FLOOD HAZARD ASSESSMENT FOR SARPANG DZONGKHAG

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

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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 Sarpang Dzongkhag and preparation of the Flood Hazard Map for Sarpang Chhu in Sarpang 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, Sarpang Dzongkhag
4. Gelephu 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 Sarpang Dzongkhag.

Acronyms

FEMD	Flood Engineering Management Division.
HEC-RAS	The Hydrologic Engineering Centre, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modelling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defence, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
GIS	Geographical Information System is a computer-based method for analysing geographical information and maps.
FHM	Flood Hazard Map
FRA	Flood Risk Assessment.
AFA	Areas for Further Assessment.
MoAF	Ministry of Agriculture and Forest.
DDM	Department of Disaster Management.
GLOF	Glacial Lake Outburst Flood.

Executive Summary

The Sarpang Chhu flowing from North to South before entering the Indian territory passes in between the two towns Sarpang on the left bank and Shechangthang (Ranibagan) on the right bank. The river has a notorious history of often getting swollen and causing havoc to the inhabitants in the vicinity. The River changes its course frequently, resulting in its banks getting wider and shallower day by day, and bringing in huge amounts of silt deposits in summer season. During the recent flooding in the year 2016, Sarpang Bazaar (Makeshifts) was completely washed away, with the ongoing flood protection works and stretches of Sarpang-Gelephu Highway also getting washed away, incurring financial loss of almost Nu.25 Million to the Government.

Therefore, the FEMD had initiated to undertake Flood Hazard Assessment of the Sarpang Dzongkhag with the main objective to achieve as follows:

- Flood hazard assessment in Sarpang Dzongkhag and identify areas vulnerable to flooding in the face of climate change and variability.
- Analyse the AoMI (Areas of Mitigation Interest) assessment in Sarpang Dzongkhag and identify and prioritize critical flood prone areas within Sarpang Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

The FEMD has also prepared a Flood Hazard Map for the Sarpang Chhu using the hydrodynamic Modeling i.e HECRAS. Due to many limitations, the Flood Hazard Map for Sarpang Chhu is in its preliminary form and needs to be updated in due course of time.

Other critical rivers under Sarpang Dzongkhag such as Mao River, Shetikhari and Aipoly streams under Gelephu are being taken up as separate studies. Therefore, this Report, presents critical areas in Sarpang Chhu under Shompangkha Gewog, Sisty Khola under Gakidling Gewog and Taklai River under Umling Gewog as Areas of Mitigation Interest and recommends for flood mitigations works.

In the past, different types of Interventions were implemented in Sarpang Dzongkhag, such as AB Mattress embankments, Gabion walls etc, However, for this study, Gabion Revetment type of flood interventions are recommended for the identified Areas of Mitigation Interest.

Introduction

Background

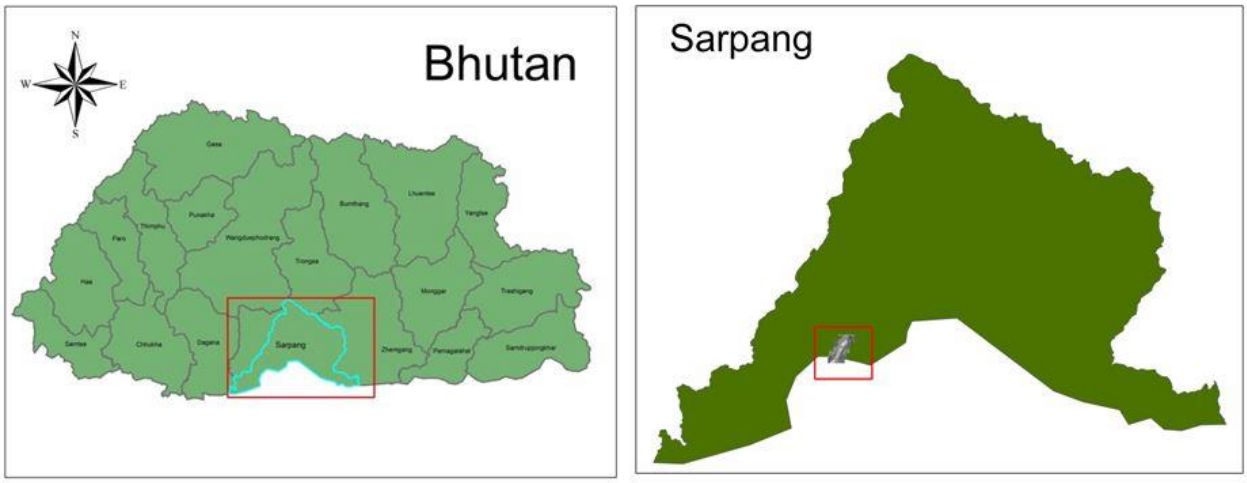


Figure 1: Bhutan Map showing the area of Interest (Sarpang).

The Sarpang Dzongkhag is situated in the central southern foothills bordering India with a Latitude of 26°52' N and Longitude 90°16' E. The Dzongkhag shares about 200 km of common border with the Indian state of Assam to the south and the Dzongkhags of Tsirang and Dagana to the west, Zhemgang to the east and Trongsa to the north. The total geographical area of the Dzongkhagis approximately1660.28 Sq.km and has undulated terrain. The Sarpang Dzongkhag is administratively supported by a Gelephu Dungkhag and consists of 12 Gewogs. Services and administrative support for five Gewogs, Gakiling(Hilley), Dekiling, Singye, Chhudzom (Dovan) and Shompangkha are provided from Dzongkhag headquarter. While seven Gewogs namely, Gelephu, Chuzargang,Umling, Sershong, Taraythang, Jigmechoeling and Samtenling (Bhur) are provided by Gelephu Drungkhag.[1]

The major crops cultivated in the area are paddy, maize, wheat, and millet. Orange, areca nut, cardamom and ginger are also grown as principal cash crops by the farmers of the Dzongkhag. Favourable terrain and climatic conditions combined with fertile agriculture land offer tremendous opportunity for farm mechanization and commercial horticultural development.

[1]Annual Dzongkhag Statistics 2011, Sarpang Dzongkhag, National Statistics Bureau.

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

Sl.No.	Name of Village	Name of Geog	Name of river/stream	Type of threat (Agriculture /Resident	Estimated Population	Past flooding record
1	Daangling	Umling	Langkhar-chu	Agriculture	20	(The area lies in between these 2 villages) monsoon floods yearly washes the land near by the river
2	Doongmin		Langkhar-chu	Agriculture	20	do
3	Gaden		Taklai-chu	Agriculture	550	2007
4	Rijong		Langkhar-chu	Agriculture	350	yearly monsoon
5	Chhuborshong		Talai-chhu & Jangkhrung-chu	Agriculture	200	
6	Chhuborshong		Langkhar-chu	Agriculture	50	yearly monsoon
7	Thongjazor		Langkhar-chu	Agriculture	20	yearly monsoon
8	Yoezergang	Tareythang	Singye-chu	Agriculture	30 h/h	
9	Yoezergang		Singye-chu	Forest		
10	Upper Karbithang	Chuzagang	Mou river		145	Once(2009)
11	Lower Dawathang		Seasonal river		200	Every year
12	Lower Dawathang		Seasonal river		150	Every year
13	Dawathang		Taklai river		150	Once
14	Pangzor		Seasonal river	Agriculture	50	Every year
15	Lower Karbithang		Mou river	Agriculture/forestry and residential	95	Every year
16	Chaskar		Mou river	Agriculture	31	
17	Chaskar		Thewar river	Agriculture	12	once(1996)
18	Chaskar		Martshani river	Agriculture	5	
19	Daragaon	Jigmecholing	Heti Khola	Agriculture/forestry and residential	30h/h	
20	Chungsing		Howangmay	Agriculture	5h/h	Landslide during the year 2000

21	Chungsing		Nabchali Chu	Agriculture	6 h/h	Landslide during the year 1997
22	Bartsham Kha		jantikhola	Forestry	7 h/h	Landslide during past year(around 1994)
23	Ossey		jantikhola	Forestry & residential	10h/h	landslide during the year 2001
24	Tormay		Ratipani	Forestry	12h/h	landslide during the year 1998
25	Sukumbasi		Ratipani		4h/h	landslide during the year 2001
26	Pakhey		Ratikhola		7h/h	landslide during the year 1975
27	Bhirgaon		Ratikhola	Agriculture	5h/h	landslide during the year 1988
28	Reti			Agriculture & forestry	7h/h	landslide during the year2009
29	Kholatar			Agriculture & forestry	4h/h	landslide during the year2004
30	Mongargaon			Agriculture & residential	6h/h	Soil erosion in the year 2010
31	Gairigaon 'A'		Reti chu	Agriculture & residential	12h/h	Landslide in the year 2010
32	Gairigaon 'B'			Agriculture & residential	6h/h	Landslide in the year 2000
33	Gogtsekha			Agriculture & residential	6h/h	Landslide in the year 2009
34	Garigaon'C'			Forestry & Agriculture	9h/h	Landslide in the year 1992
35	Batasey'A'			Agriculture & residential	4h/h	Landslide
36	Samkhara'A'		Beteni river	Agriculture & residential	6h/h	Landslide
37	Beteni		Rongchu	Agri. Forestry & residential	4h/h	Landslide
38	Samkhara'B'			Agriculture & residential	5 h/h	Landslide

39	Batasey'B'			Agriculture & residential	3 h/h	Landslide
40	Samkhara 'C'			Agriculture & residential	6 h/h	Landslide
41	Tormay		Labray stream	Agriculture & residential	7h/h	Landslide
42	Lekithang	**Gelephu**	Sanu Aipoli	Kamzhing	80	2 times, heavy flood in 2010.
43	Pemathang		Setikhari	Residential/Kamzhing	1500	Heavy flood in 2000 & 2010. This stream is main risky
44	Dzomlingthang		Setichu	Residential/Kamzhing	250	Heavy flood in 2000 & 2010.
45	Dawlachu		Pelrithang Khamey	Chuzhing/Kamzhing/residential	1200	Heavy flood in 2000 & 2010. Then flood will affect Pelrithang Middle Secondary School(total students-1000 plus)
46	Pelrithang Khatoe		Jogichhu	Chuzhing/Kamzhing/residential	100	More of Chuzhing will be affected
47	Pelrithang Khatoe		Passang Chu	Residential & Water Supply	150	Including RBA officer qtr. And the office
48	Pelrithang Khatoe		AnderiKholsa	Government Land(GRF)	200	RBP jail and PWD workers
49	Samtenthang	**Samtenling**	Paithakhola	Agriculture		Major disaster in the year 2010
50	Samtenthang		Rana Kholse	Orange Orchard		Landslide occurred in the year
51	Samtenthang		Aipoli	Agriculture, forestry		Flood occurred in the year 2010

52	Samtenling		Paithakhola	Agriculture	47	
53	Samtenling		Gowa Kholse	Residential, Agriculture	3	Yr. 2000, house was taken away by the flood. July 2010, house was at risk due to heavy downpour
54	Dechen Pelri		Shetikhari	Forestry		Major landslide at water source area benefiting Dechenpelri area
55	Chhokorling		Aipoli Kholsa	Orange Orchard		Orchard of Purna Bdr. Rai at risk
56	Khenpagang		Kopche Khola	Orange Orchard, forestry		
57	Paithakhola		Paithakhola	Orange Orchard, forestry		Orchard of Budhiman Rai at risk
58	Pangkhar	**Sershong**	Pemaling chu	Dry land	21	incidence took place in2005 & 2009
59	kapong		Pemaling chu	Dry land & wet land	30	incidence took place 2010
60	sershong		Mau chu	Dry land & wet land	79	incidence took place past 15 years
61	sershong		Threwar chu	Orange orchard	17	incidence took place 2008
62	sershong		Thremola chu	Dry land & wet land	35	incidence took place 2007
63	Tashiphu		Jangkhurung chu	Dry land	76	incidence took place 2005
64	Tashiphu		Tashiphu chu	Wet land	134	Heavy incidence took place 2009

65	Tashiphu		Jangkhurung chu	Dry land	Lhakhang area	incidence took place 2009
66	Barshong		Masani chu	Wet land	133	incidence took place 2009
67	Relangthang (Noonpani)		Khaney	Wet land	21	in 2000
68	Getemkha		Laring river	Govt. land		in 1996, 2006, 2010
69	Kalikhola		Kharey Kholsa	Dry & wet land	26	2006 continues every year
70	Gakidling(Hilley)		Gurung Khola	Wet land	31	2000 & 2010
71	Gakidling(Hilley)		Chowen Kolsee	Wet land	21	2010
72	Bunakha(Bisty)		Bistee Khola	Wet & dry land	25	2010
73	Kami Dara		Gurung Khola	Dry land	16	2009 & 2011(landslide)
74	Fokforay	**Gakidling**	Devi Kholsa	Wet land	11	1993
75	Hadisay		Hadisay Kholsa	Dry land	5	2009
76	Khaharay		Khahara Khola	Orange Orchard	6	2010
77	Piling		Thotnay Khola	Wet land	21	2007 & 2011
78	Khaharay		Khaharay Khola	Govt. land		1996
79	Khaharay Kusumay		Khaharay Khola	Orange Orchard	14	2010
80	Bimberay		Kataray Kholsa	Dry land	16	1996 & 2007
81	Bimberay		Kafaray Kholsa & majitay Kholsa	Dry land	16	2007
82	Yangchenphu	**Dekiling**	Yangchu	Govt. land. & agricultural land	10h/h	2000 & 2010
83	Darbithang		Hamchu/Leokhola	Agricultural land	8h/h	2001 & 2010
84	Trashiling		Arnekhola/mahechu	Agricultural land	8h/h	2002 & 2010
85	Darbithang		Leokhola/hamchu	Agricultural land	10h/h	2000 & 2010
86	Darbithang		Sukhakhola	Agricultural	6h/h	2001 & 2010

