FLOOD HAZARD ASSESSMENT FOR TRASHIGANG DZONGKHAG

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

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Acronyms

FEMD	Flood Engineering Management Division.
Gamri and Khardi Chu	River flowing through Trashigang 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

Executive Summary

This flood hazard assessment study focuses only for Trashigang Dzongkhag and flood hazard map have been prepared for Gamri Chu and Khardi Chu at Rangjung in Trashigang. Most of the agricultural land, settlement, Institutions and infrastructures are located along the Gamri 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 Trashigang Dzongkhag.
- Identify and prioritize critical flood prone areas within Trashigang Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

A hydrodynamic model was developed for Gamri Chu and Khardi Chu in HEC RAS software. Digital Elevation Model with 30 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. The reliability of the maps has been affected by the inadequate spatial rainfall data for the study area. The Radhi meteorological station rainfall data is used in modelling since it is the nearest station. There is no hydrological discharge data for Gamri and Tshangkhu Chu. Land cover data and soil data has not been used for modelling purpose resulting in unrealistic ground condition.

The flood hazard areas along Gamri and Khardi Chu include crematorium, Technical Training Institute (TTI), Trashigang-Rangjung highway, settlements and agricultural lands.

This project focuses only on Rangjung area in Trashigang Dzongkhag along the river valley of Gamri Chu and Khardi Chu. Most of the villages are scattered and located along the Gamri Chu valley (from downstream of Rangjung TTI to the upstream of Gamri Bridge) 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

Trashigang Dzongkhag shares its border with Mongar Dzongkhag in the west, Samdrup Jongkhar and Pemagatshel Dzongkhag in the South, TrashiYangtse Dzongkhag in the north and Indian state of Arunachal Pradesh in the east. Trashigang is 551 km away from Thimphu, the capital city and is one of the largest Dzongkhags in the Kingdom. The Dangmechu, one of the largest rivers in the country passes through the Dzongkhag. The altitude elevation ranges from 600 m to over 4500 m above sea level. The climate is mainly temperate with an annual rainfall between 1000 mm and 2000 mm. The lowest human settlement is found at an altitude of 550 m above sea level at Deno of Lumang Gewog and the highest at Merak at an altitude of 4600 m above sea level.

Trashigang Dzongkhag has a total area of 2204.5 square kilometers. It has a total of 8,610 households with population of 71,768. The density of population is 33 per sq.km. The forest cover accounts for 77.87 percent of the total. The Dzongkhag has arable land of 3.64 percent of its total area.

The Dzongkhag Administration Headquarters and the main town are located at Mithidrang, which falls under Samkhar Gewog. The Dzong is used as the Dzongkhag Headquarters and also as the seat of Dzongkhag Rabdhey.

Trashigang Dzongkhag is administratively divided into three Dungkhags, 15 Gewogs and 79 Chiwogs including a Thromde. All the gewogs, except Sakteng are connected with motor able roads.

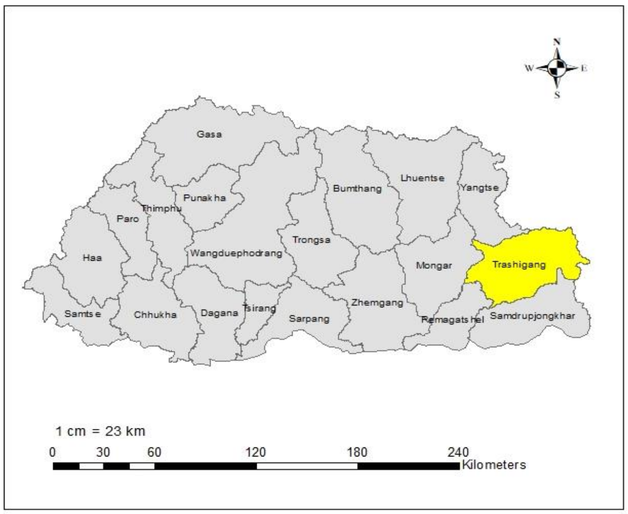


Figure 1: Study Area

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	Nagtshang/ Nangkhar/Gamku	Bartsham	Nangkhar Ye/Gamku Ye	Both residential & Agriculture	100 (approx.)	Previous flooding(date not available) have washed agriculture lands
2	Saling	Bidung	GamriChu	Both residential & Agriculture	100 (approx.)	Scouring takes place at the base of the hillock where the village is located
3	Tsulungdrang(opposite Lungtenzampa)		GamriChu	Agriculture and few residential	40 (approx.)	2004 flood washed away wetlands in the area
4	Bodhidrang, Rongthong	kanglung	Bodhidrang	Agricultural	600 (approx.)	Records of livestock and agricultural lands being washed away frequently. Major flood in 2004, wherein the bridge was washed away
5	Yonphupam	kanglung	Drainage/ outlet from Airport	Agricultural	300 (approx.)	In 2004, agricultural lands and livestock were washed away
6	Kangpara					
7	Khaling	Rashung/Pokpung	Jeri Chu	Residential and mini hydel	60	In 2004, washed away a house by flooding
8	Moshi CPS	Lumang	Phokchiri	School	175	Sliding occurred in 2004 after which it has grown every year and threatens the school
9	Yudhiri/Phaju Gongpa/Tsamang		Yudhiri	Both residential & Agriculture	240 (approx.)	Every year, flooding in the Yudhiri causes major landslides, which washes away prime agricultural lands on its banks
10	Chongdhiri/ Tongling Khatoe	Radhi	Chongdhiri	Both residential & Agriculture	300 (approx.)	Every year, flooding in the river causes major landslides, and

						washes away agricultural lands
11	Samtenrong Ye/Chhema/ Dekiling		Samtenrong Ye	Both residential & Agriculture	200 (approx.)	Every monsoon, the stream washes away agricultural lands on its banks
12	Lhakhang/Lem/Gazari	Phongmey	Dungjuri	Both residential & Agriculture	200 (approx.)	every year flooding in the Dungjuri causes major landslides, which washes away prime agricultural lands on its banks
13	Karma Gonpa		Kamrong Ri	Both residential & Agriculture	60 (approx.)	Flooding in the stream below the villages causes major sliding of the area posing risk to settlements
14	Phongmey CPS/Shingtsalo		Dorshing Ri	School and residential	250 (approx.)	In 2004, flooding washed away two houses, along with 4 students
15	Pusa	Sakteng	GamriChu	Both residential & Agriculture	50	every year scouring takes place on the bank
16	Tengma		Mani RongChu & GamriChu	Both residential & Agriculture	350 (approx.)	every year scouring takes place on the bank
17	Sakteng		Mani Ronchu	Residential	190 (approx.)	every year scouring takes place on the bank
18	Murbi		Murbirong Chu	Both residential & Agriculture	40	every year scouring takes place on the bank
19	Lungtenzampa	Samkhar	GamriChu and Thungdi Ri	Both residential & Agriculture	100	In 2004,major flooding washed away houses and agricultural lands
20	Trashigang Town		Mithidrang	Business and residential	2000 (approx.)	The lower market was completely flooded in 1994
21	Buna	Shongphu	GamriChu & Thungdi Ri	VTI, Agriculture and residential	1000(approx., including VTI students)	In 2004, major flooding washed away prime agriculture lands and

						a portion of VTI
22	Kharti		Kharti RI	Agricultural Land	20	2004 flood washed away wetlands
23	Phegpari Community	Thrimshing	Phegpari	residential	60(approx.)	Previously (date not available) washed away some of the lands where the current town is located
24	Chhiya	Udzorong	Thakhori Ye	Both residential & Agriculture	60(approx.)	It is a major sliding area caused by seeping water which comes out at the base, although there is no stream or river above
25	Kharthung/ Demkhar	Yangneer	Gudhiri Ye	Both residential & Agriculture	200(approx.)	Till 2007, flash floods occurred every year, which buried wetlands and threatened to pull down the village above

