FLOOD HAZARD ASSESSMENT FOR WANGDUE PHODRANG DZONGKHAG

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

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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 Wangdue phodrang Dzongkhag and preparation of the Flood Hazard Map for Dangchu in Wangdue phodrang 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, Wangdue Phodrang Dzongkhag

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 preliminary flood hazard assessment studies for Wangdue phodrang Dzongkhag.

Acronyms

FEMD	Flood Engineering and Management Division.
HEC-RAS	The Hydrologic Engineering Center, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defense, Army Corps of Engineers in order to manage the rivers, harbors, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
GIS	Geographical Information System is a computer based method for analyzing Geographical information and maps.
NCHM	National Center for Hydrology and Meteorology.
MoWHS	Ministry of Works and Human Settlement.
NSB	National Statistical Bureau.

Executive Summary

The Wangdue phodrang Dzongkhag is situated in the central foothills bordering Bumthang and Trongsa in the east, Thimphu, Punakha and Gasa on the west and Tsirang and Dagana on the south. The total Geographical area of the Dzongkhag is approximately 4029.03 Sq.km and has undulated terrain with 70.28% forest cover. The altitude ranges from 800m to 5800m above the mean sea level. The Dzongkhag is administratively supported by 15 Gewog.

The main objectives of the studies are listed below.

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

Gewog level assessment was carried out to capture all the flooding risk in Dzongkhag. Dangchu river was found to be most critical river where study is not carried out. Hence, the detailed assessment of Burichu river was carried out and hazard map is prepared using **HEC-RAS 2D**.

The general recommendation on flood protection structural and typical cross-sections are provided for references only. Actual design and drawing can be carrying out only after site visit as the designed structure can be site specific.

The study recommends installation of permanent rainfall stations providing hourly data to represent the spatial rainfall pattern over the entire Dangchu catchment. Further, a proper study is to be done to select the best method for rainfall interpolation and estimation. The study also recommends that necessary equipment for acquisition of discharge data be installed along the river at suitable location for future updates of the flood hazard map.

The purpose of this study is only applicable for flood prone awareness programs and drafting the flood management plans. It is not recommended for any administrative purpose since other hazard might not been considered during the mapping.

Introduction

Background

The Wangdue phodrang Dzongkhag Figure 1 is situated in the central foothills bordering Bumthang and Trongsa in the east, Thimphu, Punakha and Gasa on the west and Tsirang and Dagana on the south. The total Geographical area of the Dzongkhag is approximately 4029.03 Sq.km and has undulated terrain with 70.28% forest cover. The altitude ranges from 800m to 5800m above the mean sea level. The Dzongkhag is administratively supported by 15 Gewog.[1]
Paddy, maize and millet are the main cereal crops grown while vegetables are the principal cash crops. Paddy, chilli and potato cultivation is very famous in the Dzongkhag. Wangdue Phodrang Dzongkhag is highest producer of wheat (16% of the national output in 2013), highest producer of potato, and the third highest producer of paddy in the nation producing around 11% of the national output in 2013 The Dzongkhag's arable land is about 7758.05 acres, of which 33.83 % is dry land and 54.24% is wetland. The fallow land accounts to about 11.94%. The insufficient irrigation supply, crop raiding by wild animals, pest and diseases and labour shortages are the main constraints for farming in the Dzongkhag. [2]

Figure 1: Bhutan Map showing the study area.

[1]Annual Dzongkhag Statistics 2017, Wangdue phodrang Dzongkhag, National Statistics Bureau.
[2]Annual Dzongkhag Statistics 2015, Wangdue phodrang Dzongkhag, National Statistics Bureau.

Table 1: Cultivated Area, Production and Yield of Major Crops, Wangdue phodrang (2012-2016).

Cultivated Area, Production and Yield of Major Crops, (2012-2016)						
Crop/Productions		**2012**	**2013**	**2014**	**2015**	**2016**
Wheat	Area (Acres)	1057.0	873.0	878	1204	1204
	Production (Kg)	938616	703638	591772	817516	817000
	Yield (Kg/Acre)	888	806	674	679	679
Barley	Area (Acres)	350.0	276.0	168	177	177
	Production (Kg)	268100	178572	124824	100890	101000
	Yield (Kg/Acre)	766	647	743	570	570
Paddy	Area (Acres)	4208.0	4455.0	4854	5141	5141
	Production (Kg)	6640224	8362035	9174060	7742346	7741000
	Yield (Kg/Acre)	1578	1,877	1890	1506	1506
Maize	Area (Acres)	369.0	340.0	300	493	493
	Production (Kg)	430623	330140	316200	581247	581000
	Yield (Kg/Acre)	1167	971	1054	1179	1179
Buckwheat	Area (Acres)	424.0	356.0	365	565	565
	Production (Kg)	233624	182272	167900	346345	346000
	Yield (Kg/Acre)	551	512	460	613	613
Millet	Area (Acres)	8.0	23.0	25	2	2
	Production (Kg)	5368	12696	12625	488	1000
	Yield (Kg/Acre)	671	552	505	244	244

As per the site investigations, it has been learnt that Wangdue Dzongkhag experiences frequent flash flood 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 settlements and agricultural land. The Dzongkhag had experience flooding but don't have a proper record of the damage caused by the flood events. The most recent flash flood of July, 2017 in Wangdue caused damages to flood protection walls, roads, bridge and other infrastructure. The details of the damages caused by the flood in July, 2017 in Wangdue phodrang Dzongkhag are given below.