				& residential		
87	Doloungang		Bichkhola	Agriculture land (damaged irrigation channel in past)	10h/h	2002 & 2010
88	Menchungthang/ rateygoen		Rateykhola	Agricultural land	8h/h	2000 & 2010
89	Chokhorling		Rateykhola	Govt. land(risk to irrigation channel)	10h/h	2000 & 2010
90	Nubgang		Monsoon season	Below forest & above residential area	4h/h	2001 & 2010
91	Nubgang		Nataykhola	Govt. land & residential	6h/h	2000 & 2010
92	Nubgang		Kharakhola	Govt. land & residential	7h/h	
93	Khekching	**Shompangkha**	Khekching Khola	Orange Orchard	8h/h, 40 popl.	prone to slide every monsoon season
94	Daleni		Daleni Khola	Agriculture, orchard & forestry	11h/h, 55 popl.	prone to slide every monsoon season
95	Lapsi Botay		Khekching & Noonpani	Agriculture, orchard & forestry & residential	4h/h, 20 popl.	Slide risk every monsoon season
96	Kholmey		Chi-Shiney Kholsi	Agriculture, orchard & forestry & residential	4h/h, 20 popl.	Slide risk every monsoon season
97	Lower Chaar		Devithan Kholsi & Sarpang Chhu	Agriculture, orchard & forestry & residential	6h/h, 30 popl.	Severe flood in 1996 & high risk of flooding during monsoon season
98	Phan-Phanay		Khekching Khola	Agriculture, orchard & forestry & residential	1h/h, 5 popl.	Slide risk every monsoon season
99	Dharey		Dharey Kholsi	Agriculture, orchard &	3h/h, 5 popl.	Slide risk every

				forestry		monsoon season
100	Kharey-Pakhey		Bala kholsi	Agriculture, orchard & forestry & residential		Slide risk every monsoon season
101	Chishiny Khanda		Chishiny khola	Agriculture, orchard & forestry	3h/h, 5 popl.	Slide risk every monsoon season
102	Maina Tar		Kharey Kholsa	Agriculture, orchard & forestry	1h/h, 9 popl.	Slide risk every monsoon season
103	Sarpang Bazar		Sarpang Chhu & Kami Khola	Agriculture, orchard & forestry & residential	250 popl.	whole town was washed away by flood in 1996. sever prone to flood during monsoon season
104	Chanao-Tay		Kami Khola	Agriculture, orchard &residential	1h/h, 5 popl.	Slide risk every monsoon season
105	Shompangkha village		Kami Khola	Agriculture, orchard & Acrenut orchard	30h/h, 170 popl.	Slide risk to irrigation channel
106	Pakhey Gaon		jaidhan & Bhauni Kholsi	Agriculture, Orchard, RWSS, forestry & residential	15h/h, 80 popl.	Slide risk every monsoon season
107	Pakhey Gaon		Chamling Khola	farm road, forestry & residential	2h/h, 13 popl.	severe slide & flood in 2010. prone to damage during monsoon season
108	Pakhey Gaon		Lampatey kholsi	Agriculture, farm road, residential & forestry	3h/h, 17 popl.	Prone to slide during monsoon season
109	Pakhey Gaon		Barar kholsi	Agriculture, farm road, residential &	2h/h, 12 popl	Prone to slide during monsoon

				forestry		season
110	Pakhey Gaon		Goley Kholsi	Agriculture, farm road, residential & forestry	3h/h, 27 popl.	Prone to slide during monsoon season
111			Khar Khola	Agriculture & residential	21h/h, 107 popl.	Severe flood in the year 2000. prone to flood & slide every monsoon season.
112	Phurpaling Village		Kafley Khola	Agriculture & residential	38h/h, 190 popl.	Prone to flood every monsoon season
113	App-Dara		Slide area	Agriculture & residential	4h/h, 20 popl.	Slide risk every monsoon season
114	Dargaythang Village		Jesi Kholsi	Agriculture RWSS & residential	4h/h, 20 popl.	Slide risk every monsoon season
115			Akhow khola	Agriculture & residential	16h/h, 80 popl.	Prone to flood every monsoon season
116	Phurpaling Village		Pailong kholsi	Agriculture & residential	38h/h, 190 popl.	flood risk every monsoon season
117	Norbugang village		Kopche Khola	Agriculture & residential	5h/h	flood risk every monsoon season
118	Alley Tar		Gairi Kholsi	Agriculture, orange orchard, forestry, residential & farm road	6h/h, 30 popl.	prone to soil erosion during monsoon season
119	Tinjurey alley		Alley Kholsi	Farm road, orchard & residential	3h/h, 36 popl.	Prone to flood every monsoon season
120	Jogi Dunga village		Teen-pati kholsa	Agriculture, residential, forestry & orchard	4h/h, 24 popl.	Slide risk every monsoon season

121	Jogi Dunga village		Saumigairi kholsi	Orange orchard	2h/h, 24 popl.	Slide risk every monsoon season
122	Alley Tar village		Noonpani kholsi	Orange orchard	6h/h,33 popl.	Prone to flood every monsoon season
123	Balu-kur		Noonpani kholsi	Orange orchard	2h/h, 16 popl.	Flood/slide risk every monsoon season
124	Khoshing		Marshy area	Farm road		severe slide erosion in the year 2010. prone slide during monsoon.
125	Doban	**Chudzom**	Moukhola	Dry & wet land	13h/h, 20 popl.	2010
126	Pangkhey		Pangkhey Khola	Dry & wet land	popl. 20	2006
127	Ghurgring		Moukhola	Wet land	15 popl.	2010
128	Lhatpsakha/deolari	**Singye**	Chawn kholsi	Terrace field	50 popl.	4 acres damaged
129	Thoemba		Mirgay kholsi	Dry land	1h/h	60 decimal damaged
130	Shariphu/Balatung		Halmaji kholsi	Orange orchard		1 acre damaged
131	Peljorgang&yarpheli		Samatung kholsi	Dry land	2h/h	3.15 acre damaged
132	Shariphu/Balatung		Balatung khola	Dry & wet land	4h/h	1.50 acre damaged
133	Yarpheling		Kaijali kholsi	Dry land	4h/h	
134	Nyenyul/sisty		Losgunay kholsi	Land & residential	25 popl.	Flood & soil erosion
135	Nyenyul		Chalashi kholsi	wet land & residential	13h/h, 16 popl.	Flood & soil erosion
136	Nyenyul		Sisty khola&kaijalay stream	Irrigation channel	11h/h, 81 popl.	Flood & soil erosion
137	Nyenyul		Sisty river	Land & residential	7h/h, 30 popl.	Flood & soil erosion
138	Nyenyul		Romdali kholsi	Land & residential	40 popl.	Soil erosion
139	Rishong/khopan		sisty khola	orange orchard	1h/h	3 acres damaged
140	Rishong		sisty khola	Wet land		50 decimal damaged

141	Tashitse/laborbotey		Kharbari khola	orange orchard		2 acres damaged
142	Tashitse		nurpani khola	orange orchard		25 decimal damaged
143	Rishong		Pelsa khola	orange orchard		30 decimal damaged
144	Rishong		Santi kholsi	Dry land		50 decimal damaged
145	Sangaythang		Khar khola	orange orchard		1 acre damaged
146	Sangaythang		Sadu kolchi	Land & residential	2h/h, 12 popl.	20 decimal damaged
147	Sangaythang		Naki chu	orange orchard		25 decimal damaged
148	Sangaythang		Samatung khola	Dry land	2h/h, 8 popl.	10 decimal damaged

Table 2: Historic flooding events reported by the Media

Sl. No.	Place of incident	Name of river/stream	Types of threat	Flooding Date	Remarks
1	Sarpang Bazaar	Sarpang Chhu	Shops and vegetable market area completely washed away	25th July 2016	Gelephu Flood
2	Gelephu	Shetikhari	Risk to Lives and damages of, Major Road Block	25th July 2016	Gelephu Flood
3	Gelephu	Small Aipoly	About 50 meter of Gelephu -Assam highway near border gate was completely washed away, after detention pond below Gelephu Airport Burst on evening of 27th Aug, 2017. No casualty/injury reported.	27th Aug, 2017	Seasonal Heavy rainfall
4	Gelephu	Small Aipoly	Incessant rainfall has caused flash flood loaded with debris, damages on const. of flood protection gabion wall along small Aipoly.	10th Sept. 2018	It is a recurrent issue.

Objective of the Study

Objective 1: Flood hazard assessment in Sarpang Dzongkhag and identify areas vulnerable to flooding in the face of climate change and variability.

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

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

Climate and Hydrology

The climate in Sarpang 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. The average temperature of Sarpang Dzongkhag is about 22.4° C with a minimum of 18.6°C and maximum of 26.2° C. The daily maximum rainfall for the period 1996 till 2014 is provided in ***Figure 2.*** The Sarpang Station received the maximum rainfall of 495 mm on 3rd August, 2000 as per the record provided by DHMS. Likewise, it also received maximum daily rainfall of 393 mm on 25th July, 1996 followed by 364 mm of rainfall on 27th June, 2009. From the figure below, it can also be seen that the maximum daily rainfall occurs between the months of May till September.

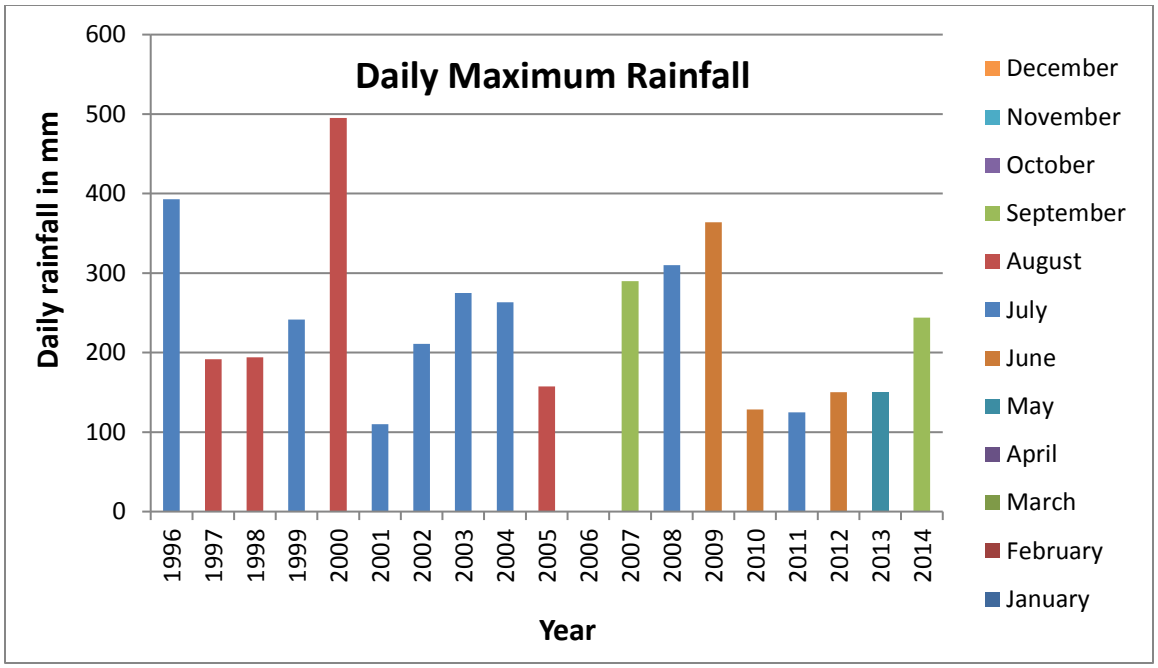


Figure 2: Daily Maximum Rainfall (mm) in Sarpang Station.

Similarly, *Figure 3* also gives information on the total monthly rainfall for the period 2011 till 2014.

