FLOOD HAZARD ASSESSMENT FOR SAMDRUP JONGKHAR DZONGKHAG

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

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1. National Centre for Hydrology and Meteorology, Ministry of Economic Affairs, Bhutan
2. National Statistical Bureau, Bhutan
3. Samdrupjongkhar Thromde, Samdrupjongkhar Dzongkhag

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Acronyms

FEMD	Flood Engineering and Management Division.
Dungsum Chu	River flowing through Samdrupjongkhar Thromde
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.
RSTA	Road Safety and Transport Authority.
DES	Department of Engineering Services.
NCHM	National Centre for Hydrology and Meteorology.
MoWHS	Ministry of Works and Human Settlement.
DHS	Department of Human Settlement.
Nu.	Bhutanese currency in Ngultrum.

Executive Summary

Samdrupjongkhar Thromde has been experiencing flood every rainy season. It not only experienced the flooding in August, 2015, it also experienced flooding in the year 2004 and 2012. The most recent flashflood of August, 2015 in Samdrupjongkhar caused damages to flood protection walls, roads, bridge and other infrastructureFigure 2: Compound wall damaged.. The rainfall for 29th and 30th August, 2015 was 142 mm and 215.8 mm respectively. The flooding at Dungsum Chhu in Samdrupjongkhar on 30th August 2015 has caused damage of worth more than Nu. 6,089,497.38 (about US$ 94,000) and also washed away a suspension bridge connecting the Primary School to the rest of the Thromde leaving it inaccessible for the inhabitants.

The main objectives of the studies are listed below.

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

Gewog level assessment was carried out to capture all the flooding risk in Dzongkhag. It has been observed that higher discharge with sediment loads due to bed erosion, bank erosion and landslides caused by higher velocity and weak geology is seen as the main problem in the area. Moreover, rivers are mostly seasonal (Runoff -fed) with no or significantly low discharge as compared to rainy seasons.

Dungsamchu was found to be most critical river where study is not carried out. Hence, the detailed assessment of Dungsamchu was carried out and Hazard map, Vulnerability Map and Risk Map are prepared.

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

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

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

Introduction

Background

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

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

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

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

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

Floods are recurrent phenomena in Bhutan from time immemorial causing extensive damages during the monsoon season (June – September). Floods of varying magnitude, affect some or most parts of the country, almost every year due to different climates and rainfall patterns. With the increase in population and developmental activities in the country, there has been a tendency to occupy the flood plains, often resulting in serious flood damages and loss of live over the years. Of late, some areas, which were not traditionally prone to floods, also experienced severe inundation. Floods cause severe bank erosion if the river banks are fragile and not protected against the heavy flood discharges.

On the other hand, flooding in southern and as well as in northern Bhutan is becoming a regular phenomenon. Considering the fragile geological conditions along the southern foothill, flash floods carrying sizeable amounts of boulders and debris cause substantial damages to the property, agricultural land and loss of lives in Bhutan from time to time. In 2004, flash floods that occurred in the 6 eastern Dzongkhags killed 9 people, washed away 29 houses, damaged 107 houses and destroyed 664 acres of wet and dry farm roads (National Adaptation Programme of Action: update of Projects and Profiles 2012. The cyclone Aila of 2009 led to loss of 12 lives and damages to agriculture, roads, bridges, schools, hydro projects and other infrastructure. The flashflood of August, 2015 in Samdrupjongkhar caused damages to flood protection walls, roads, bridge and other infrastructure. Lots of investment has been made in the past for flood protection works along the banks of Dungsumchu. And as per the site investigation also, more protection works are required to reduce the population's vulnerability to flood. However, till now no proper detailed engineering study has been conducted in the past for training of Dungsumchu to reduce the flood impacts before implementation of the structures. Further, the Urban Development Plan for Samdrupjongkhar Thromde 2013-2033 also highlights the need to identify feasible technical solutions to address the flooding problems.

The Technology Needs Assessment and Technology Action Plans for Climate Change Adaptation, March 2013 also emphasized on reducing the vulnerability of people, infrastructure and agricultural fields to natural disasters such as flash floods. Enhancing river training works was identified as a potential technology option in this regard.