Table 2: History of flooding in Wangdue Phodrang Dzongkhag

Sl.No	Name	Description	Incident Date
1	Tashitsho Irrigation Channel (Nahi Gewog)	Intake point and pipelines are completely washed away by Nahi River. About 50 to 60 acres of wetland depends on this Irrigation water	9/7/2017 at 9:00 PM
2	Jagarjaphu Irrigation Channel (Nahi Gewog)	Intake point and pipelines are completely washed away .it benefits to 10 acres of wetland belonging to Yuesawom and Hebesa Chiwog.	9/7/2017 at 9:00 PM
3	Razhilumba Irrigation Source (Nahi Gewog)	Washed away intact post and caused major landslide along the irrigation channel.It benefits to 50 to 60 acres of land.	9/7/2017 at 9:00 PM
4	Sibjikha Irrigation Channel (Nahi Gewog)	At source and pipeline damaged by major landslide. It irrigates 7 households of Nabisa	9/7/2017 at 9:00 PM
5	Domzhilumba Rural Water Supply & Sanitation (Nahi Gewog)	Nahi River completely washed away intact post and pipeline that benefits to 7 households of Yusawom Chiwog	9/7/2017 at 9:00 PM
6	Zocha Gabion Wall (Nahi Gewog)	It was washed away partially by Nahi River	9/7/2017 at 9:00 PM
7	Taksha Silli Sub post (Dagar Gewog)	Heavy Rainfall caused landslide below structure of Taksha Silli Sub post.	22/7/2017
8	Nebachu Irrigation Channel (Athang Gewog)	About 40m of intake point of Nebachu irrigation channel damaged	22/7/2017
9	Menzuga and Tonglobji Irrigation Channel (Gasetshog Wom Gewog)	About 6 meters Menzuga Irrigation Channel and 11 meters of Tonglobji Irrigation Channel washed away.	9/7/2017 at 00:00 AM
10	Pangsho Yu Wom Irrigation Channel	Nahi River Washed away Irrigation channel which was renovated just year ago.	9/7/2017

Objective

Objective 1: Detailed flood assessment of Rivers in Wangdue Phodrang Dzongkhag.

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

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

Study Area

Athang Gewog is considered to be the most remote and least accessible Gewog in Wangdue Dzongkhag with poor communication network, making it difficult to deliver cost effective services efficiently and for all round development to take place. Athang Gewog consists of 9 villages (Rukha Lawa, Nashina, Phatakha, Lopokha, Kago, Lhomtshokha, Zawa and Jarigang Gembo) and 142 households. It has an area of 785 sq. km.There are 2 community primary schools (Lopokha & Mithana), 2 ORCs, 1 RNR center, 1 Gups office in Kamichu. It has high potential for livestock and has established several fisheries to generate income.

Bjena Gewog is located on the highway from Wangdue to Trongsa which is approximately 0.2 km away. The Gewog is at an altitude range of 1500-3000 meters above sea level falling under warm temperate agro-ecological zone.For the Chiwogs at low lying areas, chuzhing (Wet land) dominates the agriculture activities followed by khamzhing (Dry land) and few patches of Tseri (burn and slashes) cultivation. In the high elevated Chiwogs, potato is the main cash crops followed by livestock products like cheese and butter. The Gewog has about 44% of land under forest cover which consist mainly of broadleaf trees and conifers. The area under forest cover is approximately 236.05 acres. The Gewog's total population is about 2110 as per 11th five-year plans and it has 521 households consisting of nine villages.

Dagar Gewog is located in the southern part of the Dzongkhag. The Gewog falls at 800- 2700 metres above sea level covering mainly with broad leave and pine forest. Its estimated land area is 343.5 sq km. About 98% of the total area is under forest cover. The Gewog enjoys a very warm climate in summers. Dagar Gewog comprises of 5 Chiwogs (Uma- Khato, Kamichu-Uma Khamoe, Kamina Wogay, Gyapakha and Sili Taksha) with 152 households. There are 2 community primary schools (Sha Tasha PS and Uma PS), 2 BHUs (GR II in Kamichu & GR III in Uma), one Gups office in Kamichu.

Dangchu Gewog is located on the highway from Wangdue to Trongsa which is approximately 18 km away. The Gewog is at an altitude range of 2000-5000 meters above sea level falling under warm temperate to alpine agro-ecological zone. Especially Chiwogs at low lying areas, chuzhing (wet land) dominates the agriculture activities followed by khamzhing (dry land) and also few patches of Tseri (burn and slashes). In high elevated Chiwogs, potato is their main cash crops followed by earning income through the sale of livestock products like cheese and butter and non-wood forest products like Cordyceps. The Gewog has about 75% of land under forest cover consisting of mainly broadleaf trees and conifers. The Gewog's total population is about 1299 as per 11th five-year plans and it has 266 household consisting of 16 villages.

Gangtey Gewog is known for the colorful mask dance Tshechu of Gangtey monastery and also the crane festival welcoming the black necked crane in the winter month. The valley is also covered by a rich savanna grass in the marshy land where special variety of dwarf bamboo (Yushaniamicrophylla) on which the black-necked cranes feeds is grown. The Gewog is about 65 km from the Dzongkha. It falls at an altitude range of 2800-3500 meters above the sea level. It is almost covered with coniferous forest. The summer is hot with monsoon rain and winter is dry and with snow fall. The soil texture is pre-dominantly sandy loam. The Gewog has an area of

49.90 sq km with a population of approximately 3000. There are 325 registered households under 14 villages.

Gasetshog Gom is one of the smallest yet most developed Gewog in Wangdue Dzongkhag. The Gewog lies at an altitude of 1300 to 2200 metres above sea level. It has hot and humid summer and dry and cold winter. Its climatic condition ranges from sub-tropical to sub temperate with an annual rainfall of 720 mm to 2000 mm. The soil texture is predominantly clay loam basically favoring the growth of oak trees and gumashing. Its approximate road connection is 25 km from the Wandue-Tsirang Highay. Its estimated area is 28.6 sq km. It comprises of 5 Chiwogs (Changchey- Matsipokto, Khamena, Khataykha, Changkha and Dabcheykha-Matsikha) with 187 households. Gewog has 1 Lower Secondary School, 1 Middle Secondary School, 1 grade II BHU, 1 RNR Centre, 1 Gup's office in Gumina, 1 PWD Regional Workshop, 1 power generating station and 1 forest range office.

