



FLOOD HAZARD ASSESSMENT FOR MONGAR 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.
Tshangkhu Chu	River flowing through Mongar 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 Mongar Dzongkhag and flood hazard map have been prepared for Tshangkhu Chu at Thridangbi in Lingmethang. Most of the agricultural land and few houses are located along the Tshangkhu 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 Mongar Dzongkhag.
- Identify and prioritize critical flood prone areas within Mongar Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

A hydrodynamic model was developed for Tshangkhu Chu in GIS 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. Since there was only one rainfall station in the Mongar town catchment. There is no discharge data for Tshangkhu Chu. Land cover data and soil data has not been used for modelling purpose resulting in unrealistic ground condition.

Introduction

Background

Mongar Dzongkhag is 450 km east of Thimphu, the capital city of Bhutan. It lies between 27.25 latitude and 91.2 longitudes. It has an area of about 1,940.26 sq.km with elevation ranging from 400-4000 meters above sea level. The lower and southern parts are sub-tropical while northern and higher regions have temperate climatic conditions. Summer can be hot and humid and winter cold.

The Dzongkhag is enclaved by Trashigang, Lhunzhe, Pemagatshel, Samderup Jongkhar, Zhemgang and Bum-thang Dzongkhags. The kuri Chu, Sheri Chu and Dangme Chu are important rivers in the Dzongkhag.

For Administrative prospers, the Dzongkhag is divided in to 17 Gewogs and a Drungkhag located at Weringla to cover the two Gewogs of Gongdue and Slambi. The other Gewogs are Balam, Chali, Chaskar, Dramitse, Drepong, Jurmey, Kengkhar, Mongar, Narang, Ngat-shang, Saleng, Sherimung, Thangrong, Tsakaling and Tsamang.

The population is estimated at 41852 for year 2013 with male and female almost equally divided. While maize and rice are grown abundantly, citrus fruits and vegetables, dairy and poultry products are increasingly becoming important sources of cash income (Source www.mongar.gov.bt)



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	Jadung	Balam	Sangshingwang	Dry land	10 h/h	40 ppl.
2	Kharigap	Chali	Muddy area	Wet & Dry land	3 h/h	8 ppl.
3	Wanglorongma		Wanglorongma	Paddy field		
4	Talingjug		Muddy area			Chali LSS
5	Kheshingra	Chaskhar	Morabri	Dry land and Wet land	10 h/h	50 ppl.
6	Between changshingnang & Tonglabainang		Durdari	Dry land and Wet land & Pam farm road		25 ppl.
7	Kadam		Phagpakheri	Wet land and Pam farm road & lhakhang		60 ppl.
8	Zunglen	Drepong	Zunglen Tsho	Dry land		150 ppl.
9	Chaksazor		Zunglen Tsho	Dry land		80 ppl.
10	Laptsa	Gongdud	Gonglamri & relepong	Slope	3 h/h	14 ppl.
11	Yarakla	Jurmey	Menzangri		7 h/h	35 ppl.
12	Ngamphu		Rangthungwongri	Wetland	3 h/h	12 ppl.
13	Kurtakoe		Steep slope		3 h/h	15 ppl.
14	Brumshing	Khengkhar	Brumshingchu	Dryland	1 h/h	5 ppl.15 ppl.
15	Tsangnari		Tsangnari	Dryland	3 h/h	15 ppl.
16	Kumparimunma		Loose soil	Dryland	2 h/h	10 ppl.
17	Aringjug		Loose soil	Dryland	25 h/h	30 ppl.
18	Nanaric		Steep slope	Dryland	30 h/h	100 ppl.
19	Tongla		nampaimori	Dryland	25 h/h	50 ppl.
20	Saling	Saling	Sangshingchujuk	Dryland	7 h/h	35 ppl.
21	Thrdangbi		Nanlagang	Dryland	3 h/h	9 ppl.
22	Resa		Gonparitshangri	Dryland	6 h/h	30 ppl.

23	Thridangbi		ChangkhuChu	Dry/Wetland		
24	Kalapang		Domrangri	Dryland	2 h/h	8 ppl.
25	Ragpaythang		Kurichu	Dryland		
26	Thilling	Shermu ng	Dendari	Dryland	Mule Track	
27	Drongphu		Irrigation water	Paddy field		
28	Soenakhar		Rodpari	Wetland	2 h/h	9 ppl.
29	Muhung		Samdrang	Paddy field		120 ppl.
30	Tshoyubi	Silambi	Karmalingri & tari	Dryland	3 h/h	15 ppl.
31	Panggerteng		Loose soil		4 h/h	20 ppl.
32	Demongla	Tsakaling	Lungangchu		16 h/h	60 ppl.
33	Singmanaka		Rogpachu		6 h/h	40 ppl.
34	Khuling	Tsaming	Satoetsho	Wet and dryland		
35	Jadung	Balam	Sangshingwang	Dry land	10 h/h	40 ppl.
36	Kharigap	Chali	Muddy area	Wet & Dry land	3 h/h	8 ppl.
37	Wanglorongma		Wanglorongma	Paddy field		
38	Talingjug		Muddy area			Chali LSS
39	Kheshingra	Chaskhar	Morabri	Dry land and Wet land	10 h/h	50 ppl.