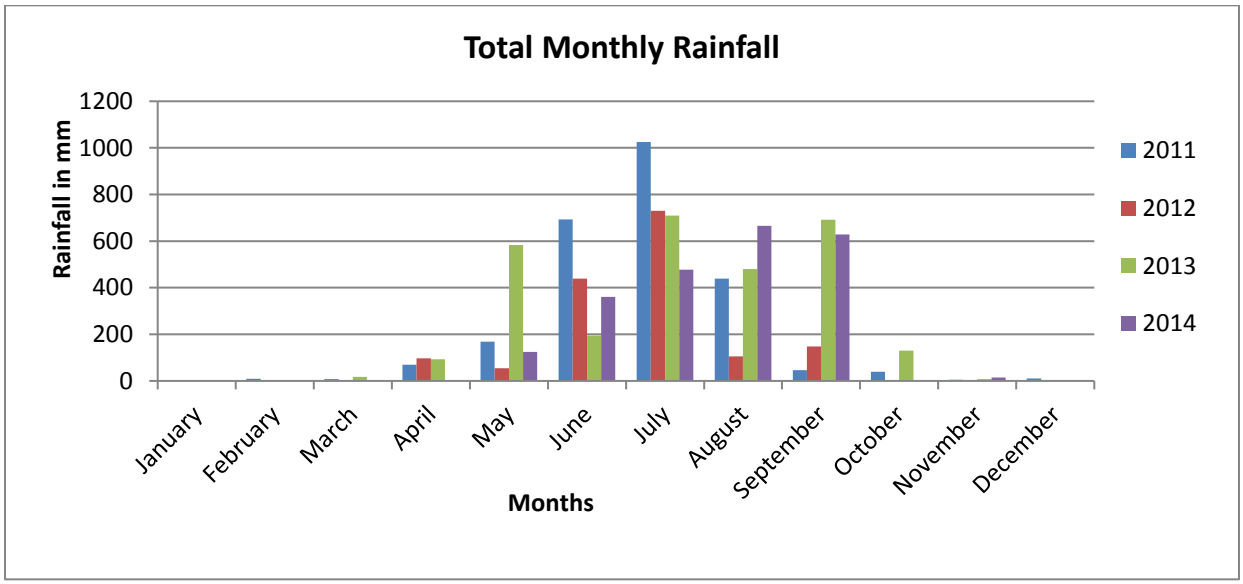


Figure 3: Total Monthly Rainfall recorded at Sarpang Station.

Geotechnical Investigation[2]

The geotechnical investigation of Sarpang township has been carried out in May, 2014 by the "Department of Human Settlement" under MoWHS. The investigation comprised the study of the nature of slopes, the types of exposed rocks, ground conditions such as presence of sinking areas, and risks to the site due to flooding and landslides.

Based on the study conducted, the hazard map as shown in *Figure 4* is divided into three zones: high hazard zone (red), medium hazard zones (yellow) and low hazard zones (blue).

High Hazard Zone: The high hazard zone covers the area with slopes greater than 230 (42 %), and areas which are vulnerable to flood, landslides and other unstable conditions. About 50 % of the area mapped falls under this zone, which is expected given the nature of the steep topography, fragile geology and risk of flooding from the Sarpang river as well as seasonal flooding (debris flow) during monsoon seasons. It is recommended that no settlement is approved within this zone because of the high risk of property damage and loss of lives.

Medium Hazard Zone: The medium hazard zone covers the area with slopes between 150 and 230 (27 % and 42 %), and areas which could prove to be hazardous in the absence of proper engineering efforts and mitigation measures. About 10 % of the area mapped falls under this zone. Although construction could be allowed in this zone on a case by case basis, it is paramount that destabilizing factors are studied in detail to provide relevant mitigation measures.

Low Hazard Zone: The low hazard zone covers the area with slopes less than 150 (27 %) and areas with no perceivable dangers to human settlement under normal conditions. About 40 % of the area mapped falls under this zone. Due to the minimum threat to human lives and property, this zone is deemed most fit for future settlements and other engineering works. However, it should be noted that misguided construction and unforeseen natural calamities could destabilize this zone in the future. Therefore, it is recommended that thorough study of impacts of manmade structures is done before approval of any projects in this zone as well.

[2] Geotechnical Report, Sarpang Township, Bhutan

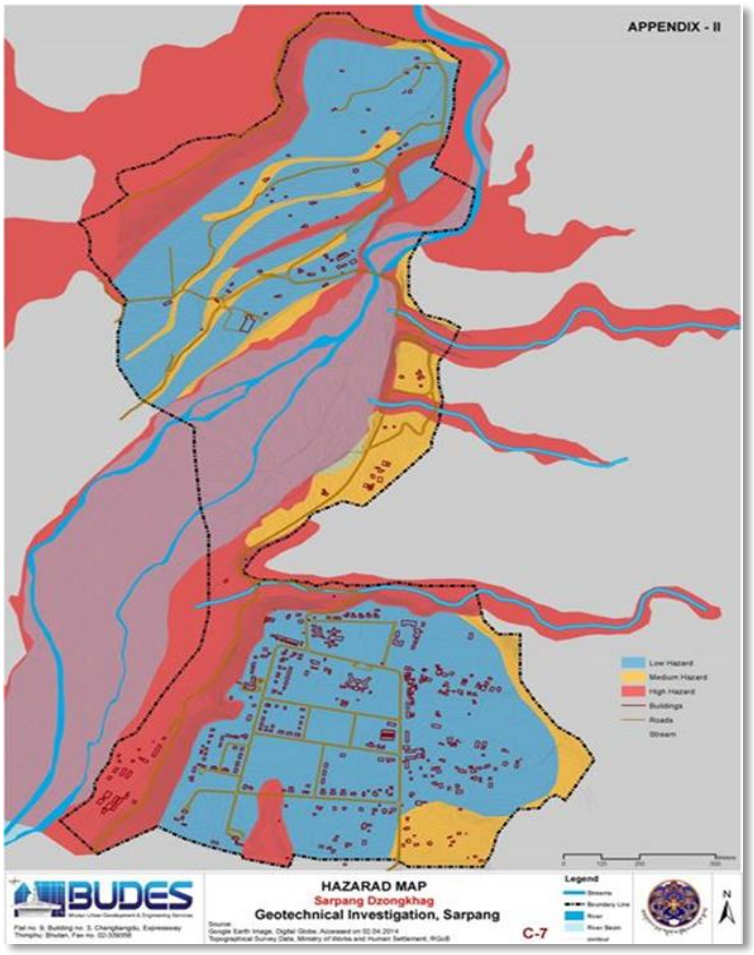


Figure 4 : Hazard Map for Sarpang Township.

Problem Statement

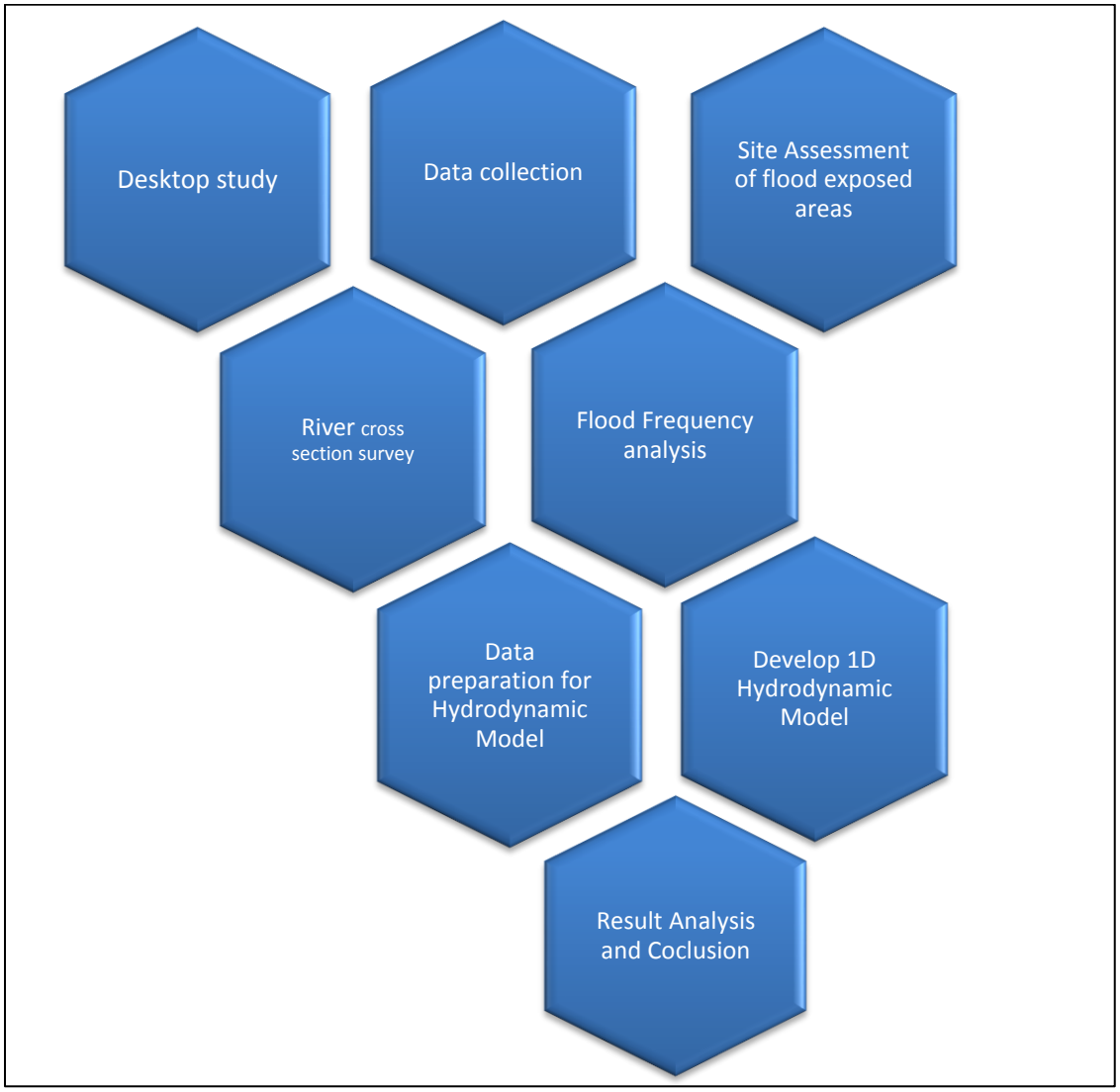
Bhutan is prone to multiple natural hazards that pose varying degrees of risk to the lives and livelihoods of its population. Flash floods and landslides pose an annual threat to human lives, properties and livelihoods, especially in the southern parts of the country. Sarpang Dzongkhag located in the southern part of Bhutan has a history of flooding due to erratic rainfall pattern. The flooding causes damage to the lives (people and cattle), properties and agricultural lands. The problem of flooding is aggravated by high rates of erosion due to fragile geology resulting in rivers changing its course towards the settlements, debris flow, flash flood etc. Geologically, southern Bhutan falls under Siwalik Zone, where soil predominantly consists of sandstones, siltstones, clay shale and boulder beds. These types of soils are very susceptible to erosion. Therefore, the flash flood in the Dzongkhag usually overtops the banks and erodes sediments from upstream. The sediments are then deposited in large scale in the downstream portion of the river and finally a new river course is developed over once fertile agricultural land. Some of the best potential agricultural land is found in the Sarpang Dzongkhag and yield per acre is high

where irrigation facilities exist. The favourable terrain and climatic conditions combined with fertile agriculture land offer tremendous opportunity for farm mechanization and commercial horticultural development in the Dzongkhag. However, the floods in summer make the once fertile land infertile and unsuitable for agricultural use.

Further, infrastructure like roads, bridges, flood protection structures etc. are also being washed away by the flood every year as seen in *Figure 5* and hence, the Dzongkhag continue to invest huge amount of money for reconstruction works every financial year. Huge investment has also been made in the past for flood protection works. Further, due to climate change, the rainfall pattern and rainfall intensity has changed increasing the vulnerability of the community to flooding in the Dzongkhag. Therefore, to reduce the vulnerability of the community to flood, preliminary flood hazard assessment is carried out to identify the critical river in the Dzongkhag. Further, for the identified critical river, preliminary flood hazard map will be developed accordingly.

Figure 5: Flood event in Sarpang Dzongkhag

Methodology



Data Collection and Assessment

Hydrological and Meteorological Data

Data collection is the process of gathering relevant information to evaluate outcomes. Accurate data collection is therefore, essential to maintain the integrity of any research conducted. While conducting the preliminary flood hazard assessment for Sarpang Dzongkhag, following data were collected from various sources:

Hydro-Met Data

Gathering hydrologic data directly from rivers and streams is very valuable for modeling purpose, however, it is difficult and tedious. If such data are collected for many years through stream gauging, models can be used to determine the frequency of given flood events and also find the area of inundation. Historical data for at least twenty years are recommended for any kind of assessment done on rivers. In Bhutan, most of the rivers are ungauged and hence it poses a challenge while undertaking such kind of assessment. Further, the problem is aggravated by lack of expertise on the subject like hydrology and hydraulics. The hydro-meteorological data are maintained by National Center for Hydrology and Meteorology under Ministry of Economic Affairs.