Gasetshog Wom (Lower Gaselo) Gewog is located in the south-western part of Wangduephodrang Dzongkhag. The landscape is mainly rugged with pockets of gently facing slopes. The Tsang Chu runs along the Gewog's eastern border, forming the border between Gasetshog Wom and Ruebesa Gewog. The Gewog falls at 1540-1848 metres above sea level (masl) covering mainly with broad leave and chirpine forest. The summer is warm and humid and winter is cold and dry. The soil texture is predominantly clay loamy, sandy loam and red soil. It has an area of 207.85 sq km. Gasetshog Wom has 5 Chiwogs (Haetshokha, Shingkhey Khatoe, Shingkhey Khamoe, Maedpisa Tabchikha and Haebisa) with 8 villages and 106 households. The settlements are widely scattered. It has 1390 acres of wet land and 336.14 acres of dry land. The Gewog has a population of about 818 and Dzongkha is their predominant spoken language. There is 1 Community Primary School (Haebisa), 1 RNR Centre, 2 NFE Centres, and two Out Rich Clinics. The Gewog has internal feeder road that connects it to Basochu power site at Haebisa. The Wangdue Tsirang highway passes through it.

Kazhi Gewog is about 18 km drive towards north from Wangdue phodrang Dzongkhag. It falls at an altitude range of 1600–4000 meters above the sea level experiencing different climate conditions in two different agro-ecological features. It has cool winter in the south and cold winter in the north. Due to its diverse ecological features the forest in the south are dominated by chir, blue pine, evergreen oak trees whereas in the north the forest are covered with fir trees. The soil texture is predominantly sandy clay in the south which is favorable for growing tubers, chilli and paddy. In the north, farmers are mostly yak herders and their main income is from the collection of cordyceps which has very high market value as of now. The Gewog is known for its chilli product "shaagi Emma".The Gewog has an area of 622 sq. km with a population of 1751. There are 231 registered households under 19 villages.

Nahi Gewog is located in South Western part of Wangdue Phodrang Dzongkhag. The Gewog falls at 1000 to 3400 metres above sea level (masl) covering mainly with chirpine, oak trees and mixed conifer species of forest. The summers is hot upto 26 ˚C and winter is cool with temperature as low as 5˚C. The soil textures are predominantly sandy, sandy loam to clay and are generally fertile. It has an area of around 739.2 acres inhabited by 5 Chiwogs (Nabisa, Yuesa Gom, Yuesa Wogm, Hebesa and Khujula) with 109 households. The terrain is mostly rugged with few cultivated pockets of gentles slopes. The Gewog has 1 Community Primary School, 1 ORC, 1 RNR center and 1 Gup's office. The farm road connection has reached up to Gup's office (Paygang) only.

Nyisho Gewog is located in the central part of the Dzongkhag and it has an area of 111.5 sq. km. The altitude ranges from 1500-3000 meters above sea level. The Gewog has sub-tropical climatic condition. The land under forest cover is approximately 70% comprising of cool broad leaved trees and chirpine. The soil texture is predominately sandy loam to clay loam which is favorable for the cultivation of garlic, paddy, and chilli. The Gewog has five Chiwogs and twelve villages with a population of roughly 2304.

Phobji Gewog is about 65 km towards north from Wangdue Phodrang with an altitude range of 2800-4000 meters above the sea level (masl). It is mostly covered with blue pine forest. The soil texture is predominantly sandy loam, which favor primarily growing tubers. The summer is hot with monsoon rain and winter is dry and snowy. The Gewog has an area of about 138.20 sq. km with a population of 4000. There are 36 villages with 386 registered households. The Gewog is known as winter roosting for black necked crane due to abundant dwarf bamboos in the Gewog. It experiences alpine vegetation with snow in winter.

Phangyul Gewog is located at the center part of Wangdue phodrang Dzongkhag. The Gewog is at an altitude range of 1500-3000 meters above sea level enjoying cool winter and hot summer with moderate rainfall. It falls in between cool temperate to warm temperate in agro-ecological zone with annual rainfall of 650-850mm. Almost 68% of the Gewog is covered by forest and the main species available are chirpine and evergreen oak trees. The soil texture is sandy clay to sandy loam, which is favorable for the cultivation of any types of vegetables, cereals crops and oil seeds. The Gewog is about 10 km drive from the Dzongkhag.

Ruebesa Gewog is located in the west central part of the Dzongkhag. The Gewog falls at an altitude range of 900-2400 metres above sea level (masl). The Gewog has mainly blue pine forest. The summer is hot with monsoon rain and winter is dry and temperate. The soil texture is predominantly sandy loam and clay loam. It has an estimated area of 163.60 sq km. The landscape of the Gewog is mostly rugged with few pockets of gently sloping areas. Ruebesa consists of 10 villages (Zamding, Samdrupgang, Ruemey, Nyala, Nyezergand, Daphu, Jala, Ruechay, Ula and Shuelay) with 309 households. The Gewog has population of about 3400. There are 2 Community Primary Schools, 1 grade II BHU and 1 AEC (Agriculture Extension Centre). Nyezergang Lhakhang stands as an important religious institution of the Gewog.

Sephu Gewog is about 85 km towards north from Wangdue Dzongkhag. It falls at an altitude range of 2600–4000 meters above the sea level (masl) mainly covering with blue pine forest. The summer is hot with monsoon rain and winter is dry and snowy. The soil texture is predominantly sandy clay and sandy loam, which favor primarily growing of tubers. The Gewog has an area of about 1105.996 sq. km with a population of 2011. There are 314 registered households under 15 villages.