Objective

Objective 1: Detailed flood assessment of Mongar Dzongkhag.

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

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

Study Area

Sherimuhung Gewog:

Total area: 304 Sq.km

Total population: 3245

Total households: 399

No of schools: 3 (1 Lower Secondary School and 2 Primary School)

No of BHUs: 2 BHU II and 2 Out of reach clinic.

Total Lhakhang: 2 (community)

Economic activities: Potatoes and Mandarin

Balam Gewog:

Total area: 27 Sq.km

Total population: 2027

Total households: 220

No of schools: 1 Primary School (Balam Primary School)

No of BHUs: 1 BHU II and 3 Out of reach clinic.

Total Lhakhang: 2 (community)

Economic activities: Potatoes, maize, dairy farm, poultry farm, piggery, hazel nut plantation and bio gas.

Saling Gewog:

Total area: 479.5 Sq.km

Total population: 3727

Total households: 355

No of schools: 5 Primary Schools and 4 ECR

No of BHUs: 1 BHU I, 1 BHU II and 6 Out of reach clinic.

Total Lhakhang: 2 (community)

Economic activities: Vegetable farm, dairy farm, poultry farm, hazel nut farm and community forest.

Tsakaling Gewog:

Total area: 72 Sq.km

Total population: 2140

Total households: 216

No of schools: 2 Primary Schools and 1 ECR

No of BHUs: 1 BHU II, 1 Sub post and 3 Out of reach clinic.

Total Lhakhang: 4 (community)

Economic activities: Vegetable farm, dairy farm, poultry farm, hazel nut farm and community forest.

Chaskar Gewog:

Total area: 51.20 Sq.km

Total population: 3734

Total households: 466

No of schools: 1 Central Schools and 1 Primary School.

No of BHUs: 1 BHU II and 5 Out of reach clinic.

Total Lhakhang: 2 (community and private)

Economic activities: Vegetable farm, dairy farm, poultry farm, hazel nut farm and community forest.

Drepong Gewog:

Total area: 54 Sq.km

Total population: 2117

Total households: 252

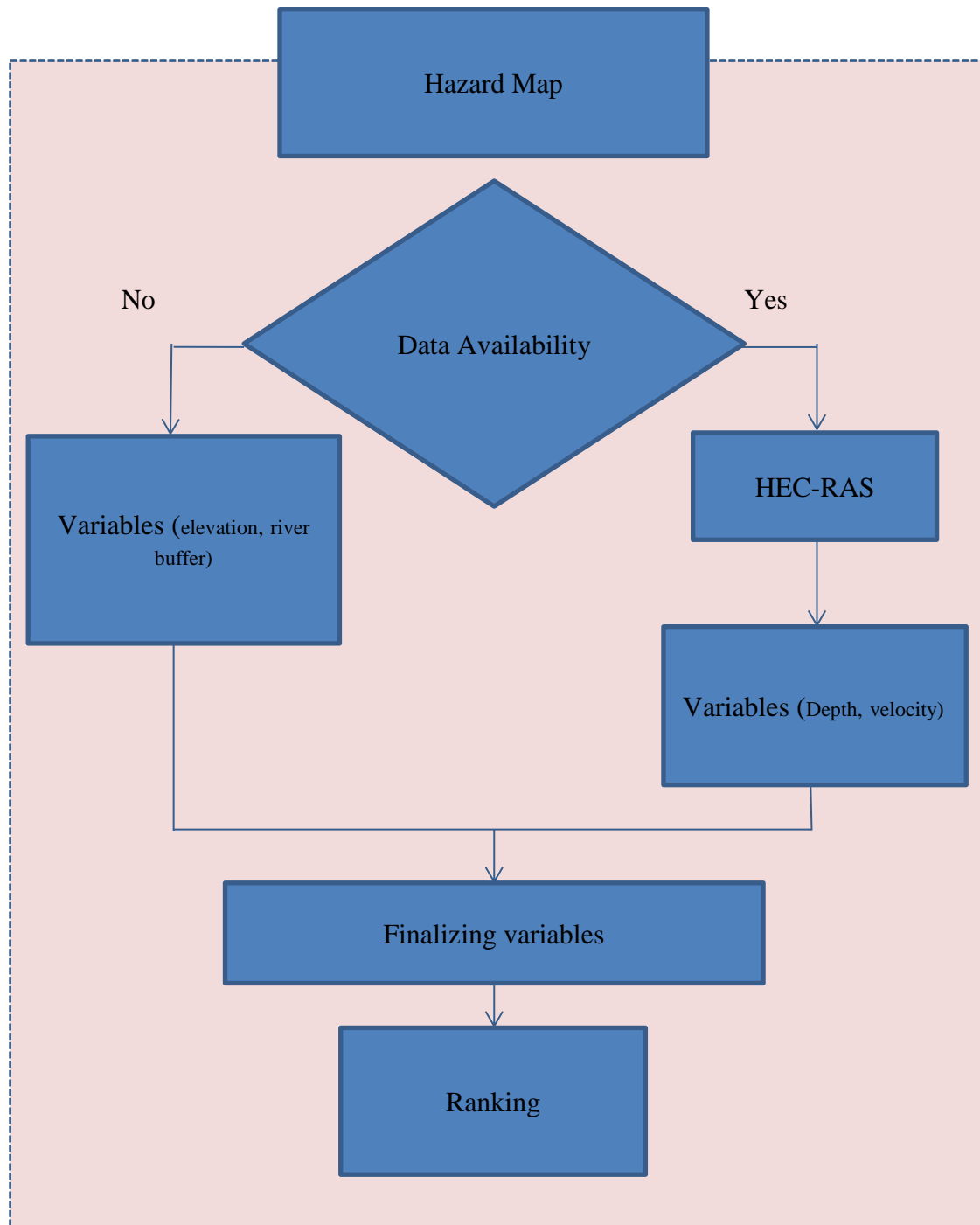
No of schools: 3 Primary School.