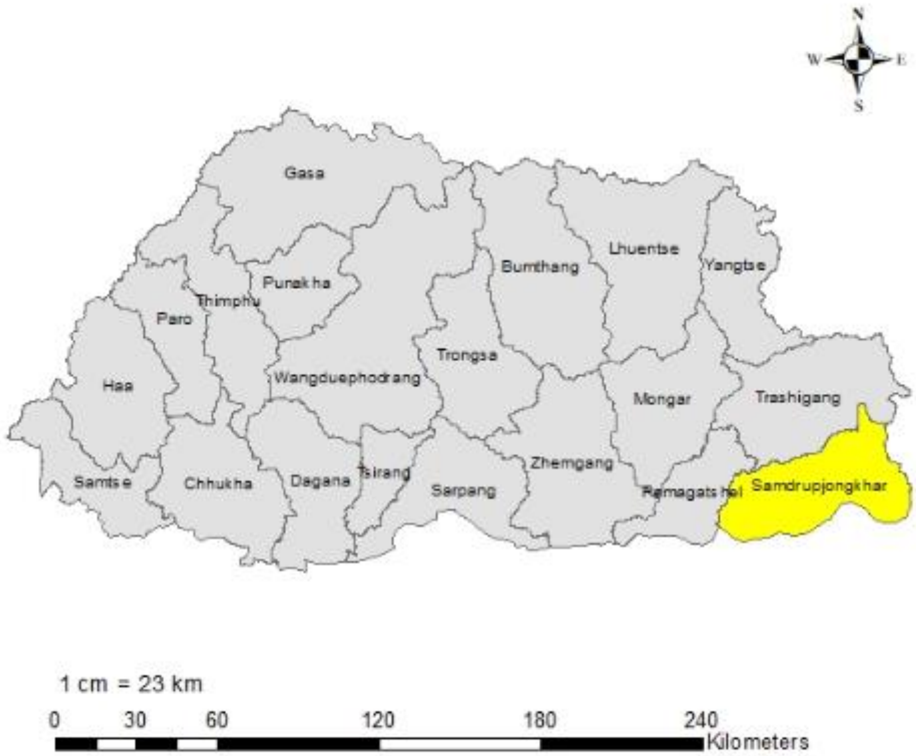


Figure 1: Bhutan Map showing the Study area.

Samdrupjongkhar Thromde has been experiencing flood every rainy season. It not only experienced the flooding in August, 2015, it also experienced flooding in the year 2004 and 2012. The most recent flashflood of August, 2015 in Samdrupjongkhar caused damages to flood protection walls, roads, bridge and other infrastructure as seen in Figure 2**,** Figure 3**,** Figure 4**,** and Figure 5Figure 2: Compound wall damaged.. The rainfall for 29th and 30th August, 2015 was 142 mm and 215.8 mm respectively. The flooding at Dungsum Chhu in Samdrupjongkhar on 30th August 2015 has caused damage of worth more than Nu. 6,089,497.38 (about US$ 94,000) as given in Table 1 and also washed away a suspension bridge connecting the Primary School to the rest of the Thromde leaving it inaccessible for the inhabitants.

Figure 2: Compound wall damaged.

Figure 3: Meat shop inundated in lower market.

Figure 4: Suspension bridge damaged.

Figure 5::Flood protection structure damaged.

Table 1: Damage caused by flood of 30th August, 2015.

Sl.No	Work Description	Location	Unit Length	Amount
1	Gabion wall	Truck parking	72.5	213,723.48
2	R.C.C Wall	Near Samdrupjongkhar Primary School	29.3	1,820,458.34
		Near Cement Godown	7.0	434,921.79
3	Road	NHDC Colony	150	936,065.10
		Truck Parking	72.5	452,431.47
4	Brick wall fencing	RSTA Boundary Wall	49	202,183.62
5	Suspension Bridge span 43 m	Near Samdrupjongkhar Primary School	1	1,500,000.00
6	HDPE pipeline 150mm	Gravity water source above Pinchina checkpost	210	353,669.40
7	Check dam and water drainage channel	Gravity water source above Pinchina checkpost	LS	60,000.00
8	Infiltration GI pipeline 150mm	Gravity water source below Pinchina checkpost	60	116,044.20
GRAND TOTAL AMOUNT IN NGULTRUM				**6,089,497.38**

Objective

Objective 1: Detailed flood assessment of Dungsumchu in Samdrup Jongkhar Dzongkhag.