Thaedtsho Gewog is located in the west central part of Wangdue Dzongkhag located at the bank of Puna-Tsang Chhu River. The Gewog falls at 1100-1400 meters above sea level (masl) covering mainly with blue pine forest. The summer is hot with monsoon rain and winter is dry and temperate.It has an area of 614.93 sq km with 5 chiwogs (Martalongchu, Thangoo, Jang Rinchengang, Lho Rinchengang, and Wangjekha) and 436 households. The Gewog has population of about 1270 and Dzongkha is their predominant spoken language. The Gewog has 1 Community Primary School, 1 Primary School, 1 Lower Secondary School, 1 Higher Secondary School, 1 RNR Research Center, 1 Regional Druk Coorporation, Regional Agriculture Machinery Center, 1 BHU and 1 Gewog Center (Gup's office).

Methodology

Data Collection and Assessment

Hydrological and Meteorological Data

The hydro-meterological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). The location of the hydro-met stations is depicted in Figure 2.

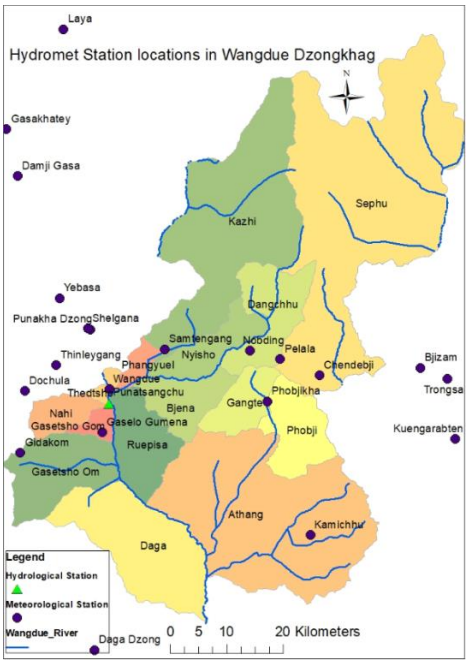

Figure 2: The location of the Hydro-met station in the study area

There are 9 meteorological stations available in the Wangdue Dzongkhag. All the data have a temporal scale of daily data interval and the data availability varies from each station. However only 2 meteorological stations in watershed of study area. The details of the met station is shown in Table 3.

Table 3: Met station in study area

Sl.No	Met station name	Temporal data available
1	Wangdue	1996/01/01 to 2016/01/31
2	Phobjikha	1995/01/01 to 2016/01/31

Scientific Data

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

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

Sub-basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width are derived from the DEM.
Collected about 0.03 km resolution Digital Elevation Model (SRTM30) has been used to create a basin model. SRTM30 is a global DEM covering the full extent of latitude from 90 degrees

South to 90 degrees North, and the full extent of longitude from 180 degrees West to 180 degrees East, which freely available and has been contributed by organizations contributed by funding or source data: The National Aeronautics and Space Administration (NASA) and other. The horizontal coordinate system is decimal degrees of latitude and longitude and referenced to WGS84. The vertical units represent elevation in meters above mean sea level.

Site Assessment at Gewog Level

The field surveys have been carried out in all Gewogs under Wangdue 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's 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.

Athang Gewog

There are only two major rivers in Athang Gewogs. **Nyebachu** caused flooding in 1968 and 2017. But there is no much effect on settlement and Agricultural land. **Marachu** also caused flooding 1968 and 2017 in whole village was washed away and 3 acres of wet land effected respectively.

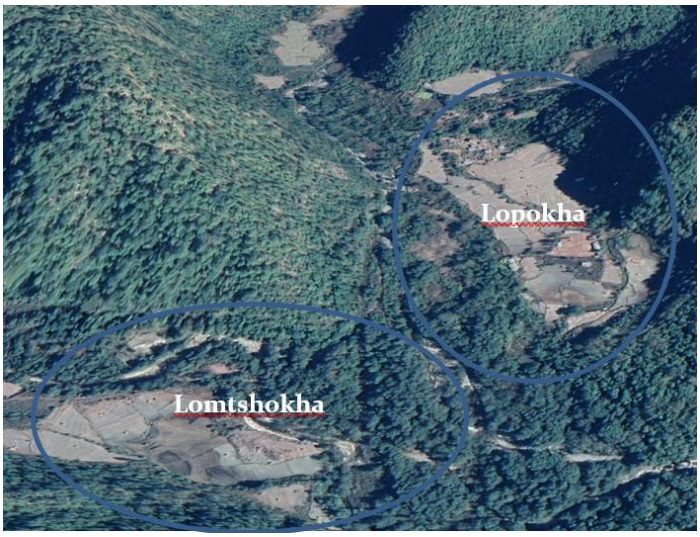

Figure 3: Flooding threat to Lopokha and Lomtshokha by Nybechu and Mara chu respectively.

Kamichu and **Phunatsangchu** has no affects to Agricultural land and settlement. **Taksha chu** caused two floods in 1990 and 2017 washing away Bridge in Tsirang -Wangdue Highway and two temporary sheds of LNT labourers respectively. Gabion wall constructed by project was also destroyed in 2017 flooding. The failure of wall is mainly due to poor design of wall. There are no diaphragms and mesh used is hand woven.

Restoration of wall maybe carried out using proper design. To do this, Gewog Administration is advised to seek design from Dzongkhag or FEMD in future.