No of BHUs: 1 BHU II and 3 Out of reach clinic.

Total Lhakhang: 2 (community)

Economic activities: Vegetable farming, poultry farming and hazel nut farming.

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.

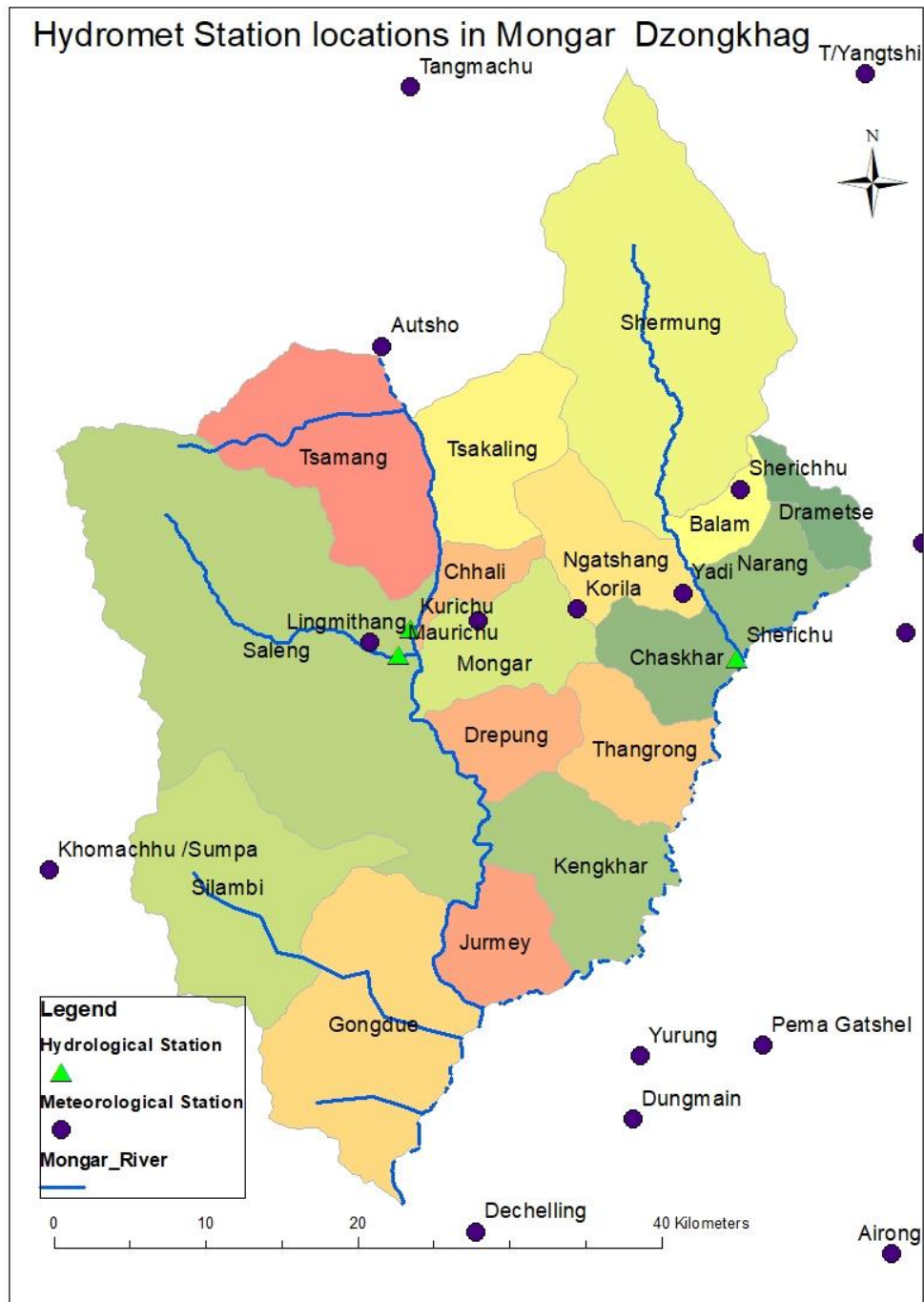


Figure 2: The location of the Hydro-met station in the study area

Meteorological Data

There are 5 meteorological stations available in the watershed study area. Only Mongar met station has temporal daily data from 1994 to 2017.

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.

Along Sheri Chu under Sherimuhung Gewog, critical structure identified is crematorium only but in case of Saling Gewog, large areas of agricultural lands have been destroyed in the past. Therefore, in this assessment, preliminary flood hazard map have been prepared for Tshangkhu Chu in Saling Gewog. River shapefile was prepared by digitizing from the image extracted in QGIS software as shown in Figure 3.