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

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

Study Area

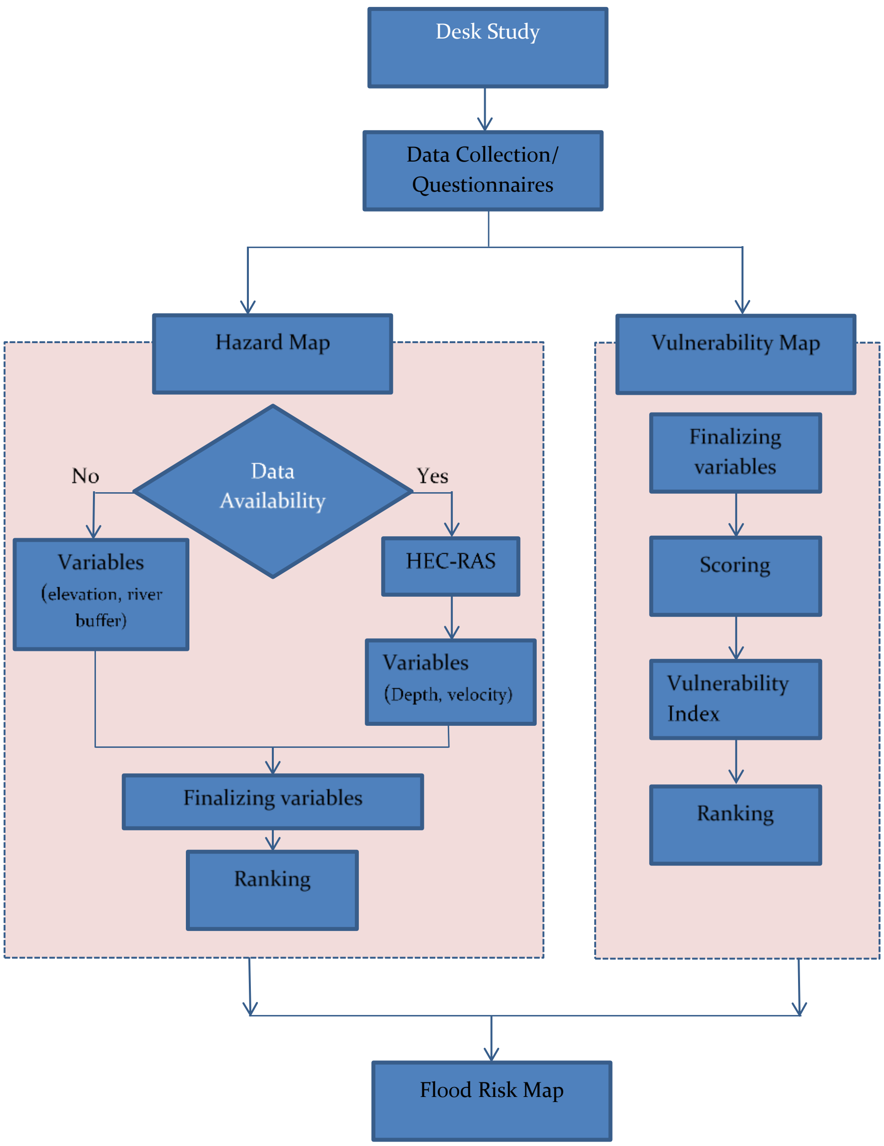
Samdrupjongkhar Dzongkhag lies in the South Eastern part of Bhutan bordering the Indian states of Assam and Arunachal Pradesh. The Dzongkhag has a total area of approximately 1,877.67 Sq.Km. The Dzongkhag Administration unit comprises of 2 dungkhags namely; Samdrupchholing and Jomotshangkha and has 11 Gewogs viz; Orong, Deothang, Gomdar, Wangphu, Phuntshothang, Pemathang, Martshala, Samrang, Serthi, Lauri and Langchenphu.With large fertile plain area, rich mineral deposits and sub-tropical climate, the Dzongkhag has high potential for agricultural and economic activities. It is also the gateway and commercial hub for other five eastern Dzongkhags with many industrial and mining operations.

