map can be prepared based on different variables such as flood depth, flood duration, velocity, rainfall, elevation, soil and distance from the river. The variables to be used for flood hazard map were based on the availability of the data for Barsa Chhu (River). The variables such as flood depth, flood duration and velocity are to be gathered after running HEC-RAS model. The input for the model is the river discharge, river cross-section and DEM (Digital Elevation Model). Therefore, cross-section survey for river was conducted. However, due to lack of discharge data for Barsa Chu (River), HEC-RAS could not be used. Hence, the variables such as flood duration, flood depth and velocity couldnot be taken into consideration for preparation of flood hazard map. The Table 6 shows the justification on considering only few variables to prepare flood hazard map for Barsa Chhu.

Table 6: Variables for flood hazard map.

Sl.No	Variables	Remarks
1.	Flood depth	Couldn't be considered since HEC-RAS could not be run due to lack of discharge data.
2.	Flood duration	
3.	Velocity	
4.	Rainfall	Though there are two rainfall stations near Barsa Chhu, it could not be used to run rainfall-runoff model due to lack of relevant parameters such as soil data, land cover data etc. for the Barsa Chhu catchment.
5.	Elevation	This variable is being considered.
6.	Soil	Couldn't be considered due to lack of soil data.
7.	Distance from the river	This variable is being considered as planners use a standard buffer zone near water bodies (river, stream etc.)

For preparation of flood hazard map, two variables such as elevation and distance from the river have been considered important in this study. The Table 7 gives the detail of the ranking and weighting:

Table 7: Classes and ranking of variables

Variable	Classes	Ranking	Weighting	Remarks
Main rivers (River buffer)	0 – 30 m 30-100m >100m	2 1 0	25	As per the standard use by planners.
Elevation	<= 320 m 320-360 m 360-400 m >400 m	3 2 1 0	75	The elevation is used from the DEM and it has been given ranking as per the judgment of the Engineer.

The high ranking in case of river buffer are given to the nearer infrastructures since, it is more vulnerable to the flood. The ranking for the low elevation areas are higher, since river can easily

inundate the low-lying areas. Further, the weightage of 75 is given to the elevation because of the past flooding experiences. It has been observed in the past that low lying areas near the river are mostly inundated during flooding.
After finalizing the variables, the flood hazard map has been prepared using raster calculator in GIS.

Result Analysis and Conclusion

The elevation map in Figure 32 is generated from Digital Elevation Model (DEM) of 30-meter resolution. Similarly, the river buffer in Figure 33 is calculated using Euclidean distance in spatial analyst tools.

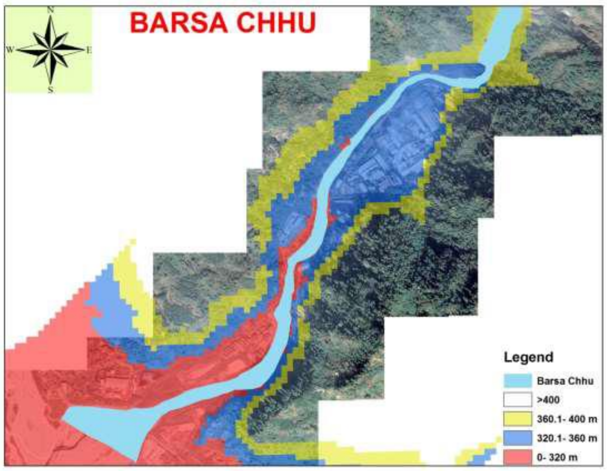

Figure 32: Elevation Map for Barsa Chhu.

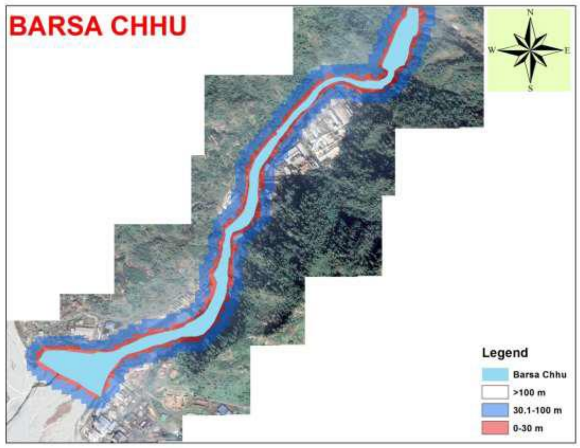

Figure 33: River Buffer for Barsa Chhu.