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	Kanglung-Trashigang	Cloud Brust	Bridge Destruction	22nd August 2016	21st August 2016	Rain due to cloud burst in washes away two bridges
2	Trashigang town	Mithidrang	Flash flood	23rd July 2018	22nd July 2018	Mud flow overflow.
3	Buna	Buna Stream	flash Flood	2rd August(BBS) 3rd Aug. Kuensel	1stAugust2018	Flash flood in Buna 12.5 km from Trashigang towards Ranggung washes off road, 1.7 acre as paddy fields and poultry farm.

Objective

Objective 1: Detailed flood assessment of Trashigang Dzongkhag.

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

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

Study Area

Trashigang town: The town lies to the east side of the valley above the Drangme Chu River just south of where it is joined by the Gamri River. Trashigang is the eastern terminus of the Lateral Road, Bhutan's main highway leading to Phuntsholing in the southwest.

The population of Trashigang was estimated to about 3000 in according to the 2005 census. Mithidrang River flows along the town of Trashigang.

Shongphu Gewog: Shongphu Gewog has an area of 92.4 sq. km located to the north east of Trashigang Dzong and has borders with Samkhar, Bidung, Radhi and Merak Gewogs of Trashigang Dzongkhag. Gewog has 7 villages viz Galing, Changme, Shongphu, Chaling, Yobinang, Gongtsephangma and Buna Rangjung.

Samkhar Gewog: Samkhar Gewog has a total area of 90.1 square kilometer with 84.25% is under forest coverage and 15.75% of land is utilized mainly for Chimsa, Chuzhing, Kamzhing, Pangzhing, Tsheri, Tsesa, Open grazing land, Developed pasture, Orchard and for Sokshing. The Gewog has about 630 households including Trashigang Throm with a population of approximately 6350+. The 6 major chewogs namely Rangshikhar, Pam, Samkhar, Khapti, Bikhar and Yenangbrangsa are all populated with more than 60+ household and over 1000 population.

The people of this Gewog mainly rely on the agriculture product like paddy, maize, potato and mandarin which are infect surplus. Other agriculture products like radish, beans and cabbage are also produced in large quantities. Paddy is followed by wheat in wetlands in some villages. Dry land is dominated by maize and potato. Pam area is known for spring potato production and Samkhar village is prominent for special local corn flake “Tengma” production. Nowadays most of the people of this Gewog are all highly interested in commercial dairy production because of the establishment of milk processing unit at Chennary, Trashigang. With the increase of dairy groups the number of Bio-gas plant construction is also increasing in the Gewog.

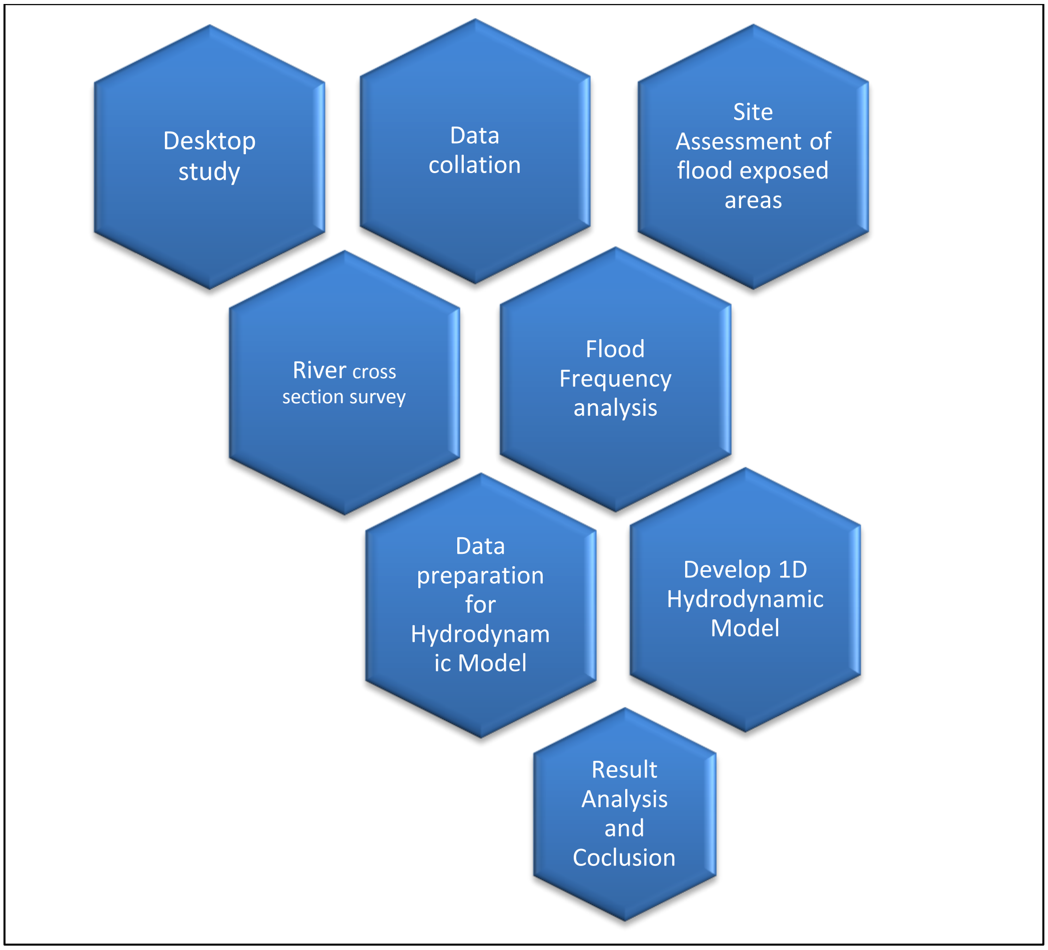
Phongmey Gewog: Phongmey gewog has an area of 101.20 sq. km. Gewog has 28 villages with 824 households. It is one of the rice producing areas with large paddy fields. The main products are paddy, wheat, soya-bean and walnut. Butter, cheese and egg form the main livestock products.

Radhi Gewog: Radhi is located some 30 km east of Trashigang Dzongkhag on a north facing slope. It is partly a dry Chirpine belt in its lower part and the upper part is covered with a cool broadleaf forest. It is drained mainly by two small rivers systems, namely Chongdiri in the east and Yudiri in the west. It covers 29 square km within an altitude ranging from 1,080 masl to 3,220 masl. The monthly average temperature varies between 12 degree Celsius to 22 degree Celsius and the average annual rainfall is1, 353 mm and is a part of the Gamrichu watershed. (Meteorology Section, DOP).