Samdrupjongkhar is the district headquarters of the Samdrupjongkhar Dzonkhag and is also one of the Class A Thromdes in Bhutan. Presently, the Thromde (Municipal) area includes the area under the Samdrupjonkhar town as well as the settlement in Dewathang, 18 km uphill with the connecting road in between. The area of Samdrupjongkhar town is 2.08 sq. Km. It had a population of 5,952 with a density of 2,862 persons per sq. km. and sex ratio of 116.5 males per 100 females according to the PHCB 2005. The area of Dewathang town is 2.39 sq. Km. It had a population of 2,644 with a density of 1,106 persons per sq. km. and sex ratio of 108.7 according to PHCB 2005.

Jomotshangkha Dungkhag is one of two Dungkhag in Samdrup Jongkhar Dzongkhag which consist of three gewogs (Serthi, Lauri and Langchenphu). There are four major rivers in jomotsangkha dungkhag (ChuKarpo, Jomri chu, Jangsa chu and Rongchuthang chu.)

Samdrup choling Dungkhag in Samdrup Jongkhar Dzongkhag consist of four gewogs (Phuntshothang, Pemathang, Martshala and Samrang). There are two major rivers in Samdrup choling dungkhag (Samrang chu and Nyera Amari chu.

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 6.

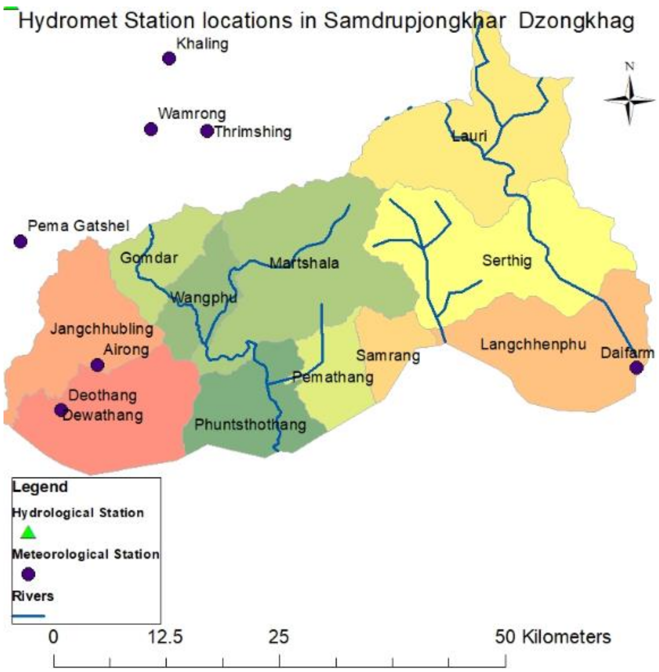


Figure 6: Map showing the Hydro-met location in study Area.

Meteorological Data

There are 2 meteorological stations available in the watershed study area. All the data have a temporal scale of daily data interval and the data availability varies from each station. The details of the met station are shown in Table 2**Error! Reference source not found.**.

Table 2: Met stations and temporal data available

Sl.No	Met station name	Temporal data available
1	Deothang	1996/01/01 to 2017/12/31
2	Airong	1995/01/01 to 2017/12/31

Table 3: Maximum rainfall event from 1996-2015 in Deothang.

Year	**Maximum Daily Rainfall(mm)**
1996	210
1997	391.4
1998	180.5
1999	210
2000	274

2001	126.4
2002	195
2003	210
2004	245
2005	251
2006	201
2007	253.6
2008	206
2009	228
2010	118.7
2011	127.7
2012	288.1
2013	138.6
2014	162.8
2015	215.8
Maximum	**391.4**

Scientific Data

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

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

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

Site Assessment at Gewog Level

There are two main rivers in Jomotshangkha area: Chukarpo on the left and River Jomri on the right side of the town. It was found that there is a high possibility of the rivers changing its course within the riverbank plains. This could pose a threat because the rivers cut away at the landforms little by little, reducing the total area of the site. The flood analysis report from ***Getotechical Report, Jomotshangkha*** revealed that in every 100 years, peak value of 286.65 m^3/s and in every 150 years, a peak value of 299.16 m^3/s could hit the Jomotshangkha valley by

Chukarpo. For River Jomri, the values were 1256.81 m^3/s for 100 years and 1311.65 m^3/s for 150 years.