The flood hazard map as shown in Figure 42 has been prepared based on the given weights for river buffer and elevation using raster calculator in GIS. The weight of 75 is given to the elevation data and 25 are given to the river buffer. Both the maps are then overlaid to prepare flood hazard map for Barsa Chhu using the equation in raster calculator as follows:

(*River Buffer *25+Elevation *75*)

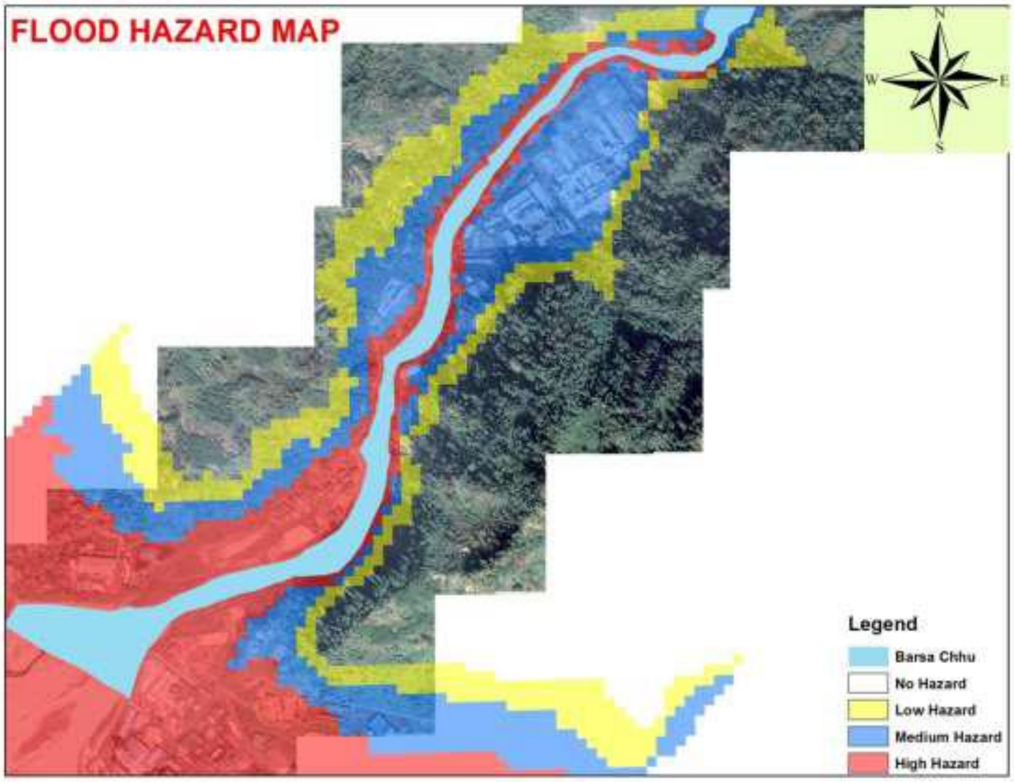

Figure 34: Flood Hazard Map for Barsa Chhu in Pasakha.

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

Further, after the preliminary flood map is prepared, the flood map should be validated to determine the reliability and accuracy of the generated flood hazard maps by comparing the actual flooding data from the field to the flooding that was generated.

Interventions

Gabion Walls

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 35. 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.

Advantages

1) The construction materials for the gabion walls are easy and cheaper to transport and use at site. (Stones and gabion boxes)
2) The flexibility of the wire mesh and the stones results in their modularity and ability to be stacked in various shapes.
3) It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.
4) In some cases, strength of gabion walls may increase with time as silt and vegetation fill the voids and reinforce the structure.
5) Their permeability allows the gabion baskets to drain water easily preventing buildup of water pressure behind them.
6) They are environmentally friendly (green alternative) and requires no special masonry or skilled labor to construct it.
7) In some areas, gabions might be the only practical choice, particularly in remote sites that are off limit or inaccessible to heavy machinery.