Sarpang Chhu in Sarpang Dzongkhag is ungauged and hence there is no historical discharge data for the river at present. As per the detailed engineering and feasibility study for Lhaimoizingkha and Sarpang flood protection carried out in 2013 by Lhawang Consultancy, the discharge of different return period for Sarpang Chhu is as presented in *Table 3*. Furthermore, the only available data for the Sarpang Dzongkhag is the daily rainfall data collected at Sarpang, Bhur and I-bridge at Chisopani in Gelephu.

Table 3: Discharge of different return period for Sarpang[3].

Sl.No	Return Period (year)	Discharge (m^3/s)
1	25	390
2	50	453
3	100	515

[3] Detailed Engineering and Feasibility Study Report for Lhamoizingkha & Sarpang Flood Protection.

DEM (Digital Elevation Model)

SRTM (Shuttle Rader Topography Mission) DEM with 30 meter resolution is used for this project. When the river model simulates the design flows in the river channel and the flow is too large for the channel, the water comes out of bank and onto the floodplain. The model will then need elevation data that defines the terrain (topography) in order to simulate where this flood water will go and how deep it will be. For this, we use a Digital Elevation Model (DEM) and it is clipped for the study area using the ARC-GIS. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

Land cover Data

Land cover data from Department of Forest and Park Services has been collected. However, it could not be used for modeling purpose since, the soil data collected from National Soil Service Centre is not enough to derive the curve number.

Site Assessment of the Study Area

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.

Shompangkha Gewog in Sarpang Dzongkhag

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

Table 4. Of the six rivers in the Gewog, Sarpang Chhu and its tributary Kamichu are perennial. The rest of the rivers in the Gewog are seasonal. The two rivers such as Kamichu and Kharay Khola are the tributaries of Sarpang Chhu. Rest of the three rivers such as Kafley Khola, Khar Khola and Akho Khola doesn't join Sarpang Chhu. In the Gewog, Sarpang Chhu is the most notorious river causing destructions during the rainy seaons.

Table 4: Critical areas under threat from erosion in Shompangkha Gewog.

Sl. No	Threat from flood(location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Crematorium	Shompangkha	26°51'36"	90°15'29"	260	Left bank
2	Piggery farm	Shompangkha	26°51'36.2"	90°15'29.8"	261	
3	Druk wire factory	Shompangkha	26°51'44.3"	90°15'36.5"	265	
4	Kamichu confluence	Shompangkha	26°52'08"	90°15'49.4"	285	
5	Near BOD	Shompangkha	26°52'18.4"	90°16'02.4"	302	
6	Kharay Khola	Shompangkha	26°52'39.4"	90°16'07.3"	305	
7	Hillay check post	Shompangkha	26°52'10"	90°15'25.6"	290	Right bank
8	Kaflay Khola	Shompangkha	26°51'32.1"	90°18'57.7"	295	
9	Khar Khola	Shompangkha	26°51'13.8"	90°17'55.1"	271	
10	Akho Khola	Shompangkha	26°51'01.2"	90°17'14.3"	282	

Sarpang Chhu in Sarpang Dzongkhag.

Sarpang Chhu is the main perennial river flowing along Sarpang Bazaar in Shompangkha Gewog under Sarpang Dzongkhag. The Sarpang Bazaar is the market where commercial transactions of the towns are carried out. It is mostly made up of bamboo houses (temporary structures) clustered together along the left bank of Sarpang Chhu. The permanent traditional Bazaar was washed away during one of the flash floods in the past as per the local residents. The Gelephu-Tsirang national highway also passes through the Sarpang Chhu.

There are about three tributaries of Sarpang Chhu discharging into the main river below the downstream of the Hilley Bridge as seen from *Figure 6*. As per the local residents, Kamichhu is perennial while Kharey Khola[4] and the third stream are seasonal. The third stream is the

[4] Khola is the southern Bhutanese term for a "Stream"

discharge from the catchment around BOD in Sarpang Bazaar during rainy seasons. The existence of the two seasonal streams can be confirmed from the presence of stream flow path filled with debris of various sizes.

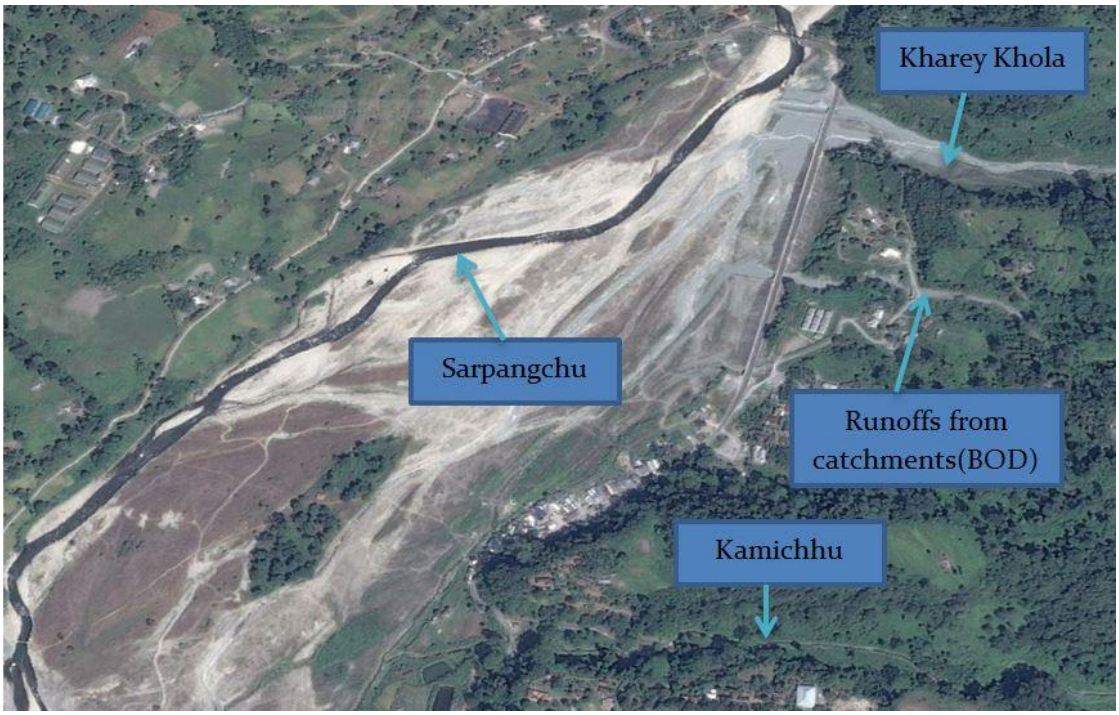


Figure 6: Sarpang Chhu with its tributaries.

The Sarpang Chhu has been creating havoc to the inhabitants and increasing the vulnerability of communities to the flooding every rainy season as seen from *Figure 7*. It has been changing its courses every season thus, rendering some of the fertile agricultural land useless, making people homeless and causing severe damages to roads and other infrastructures. As per the site investigations through visual inspection, the catchment of the Sarpang Chhu upstream of Hilley Bridge looks fragile and fresh landslides were seen. This can be confirmed from the siltation problem observed in Sarpang Chhu during the rainy season resulting in increased height of river bed. In the past, Sarpang Chhu has been trained by constructing flood protection structures. However, the structures had were repeatedly damaged or washed away because of the recurrent flash floods.

As per the record, lots of investment has been made in the past for flood protection works along the banks of Sarpang Chhu and still more protection works are required. A mixture of flood protection works such as embankment with AB mattresses, gabion walls, RRM walls etc. with different heights and designs have been constructed along the banks of Sarpang Chhu. Some of the walls are still functioning partially at present.

Figure 7: Critical areas along Sarpang Chhu.

Gakiling Gewog in Sarpang Dzongkhag

In the Gakiling Gewog, there are three rivers namely Gurung Khola, Sisty Khola and Hilley Khola. Out of the three rivers, only Sisty Khola is perennial whereas both the other two rivers (Gurung Khola and Hilley Khola) are seasonal. The Gurung Khola flows through Gakiling Gewog and joins Sarpang Chhu at its right bank near the Indo-Bhutan Border. During our preliminary flood hazard assessment in the Gewog, only four critical flood prone areas are identified as observed in *Table 5.*

Table 5: Critical flood prone areas in Gakiling Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Gurung khola	Gakiling	26°52'10"	90°15'25.6"	290	Right bank
2	Gakiling village	Gakiling	26°52'00"	90°15'28.4"	286	
3	Sisty khola	Gakiling	26°51'41.8"	90°13'54.9"	265	
4	Hilley khola	Gakiling	26°51'42.2"	90°14'42.4"	301	

As per our assessment, the Gurung Khola only affected the agricultural fields in the Gewog and it was not found to be too critical. Similarly, Hilley Khola also doesn't pose much danger to the communities in the Gewog. On the other hand, Sisty Khola was found to be critical since it has affected settlements, agricultural fields and also infrastructure such as bridge along its left banks. 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 8.* Similarly, it has been observed that the difference in elevation between the river bed level and top bank level is only about 1.5 m in some stretches along the river. This situation might increase the vulnerability of the communities to flooding during extreme events. Further, the bridge scour may lead to the failure of the suspension bridge affecting the connectivity of the Sisty village.

Therefore, if proper interventions are not done at this stage, then there is higher probability of river breaching their banks and entering the Sisty village. Hence, it is highly recommended to construct flood protection structures along the left bank of Sisty Khola and also to restore the foundation of suspension bridge abutment.

Figure 8: Flood prone areas in Gakiling Gewog.

Dekiling Gewog

The team during the assessment visited the three critical rivers namely Tinpati Khola, Leukhola and Dholkhola in Dekiling Gewog. It was observed that these rivers do not posed any threat to the agricultural land and also the settlements, however during the monsoon season, there is a threat from the rivers to the Sarpang-Gelephu Highway. This fact is proven by interventions carried out by Department of Roads (DOR) under the Ministry of Works and Human Settlement (MoWHS) to safeguard the roads. During the site investigation, only three critical flood prone areas were identified as presented in
Table 6.

Table 6: Critical flood prone area in Dekiling Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Tinpatikhola	Dekiling	26°52'01"	90°19'30.5"	337	River
2	Leukhola	Dekiling	26°52'59.6"	90°20'33.8"	337	River
3	Dholkhola	Dekiling	26°54'08"	90°21'17.4"	336	River

(a) (b)

(c)

Figure 9: (a) Tinpati Khola (b) Leukhola and (c) Dholkhola

As seen in the *Figure* 9, the settlements are not located near the rivers, therefore, there are not so much destructions by the rivers during the rainy seasons. All the three rivers are seasonal. During the assessment, it has been observed that there is minor scouring along the river banks of the three rivers. Tinpati Khola and Leukhola are of meandering nature and lots of forest land has been converted to the flood plains along the rivers.

Samtenling Gewog

In the Samtenling Gewog, there are four rivers namely Bhur Khola, Paithrai Khola, Big Aipoly and Small Aipoly. Apart from the Bhur Khola, all the other three rivers are seasonal. The site investigations resulted in identifying four critical areas in Samtenling Gewog as given in *Table* 7.

Table 7: Flood prone areas in Samtenling Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Bhur Khola	Samtenling	26°55'24.6"	90°23'55"	337	Left bank
2	Paithrai khola	Samtenling	26°53'40"	90°26'25.2"	332	Right bank
3	Big Aipoly	Samtenling	26°54'01.9"	90°27'23.6"	343	
4	Small aipoly	Samtenling	26°52'45.6"	90°28'22.9"	272	

Presently, as per the visual inspection and hearsay during the site investigations, there seems to be no threat from the Big Aipoly to the settlements and agricultural fields. However, if it changes is course, the Gelephu Domestic Airport will be under threat from flooding since it flows right above the airport as shown in *Figure 10(a).* Likewise, the Bhur Khola also does not pose much flooding hazard to the settlements and the agricultural fields since it is located far away from the community. On the contrary, Small Aipoly and Paithrai Khola are the rivers which are prone to flooding in the Gewog.

(a) (b)

Figure 10: (a) Big Aipoly and (b) Bhur Khola.

Paithrai Khola in Samtenling Gewog

Figure 11: Threat from the Paithra Khola.

During the site investigation, it has been observed that Paithrai Khola is one of the notorious rivers posing threat to the settlement and agricultural fields in Samtenling Gewog. This is confirmed by the fact that Dzongkhag Administration has also carried out interventions in the past to reduce the vulnerability of community to flooding in Samtenling village as shown in *Figure 11*. The past interventions carried out have also failed in some places due to erosive nature of the river during the rainy season. The river beds are also covered with sediments implying debris problem in the rivers. From the visual inspection, it can be seen that scouring is happening along the river banks. Therefore, some more interventions are required to protect both the settlements and agricultural lands from flooding from Paithrai Khola in the Gewog.

Small Aipoly in Samtenling Gewog

The small Aipoly stream during monsoon season always causes the flash flood in and around the international Check Post at Gelephu making the lives of people living in that locality quite miserable and even cause damages to the public and private properties. The stream brings in huge quantities of debris during the rainy season and also keeps on changing its course. The flood scenario caused by small Aipoly dates back to decades. With the coming up of domestic airport, flooding situation may have been aggravated as runoff from the airport and surrounding areas drained off to small Aipoly, thereby increasing the volume. The only solution to prevent flooding was to divert the small Aipoly stream to the Big Aipoly. However, the diversion work couldn't be implemented due to some trans-boundary issues.