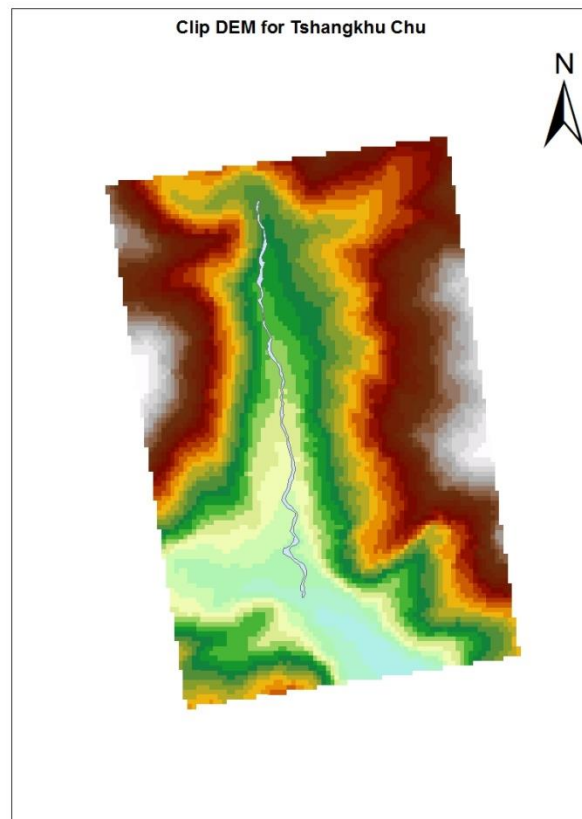


Figure 3: DEM showing Tshangkhu Chu

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.

Site Assessment at Gewog Level

The field surveys have been carried out in 6 Gewogs (Sherimuhung, Balam, Saling, Tsakaling, Chaskhar, Drepong Gewogs and Dzongkhag Municipal) under Mongar Dzongkhag in order to create corner stone data for future project formulation. During the survey, the team inspected the potential flood risk sites and collected basic land geographical data, demographic data (the number of households under the risk etc.) and past flood event records with the cooperation of local Gewog and Dzongkhag officials.

During the field survey, the team inspected the potential flood risk sites as well as visited the Gewog offices and villages to collect the data. At the Gewog offices, all information was collected as per the field survey format (Annexure I).

Sherimuhung Gewog: During the assessment, critical areas which are under the threat from erosion due to flooding in Sherimuhung Gewog are identified as listed in Table 2

Table 2: Critical River in Sherimuhung Gewog.

Sl.No	Name of River	Threat from flood (location)	Village	Coordinates		Elevation	Remarks
				Northing	Easting		
1	Sheri Chu	Crematorium	Pakala Shing	27 °20' 04.84 "	91 °21' 29.91 "	908	Right Bank

Sheri Chu:

Sheri Chu is the main perennial river flowing along Pakala Shing village under Sherimuhung Gewog. The most critical structure along Sheri Chu is cremation ground which is under construction at Pakala Shing area. This cremation ground once completed will benefit to 5 Gewogs i.e. Ngatshang, Chaskhar, Thangrong, Balam and Sherimuhung Gewogs. According to the Gup, 20 years ago, some portion of the Sheri Chu water entered into the existing cremation ground area which we can see the flow path even today. Scouring along crematorium is taking place during high flow discharge in monsoon season. This situation might increase the vulnerability of the crematorium to flooding during extreme events. As per the Gup, there is no other suitable place which is accessible to road and benefits all five Gewogs other than this existing location. Considering the importance of the crematorium, Gewog Administration had requested an excavator from the private company and constructed some temporary boulder

barrier. As per the Gup, 200 metres gabion wall is required to protect cremation ground for permanent solution.



Figure 4: Location of crematorium along Sheri Chu



Figure 5: Crematorium under construction

Balam Gewog: In the Balam Gewog, there are two streams and one river namely Shangsiriwang runoff stream under Jadung village, Denporodrang stream under Bakaphay village and Sheri Chu under Sheri village. During our preliminary flood hazard assessment in the Gewog, only three critical flood prone areas are identified as observed in Table 3.

Table 3: Critical flood prone areas in Balam Gewog.

SL.No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation	Remarks
				Northing	Easting		
1	Shangsiriwang	Dry land	Jadung	27 ° 18' 31.29 "	91 ° 20' 2.756 "		Both banks
2	Denporodrang	Wet land	Bakaphay	27 ° 20' 44.74 "	91 ° 24' 56.94 "		Both banks
3	Sheri Chu	Wet land	Sheri	27 ° 17' 25.21 "	91 ° 22' 05.70 "		Left bank

Shangsiriwang Runoff: Jadung Chiwog is mostly affected by this seasonal runoff stream. According to the Tshogpa that, till now about 5 acres dry land consisting of walnut and hazelnut plants have been destroyed and washed away. In the past, with the assistance from the Dzongkhag forest, they have carried out land management works such as bio-engineering and constructed dry rubble masonry. During the site visit, it was observed that, area have been stabilized due to land management works carried out in past.