Disadvantages

1) The life expectancy of gabions depends on the lifespan of the wire, not on the contents of the basket.
2) Aesthetically not pleasing to sight.
3) When the velocity of the streams and rivers are high, the gabion mesh baskets can tear open, spilling the rock fill.
4) The gabion baskets are easily damaged by corrosion and also debris floating in the water.
5) The damaged gabions baskets are hazardous to public safety.
6) The gabion walls on failing will result in releasing non-indigenous stones in that area.

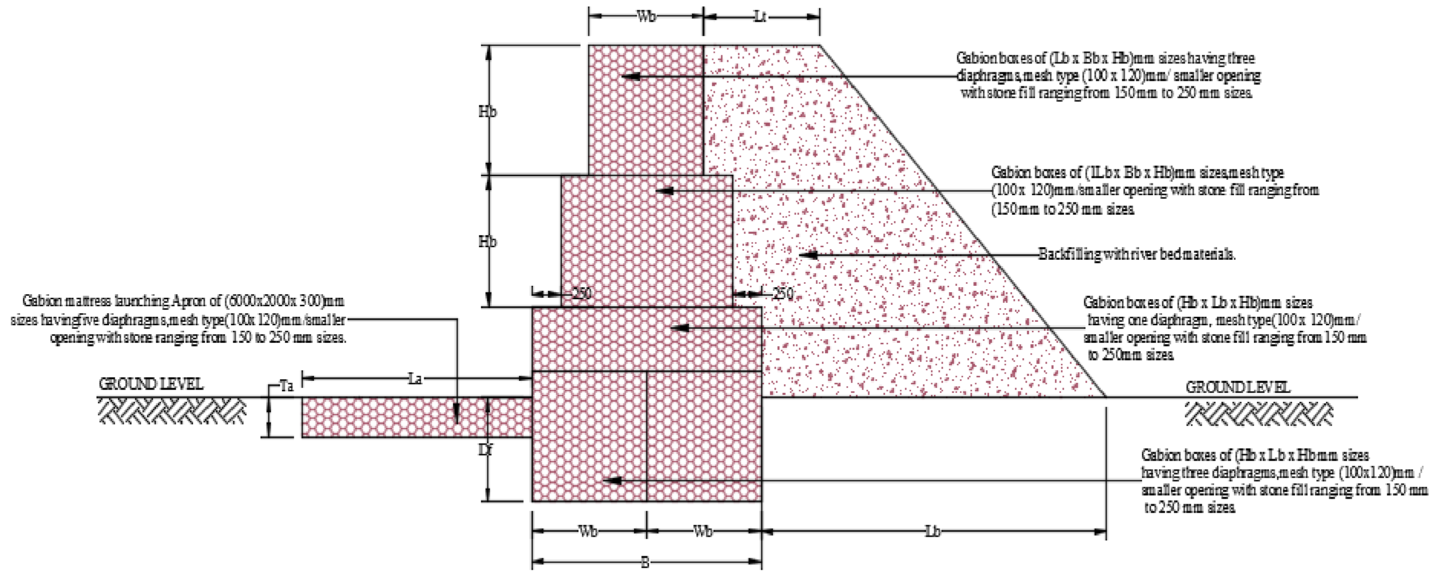

Figure 35: Typical cross-section of gabion wall

Gabion Revetment

The revetments are sloping structures placed on the bank of the river to protect it from erosion by absorbing the energy of the incoming water. Prior to revetment construction, the existing ground should be stabilized by grading to an appropriate slope to prevent slide failure of the revetments after construction. If required, fill material should be added to achieve uniformity and it should also be free of large stones. Finally, it should be firmly compacted before the construction of revetment begins. The revetments are made of different materials such as plain cement concrete, articulating block mattress, gabion mattress etc. The Figure 36 shows a gabion revetment used to reduce the impact of flood water during flooding in southern part of Bhutan