The main agricultural crops that are grown by people of Radhi are paddy, maize, soya bean, potatoes and vegetables, which are mostly used for household consumption except for rice which is mostly sold.

Radhi is a relatively small Gewog, it has 21 villages viz Tsangkhar, Dekiling, Dungsam, Radhi Pangthang, Khudumpang, Jonlapam, Jonla Tsatse, Tangthrang, Bongman, Chema, Melongkhar, Tsamang, Tonglingpam, Khatoe, Kadam, Drung Gonpa, Langteng, Tokshingmang,Naktshang, Phajogonpa, Langteng Sotshong with 758 households and total population of 5437.

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.

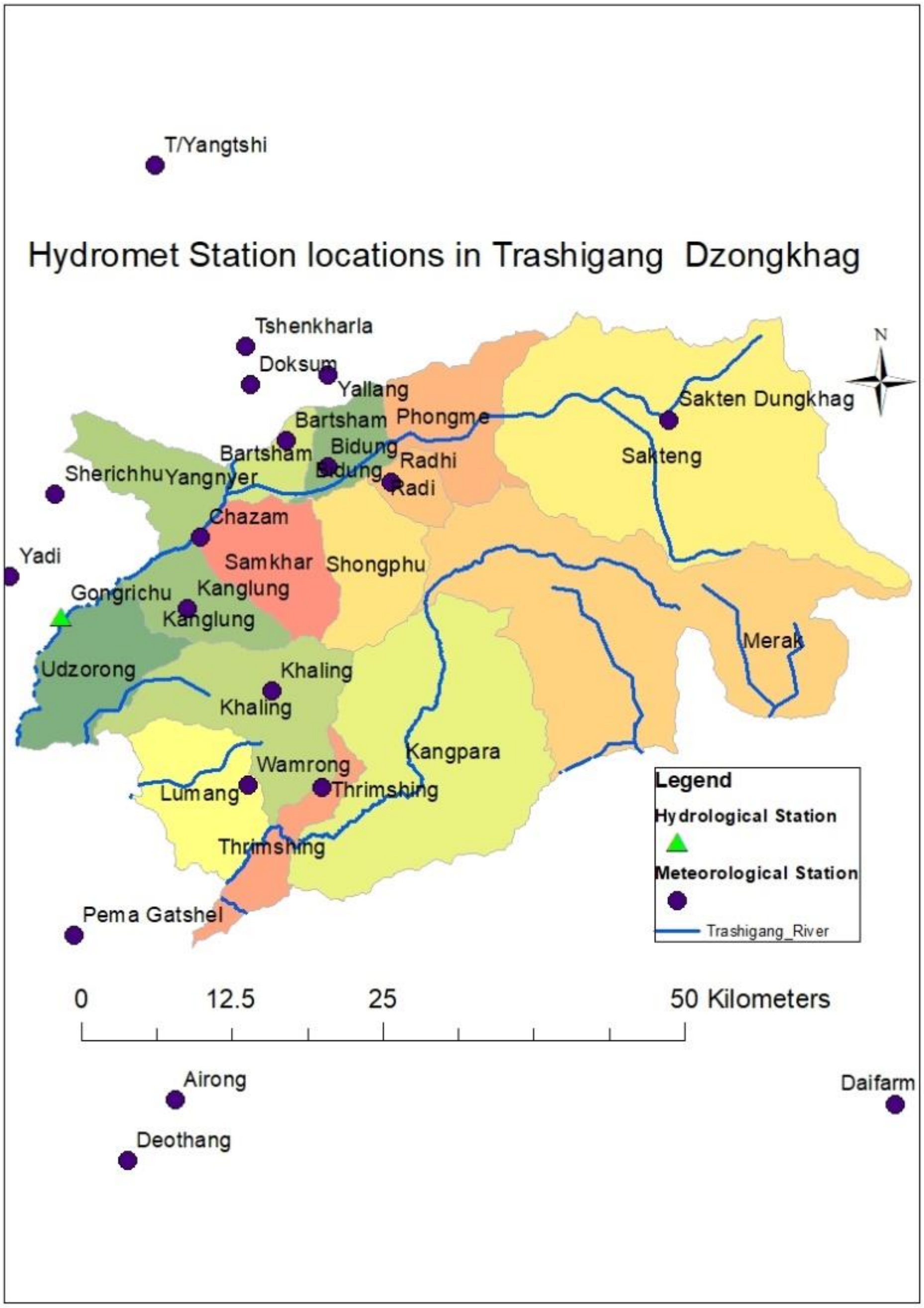


Figure 2: The location of the Hydro-met station in the study area

Meteorological Data

There are 8 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 3.

Sl.No	Met station name	Temporal data available
1	Kanglung	1994 to 2012
2	Chazam	1990 to 2012
3	Sakteng	2012
4	Radhi	1996 to 2014
5	Thimshing	2005 to 2012
6	Wamrong	2005 to 2012
7	Bartsham	2010 to 2012
8	Bidung	2012

Table 3: Meteorological station in the study area

Radhi meteorological station nearest Gamri and Khardi Chu.

Scientific Data

DEM (Digital Elevation Model)
Digital Elevation Model with SRTM 30 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.

Site Assessment at Gewog Level

Mithidrang Town: The team met with Municipal Engineer of Trashigang Dzongkhag.We had thorough discussions regarding the construction of flood defense works.We have also visited the site along with the Municipal Engineer and jointly measured the proposed works which will be carried out in fiscal year 2016-2017.
During the discussions,Municipal Engineer said that they have tendered out the works for fiscal year 2015-2016.The works includes 180 metres of RRM wall with plumb concrete and PCC channel which will start from end of existing channel at upstream towards north.The design and drawings for the same was prepared by Flood Engineering and Management Division.The Dzongkhag Administrations have some fund available,they have decided to construct RCC wall with PCC channel till existing highway bridge at town in this fiscal year.Shortly,Dzongkhag administration will issue work order for these works.

Proposed works for fiscal year 2016-2017 at Mithidrang.

Figure 3:Downstream of highway bridge

Figure 4: RRM wall at both banks.

Figure 3 is at the downstream of the highway bridge at the left where the stream usually hits directly. Here, the RRM wall is in curve shape because of the nature of the ground and the height is also quite low. During monsoon season when the water level is high, the river is hitting the curve portion of the wall directly and weakens the wall and sometimes overflow takes place. With existing building built close to the channel, there is no option of increasing the width of the channel. The Dzongkhag Administration have identified this area and proposed to demolish existing RRM wall spanning of 20 metres and replace with RCC wall.

Figure 4 shows the RRM wall at both the banks. This wall was constructed quite a long time ago. Average width of channel is 8 metres. Most of the channel surfaces are spoiled due to continuous flow of water. Therefore, Dzongkhag Administration have proposed to demolish the existing RRM wall at both banks spanning of 130 metres till the first wooden bridge and reconstruct the RCC walls at both banks including PCC channel. Average height for proposed RCC wall is 4 metres excluding first 20 metres span at left bank. At the right bank, on top of the RCC wall, they have also proposed to construct railing for the people to walk.