Figure 6: Google image of Shangsiriwang stream



Figure 7: Google image of Denporongdrang stream

Denporongdrang stream: According to Balam Tshogpa that, prior to year 2016 flood was not observed under Balam Chiwog. Denporongdrang is a small stream which carries discharge in monsoon season only. In the year 2016 and 2017 during monsoon season 2 acres of dry and wet land was destroyed by the flash flood. Additionally 4 acres of dry and wet land was also destroyed in April-May 2018. In the past, Gewog have constructed RRM wall and we were informed that the wall is functioning well. However, Balam Tshogpa informed FEMD team that, they require additional 600 metres RRM wall to protect wet land in the area.

Sheri Chu: According to the Sheri Tshogpa, flooding along Sheri Chu occurs annually and till now about 10 acres of paddy field have been damaged by the Sheri Chu. Flood protection works have not been done in the past. The water level during our field visit was within the safe level below wet land. Tshogpa clarified that, during the rainfall events water level almost reaches equal to the height of paddy field and during extreme rainfall water enters the paddy field.

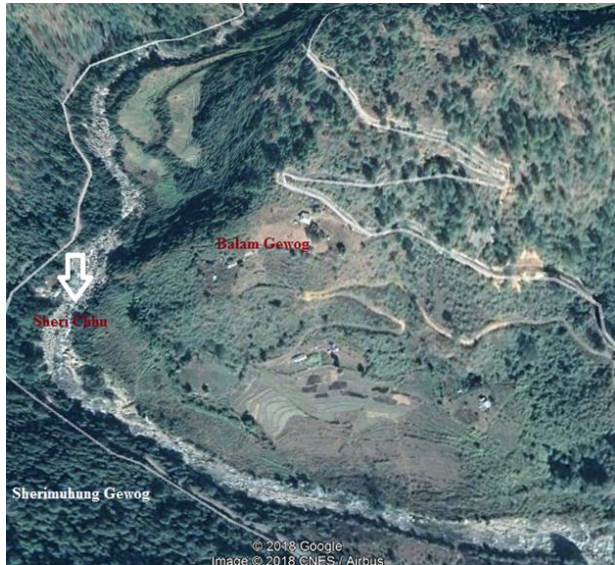


Figure 8: Google image of Sheri Chu

Saling Gewog: During the assessment, critical areas which are under the threat from erosion due to flooding in Saling Gewog are identified as listed in Table 4.

Table 4: Critical flood prone areas in Saling Gewog.

Sl. No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation(M)	Remarks
				Northing	Easting		
1	Tshangkhu Chu	Wet land and one RCC house	Thridangbi	27 °16' 50.05 "	91 °08' 47.08 "	800	Both banks

As per our assessment, Tshangkhu Chu along Thridangbi village is the most critical river under Saling Gewog. It is a small river which flows along agricultural land. There are only 4 houses located along Tshangkhu Chu. Out of 4 houses only 1 double story RCC building is at the risk due to flooding. According to the Gup, heavy flood occurred in 2012. Of course every year flood events take place but not like 2012 flood. In 2012, two oxen were washed away and 40 decimal wet lands were destroyed. Considering the importance of the agricultural land and settlement, we have conducted cross section survey along Tshangkhu Chu to find out the inundation areas along it. Till now, Gewog administration has not constructed any flood protection structures except 40 meters long gabion wall for the protection of Bailey bridge. Through visual inspection, it can be seen that the rivers during the rainy season has caused scouring along the river banks and also around bridge abutments as presented in figure 10. Similarly, it has been observed that the difference in elevation between the river bed level and top bank level is only about 1.0 m in

some stretches along the river. This situation might increase the vulnerability of the wet land to flooding during extreme events.

Therefore, if proper interventions are not done at this stage, then there is higher probability of river breaching their banks and damaging the agricultural land and settlement. Hence, it is highly recommended to construct flood protection structures along the left bank as well as right bank.



Figure 10: Tshangkhu Chu along Thridangbi village

Figure 9: Google image of Tshangkhu Chh

Tsakaling Gewog: There are only two streams in Tsakaling Gewog. They are Lungkang Chu and Shangman Chu. These streams remain dry in winter season. There are settlements along the Lungkang Chu only. Thumling village is mostly affected by this stream due to landslide. According to the Gup, in the year 2011 and 2012 two household from Hisa village were relocated to Thumling village which is quite far from landslide area. However, if some land management works along landslide prone areas are not done, there is possibility of scouring and landslide reaching Thumling village. There are four households in Thumling village which are located very close to landslide and have threat. Along the Shangman Chu, there is no settlement.

Table 5: Critical flood prone area in Tsakaling Gewog.