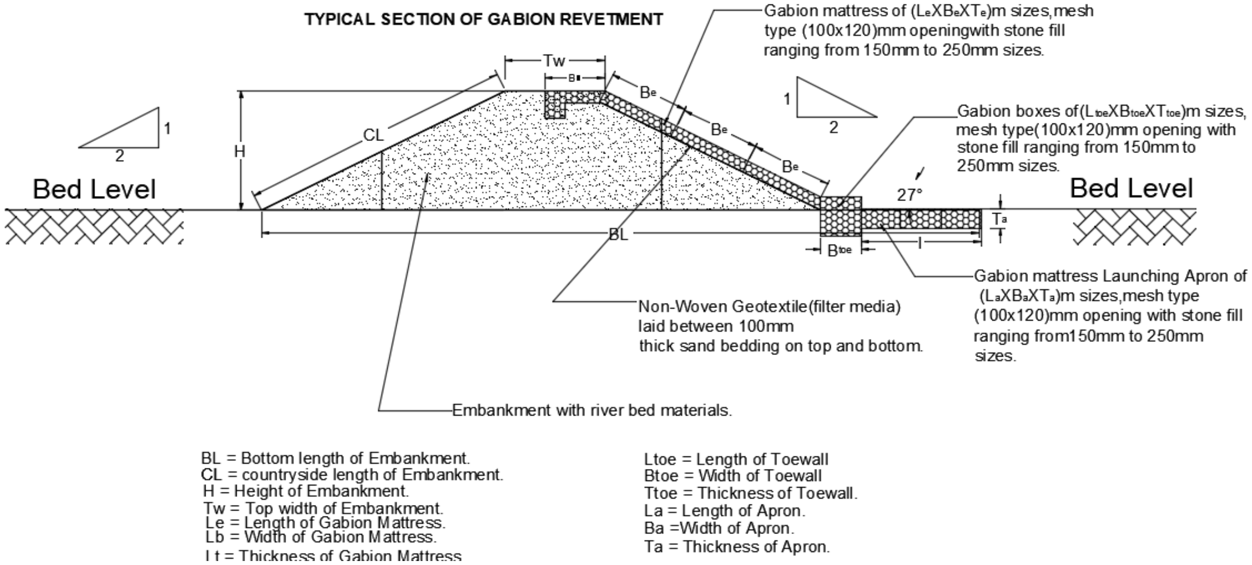

Figure 36: Typical cross-section of Gabion revetment.

Advantages

1) The construction materials for the gabion revetments are easy and cheaper to transport and use at site. (Stones and gabion boxes)
2) The flexibility of the wire mesh and the stones results in their modularity and ability to be stacked in various shapes.
3) It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.
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6) The gabion revetment on failing will result in releasing non-indigenous stones in that area.

Recommendation for flood management

- To produce more accurate Flood Hazard Map, it is recommended to use a high-resolution DEM. Further, more topographical survey is to be conducted for the areas near the rivers.
- The study recommends installation of permanent rainfall stations providing hourly data to represent the spatial rainfall pattern over the entire Barsa chu catchment. Further, a proper study is to be done to select the best method for rainfall interpolation and estimation.
- The study strongly recommends that necessary equipment for acquisition of discharge data be installed along the river at suitable location for future updates of the flood hazard map.
- To improve the quality of flood hazard map, it is recommended that modeling (hydrologic and hydraulic) should be done using any relevant software.
- In future, the variables are to be fixed based on the local conditions and then only, flood hazard mapping should be done.
- The weightage for the flood hazard map should be based on past studies and it should be also updated regularly.

Limitations of the study

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

- ✓ The elevation data required for the map was extracted from STRM. A major problem with using SRTM data for hydrodynamic modelling of a floodplain is that it is not "bare-earth" and contains information about vegetation and urban areas that block the water movement in the model.
- ✓ The Digital Elevation Model used in this study was SRTM DEM with 30-meter resolution which is freely available.
- ✓ There is no rainfall and discharge data for Barsa Chhu catchment resulting in using variables such as river buffer and elevation only for preparation of flood hazard map.
- ✓ The equation used in raster calculator for preparation of Flood Hazard Map is (River Buffer *25+Elevation *75) after discussion amongst the engineers in the Division.
- ✓ The classes, score and ranking for the variables in this study were finalized based on previous studies and also after discussion amongst the engineers.
- ✓ Some Gewog couldn't be visited because of road connectivity and distance, therefore the information documented in this report is via telephonic conversation.
- ✓ The purpose of this study is only applicable for flood prone awareness programs and drafting the flood management plans. It is not recommended for any administrative purpose since other hazard might not been considered during the mapping.

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