Figure 7: Map showing ChuKarpo and Jomri river in Jomotshangkha Dungkhag.

Figure 8: Existing RRC revetment was destroyed in 2016 flooding.

Chukarpo is seasonal river with very small discharge in summer and high discharge with lots of debris in summer. It changes its course every season within the width river bank (approximately 300m).

Figure 9: Jomri river causing bank erosion which leads to landslinde in jomotsangkha.

Jomri River causes bank erosion on the right bank leading to landslides. Jomotsangkha hospital, Mandir and forestry office in located on the top of the landslide area.

Jangsa River is located approximately 6kms away from jomotsangkha town. River is at great threat to settlement and agricultural land. Main problem seen as per site investigation is seen as river bank erosion rather than inundation.
Rongchuthang River is a seasonal river which has river bed level equal to ground level, giving river all the freedom of flow in all direction, leading to change in river course during every heavy rainfall. This has resulted in washing away of Agricultural land in Rongchuthang village.

Figure 10: Ground level and river bed level is almost equal in Rongchuthang river.

Figure 11: Existing Gabion wall has failed.

River cross section survey

Taking cross-section survey of a river channel is important while conducting river analysis to find the river discharge, velocity, river profile etc. Cross-sections are required to represent channel geometry in a river hydraulic model. The accuracy of the simulated water levels and the floodplain delineation largely depends on the shape as well as extent of these cross-sections. The cross-section survey of Dungsumchu was carried out by FEMD, DES, MoWHS. About 57 numbers of cross-section data along Dungsumchu were collected in the first batch and then, depending on the critical areas and location of the structures, 52 numbers of surveys was carried out in the second batch. The dimension and location of the structures were also collected to be used in the model. The Figure 12**Error! Reference source not found.** shows how the survey has been conducted for this study.

Figure 12: River cross-section survey.

Vulnerability Assessment Survey

The flood vulnerability assessment survey was carried out jointly by FEMD and Samdrup Jongkhar Thromde officials. The objective of the survey is to evaluate the degree of risk posed by Dungsum Chu in Samdrup Jongkhar Thromde to carry out "***Flood Risk Assessment for Dungsum Chu basin in Samdrup Jongkhar***".

Based on the land use characteristics in the study area, the technical team from AIT has designed the questionnaire to fully capture the vulnerability of five different land uses. The different land uses found in the study areas are residential, institutional, industries/commercial, infrastructure and agricultural. The following numbers of survey were carried out in each of the area:

1. Residential: Total of 230 households was interviewed uniformly across the study area. The samples were taken from houses near the river and also away from the river to spatially overlay the vulnerability on the hazard maps to estimate the risk.

2. Institutional: As per the land use map, 10 institutions were interviewed. These include Hospital (2), School (3), Regional Labour and Human Resources (1), Road Safety and Transport Authority (1), Royal Bhutan Police (1), Forestry Division (1) and Municipality (1).

3. Industries/Commercial: The team conducted 26 interviews at different locations as per the land use map for commercial areas. In each area about 3 to 4 interviews were carried out.

4. Infrastructure: 4 interviews were conducted for the offices dealing with infrastructure developments such as Department of Road (DoR), Bhutan Power Corporation (BPC), Municipality and Bhutan Telecom Limited (BTL).

5. Agriculture: As per the site investigation, Samdrup Jongkhar Municipality area does not have adequate agricultural land where crops are cultivated and further, the land use map also does not show agricultural land in the Municipality. Therefore, survey was not taken for agricultural land use.

Figure 13: Enumerators carrying out vulnerability assessment survey

Vulnerable Flood Prone Area

The freely available global DEM such as SRTM 30m and SRTM 90m and the ALOS 10m DSm were explored to find the most suitable DEM for the study area. All the DEMS were corrected as per the site location and resampled to create a terrain for the 2D hydrodynamic model. The results of the models were compared and it was found that ALOS 10m DSM represented the study area better than other globally available DEM. Thus for this study, ALOS 10m DSM was used.