Therefore, to reduce the impacts of flooding near the international check post, FEMD constructed a detention pond with a capacity to store the runoff of 38,100 cum for a certain period of time as presented in *Figure 12.* The concept of detention pond was introduced for Aipoly as a pilot project. The water is to be stored and discharged in a controlled way through the outlet within the capacity of the storm water drain near the culvert. The detention pond was designed to be a pool created by excavating the earth below the ground level. The maximum hydrostatic pressure developed with full capacity would be withstood by the natural ground without having to reinforce with additional structures other than revetment. Further, a floodway is also constructed at the downstream of the detention pond to properly discharge the water retained in the pond to the drain near the international check post.

Figure 12: Detention pond and floodway in Gelephu.

Gelephu Gewog

The Gelephu Gewog has five rivers namely Shetikheri, Dowla Khola, Jogi Khola, Lodrai Khola and Mao River. Except for Mao River being perennial, all other rivers are seasonal flowing only during the rainy season. During the site visit, eight critical flood hazard areas were identified as shown in
Table 8. Out of the five rivers, only Shetikher, Mao River and Lodrai Khola cause destructions to the settlements, agricultural fields and infrastructure during the monsoon season.

Table 8: Flood prone areas in Gelephu Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Shetikhari	Gelephu	26°53'33.5"	90°29'54.2"	251	Left bank
2	Dowla khola	Gelephu	26°53'49.6"	90°30'04.9"	249	
3	Jogi Khola	Gelephu	26°54'41"	90°30'03.7"	269	
4	Lodrai Khola	Gelephu	26°55'23.9"	90°30'16.5"	290	
5	Mau Khola	Gelephu	26°54'54.9"	90°30'31.8"	256	Right Bank
6	Confluence of Dowla and Mau khola	Gelephu	26°59'41.7"	90°30'10.6"	240	Left bank
7	Confluence of Shitikhari and Mau khola	Gelephu	26°53'37.3"	90°30'10"	244	Left bank
8	Mau Khola (infiltration gallery)	Gelephu	26°52'49.7"	90°30'14.2"	255	Left bank

Mao River in Gelephu.

Mao River, over the past many decades, has been eroding both the banks. The Mao River, with an average flow of just 40 cubic meters per seconds, has developed a very wide channel as seen from *Figure 13.* At certain sections, the width of the river channel is as wide as 1,500 meters. Without immediate attention, these plains are under high risk from the threat of degradation. During the monsoon period from June till September four gewogs of Sarpang Dzongkhag are inaccessible due to the Mao River. During the monsoon period the river gets swollen and the whole area on the left bank is completely cut off, leading to great inconvenience to the entire population of the four gewogs.

Built with a huge cost is the water treatment plant of Gelephu Town, which is located on the right bank of Mao River. The Mao River Infiltration Gallery which produces 4MLD was constructed under Danida funding in 2010. There are also other infrastructures like private houses, private fisheries, Bhutan Olympic committee (BOC) located very close to the right bank. These infrastructures are in grave risk of being flooded and washed away. Moreover, the left bank also has been experiencing constant erosion. A few meter width of land is being eroded every monsoon.

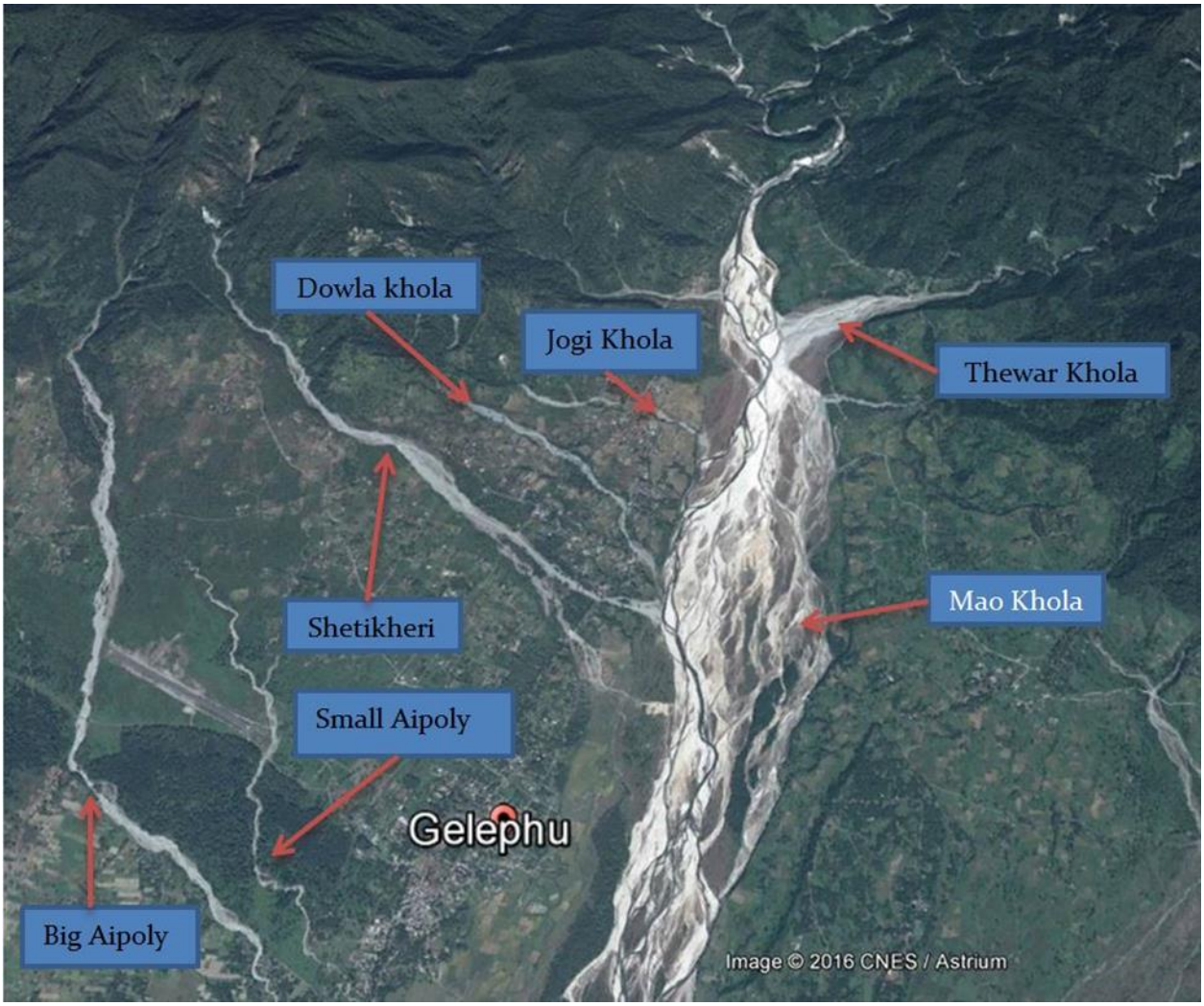


Figure 13 : Mao River in Gelephu with its tributaries.

Shetikheri in Gelephu.

Shetikheri is a tributary of Mao River and it is a seasonal stream. Upon site investigation of the catchment, numerous landslides were seen. The landslides may be triggered by human activity such as construction of high tension transmission towers. Further, a road has also been constructed at the upstream near the source with no proper drainage, this may have also

contributed to the increase in runoff and sediment load. The source of the Shetikheri is as shown in *Figure 14.*

(a) (b)

Figure 14: (a) Source of Shetikheri (b) Landslide at source.

During heavy rain over an extended period of time, it carries huge volume of debris as given in *Figure 15.*

(a) (b)

Figure 15: (a) Scour depth on the pillars (b) Debris collected at the downstream of Shetikheri.

It normally starts to meander along its way causing flooding at various locations downstream. As per the assessment, there is an erosion of the bank on the upstream portion and thus, the sediments are transported to the lower plains in the downstream portion of the river during rainy season. As the sediments are transported to the floodplains, the elevations of the floodplains are raised and thus, the flow path of the river is reduced. Therefore, the river flows through a new path during peak season with lower elevation resulting in meandering rivers. The Shetikheri stream is adjacent to Pelrithang village (Left Bank) and Zomlingthang village (Right Bank) and encroachment towards these settlements during the monsoon is common due to its meandering nature. Meandering or change in course is caused mainly due to the deposition of massive quantity of debris during the flooding.

Past interventions for flood protection has also been done by construction gabion walls of height ranging from 2 to 3 metres at critical points. Further, in order to prevent flooding of the adjacent villages, channelization/floodway was constructed as given in *Figure 16.* A floodway of 12m width was constructed upstream of the culvert on the main highway in the year 2012 with technical backstopping from FEMD. In the financial year, 2015-2016, floodway of width 20 metres and length 700 metres was awarded to contractor, which was still ongoing at the time of flooding in July, 2016. Further, during the financial year 2016-2017, gabion walls with apron have been designed at the identified critical areas by FEMD to reduce the vulnerability of communities to flooding in Gelephu Gewog.

Figure 16: Past interventions along Shetikheri (Gabion walls and floodways).

Dowla Khola and Jogi Khola in Gelephu.

Both Dowla Khola and Jogi Khola are seasonal and doesn't pose much danger to Gelephu town. However, Dowla Khola during rainy season damages the Gelephu- Zhemgang Highway making it inaccessible to the public. It doesn't affect the agricultural fields and the settlements. On the other hand, Jogi Khola affects the settlement and the agricultural fields in and around Gelephu Gewog since it flows through the settlements as given in *Figure 17.* If left without any

interventions, there is high chance of it changing its course and affecting the settlements in the Gelephu Thromde.

(a) (b)

Figure 17: (a) Dowla Khola and (b) Jogi Khola.

Lodrai Khola in Gelephu.

As per the assessment, the Lodrai Khola does not impact the agricultural fields and settlements in the Gewog since the Dzongkhag has provided RCC(Reinforced Cement Concrete) flood protection walls along the right bank of Lodrai. However, the river has eroded the left bank of Lodrai Khola near the RBA (Royal Bhutan Army) colony at the confluence of Mao River. There is an urgent requirement of flood protection structures near the colony as seen from *Figure 18.* Nevertheless, foundation work for the flood protection works are going on as per our observations.

(a) (b)

Figure 18 : (a) Left Bank and (b) Right Bank.

Sershong Gewog.

In the Sershong Gewog, there are three rivers namely Thewar Khola, Masana Khola and Jangkurung Chhu. In addition to these rivers, the Gewog also is located at the left bank of Mao River, thereby making it more vulnerable to flooding from the Mao River. The critical flood prone areas in the Gewog are as given in the *Table 9.*

Table 9: Flood prone areas in Sershong Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Thewar Khola	Sershong	26°55'21.1"	90°31'35.6"	273	Left bank
2	Masana Khola	Sershong	26°54'45.7"	90°31'07.7"	259	
3	Mao River Left bank	Sershong	26°55'39.4"	90°30'32"	238	

Thewar Khola and Masana Khola in Shershong Gewog.

During site investigations, it was found out that both the Thewar Khola and Masana Khola are seasonal and do not affect the settlements and the agricultural fields at present. However, some agricultural fields near the rivers are left fallow indicating that minor damages are caused to the fields nears the rivers. Further, during rainy season both the swollen rivers caused road blockages since both the rivers pass through the roads as seen in
Figure 19. When the Thewar Khola gets swollen, the connectivity between Shershong village to Norbuling village in the Shershong Gewog and also connectivity between Shershong Gewog and Chuzaygang are affected. Similarly, when Masana Khola gets swollen, there are no connectivity between Shershong Gewog and Chuzaygang Gewog.

(a) (b)

Figure 19: (a) Thewar Khola and (B) Masana Khola in Shershong Gewog.

Mao River and Jangkurung Chhu in Shershong Gewog.

During the assessment, the team observed the Shershong village located on the left bank of Mao River is threatened by the Mao River. There are chances of Mao River breaching its bank and damaging the agricultural fields in Shershong village in future as seen in figure below.

(a) (b)

Figure 20 : (a) Mao River and (b) Jangkurung Chhu.

The team observed that Jangkurung Chhu does not pose much threat to the settlements at present. However, it has been noticed that a lone house on the right bank of the river is threatened by the landslides caused by the erosion of the river bank. Therefore, a google image time series analysis has been carried to see the meandering nature of the stream. It is observed that the river course changes from time to time as presented in *Figure 21*.

(a) (b)

Figure 21: (a) Flowpath in 2010 (b) Flowpath in 2013.

Umling Gewog

In the Umling Gewog, there are only one critical river namely Taklai River. The *Table* 10 gives the flood prone areas in Umling Gewog.

Table 10: Flood prone areas in Umling Gewog.