Figure 5: Location of proposed RCC wall

Figure 5 shows the location of archery ground at right bank. At the left bank, there are structures like pavilion and parking area. At this left bank, there is no wall constructed and scouring is likely to take place slowly which will pull down pavilion in future. In order to protect the structures, Dzongkhag Administration has proposed to continue with the RCC wall at the left bank between two wooden bridges which spans 106 metres. According to the Municipal Engineer, if budget is available they want to construct RCC wall with railing at right bank as well at the archery ground.

Shongphu Gewog.

Rangjung: The team met with the Offtg. District Engineer, Trashigang and had a small meeting with him. During the meeting, we have briefed him regarding our visit. He deputed one technician to accompany us to visit the flood prone areas and two helpers to assist in cross section survey at GamriChu, Rangjung.

As per the mandate of FEMD, flood hazard assessment studies and preparation of flood hazard mapping for five Dzongkhags has to be done annually. In this fiscal year, Trashigang Dzongkhag is one of it. For the preparation of flood hazard mapping, GamriChu in Rangjung is selected since it is a big river which flows along Technical Training Institute at Rangjung and major agricultural lands.

Figure 6: Location of washed wet land

Figure 7: Scoured area downstream of TTI, Rangjung.

Figure 6 above shows the starting point of the cross section survey. Before 2004 flood, river course was about 65 metres away from the present paddy field towards the river. According to the local people, about 20 acres of paddy field have been washed away by flood and river has meandered towards the paddy field and continued flowing through it. Presently elevation difference between river bed level and top of paddy field is 5.0 metres. However, maximum flood depth and areas of inundation will be shown in flood hazard map and accordingly appropriate mitigation works can be planned.

Figure 8:PCC revetment along Rangjung TTI

Figure 9: AB mattress along Rangjung TTI

Technical Training Institute is located at the left bank of GamriChu. There is only seven metres gap between TTI and river bank. AB mattress of span 215 metres and 85 metres have been provided at two locations and PCC revetment of span 150 metres have been provided at one location. The condition of PCC revetment appears good but AB mattress is deteriorating slowly.

Figure 10: Location ofcrematorium along of Gamri Chu.

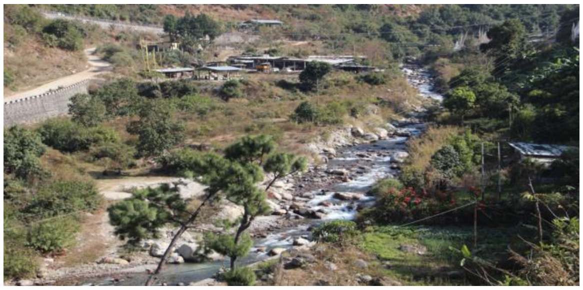


Figure 11: Khardi Chu

Gamri Bridge is crematorium, Gamri Bridge is sufficiently high. Crematorium is located at left bank of GamriChu and the area is quite flat which is vulnerable to flood. In this area above Gamri Bridge, we have done cross section survey of 365 metres upstream of Gamri Bridge which covers the crematorium area as well. Therefore, flood hazard map will show the exact areas of risk and depth of flood. Beyond 365 metres upstream of Gamri Bridge, the river is quite narrow and less risk of flood.

Before 2004, most of the areas at right and left banks of Khardi Chu were agricultural lands, after 2004 flood; it was completely washed away and caused huge losses to the land owners. Maximum flood depth at this area observed at site is 2 metres. Cross section survey of KhardiChu has also been done and realistic flood depth will be reflected in flood hazard maps.

Samkhar Gewog.

Lungten Zampa: Trashigang-Rangjung highway was washed away, washed away around 8 acres of paddy field, it has also washed away 11 houses by 2004 flood in Lungten Zampa. Suspended bridge at Lungten Zampa was also washed away. Presently, few shops and houses are located only 40 metres from the left bank of Gamri Chu. According to the Samkhar Gewog Gup, major flood like 2004 did not take place till now. Flooded area can be reclaimed by constructing appropriate flood protection works.

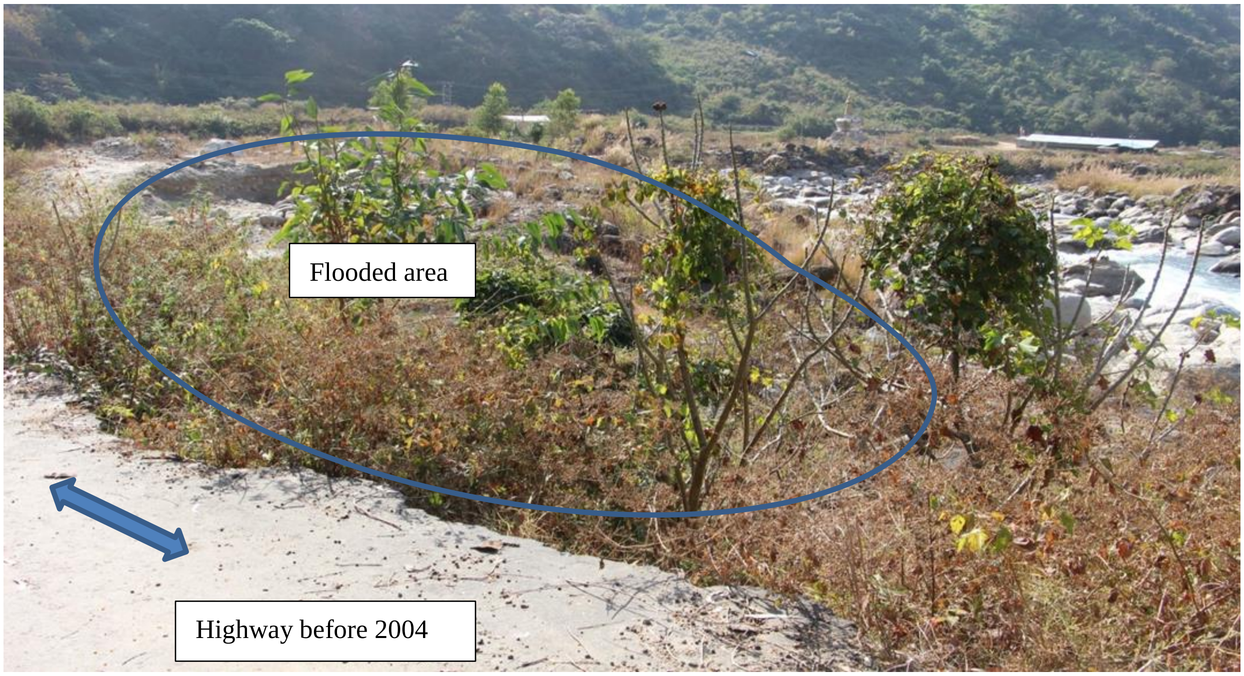


Figure 12: Flooded area at Lungten Zampa by Gamri Chu.