Outfall below the RSTA office

There is an outfall below the RSTA office as shown in Figure 14 to discharge off the runoff from the industrial area into the river. The storm water drain from the industrial area runs along the left bank of Dungsumchu till the outfall near RSTA. From visual inspection, it can be seen that the storm water drain only caters to some areas above the football ground. The outfall is located between the two flood protection walls and there is an opening in between to allow storm water runoffs from the surrounding areas (RSTA, bus booking etc.) to discharge into the river. During the flash flood in August, 2015, the back flow from the river into the surrounding area from the opening and the outfall caused inundation of the surrounding areas and collapsed of the compound wall around RSTA office. As per the site investigation, this area was found to be one of the most critical areas.

Figure 14: Outfall below the RSTA office.

Areas behind Dzong

There are settlements in the area behind the Dzong and the area is situated at a much lower elevation than the Dzong area as shown in Figure 15. There are about 10 households living in the area and they come from low income group. The settlement area at present is acting as a buffer zone for Dzong against the flood. During the site investigation, it was found out that there was a major scouring along the left bank of the Dungsumchu behind the Dzong. The river has been meandering and the normal flow path of the river is towards the left bank. The flowing water in the river erodes the outer banks and deposits them on the inside. There is not much elevation difference between the river bed level and the settlement area on the left bank (River bed level- Elevation 200 m, Latitude 26°48'25.7", Longitude 91°30' 15.1" and Settlement Area- Elevation 206 m, Latitude 26°48'25.7", Longitude 91° 30'9.1").Therefore, there is higher chance of settlement area getting inundated by the flood posing risk to the lives of people. If this area is not protected immediately, then the scouring will take away the land acting as a buffer zone and further, it will increase the vulnerability of the people and infrastructure in the Dzong area to the flood. Since the river direction is towards the Dzong, the area behind the prison will also be affected if no immediate measures are done.

Figure 15: Area behind the Dzong.

Area behind the prison

The area behind the Prison as presented in Figure 16 located on the left bank of Dungsumchu is also vulnerable to flood. The prison is located along the left bank of Dungsumchu and there are visible signs of scouring along the bank. If flood protection measures are not done immediately, the compound wall of the prison might fail.

Figure 16: Areas behind the prison.

Left bank below the damaged suspension bridge till the access road to school

The left bank along Dungsumchu starting from the damaged suspension bridge till the access road to school is also very fragile and prone to erosion. If the scouring and erosion is not prevented immediately, more erosion will take place and the existing infrastructure like road, drains etc. on the left bank will be affected.

Walls near the international border

Some portion of the flood protection works on the right bank of Dungsumchu near the international border has collapsed due to scouring of the foundation by the flowing river as seen in Figure 17. However, there are some portions which are still standing intact and there are also visible signs of scouring in the foundation of the wall. The protection walls are preventing river breaching the bank and also erosion of the river bank.

Figure 17: Damaged wall near international border

Flooding from the irrigation canal in the lower market

As per the local resident, the main source of flooding in Samdrup Jongkhar Municipality during the rainy season in lower town area is due to over flow of water from the irrigation canal. The canal takes water from Dungsumchu to the border town of India. There are two irrigation canals inundating roads and causing inconvenience to the people during the rainy season. The Figure 18 and Figure 19 show the irrigation canal and its intake point at Dungsumchu in the lower market.

Figure 18: Irrigation canal in lower market.

Figure 19: Weir and irrigation canal intake.

Flooding from the irrigation canal in the lower market

The upper town area is located approximately 350 metres away from Dungsum Chu and is at a high elevation as compared to the lower town. The people residing in this area blame the overflow from the storm water drain during monsoon as the main reason for flooding. They frequently experience overflow from drainage during rainy season.