Sl. No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation (M)	Remarks
				Northing	Easting		
1	Lungkang Chu	Settlement and agricultural land	Thumling	27 ° 28 ' 40 "	91 ° 13 ' 37 "	1552	Both banks

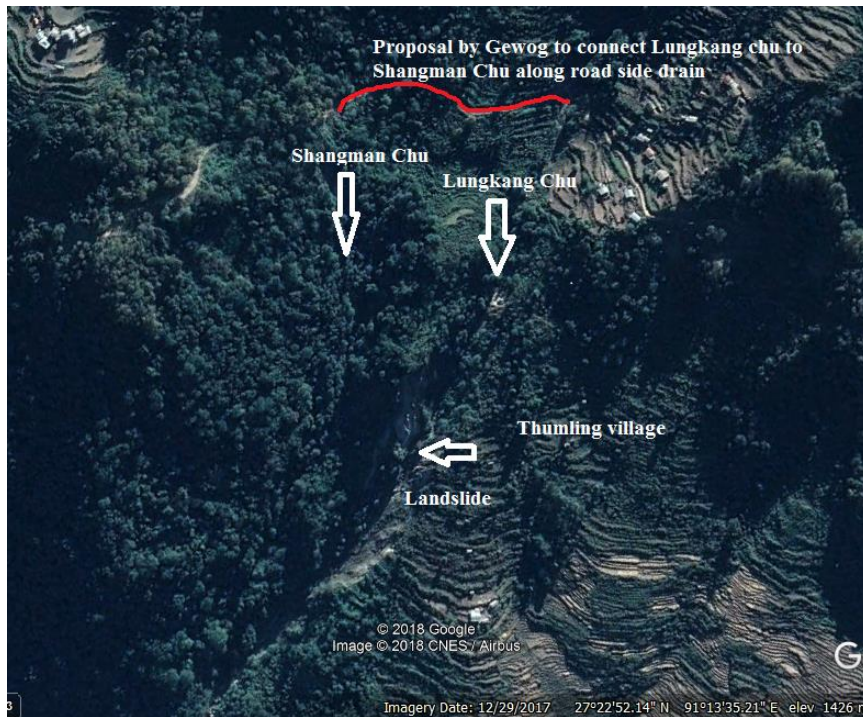


Figure 11: Google image of Shangman Chu and Lungkang Chu along Thumling village

Dzongkhag Municipal: Under the Monger Dzongkhag Municipal, there are two seasonal streams which are posing threat due to flash flood and Kurichu at Gyalposhing town.

Table 6: Critical flood prone area in Dzongkhag Municipal

Sl. No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation (M)	Remarks
				Northing	Easting		
1	Runoff seasonal	Automobile workshop	Municipal	27° 16 ' 32"	91° 14 ' 06 "	1518	workshop
2	Rawangyoe	footpath	Municipal	27° 16 ' 22"	91° 14 ' 38 "	1654	both banks
3	Kurichu	Gyaploshing	Municipal	27° 13 ' 30"	91° 11 ' 41 "	576	scour

Runoff seasonal stream at automobile workshop area: The main source of runoff is due to water flow from road at upstream. Road is not having proper side drains. There is a risk to automobile workshop at the downstream. There are 24 workshops situated at this location. In the past Dzongkhag municipal have constructed gabion (hand woven) check wall. During the field visit it was found that, the check wall is functioning well to slow down the velocity and control debris. According to the municipal engineer, in the 12 five year plan, they want to propose for construction of 650 metres step fall drains and 1000 metres gabion side wall at both the banks to streamline the runoff flow. If the road side drain is managed properly, the runoff will be controlled and risk will be minimised at the workshop.



Figure 12: Location of automobile workshop



Figure 13: location of residence

Rawangyoe seasonal stream: This is a seasonal stream which affects only footpath. During monsoon season, there is a risk for school going children and people residing nearby. According to the Dzongkhag municipal till now it has not affected anyone but there is every possibility of heavy rainfall due to climate change in future. Dzongkhag municipal is planning to construct embankment with gabion crate revetment with the provision of footpath for the people to walk.

Kurichu at Gyalposhing: According to the Dzongkhag municipal engineer, scouring at the left bank of Kurichu happens every time during the cleaning schedule of the hydro power plant. During the field visit, we have observed some boulders and soil was falling at the left bank. There is a possibility of taking away the land in future if mitigation measures are not carried out. Thorough study should be carried out and come up with suitable measures to avoid further landslide due to scour.



Figure 14: Google image of KuriChu



Figure 15: Location of scouring area in Gyalposhing.

Chaskhar Gewog: Comprises a total area of 51.20 Sq.km having total population of 3885 and 480 households. Under the Chaskhar Gewog, there is only one perineal river and one seasonal river. They are Durdari and Morabri respectively as mentioned in Table 7.

Table 7: Critical flood prone area in Chaskhar Gewog

Sl. No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation (M)	Remarks
				Northing	Easting		
1	Durdari	Wet land	Between Changshingnang and Tonglabainang	27° 16' 25"	91° 22' 30 "	1077	
2	Morabri	Dryland and settlement	Kheshingla	27° 16' 12"	91° 21' 36 "	1511	

Durdari: This is a small and perineal river which passes through the Mongar – Trashigang highway. During the site visit, we have measured its discharge and calculated 0.36 cumecs. This river is having threat to only wet land. According to the Gup, last flooding occurred between 4-10 years ago which lasted about 1-2 days due to heavy rainfall. Till now 2 acres of wet land have been destroyed by the flash flood. In case of sudden flood in future, there is a risk to additional 2 acres wet land in the area. Gewog wants to seek both financial and technical assistance for the construction of flood protection structures.



Figure 16: Location of destroyed wetland along Durdari.

Morabri: This is a seasonal stream which collects runoff water from its catchment area. Till now, 8 acres dry land belonging to 7 households has been damaged due to landslide. It has not affects human till date. According to the Gup, there is a risk to another 5 acres dry land and 3 houses if mitigation works are not done in future. Gewog Administration is planning to put budget proposal in 12 Five Year Plan.