Thungdi Ri: Thungdi Ri joins the GamriChu just above the Lungten Zampa. Its coordinates is N=27° 20' 51" E=91° 37' 28" and elevation of 980 metres. Before 2004 flood, Thungdi Ri used to flow from left side of the bridge as shown above and the same river changed its course to other direction post flood. Since the river has already changed its course, the area looks quite dry and strong. However, in future, if major flood arises, the river might flow from previous water way as Well. The Bridge is located at safer height from the water surface at present.

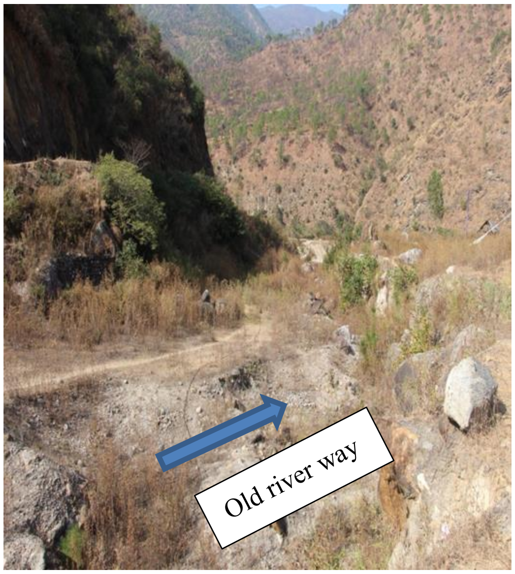


Figure 13: Thungdi Ri before 2004

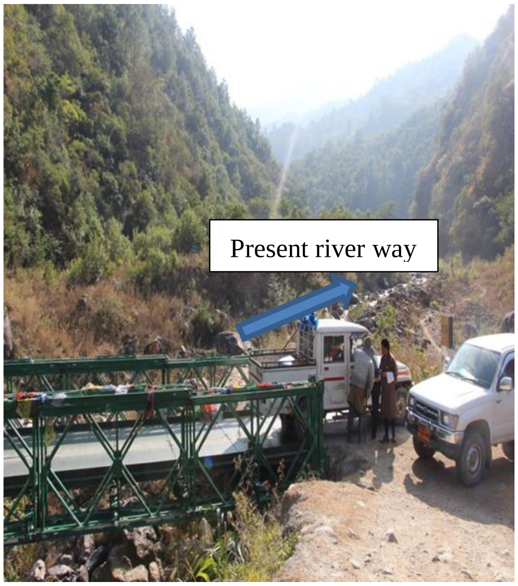


Figure 14: Thungdi Ri after 2004.

Phongmey Gewog.

Dungju Ri: Possess major threat to paddy field and farm road. Stream looks very small at present. During monsoon run off water from nearby catchment area collects here and adds its discharge. During 2004 flood, it has washed away large area of paddy field below the farm road. After 2004 flood, every year scouring is taking place and its further damaging the paddy field. As per our field observation, soil is sandy and silty.

Figure 15:Dungju Ri flow across farm road

Figure 16: Dungju Ri below farm road

Dorshing Ri: At present, we cannot see big discharge from this stream,vegetation has grown and the area has been stabilised.In 2004, this stream washed away two houses along with 4 students.There are still 13 house holds residing at left and right bank of this stream.Phongmey CPS is relocated at 50 metres left from the previous location.

Figure 17: Location of Phongley CPS before 2004 flood.

Radhi Gewog.

Samtenrong Ye: In Samtenrong Ye, there are two small streams flowing through paddy field. Areas between two streams were paddy field in the past. Due to water continuously flowing through the field, soil became saturated and slowly sinking and moving down the entire area. Dzongkhag and Gewog Administration have planted about 500 bamboo tress to stabilize the soil. Every monsoon, its taking away paddy fields. This area is in middle of the village. Major damage of paddy field happened long time back and the exact year and date is not available in the Gewog.

Figure 18: Location of two streams in Samtenrong Ye.

Chongdhi Ri.: Chongdhi Ri has threat to whole region of Chongling, Khatoe of Radhi Gewog. According to Radhi Gup, major flood was taken place in 1987-1988.Every year; it's causing major landslides and washes away agricultural lands. Gewog Administration has started planting trees at the source of this river. According to the Gup, slowly the flooded area is improving after trees plantation. However, it has already caused huge damage to the paddy field in the past. Since the river stretch is very long and area is vast, planting trees at both the banks could save existing paddy fields in future.

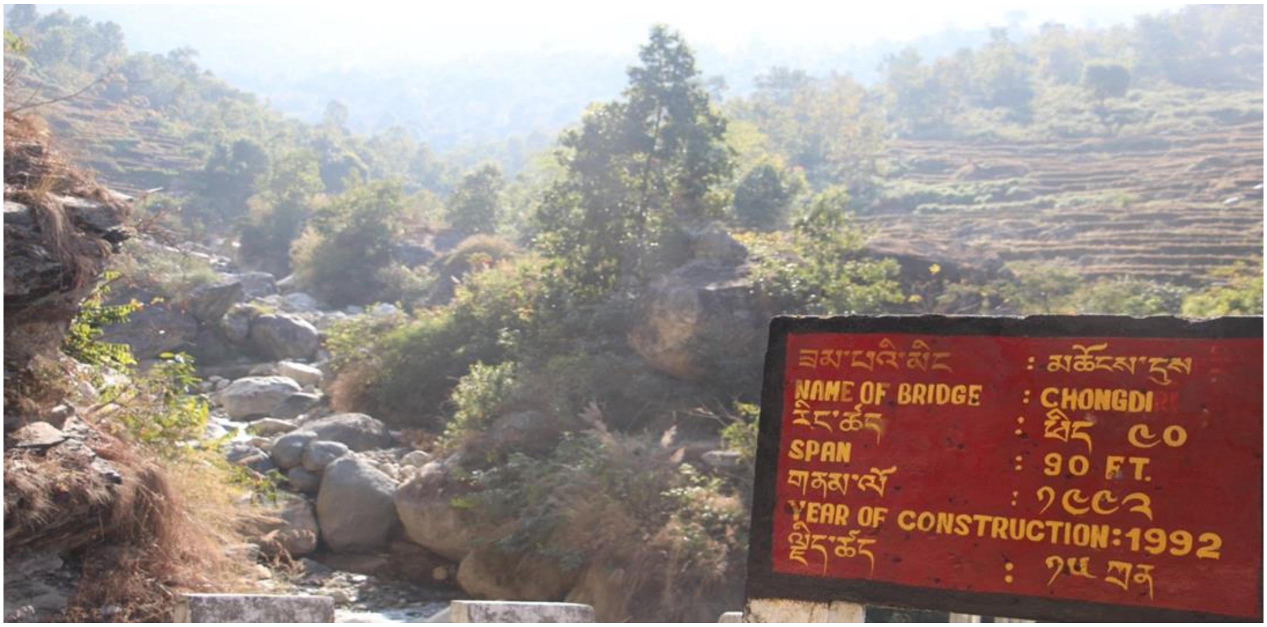


Figure 19: Chongdi Ri in Radhi Gewog.