Figure 4: Gabion wall constructed by PHPA II along Kamichu

Figure 5: Failure of Gaboin wall constructed by PHPA II along Kamichu

Dangchu Gewog

Flood by **Dangchu** in 2015 washed away RRM wall which was constructed to protect Gewog Office and Dangchu village from flooding. The wall is yet to restore. Source of Dangchu river is mainly the lakes on upstream and summer rainfall. The river bed level and ground level are minimal in most of the areas. School, Gewog Center, Dangchu Village, Tekikha Village, Kichu Resort, Forestry Office and Colony, Prison and temporary sheds for Wangdue phodrang dzong construction project, falls under risk Zone of Dangchu River.

Figure 6: Dangchu village and Gewog centre under threat.

Figure 7: Tekikha village and Agricultural field under threat.

Figure 8: Kichu Resort under threat.

Figure 9: Prison under threat.

Figure 10: Forestry Office and Colony under threat.

Figure 11: Temporary sheds of Labours in Wangude Dzong reconstruction project under threat.

Kazhi Gewog

Baychu has not affected settlement and Agricultural land till date. However, it has potential threat to small town in chuzomsa. Flood protection structures on both banks at chuzomsa may be constructed to protect chuzomsa from flooding threat.

Figure 12: Two houses on right bank of Baychu under threat

Figure 13: Marble and Incent sticks factory under threat.

Figure 14: Chuzom under threat by Baychu

Gewog Administration is mainly concerned with drying up **Sangchu** which is the main source of Drinking water supply and Agriculture water in the Gewog. It's not mandates of Flood Engineering and Management Division to protect water source. Hence, Gewog Administration is advised to consult concerned agency (Water Supply and Sanitation Division, Department of Engineering Services, MoWHS) for necessary action.

Nahi Gewog

Hinley Rongchu River is only river in Nahi Gewog. River is very beneficial to the people in the Gewog as it is the source of Drinking water supply and Irrigation. But in recent years, the river affected the Gewog immensely. Each flooding events are discussed below.

- **2014 flood**

  During 2014 flooding, Nebesa Chiwog bridge was washed away and restored in 2015. Bridge constructed by JICA in 2012 just above the Nahi primary school was also affected.

- **2016 flood**

  2016 flood is the largest flooding event recorded in Hinley Rongchu River. Following major destructions were caused.

  1. Bridge constructed by JICA just above the Nahi primary school was completed washed away.
  2. Nebesa Chiwog Bridge which was restored in 2015 was again washed away and was restored in 2017
  3. Irrigation channel source for Yusawom Chiwog was washed away and restored in 2017
  4. Suspension Bridge connecting School was washed away. Traditional bridge (Bazam) is constructed in 2017 to connect school.
  5. Approximately about 50 Decimals of Paddy field washed away.

- **2017 flood**

  2017 flood is the second largest flooding event recorded in Hinley Rongchu River. Irrigation channel source for Yusawom Chiwog restored in beginning of 2017 was washed away.

Figure 15: Agricutural land in downstream of bridge connection Nebesa Chiwog on left Bank.

Figure 16: Irrigation Channel source of Yusawom and Hebesa Chiwog on left Bank

Figure 17: Paddy field and chorten in Yusawom Chiwog under threat in left Bank

Figure 18: Bridge connecting Yusawom and Yusagom Chiwang is under reconstruction after it was washed away in 2016

Phobji Gewog

Phobji Gewog has two rivers affecting settlement and Agricultural land. **Pakshingzangpa** chu affects one motorable bridge and approximately 17 acres of dry land.

Figure 19: Upstream of PakshingZangpa bridge.

Khem chu affects 4 houses, 30 people, 150 cattle and about 6 vehicles in khewa village. Recent flood in 2016 destroyed about 1 acre and 3 acres of potatoes in Pakshingzangpa and Khewa village respectively. Moreover, Khewa village was evacuated during 2016 flooding.

Figure 20: Khem chu in Khewa Village.

Sephu Gewog

Nikachhu is only river that causes flooding to settlement and Agricultural land in Sephu Gewog. This river flows from highland of Sephu Gewog and finally joins mangde chu in Trongsa. Nikachhu washed away Bazam Bridge in August 2008 and was restored in December 2008. It was once again washed away in August 2013 and restored in December of same year. Gewog also has other rivers like Chusaygang chu, Sarchona chu & Tsa chu, but there is no effect of these rivers to settlement and Agricultural land.

Figure 21: Threats caused by Nikachu

- **Downstream of motorable bridge connecting Lubzor and Lubzor Phakha**

  There is a dry land of about 1 acres on the downstream of motorable bridge connecting Lubzor and Lubzor Phakha on the left bank of Nikachhu. Since there minimal elevation difference between river bed and dry land, this area is prone to flooding.
- **Upstream of motorable bridge connecting Lubzor and Lubzor Phakha**

  There is about 2 acres of dry land and 2 huts on the upstream of motorable bridge connecting Lubzor and Lubzor Phakha on the right bank of Nikachhu. Since there minimal elevation difference between river bed and dry land, this area is prone to flooding.
- **Motorable bridge connecting Lubzor and Lubzor Phakha**

  The bridge itself is prone to flooding as there is no wing wall to protect the bridge abutments. Wing wall of 20 meters each on four sides of the bridge maybe constructed to prevent the bridge from flooding.
- **Milk processing unit at Busa Village**

  Milk processing unit at Busa Village process abt 100 litres of milk every day to produce butter and cheese. This processing unit is located at confluence of Busa chu and Nikachu. There are high chances of creation of artificial pond at the confluence which might lead to flooding of this unit. Busa chu can be diverted along the flow direction of Nikachu with Gabion wall with embankment as to prevent the creation of

artificial pond.

Thaedtsho Gewog

Punatsangchu has long history of flooding. In 2009, two houses in Thango village were completely washed away. Again in 20016, Thango village was inundated and artificial pond was created behind Hotel Pema Karpo. Two excavators were used to draw water out of this pond.