Sl.No	Threat from flood (Location)	Gewog	Coordinates		Elevation in m	Remarks
			Northing	Easting		
1	Taklai Khola	Umling	26°50'34.6"	90°31'50"	211	Left bank

Taklai Rivers flows through Zamlingthang village under Umling Gewog. Almost 75% of the paddy field was washed away by flash flood in mid-2016. These areas affected by the flood were mainly used for agriculture purposes and there were no household. During the site investigations also, the flooding threat was mainly to the agricultural land used for rice cultivations in the Gewog. The recent flood in 2016 also resulted in the river bed level reaching almost the same level as existing ground level as given in *Figure 22* and therefore, an appropriate flood protection structures are required on the left bank of the Taklai River to protect the agricultural field.

Figure 22: Agricultural field on the left bank of Taklai Chhu.

Past Flood Event in The Study Area[5]

As per the site investigations, it has been learnt that Sarpang 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. Sarpang Chhu has temporary structures and agricultural fields along the left and the right banks respectively.

[5] Post Flood Report, Department of Engineering Services, MoWHS (August, 2016).

Shetikheri, Aipoly and Maochu also flow through settlements and agricultural fields. The Dzongkhag had experience flooding but don't have a proper record of the damages caused by the flood events. The most recent flash flood of July, 2016 in Sarpang caused damages to flood protection walls, roads, bridge and other infrastructure. The details of the damages caused by the flood in July, 2016 in Sarpang Dzongkhag are given below.

Sarpang Chhu Flood

Sarpang Dzongkhag experiences heavy rains during summer season every year. The people living in the Sarpang Bazaar, mostly made up of bamboo houses located on the left bank of Sarpang Chhu live in fear. As per the local residents, Sarpang town experienced major devastating flood in the year 1996, which washed away the whole Sarpang Bazaar. Recently, the flood in July 2016, also caused major damages to the roads, ongoing flood protection structures, agricultural fields and rendered all the people residing in Sarpang Bazaar homeless as shown in *Figure 23.*

Figure 23: Destruction caused by the flood in July, 2016.

The recent flood was caused due to continuous rain that lasted for more than a week. Non-stop rain that started since 14th July led to the swollen Sarpang Chhu which began to change its course towards the left *(Figure 25)* from its usual flow along the right bank *(Figure 24).* The meandering of the river was caused due to the sedimentation at the low point triggered by the change in direction upon hitting the huge boulder and RRM wall at the right side of the bridge abutment. From 21st July morning, the river encroached towards the Sarpang makeshift town and slowly scoured and carried away the land and the houses. By 25th July, the river had washed away 480 m of Gelephu-Sarpang-Damphu primary national highway. The river however, didn't enter the small island in the midst of Sarpang Chhu which has a Hindu Temple.

Figure 24 : Original river course (along the right bank) before the flooding of July, 2016.

Figure 25: Sarpang Chhu changed its course towards the left bank (During Flood).

The estimated damage during the flooding of Sarpang Chhu in 2016 is given in *Table 11*.

Table 11 : Estimated Damages for Sarpang Chhu Flood Protection Works.

Sl.No	Dzongkhag	Name of the Work	Length of the Floodway (KM)	Total Length damaged (KM)	Estimated damage (Nu)	Remarks
1	Sarpang	River protection work along Sarpang chhu (Phase-I)	0.4	0.4	10,797,199.54	Construction was on-going at the time of the flood
		River protection work along Sarpang chhu (Phase-II)	0.75	0.75	14,062,542.87	Construction was on-going at the time of the flood
Total Cost Estimates of the Damages					**24,859,742.41**	

(Source: Sarpang Dzongkhag)

Mao River in Gelephu Drungkhag

Figure 26: Mao River flowing towards the Infiltration Gallery.

During the flood on 22nd July, 2016 the flood water has entered the infiltration gallery filling it with huge debris and sediments as seen in
Figure 26. The flood damaged the 500m long spur wall which collapsed resulting in filling up of the infiltration gallery with debris. It also caused damages to RRM wall. The fencing (MS angle and MS wire mesh) around the infiltration gallery were also damaged incurring a loss of about Nu. 0.7 Million.

Figure 27: Destructions caused by Mao River near the Infiltration gallery.

The Inner surface of the Infiltration gallery is constructed using gabion walls. The depth of the infiltration gallery is 13m below the ground. During the flood, although efforts were made to prevent heavy debris from entering into the infiltration gallery by the Thromde officials with the help of volunteers, huge amount of silting has been deposited inside the infiltration gallery. This has resulted in reducing the pump efficiency as well as the quantity of water supply. The restoration works for the infiltration gallery incurred about Nu.0.4 Million which included the use of excavators and removing silts deposits from the gallery. Further, the flood also damaged RRM (Random Rubble Masonry) walls, compound lighting and 2 numbers of submersible pumps incurring a loss of about 0.9 Million, 0.1 Million and 0.6 Million respectively as given in *Figure 27.*

Shetikheri in Gelephu Drungkhag

During the flood in July, 2016, the floodway initially prevented flooding of the settlements near Shetikheri by restricting the flow through the floodway. However, as soon as it reached the culvert on the main highway, the flow velocity was reduced as a result of constriction of the flowpath by the culvert. Then the deposition of the sediment and debris took place as presented in *Figure 28.* The deposition of the material near the culvert led to change in course towards the

settlement on right bank, damaging the culvert on the right bank in the process. After continuous deposition on the right bank the river changed its course towards the left affecting the settlement on the left bank. In this way, lots of settlements were affected and people were evacuated with their properties to a safe location.

Figure 28: Settlements along Shethikheri affected by the flood.

The flooding also damaged roads, transmission lines and water pipe lines on national highway as given in *Figure 29.* The floodway was also damaged and covered with debris. The gabion walls constructed on the critical areas along Shetikheri was also damaged by the flood of July, 2016.

Figure 29: Destructions caused by the Shetikheri stream.

Taklaichu in Umling Gewog.

Figure 30: Damaged wall and affected paddy field locations.

The flood in July, 2016 caused major damages to the agricultural land and minor damages to the flood protection structures along Taklaichu as presented in *Figure 30.* It was apparent during the site visit to the affected area that the debris and sediment from the flooding had severely submerged some parts of the agricultural land.

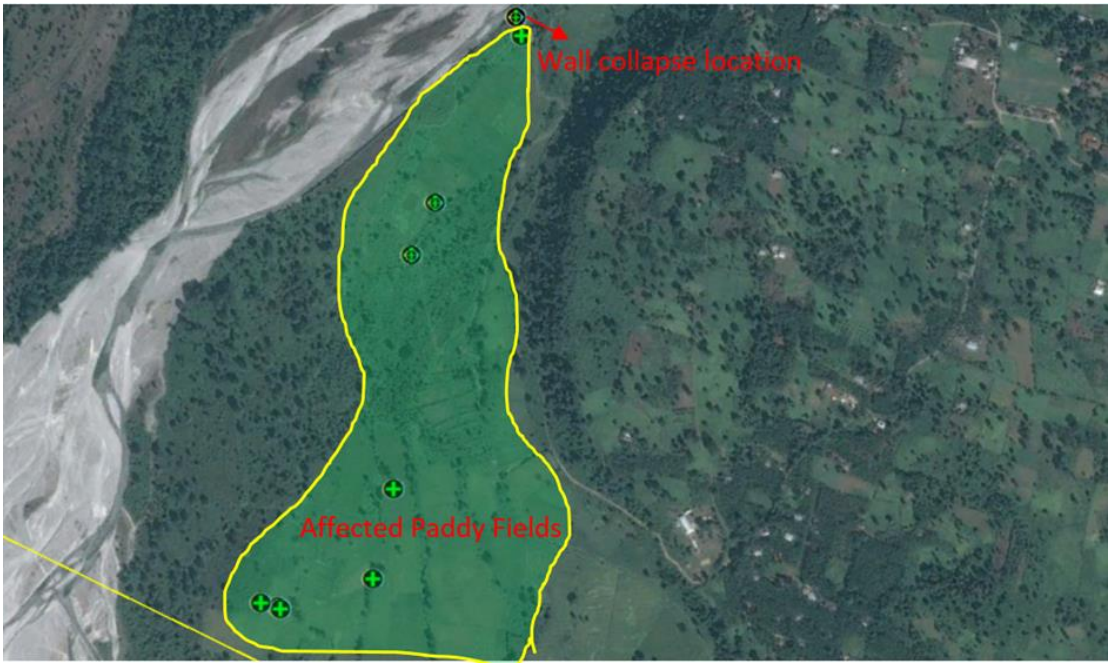


Figure 31: Paddy field damage location at Gadhen and Linger Village.

With regard to impact of flooding on to the 1000m river training walls that existed just before the flood, the team was informed by the local representatives that the wall had suffered some minor damages as a result of floods of 2008 and 2015. Due to shortage of funds, the damaged gabion walls could not be repaired. And therefore, the recent flood broke through the already damaged gabion wall which eventually collapsed resulting in free flow of Taklai River towards the paddy fields, damaging the existing 1000 meter earthen irrigation channel in the process. The earthen channel also aggravated the flooding by favoring the river flow towards the paddy fields. The *Figure 31* shows the location of the affected paddy field by Taklaichu in 2016. In total, 826 meter of gabion of 4 meter height was completely washed away. The remaining 174 meter experienced damages to the apron although the wall was still standing at the time of the visit.

Jangkurung Chhu in Shershong Gewog

The flood in July, 2016 also causes some minor damages along the river banks of Jangkurung Chhu as a result of scouring and erosion. The local people informed that there are about 25 households along the right bank of Jangkurung chhu. As per the assessment, there were signs of fresh scouring and slides along the right bank and one house was found directly exposed to the risk of flooding as seen in *Figure 32*. As per the house owner, the recent flood scours the river bank and created slides, which started to encroach into his land.

Figure 32: Minor landslide and scouring along Jangkurung chu.

Rainfall Study for the extreme event in June, 2016[6]

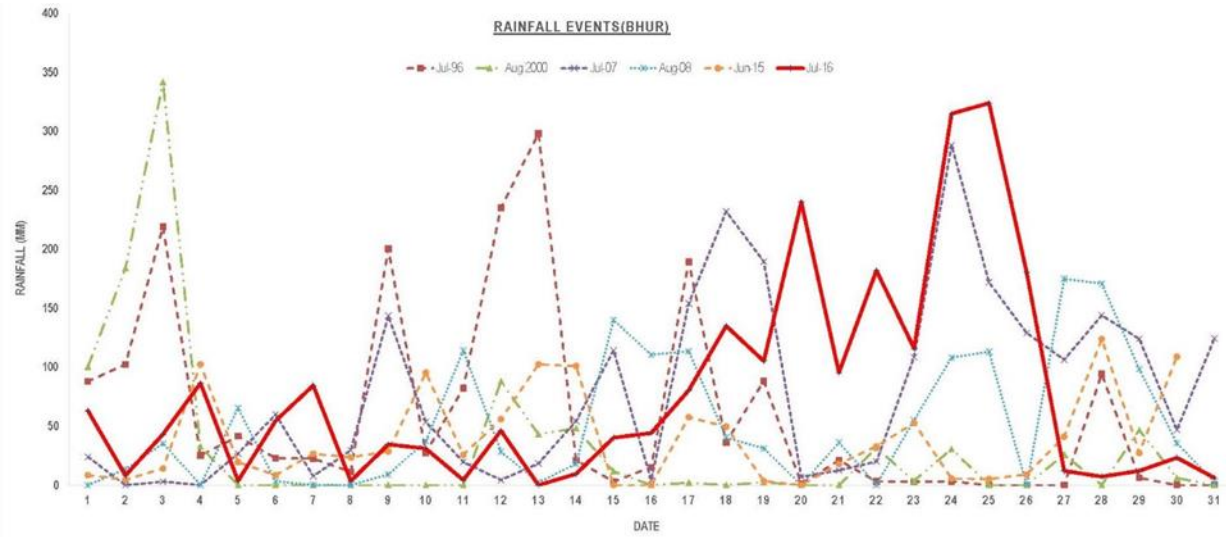


Figure 33: Bhur rainfall events.