River cross section survey

Cross section survey carried out for span of 4000 metres starting from downstream of Technical Training Institute having coordinates N= 27° 21' 15" E=91° 38' 34" and elevation=990m.It ends at two points above the confluence of GamriChu and Khardi Chu. One point 659 metres upstream of GamriChu and KhardiChu confluence. Its end point coordinates is N= 27° 21' 51" E=91° 40' 78" and elevation =1039m.Other end point from confluence is at Rangjung mini hydel having coordinates N= 27° 21' 29.33" E=91° 40' 13.65" and elevation =1089m. Its river name is KhardiChu which is a separate river and finally joins at GamriChu. It covers the span of 910 metres above confluence.

For the preparation of flood hazard map, GamriChu and Khardi Chu in Rangjung is selected since it is a big river which flows along Technical Training Institute at Rangjung and major agricultural lands. **Error! Reference source not found.** and **Error! Reference source not found.** represents the HEC-RAS schematic of Gamri Chu and Khardi Chu cross section respectively.

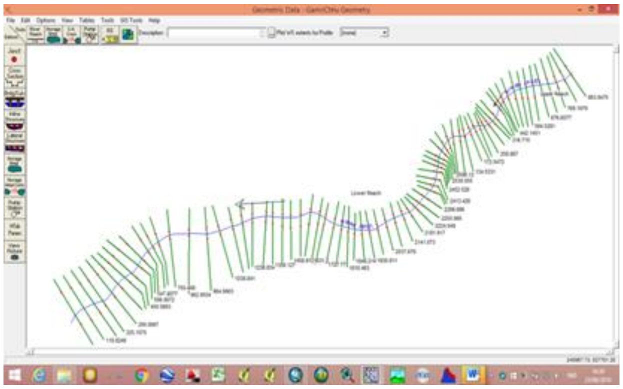


Figure 20: Cross section schematic of Gamri Chu

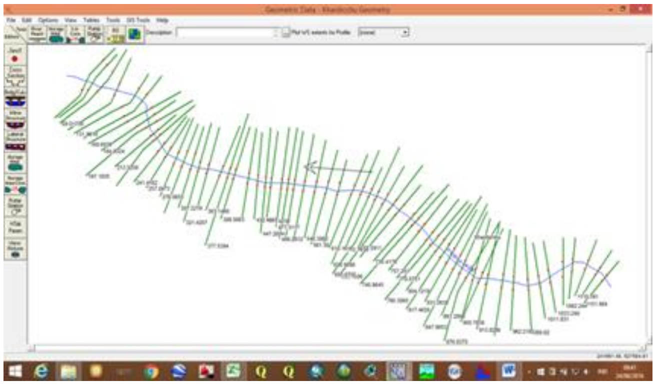


Figure 21: Cross section schematic of Khardi Chu

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'.

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

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

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

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

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

Gamri Chu and Khardi Chu observed discharge data is not available, therefore in this project rainfall data observed at Radhi meteorological station is used to calculate maximum discharge for 50 year return period. Gumbel probability analysis is carried out to calculate maximum discharge. In this project, rainfall data from 1996 to 2014 (18 years) is used to calculate maximum discharge by using Gumbel probability analysis for 50 years return periods.

The result from the Gumbel distribution for Radhi meteorological station is detailed in Table 4

Table 4: Flood frequency result using Gumble probability method for Radhi catchment area.

Return Period	Calculated probable values
2	46.1

5	67.7
10	82.0
25	95.8
50	113.6
100	126.9
500	140.2
1000	157.7

Rational method.

The Rational equation is the simplest method to determine peak discharge from drainage basin runoff. Therefore, this method is adopted to calculate the peak discharge.

Rational Equation: Q=KiA

The Rational equation requires the following units:

Q = Peak discharge, Cumecs
K= Rational method runoff coefficient
i = Rainfall intensity, mm/hour
A = Drainage area, Sq.km
The Rational method runoff coefficient (k) is a function of the soil type and drainage basin slope. In this project we have adopted k as 0.70 since the catchment area are mostly steep which contributes more runoff

Table 5: Probable discharge results using rational method

Gamri Chu	
Qp : Peak discharge(m^3/s)	**898.79**
K : runoff coefficient	**0.70**
I : mean rainfall intensity(mm/hr)	7.47
A: drainage area(km^2)	**618.60**
t1: travelling time to channel(min)	527.61
L: Longest channel(m)	**48417.53**
H:difference of altitude between channel top and outlet(m)	**3415.00**
H/L slope	0.07
t2: travelling time along longest channel(min)	198.06
tp= t1+t2 (min)	725.66
Rainfall mm/day 50 years (from Gumbel)	**113.56**

Khardi Chu	
Qp : Peak discharge(m^3/s)	**223.60**
K : runoff coefficient	**0.70**
I : mean rainfall intensity(mm/hr.)	17.21
A: drainage area(km^2)	66.83
t1: travelling time to channel(min)	173.42
L: Longest channel(m)	15409.00
H:difference of altitude between channel top and outlet(m)	3001.64
H/L slope	0.19
t2: travelling time along longest channel(min)	34.26
tp= t1+t2 (min)	207.69
Rainfall mm/day 50 years (from Gumbel)	**113.56**

Development of Model

Hydrodynamic model

The freely available ASTER DEM (30 m resolution) was used to prepare flood hazard map.

DEM preparation

Freely available ASTER DEM (30m resolution) covered study area is downloaded. The downloaded DEM is clipped for the study area. The Geographic projection is transformed into UTM. The final DEM is shown in Figure 22 for Gamri Chu basin. The DEM in TIN format is required for HEC-RAS model.

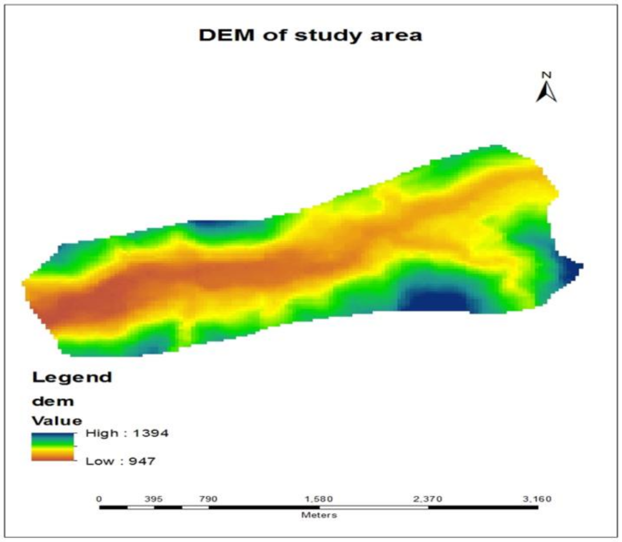


Figure 22: DEM of study area

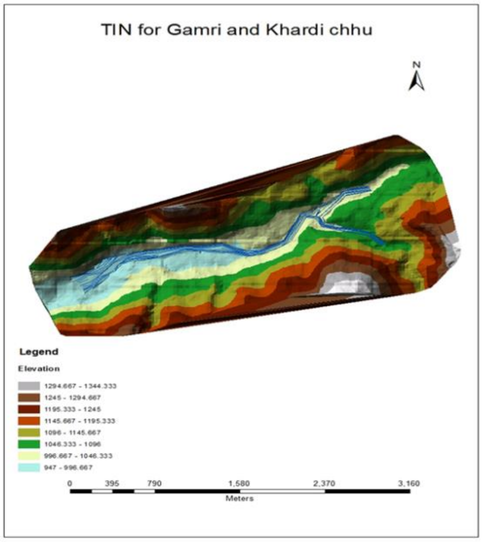


Figure 23: TIN of study area

TIN Preparation

A triangulated irregular network data model (TIN) is an efficient way for representing continuous surfaces as a series of linked triangles. Although both grids and tins can be used for surface representation, tins are especially useful for representing surface elevation, subsurface elevation and terrain modeling, especially when the represented surfaces are highly variable and contain discontinuities and break lines. The final DEM is shown in Figure 22 and TIN in Figure 23

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.