Figure 17: Landslide area along Morabri.

Drepong Gewog: According to the Gewog Mangmi, Drepong Gewog has no river along the settlement and agricultural land. Gewog have experienced only landslide due to overflow from Zhunglen Tsho in 2005. The team have visited the site and found that the lake is almost dry with little water remaining as shown in picture no.12 it has caused huge landslide at downstream of lake which has destroyed about 7-8 acres of dry land. There are 10 households and 20 acres dry land which are under risk in case of lake over flow in future. In the year 2013, Gewog Administration has constructed dry wall with the help from Dzongkhag Forest. To stabilize the slope, public have carried out bio-engineering activities such tree plantation and bamboo plantation. As per Gewog Mangmi, bamboo plantation is successful for slope stabilization and slope failure have stopped. To further stabilizing the slope, Gewog Administration is planning to carry out more bamboo plantation in future from Gewog fund.

As per the visual observation, it was found that, bio-engineering activities is working well and should be continued to protect losing agricultural land in case of lake outburst.

Table 8: Critical flood prone area in Drepong Gewog

Sl. No	Name of River/Stream	Threat from flood (location)	Village	Coordinates		Elevation (M)	Remarks
				Northing	Easting		
1	Zhunglen Tsho	Dryland and settlement	Zhunglen	27° 12' 47"	91° 17' 3"	1866	



Figure 18: Landslide area below Zhunglen Tsho



Figure 19: Location of Zhunglen Tsho.

Identifying Critical River: Based on the assessment and due to extreme past events, threat it poses to the community and agricultural lands, Tshangkhu Chu along Thridangbi village in Saling Gewog and Sheri Chu along crematorium in Sherimuhung Gewog has been identified as critical rivers requiring flood mitigation works.

Development of Model

Flood Hazard Map

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 Tshangkhu Chu

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 discharge, river cross-section survey, DEM (Digital Elevation Model), dimension and location of the flood protection structures. Therefore, cross-section survey for river was conducted. Due to lack of discharge data for Tshangkhu Chu, HEC-RAS could not be used. Hence, the variables such as flood duration, flood depth and velocity could not be taken into consideration for preparation of flood hazard map.

Table 9: 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 rainfall data is available from 1994 to 2017 for Mongar Meteorological station, it could not be used as it was not giving information on rainfall variability across Lingmethang area.
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 ranking and weighting for the two variables has been discussed thoroughly amongst the engineers in the Division. The Table 10 gives the detail of the ranking and weighting:

Table 10: Classes and ranking of variables.

Variable	Classes	Ranking	Weighting	Remarks
Main rivers (River buffer)	0 – 30 m	2	25	As per the standard use by planners.
	30-100m	1		
	>100m	0		
Elevation	<= 778	3	75	The elevation is used from the ALOS 10m DEM.
	779-800m	2		
	801-847 m	1		
	>847 m	0		

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. 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