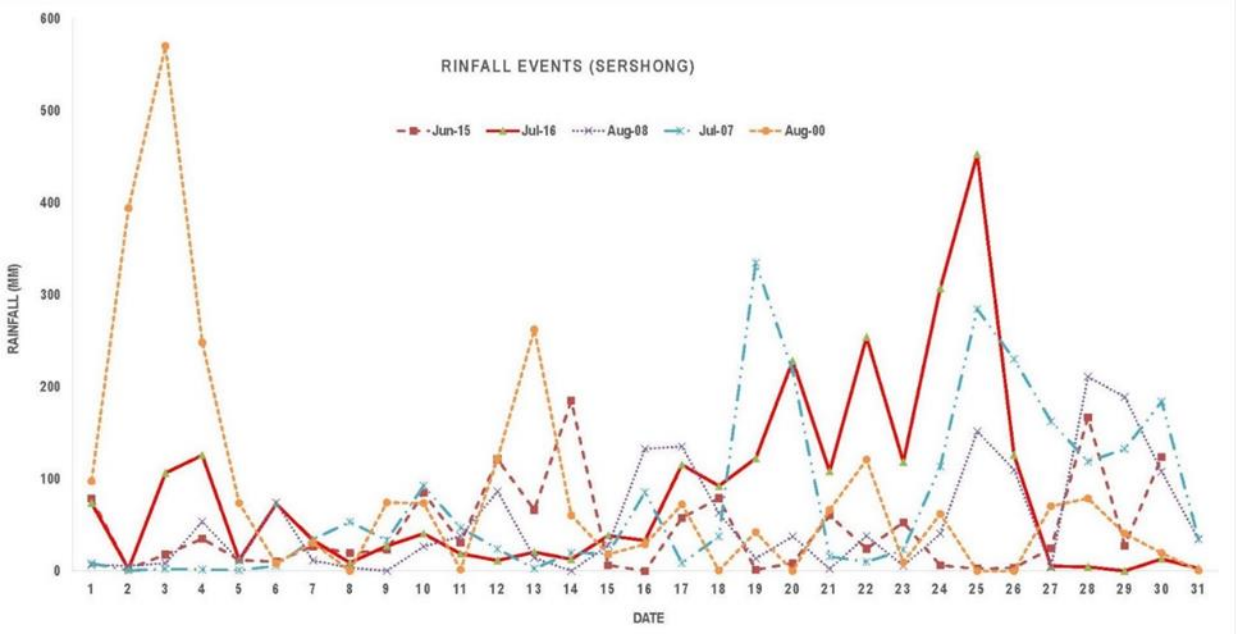


Figure 34: Shershong rainfall events.

There are only two rainfall stations in Sarpang which are located in Bhur and I-bridge in Chisopani in Gelephu. These stations maintain records of daily rainfall in the area. The rainfall data were compared for different years for the past flood events. The *Figure 33 and Figure 34*

[6]Post Flood Report, Department of Engineering Services, MoWHS (August, 2016).

illustrates high magnitude of rains received in the month during the past flood events (1996, 2000, 2007, 2008, 2015 and 2016).

From the graph plotted, it is observed that the month of July 2016 received relatively higher continuous rain in Sarpang and Gelephu indicating the uniqueness of rainfall pattern. Both the stations recorded continuous daily rainfall of more than 100 mm for more than a week. The maximum daily rainfall in Bhur and Sershong station were 324 mm and 425 mm respectively.

However, the rainfall recorded during the flood event is less than the annual maximum rainfall recorded in the previous years as depicted in *Figure 35.* As illustrated in the *Figure 33* and *Figure 34* there has been higher daily rainfall in the past years than the one recorded in July 2016. Therefore, the recent flooding event in Sarpang and Gelephu could be attributed to the continuous rainfall.

Since rainfall stations locations are not within the catchment area of the flooded rivers, it might not represent the realistic quantity of rainfall received by the catchments. As seen in the *Figure 35*, the rainfall quantity in two stations also varies considerably signifying that the data recorded in these two stations are not enough to analyze the rainfall extremity.

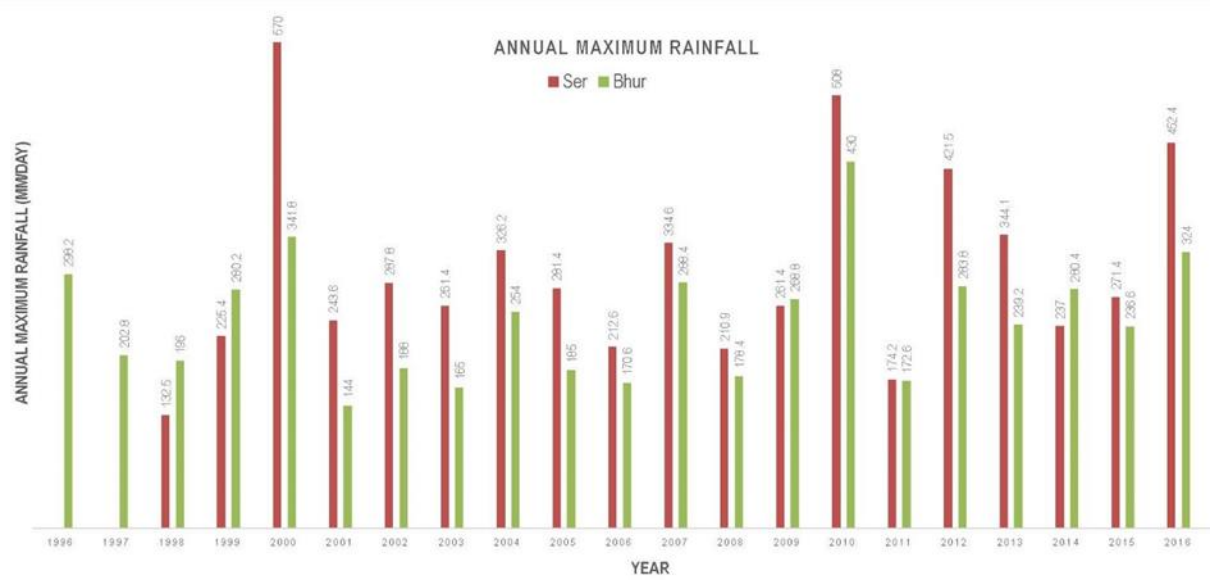


Figure 35: Annual maximum rainfall at Bhur and Shershong.

Identifying Critical River

Based on the extreme past events, threat it poses to the community, investment made for flood protection works and urgency of situation, Sarpang Chhu and Moa khola has been identified as critical rivers requiring immediate attention. However, for Mao River our Ministry as the parent

agency is drafting proposal to the Dutch Government for technical assistance on "River training and land reclamation along Moa River."

The output of the study would be design, drawing and estimate of an appropriate flood protection structures along Mao River to reduce the vulnerability of communities to flooding. In addition to this proposal, the Division also has an approved project with the World Bank. This project will focus on "Flood Hazard Assessment" of the tributaries of Mao River River. This study will complement the studies proposed to the Dutch Government for the Mao River River. Thus, for this assessment, Sarpang Chhu flowing through the Sarpang Bazaar has been defined as the critical river.

River Cross-Section Survey

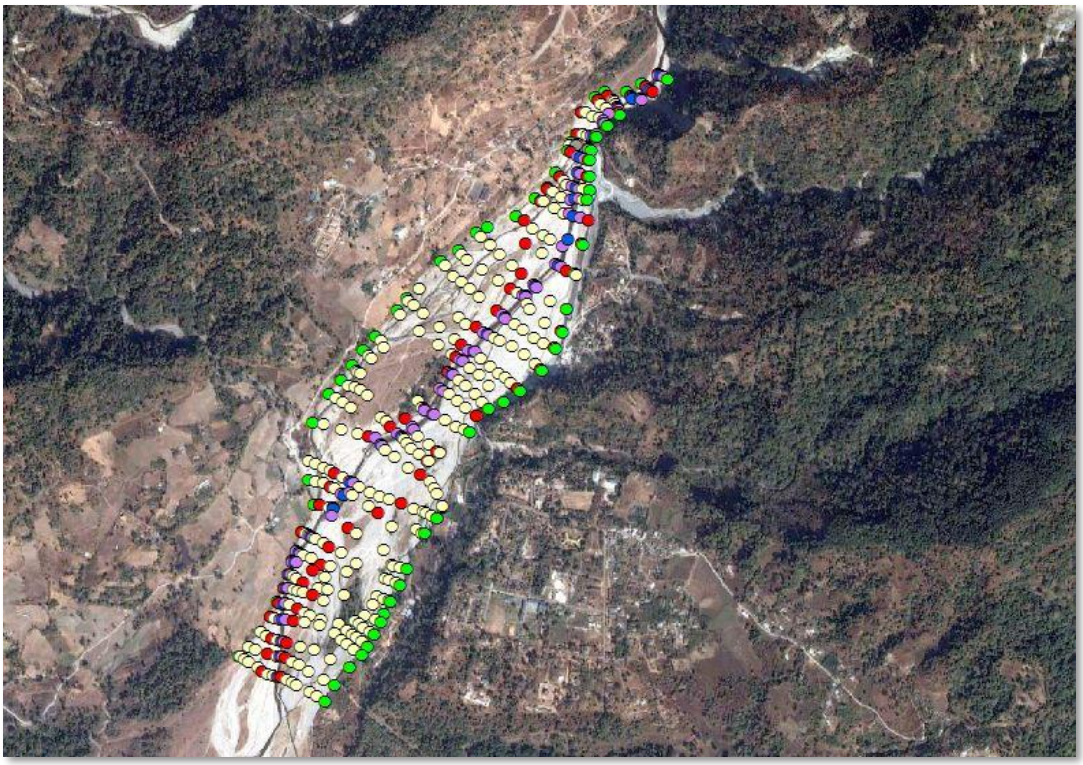


Figure 36: Sarpang Chhu cross-section survey

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, the cross-section data was derived from DEM and also surveying using total station. The cross-section survey of Sarpang Chhu was carried out by FEMD, DES, MoWHS in December, 2016 as shown in *Figure 36.* About 42 numbers of cross-section data were collected along Sarpang Chhu.

Development of Model

Hydrodynamic Model (HEC-RAS)

Sarpang Chhu in Sarpang is ungauged, therefore there was no discharge data for modeling purpose. The nearest rainfall station is Sarpang "Class C" Station with daily rainfall recorded from 1996 till July, 2015. However, it closed on July, 2015 and for some years, the data are missing. Therefore, this rainfall data cannot be used to run rainfall-runoff model to calculate the discharge of the Sarpang Chhu. The other two stations still maintain records of daily rainfall in the Dzongkhag but it cannot be used since it does not fall in the Sarpang Chhu catchment. Therefore, it will not give the realistic spatial distribution of rainfall in the Sarpang Chhu catchment.

Since there is no rainfall and discharge data for Sarpang Chhu, the discharge of different return period for Sarpang as calculated by the Lhawang Survey and Design Consultancy, 2013 has been used to prepare the flood hazard mapping. The discharge data for 25, 50 and 100 year return period for Sarpang River is obtained from modified Dicken's method as shown in Table 12.

Return period (yr)	Discharge (m^3/s)
25	390
50	453
100	515

Table 12: Discharge of different Return period for Sarpang

The surveyed cross-section data could not be used to develop the geometric data since it gave lots of error while running the river analysis system. In order to utilize collected data for river modelling in GIS, all data were transformed to a common datum (Drukref 03 Sarpang TM).The required geometric data for modelling was extracted from the DEM using HEC-GeoRAS, an extension of ArcGIS as shown in *Figure 37.*

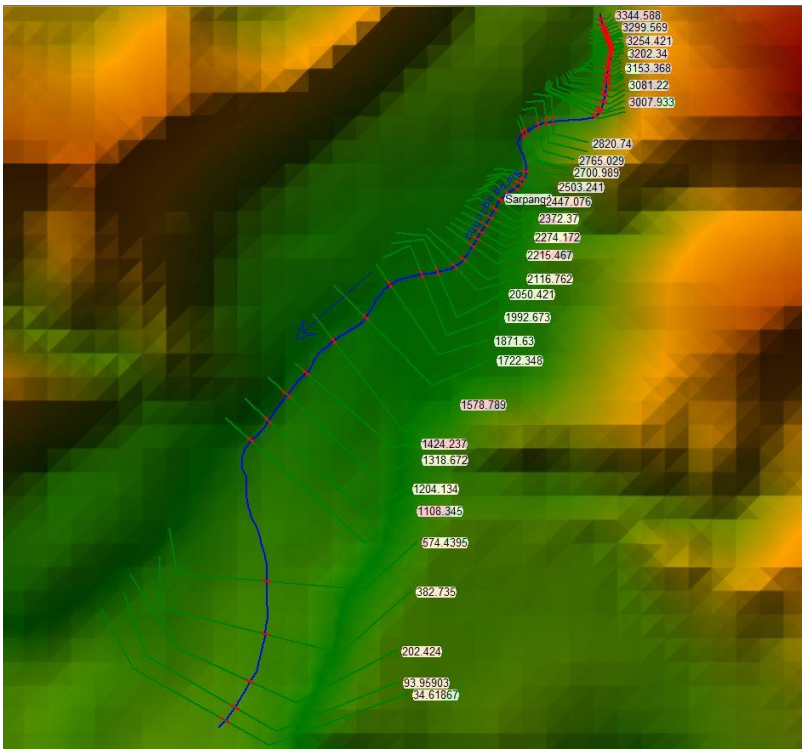


Figure 37: Geometric data used in the River Analysis of Sarpang Chhu.

The RAS Mapper in HEC-RAS 5.0.0 was used in hazard mapping phase to extract water surface profile data and depth data. The model calibration in HEC-RAS was carried out by assigning the main input parameters such as flow volume, manning roughness coefficient, channel bed slope, etc. The probable flooding area was delineated using the water surface data and DEM created for the catchment. The flood hazard map prepared clearly shows the spatial distribution of the flooded extent at peak flow which is located at areas with relatively low elevation.