HEC-RAS 1D Model setup

River centerline is sketched with the help of given river network. The river cross-section data used in modelling are obtained from ASTER DEM (30m resolution).

The schematic of geometry in HEC-RAS for Gamri Chu and Khardi Chu are shown in **Error! Reference source not found.** and **Error! Reference source not found.** respectively. 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 0.05 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 50 year return periods.

Result Analysis and Conclusion

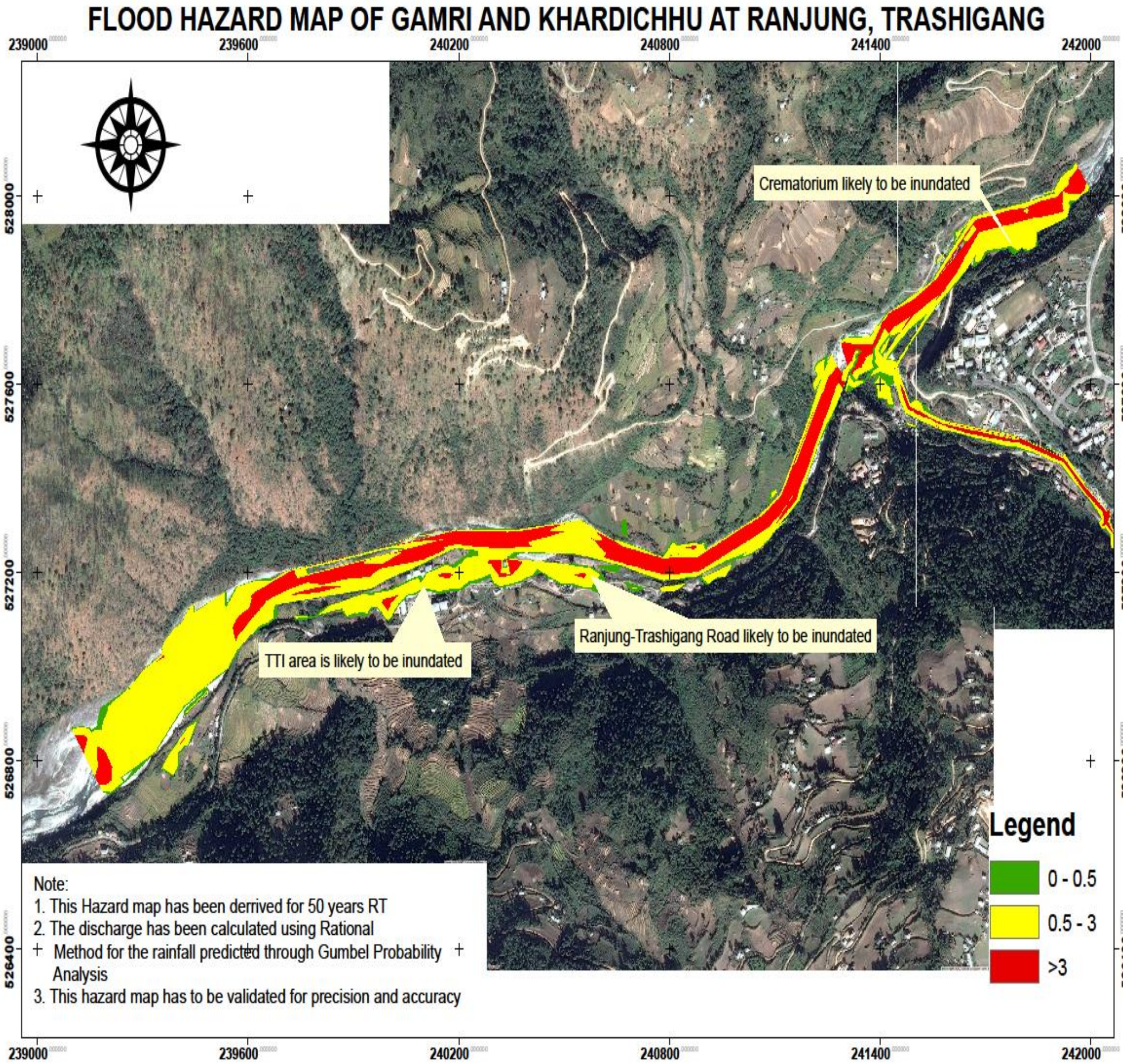


Figure 24: Flood Hazard Map for Gamri and Khardi Chu

0-0.5 Metres: Areas that are predicted to be affected relatively less during a 50 year flood event.

0.5-3 Metres: Areas that are predicted to be affected by significant overland during 50 year flood event.

>3 Metres: Areas that are predicted to be inundated by flood waters during 50 year flood event with a depth greater than 3 metres**.**

Ranifall and discharge data are two primary data for understanding hydro-meteorological characteristics of a river.There is no river gauging station in Gamri Chu hence the study area falls under ungauged basin.The data available is only rainfall data from the Radhi meteorological station from 1996 to 2014 (18 years).Since the Gamri Chu basin is ungauged, rational method has been applied to calculate the peak discharge for 50 years return period.

HEC-RAS as a 1D hydrodynamic model was selected to obtain the flow profiles for flood of 50 year return period.The observed cross-section data were used for Gamri and Khardi Chu.Steady flow option was selected for assigning flow of 50 year return period.HEC-RAS was run in subcritical mode and various tabular outputs were obtained.

Variation of water surface elevation and velocity along the selected reach of the river was obtained from HEC-RAS.Knowing the water surface elevation at a particular location for the design discharge,appropriate flood protection works can be designed.

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.7.164M in financial year 2015-2016 and Nu.20M in financial year 2016-2017 respectively in the 11th FYP for construction of 130 metres and 90 metres Reinforced Cement Concrete (RCC) wall along Mithidrang River under Trashigang Dzongkhag. RCC wall was designed by FEMD, DES and implemented by Trashigang Dzongkhag.

Intervention carried out with FEMD, DES fund.

- **Reinforced Cement Concrete (RCC) wall**: RCC walls are the walls made from the mixture of concrete and reinforcements (steel bars) as presented in figure 25 to 30. This type of walls can withstand both the compressive strength and tensile strength (capacity of the material to withstand loads tending to elongate).