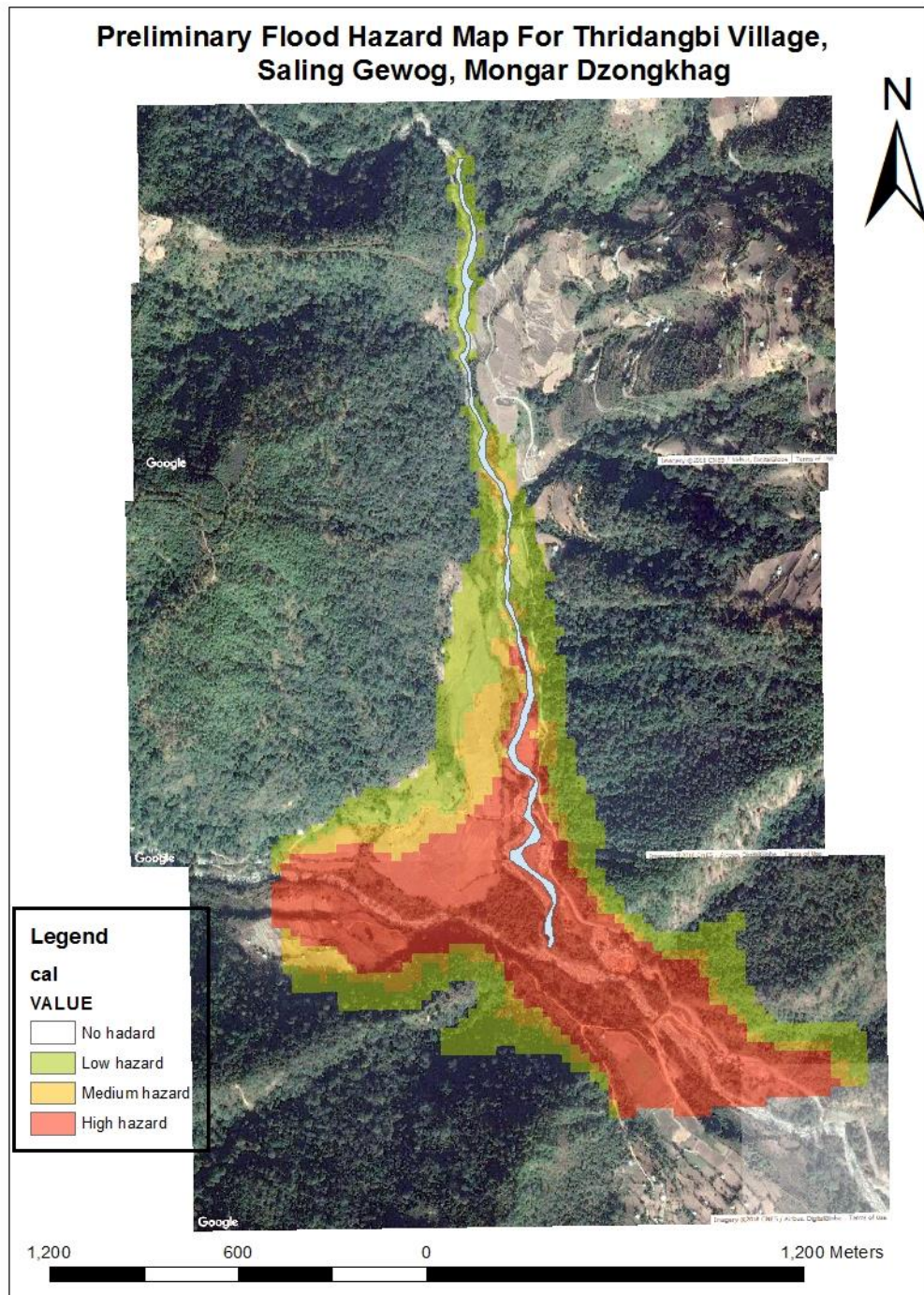


Figure 20: Preliminary Flood Hazard Map for Tshangkhu Chu

Interventions

Sherimuhung Gewog

- **Sheri Chu:** Constructed temporary boulder barrier along crematorium.

Balam Gewog

- **Shangsiriwang Runoff:** carried out bio-engineering works and dry rubble masonry wall.
- **Denporongdrang stream:** Constructed RRM wall

Dzongkhag Municipal

- **Runoff seasonal stream at automobile workshop area:** Dzongkhag have constructed gabion wall (Hand woven) check wall.

Drepong Gewog

- **Zhunglen Tsho:** Dry Rubble Masonry, bamboo tree plantation.

Recommendation for flood management

Sherimuhung Gewog

- **Sheri Chu:** Along the banks of Sheri Chu there are plenty of boulders available, construction of boulder rip-rap wall at right bank would minimize the scouring effects and the crematorium will be safe from flooding. Additionally, 2 metres height gabion wall inside the boulder rip-rap wall would further stabilize the soil and avoid scouring.

Balam Gewog

- **Shangsiriwang Runoff:** Providing gabion check dam and wooden creep wall at critical locations to control land slide debris and to streamline the flow path.
- Since the catchment area is small, bio-engineering works such as plantation of fast growing plants along both the banks would avoid scouring of cultivable lands. Bio-engineering works was tried in the past and found that it is functioning well till now.
- **Denporongdrang stream:** The profile of the stream is steep and scoring effect will be high in case of flash flood. To minimize further scouring, construction of gabion check dams at critical locations along the stream will collect debris and scouring effects will be reduced. Alternatively, locally available wooden creep wall will also reduce the impacts of flooding. Bio-engineering works such as plantation of fast growing plants in the sliding area can also minimize damage.

Saling Gewog

- **Tshangkhu Chu:** According to the Saling Gup, they require only financial assistance to meet expenditure for the construction of gabion wall at critical locations along Tshangkhu Chu. They want to propose for 600 metres length

gabion wall at left bank and 300 metres length gabion wall at right bank respectively.

Tsakaling Gewog

- **Lungkang Chu:** There is settlement along Lungkang Chu only. Gewog is planning to divert Lungkang Chu to Shangman Chu by constructing drain along farm road to avoid further landslide along Thumling village.
- To avoid scouring at some portions of upstream along Lungkang Chu, gabion check dam at critical locations would control flow and debris.
- Bio engineering works such as planting of fast growing plants, providing wooden creep walls will also control landslide.

Dzongkhag Municipal

- **Kurichu at Gyalpothing:** Thorough study should be carried out and come up with suitable measures to avoid further landslide due to scour.

Chaskar Gewog

- **Durdari:** It was observed that the level difference between river and wet land is 1.50 metres only with gentle slope. Construction of 200 metres length gabion wall at the left bank will minimize the flood risk and helps in reclaiming destroyed wet land.
- **Morabri:** We have observed that, the area is prone to landslide with a steep slope. To stabilize the slope, entire landslide prone area should be managed properly by carrying out bio-engineering works such as tree plantations, construction of wooden creep walls and check dams at critical locations. There is a possibility of major landslide if mitigations works are not carried out.

Drepong Gewog

- **Zhunglen Tsho:** It was observed that, bio-engineering activities is working well and should be continued to protect losing agricultural land in case of Lake Outburst.

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.

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

- The elevation data required for the map was 10 metre resolution ALOS. A major problem with using ALOS data for flood hazard 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 reliability of the maps has been affected by the inadequate spatial rainfall data for the study area. Since there was only one rainfall station in the Mongar town catchment.
- There is no discharge data for Tshangkhu Chu.
- Land cover data and soil data has not been used for modeling purpose resulting in unrealistic ground condition.

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