Result Analysis and Conclusion

Model output

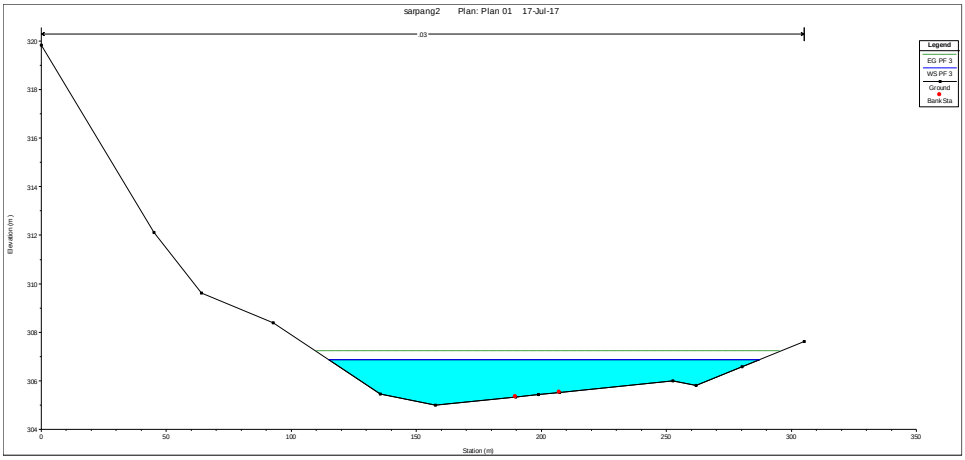
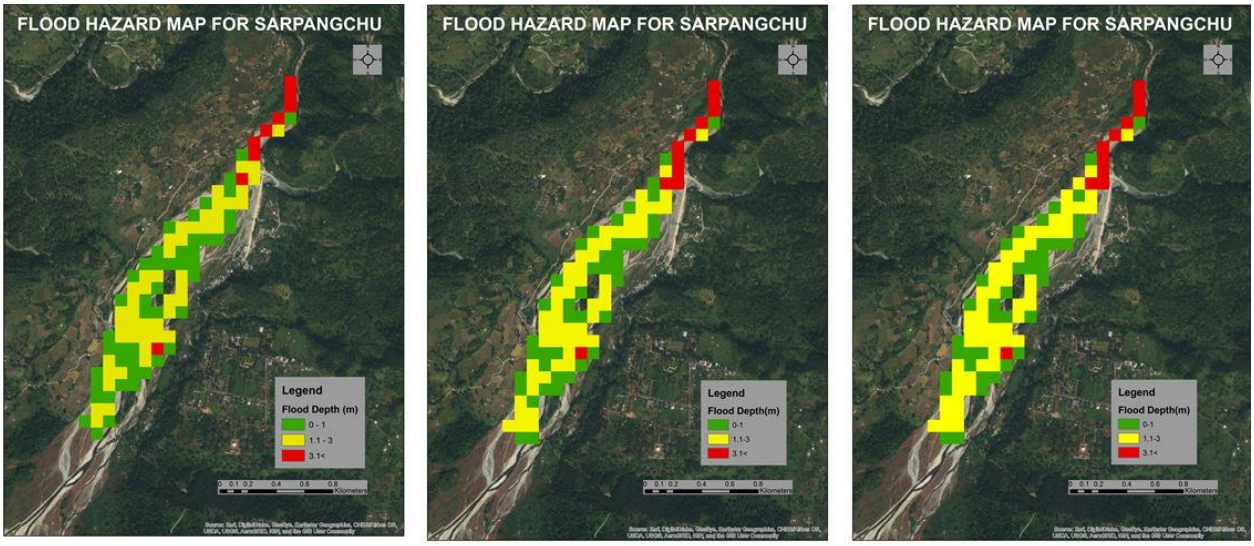


Figure 38: River Cross-section showing the water level.

River centerline is sketched with the help of given river network from the google earth image. The river cross-section data used in modeling are obtained from DEM (Digital Elevation Model). The schematic of geometry in HEC-RAS for Sarpang Chhu are shown in *Figure 38.* The cross-section consists of three parts: main channel, left bank and right bank. Manning's value of about 0.03 is assigned for main stream. 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, normal depth is assigned as upstream and downstream boundary condition. For the boundary condition of normal depth, slope of 0.01 is assigned for both the upstream and downstream condition.

Preliminary flood Hazard Map for different profile



PROFILE I-25 RT PROFILE II-50 RT PROFILE III-100 RT

Figure 39: Preliminary flood hazard mapping for different discharges.

The flood maps in *Figure 39* show a clear snap shot of the flooding visualization along the river with elevation levels and areas susceptible to flooding for different scenarios. Generally, high water depth occur 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. The maps are based on the general land characteristics and rainfall pattern over the Sarpang Chhu catchment.

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 by the flood model.

Recommendation for flood management

Areas of Mitigation Interest (AoMI) are widely stretched under the vast plains of Sarpang Dzongkhag. Therefore, as per the site investigation, following are the critical locations/ areas to be prioritized and provided river training works/interventions in order to avert further damages to public and private infrastructures, agricultural lands and also to avoid loss of lives:

i) Critical areas identified along Sarpang Chhu.
ii) Left bank of Sisty Khola under Gakidling Gewog.
iii) Critical areas along Big and Small Aipoly under Samtenling Gewog.
iv) Critical areas along Mao River and Shetikhari River under Gelephu Gewog.
v) Left bank of Taklai River under Umling Gewog.

The Department of Engineering Services, MoWHS has also outsourced to Consultancy firm, for Assessment of Flooding Hazards and Development of Climate-Resilient Flood Mitigation Measures in Shetikhari and Aipoly (Big & Small) Streams under Gelephu through the World Bank funding. And separate Project, Development to Build (D2B) under Dutch Programe is carried out on Mao River to identify suitable and sustainable infrastructural flood protection interventions in order to reduce Gelephu's vulnerability to flood by the Mao River.

These Projects are intended to bring all-inclusive report and flood mitigation measures that would immensely abate the flooding problems under Gelephu.

Interventions

Past Interventions

Small Aipoly Stream in Gelephu Thromde

Both the construction of the Detention basin and the floodway was ongoing during the flood of July, 2016. Each structure had suffered some damages during the flood event.

Detention Basin

During the recent flood of July, 2016, the whole of the earthen embankment collapsed due to the scouring at the exit of the pond caused by the outflow from the hume pipe as given in *Figure 41*. This caused flooding at the international check post downstream. The work was still ongoing during the flood. The physical progress of the work was 80% and the financial progress was 46% as of 6th July 2016.

(a) (b)

Figure 40: (a) Exit of the detention basin (b) Baffle walls at the entrance.

The estimated damage for the ongoing detention pond is shown in *Table 13.*

Table 13: Estimated damage for detention pond (Small Aipoly).

Sl.No	Location	Damaged structures	Estimated damage	Remarks
1.	Detention Pond, Small Aipoly, Gelephu	✓ South-east wall towards the outlet has collapsed ✓ The humepipe discharge outlet provisions have been washed away	About 1.00 million	On-going

	Thromde	✓ The baffle/deflection wall at the upstream has been submerged by sand debris		
Total Cost Estimates of the Damages			1.0 Million	

(Source: Gelephu Thromde)

Floodway

The ongoing floodway construction protected the houses and settlements during the recent flood as it provided sufficient flow path for the discharge generated after the pond collapsed. The flood way however got filled up with sediments during the event and scouring of the flood way banks occurred throughout the entire stretch as given in *Figure 41*. The physical progress of the work was 30% and the financial progress was 20% as of 6th July 2016.

Figure 41: Flood damages along small Aipoly.

The estimated damage for the floodway along Aipoly during the floods is as given in *Table* 14.

Table 14: Estimated Damage for floodway (Small Aipoly).

Sl.No	Location	Damaged structures	Estimated damage	Remarks
1.	Floodway for Small Aipoly, Gelephu Thromde	✓ Launching apron of the revetment ✓ Gabion mesh ✓ Backfill materials washed away ✓ Other stocked materials washed away ✓ Floodway filled with debris	About 1.3 Million	On-going
Total Cost Estimates of the Damages			1.3 Million	

Gabion revetment

Many different types of interventions have been implemented under the Sarpang Dzongkhag. Some examples are AB Mattress Flood embankments along Sarpang Chhu, Gabion Floodway along Shetikhari River and also Cement Concrete walls along Lodrai river etc. Ideally, the Interventions needs to properly designed.

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).

However, due to limited data and modelling challenges, Gabion revetment flood mitigation measures are found to be more applicable and sustainable to the southern flood plains.

The earthen embankments are constructed along the river banks within the flood plains of a river. The embankments are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection against flooding has been provided in some flood prone rivers with low banks in Bhutan. To prevent the erosion of the earthen embankments, it is further protected by constructing revetments on the riverside of the embankment. When the revetment is constructed with gabion mattress filled in with stones, it is called gabion revetment. A typical cross section of a gabion revetment is shown in *Figure 42*.

Advantages of gabion revetment

- Can be used as path by the pedestrian beside river.
- The construction materials for this type of flood protection structure are easy to transport and use at site. (Stones, soils and gabion mattresses)
- It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.
- Their permeability allows the gabion baskets to drain water easily reducing the pore pressure.
- They are environmentally friendly (green alternative) and requires no special masonry or skilled labour to construct it.

Disadvantages of gabion revetment

- Aesthetically not pleasing to sight.
- When the velocity of the streams and rivers are high, the gabion mesh baskets are at risk of getting torn by the transported boulders or debris.
- The gabion baskets are at risk of being damaged by corrosion if high quality gabion baskets are not used
- Upon failure of the gabion revetment, the earthen embankment can be easily eroded.

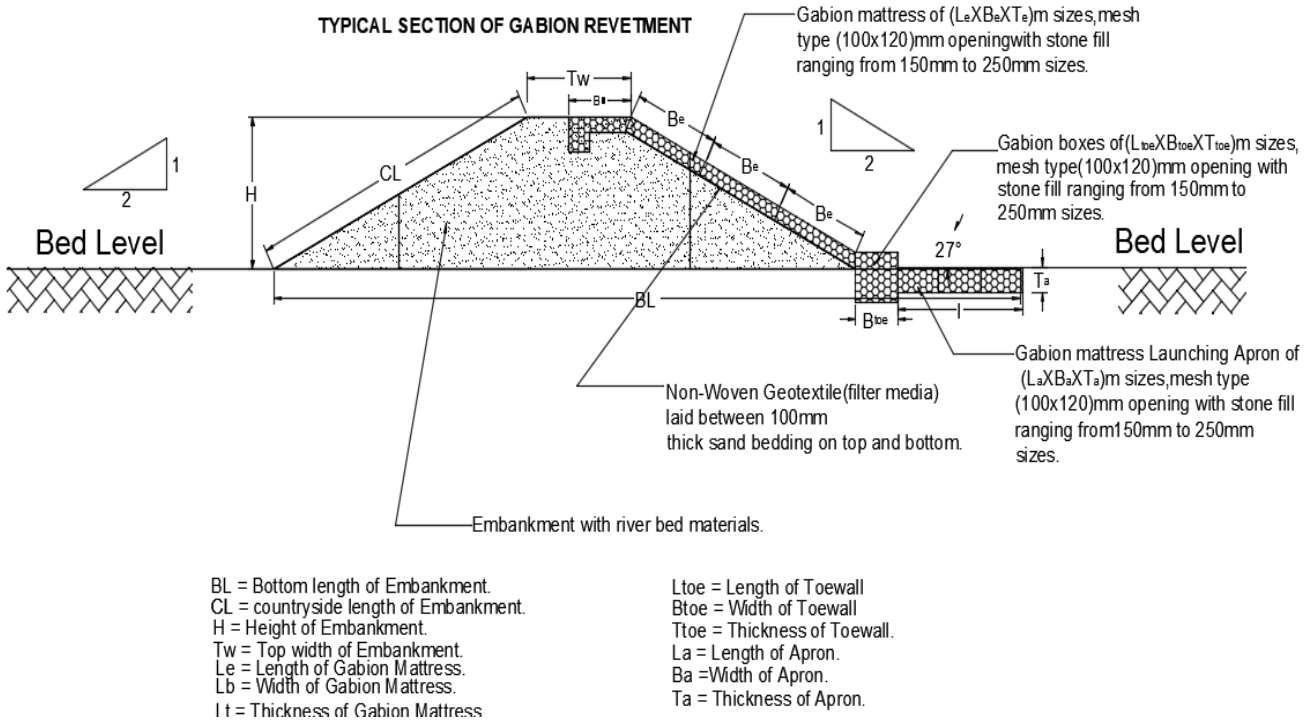


Figure 42: Typical cross section of a gabion revetment

Limitations

Although the flood hazard map has been prepared for Sarpang Chhu, 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 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 Sarpang Chhu catchment with missing data, it was not used for rainfall run-off model.

- ✓ There is no discharge data for Sarpang Chhu resulting in the use of data from the previous studies without any validation.

- ✓ During the study, the Manning's roughness is considered constant.

- ✓ The purpose of the flood hazard maps produced in this study is only applicable for flood prone awareness programs and drafting the flood managing plans. It is not recommended for any sort administrative zonation purposes since other hazards have not been considered during the mapping.

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