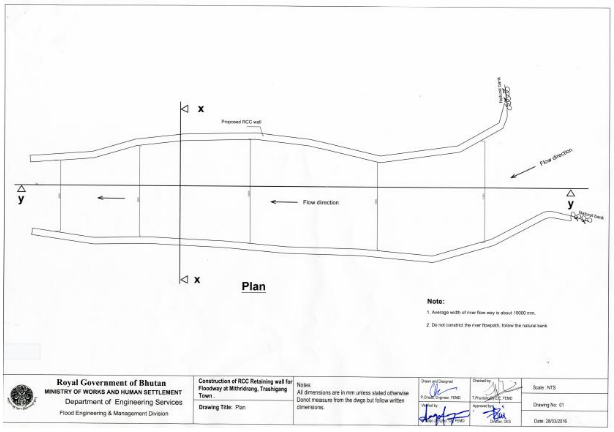


Figure 25: Plan

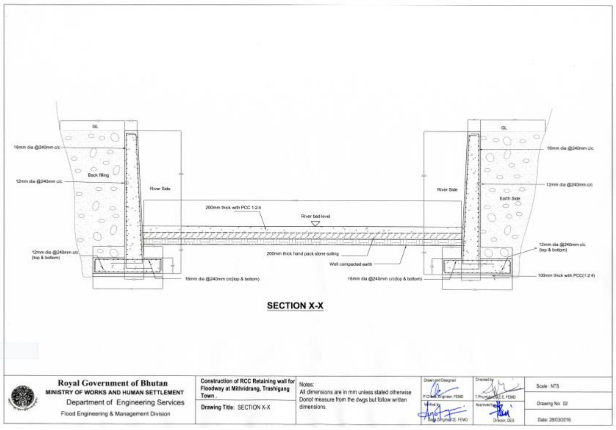


Figure 26: Section XX

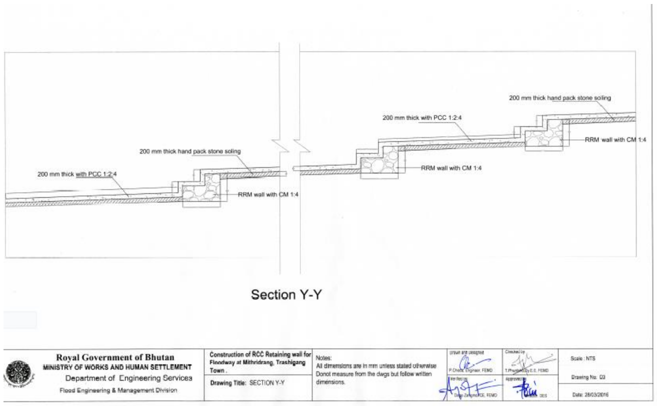


Figure 27: Section YY

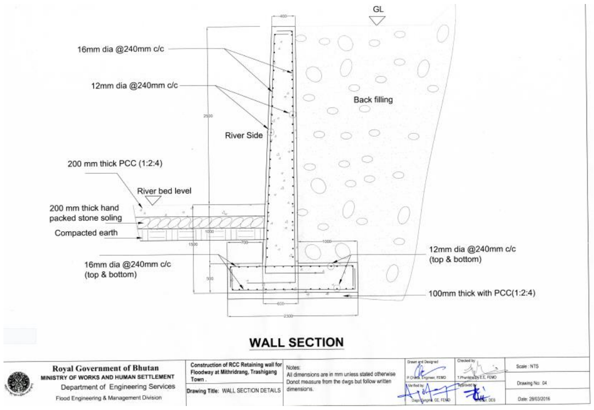


Figure 28: RCC wall section

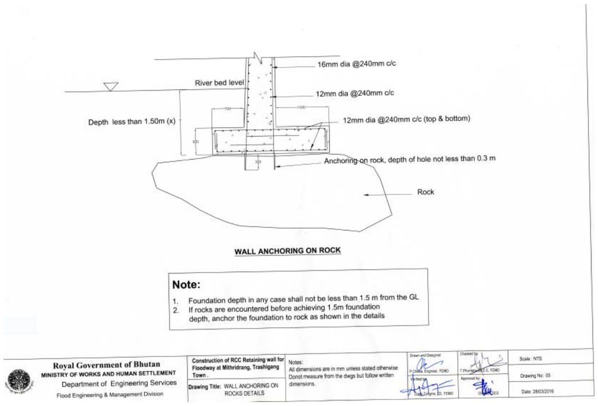


Figure 29: Wall anchoring on rock

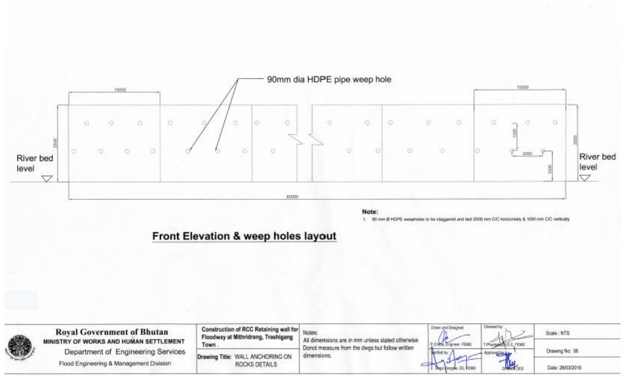


Figure 30: Front elevation and weep holes layout

Other interventions carried out in past.

Figure 31: Embankment with PCC revetment along Gamri Chu in Rangjung.

Figure 32: AB mattress along Gamri Chu.

Plain Cement Concrete (PCC) revetment: The plain cement concrete revetments are used as flood protection structure at a location where strength and durability are important factors. The PCC revetments as presented in Figure 31 are used along the left bank of Gamri Chu in Rangjung, Trashigang to reduce the vulnerability of the community to flooding.

Articulating Block Mattress (AB) revetment: Articulating Block Mattresses given in Figure 32 are used as revetments to protect river bank from erosion. The AB fabric form consists of a series of compartments. The compartments are interconnected by grout ducts and further, high-strength cables are also installed between and through the compartments and grout ducts. Once filled with concrete, the AB Mats become pillow-shaped rectangular concrete blocks with cables embedded in the concrete to link the blocks together.

Recommendation for flood management

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

1. Technical Training Institute, Rangjung
2. Crematorium
3. Wet land upstream and downstream of TTI, Rangjung
4. Rangjung- Trashigang highway

As per the flood hazard map shown in Figure 24, the settlements under red zone should be given the 1st priority, yellow zone as the 2nd priority and green zone as the 3rd priority. The areas that do not fall under any of the three zones can be identified as evacuation centres.

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

The Flood Hazard Map was successful in mapping the flood prone areas but the inundated areas could have been more accurate if a modelling specialist had modelled the river. This prepared flood hazard map requires further corrections for validation and to accurately map the inundated areas.

References

1. Preliminary flood hazard assessment of Bumthang Dzongkhag
2. Flood inundation mapping using global datasets, Kuenzang Choden, FEMD, DES.
3. Bumthang Dzongkhag website
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.
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