It was seen that, the elevation difference between river bed level and ground level is minimal as compared to the discharge of river. Hence, during flooding water flows over existing gabion walls and settlements get inundated.

Figure 22: Thango village under threat by Punatsangchu.

River cross section survey

Based on the extreme past events, threat it poses to the community, investment made for flood protection works and urgency of situation, Nahi River and Dangchu River has been identified as critical rivers requiring immediate attention. In July 2016, Nahi River caused the major destruction to infrastructures such as Tashitsho Irrigation Channel, Jagarjaphu Irrigation Channel, Razhilumba Irrigation Source, Domzhilumba Rural Water Supply & Sanitation and Zocha Gabion Wall. However, there is no rainfall station in Nahi River catchment. Hence, Dangchu River is identified as critical River in Wangdue phodrang Dzongkhag.

The cross-section survey was conducted by a team from FEMD, DES for the Dangchu river. A detailed stream cross section survey was conducted in November, 2017

Survey was conducted from upstream to the downstream from left bank towards right bank till Tekikha village. We have selected upstream site based on the location of settlement and the landscape of the area. Most of the settlement and the agriculture area have been covered during survey.

Flood Frequency Analysis

Dangchu in Wangdue phodrang is ungauged, therefore there was no discharge data for modeling purpose. The nearest rainfall station is Wangdue "Class C" Station with daily rainfall recorded from 1996 till July, 2017. Discharge obtained for 25 years return period for IFAS is used to prepare the flood hazard mapping.

Table 4: Flood frequency analysis and discharge for different return period

Return Period	Discharge
25	107.81
50	147.16
100	169.46

Development of Model

Hydrodynamic model

The freely available global DEM such as SRTM 30m and SRTM 90m and the ALOS 10m DSm were explored to find the most suitable DEM for the study area. All the DEMS were corrected as per the site location and resampled to create a terrain for the 2D hydrodynamic model. SRTM 30m is used for development of HEC-RAS.

Dangchu in Wangdue phodrang is ungauged, therefore there was no discharge data for modeling purpose. The nearest rainfall station is Wangdue "Class C" Station with daily rainfall recorded from 1996 till July, 2017. Discharge obtained for 25 years return period for IFAS is used to

prepare the flood hazard mapping. The HEC-RAS 2-dimensional model was deployed for river flood modelling in this study. We used only the DEM (Digital Elevation Model) geospatial dataset to develop the geometric data input. 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.

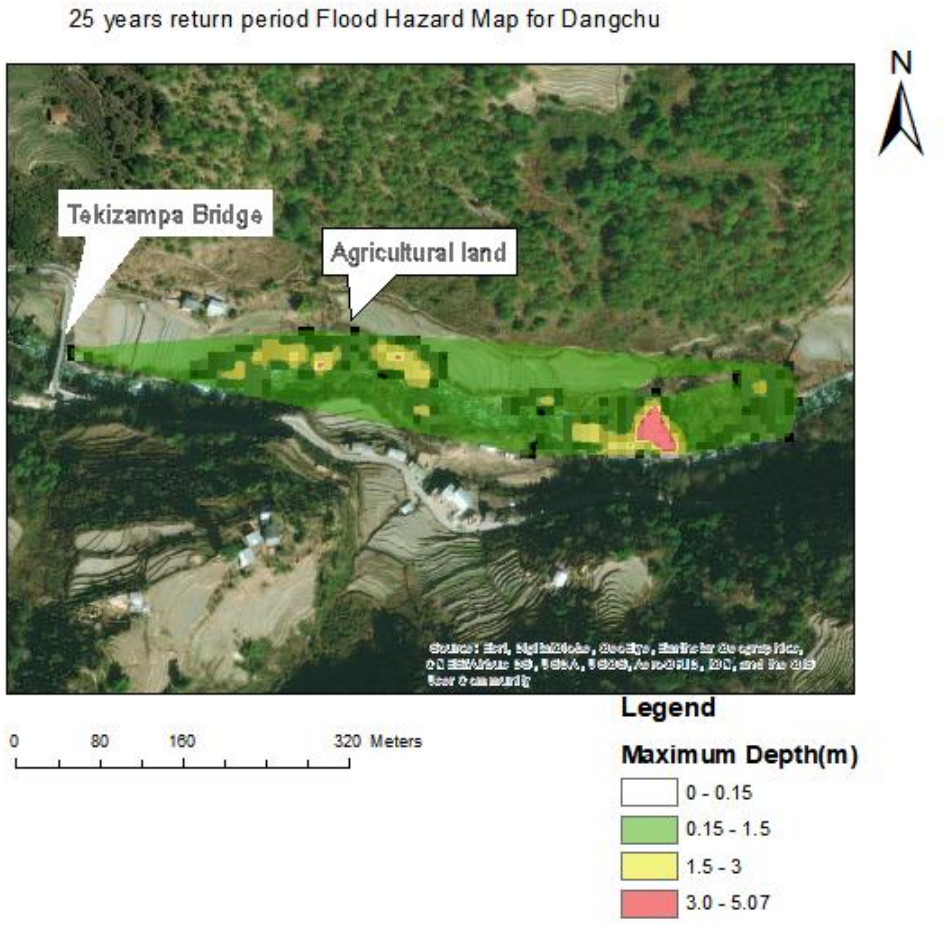

Figure 23: 25 years Return period flood hazard Map of Dangchu River.

Intervention

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).

Gabion Walls

The gabion walls are retaining walls made of stacked stones filled in gabion boxes which are either hand woven or mechanically woven by using wire meshes such as galvanized steel wire and stainless steel as given in **Error! Reference source not found.**. The stone fill should be of h ard and durable material. To reinforce the structure, all the mesh panel edges are selvedge with a wire of greater diameter than the wire mesh. The mesh panel is divided into cells by providing diaphragm at every 1 meter interval.

Advantages

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

Disadvantages

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

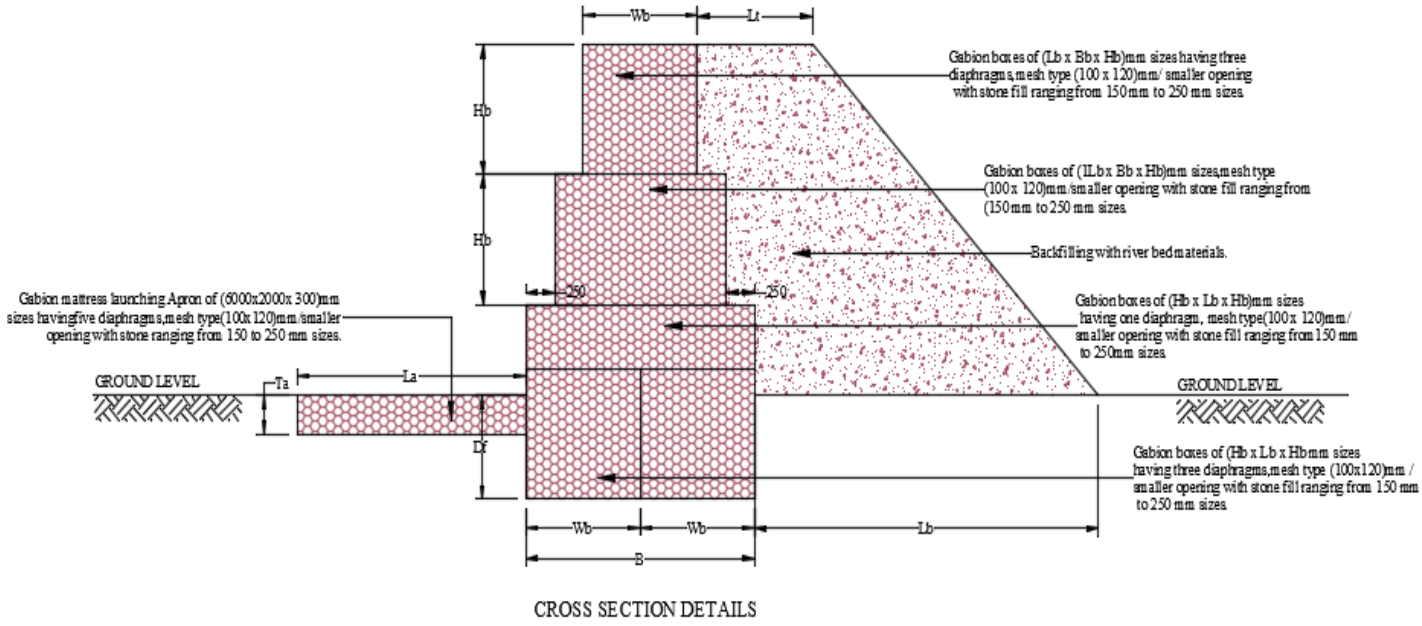

Figure 24: Typical cross-section of gabion wall

Gabion Revetment

The revetments are sloping structures placed on the bank of the river to protect it from erosion by absorbing the energy of the incoming water. Prior to revetment construction, the existing ground should be stabilized by grading to an appropriate slope to prevent slide failure of the revetments after construction. If required, fill material should be added to achieve uniformity and it should also be free of large stones. Finally, it should be firmly compacted before the construction of revetment begins. The revetments are made of different materials such as plain cement concrete, articulating block mattress, gabion mattress etc. The **Error! Reference source not found.** s hows a gabion revetment used to reduce the impact of flood water during flooding in southern part of Bhutan

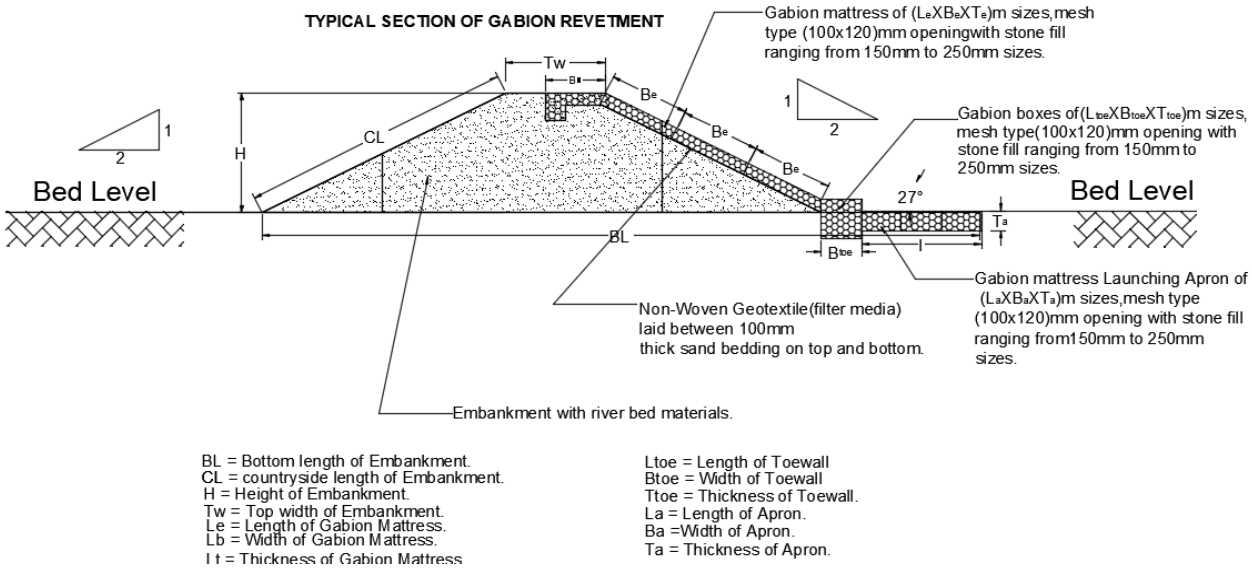

Figure 25: Typical cross-section of gabion revetment.

Advantages

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

Disadvantages

1) The life expectancy of gabions depends on the lifespan of the wire, not on the contents of the basket.
2) Aesthetically not pleasing to sight.
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5) The damaged gabions baskets are hazardous to public safety.
6) The gabion revetment on failing will result in releasing non-indigenous stones in that area.

Recommendation for flood management

- ✓ To improve the quality of flood hazard map, it is recommended that SRTM DEM be corrected after validating from the site before modeling. Further, more topographical survey is to be conducted for the areas near the rivers.

- ✓ To produce more accurate Flood Hazard Map, it is recommended to use a high resolution DEM for modeling purpose.

- ✓ The study recommends installation of permanent rainfall stations providing hourly data to represent the spatial rainfall pattern over the entire Dangchu catchment. Further, a proper study is to be done to select the best method for rainfall interpolation and estimation.

- ✓ The study strongly recommends that necessary equipment for acquisition of discharge data be installed along the river at suitable location for future updates of the flood hazard map.

- ✓ During the study, the Manning's roughness is considered constant. It is therefore, necessary to calibrate these parameters with at least at one small and one extreme flood event to improve the quality of the map.

- ✓ The maps should be updated by using land cover data and soil data for the region.

- ✓ Flood hazard maps are dynamic in nature and need to be updated on a regular basis. The change in any of the following conditions might require updates of the flood hazard maps:
  a. Changes in the physical characteristics of the watershed, such as land cover, construction of dams, flood protection works etc., which could alter the flow regime.
  b. Changes in rainfall pattern.
  c. Opportunity to produce more accurate maps (Easy access to more sophisticated procedures for performing the hydrologic/hydraulic analysis, availability of a more current spatial data layer and availability of spatial data of a higher resolution).

- ✓ In the overall assessment of wangdue phodrang following hazardous areas are identified.

Gewog	**River**	**Threats to**	**observation**	**Recommendation**
Athang Gewog	Nyeba chu	Nil	No recent flood events recent years.	
	Mara chu	Approx. 3 Acres of Agricultural Land	No recent flood events recent years.	
Dagar	Taksha chu	Bridge in	Gabion wall	Restoration of wall

Gewog		Tsirang _ Wangdue Highway and farm road.	constructed by project was also destroyed in 2017 flooding. The failure of wall is mainly due to poor design of wall.	maybe carried out using proper design.
Dangchu Gewog	Dangchu	Dangchu Village, Tekikha Village, Kichu Resort, Forestry Office and Colony, Prison	RRM wall which was constructed to protect Gewog Office and Dangchu village from flooding was washed away during 2015 flooding.	Restoration of wall maybe carried out using proper design.
	Gilkhachu	Dangchu Gewog Office and RNR Center areas	Posses potential threat to Dangchu Gewog Office and RNR Center areas	Approximately 700-meters length of flood protection structures is required to protect Dangchu village, Gewog Office and RNR Center from flooding.
Kazhi Gewog	Baychu	Chuzomsa near Tekikha village.	No flooding event recorded.	
Nahi Gewog	Hinley Rongchu River	Nebesa Chiwog bridge, Irrigation channel source, Suspension Bridge connecting School	During 2014 flooding, Nebesa Chiwog bridge was washed away and restored in 2015. Bridge constructed by JICA in 2012 just above the Nahi primary school was also affected. Irrigation water sources were also washed away in recent years	Construction of flood protection measures throughout the stretch of river would be very uneconomical. Hence, construction of protection measure at important places only is recommended
Phobji Gewog	Pakshingzangpa chu	motorable bridge and approx. 17 acres of dry land	No recent flooding event recorded.	

	Khem chu	4 houses, 30 people, 150 cattle and about 6 vehicles in khewa village	During 2016 flooding whole village was evacuated.	About 1200 meters of structure on both the side of river to prevent village from flooding
Sephu Gewog	Nikachhu	Motorable bridge, dryland and milk processing unit.	No recent flooding event recorded, however, these structures are under risk zone.	Flood protection structures maybe constructed at different section of river to protect these structures.
Thaedtsho Gewog	Punatsangchu	Thango village and hotel Pema Karpo.	In 2009, two houses in Thango village were completely washed away. Again in 20016, Thango village was inundated and artificial pond was created behind Hotel Pema Karpo. Two excavators were used to draw water out of this pond. The elevation difference between river bed level and ground is minimal and height of existing structure is not enough to retain water within the river bed.	Create embankment on the left bank of river and increase the height of existing structure to prevent overtopping.

Limitations of the study

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

- ✓ The elevation data required for the map was extracted from STRM. A major problem with using SRTM data for hydrodynamic modelling of a floodplain is that it is not "bare-earth" and contains information about vegetation and urban areas that block the water movement in the model.

- ✓ The Digital Elevation Model used in this study was SRTM DEM with 30 meter resolution which is freely available.

- ✓ 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 Dangchu catchment, the discharged obtained from IFAS maynot be correct.

- ✓ There is no discharge data for Dangchu resulting in the use of calculated discharge using IFAS software.

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

- ✓ Land cover data and soil data has not been used for modeling purpose resulting in unrealistic ground condition.

- ✓ The purpose of this study is only applicable for flood prone awareness programs and drafting the flood management plans. It is not recommended for any administrative purpose since other hazard might not been considered during the mapping.

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