Result and Analysis

The flood hazard map can be prepared based on different variables such as flood depth, flood duration, velocity, rainfall, elevation, soil and distance from the river. The variables to be used for flood hazard map were based on the availability of the data for Dungsum Chhu (River).
The variables such as flood depth, flood duration and velocity are to be gathered after running HEC-RAS model. The input for the model is the discharge, river cross-section survey, DEM (Digital Elevation Model), dimension and location of the flood protection structures. Therefore, cross-section survey for river was conducted. Further, information on the dimension and location of the existing flood protection along the banks of Dungsum Chhu was also gathered by the engineers. Due to lack of discharge data for Dungsum Chu (River), HEC-RAS couldnot be used. Hence, the variables such as flood duration, flood depth and velocity couldnot be taken into consideration for preparation of flood hazard map. Similarly, the Table 4 shows the justification on considering only few variables for flood hazard map.

Table 4: Variables for flood hazard map.

Sl.No	Variables	Remarks
1.	Flood depth	Couldn't be considered since HEC-RAS could not be run due to lack of discharge data.
2.	Flood duration	
3.	Velocity	
4.	Rainfall	Though rainfall data is available from 1996 till date for Deothang Meteorological station, it couldnot be used as it was not giving information on rainfall variability across Thromde area.
5.	Elevation	This variable is being considered.
6.	Soil	Couldn't be considered due to lack of soil data.
7.	Distance from the river	This variable is being considered as planners use a standard buffer zone near water bodies (river, stream etc.)

For preparation of flood hazard map, two variables such as elevation and distance from the river have been considered have been considered important in this study. The ranking and weighting for the two variables has been discussed has been discussed thoroughly amongst the engineers in the Division. The

Table 5 gives the detail of the ranking and weighting:

Table 5: Classes and ranking of variables.

Variable	Classes	Ranking
Main rivers (River buffer)	0 – 30 m	2
	30-100m	1
	>100m	0
Elevation	<= 163	3
	163-168m	2
	168-185 m	1
	>185 m	0

The high ranking in case of river buffer are given to the nearer infrastructures since, it is more vulnerable to the flood. The ranking for the low elevation areas are higher, since river can easily inundate the low lying areas. Further, the weightage of 75 is given to the elevation because of the past flooding experiences. It has been observed in the past that low lying areas near the river are mostly inundated during flooding.

After finalizing the variables, the flood hazard map has been prepared using raster calculator in GIS.

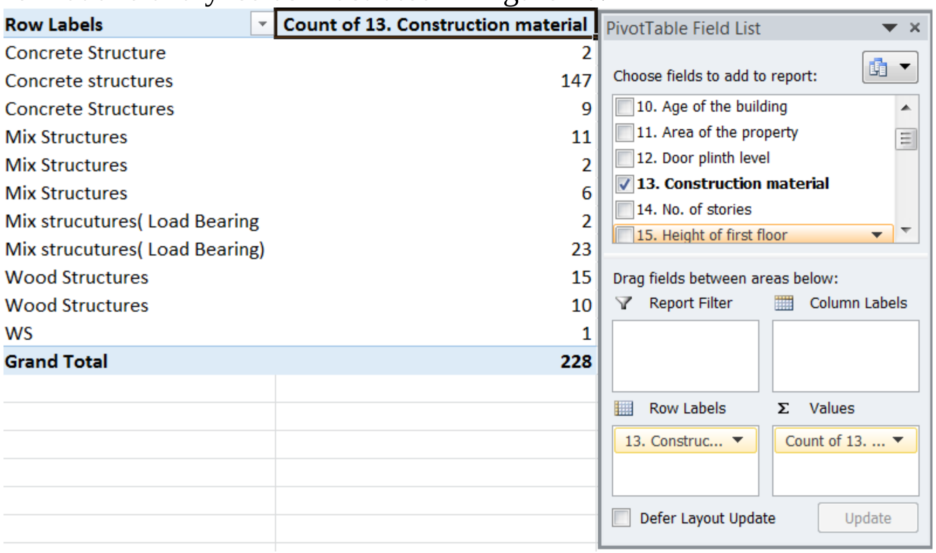
Flood Vulnerability Map

The following five steps are used to analyze the survey questionnaires for vulnerability assessment:

1. Variable selection
2. Variable Classification and scoring
3. Regional Division
4. Vulnerability index calculation
5. Weighting and ranking variables

Variable selection

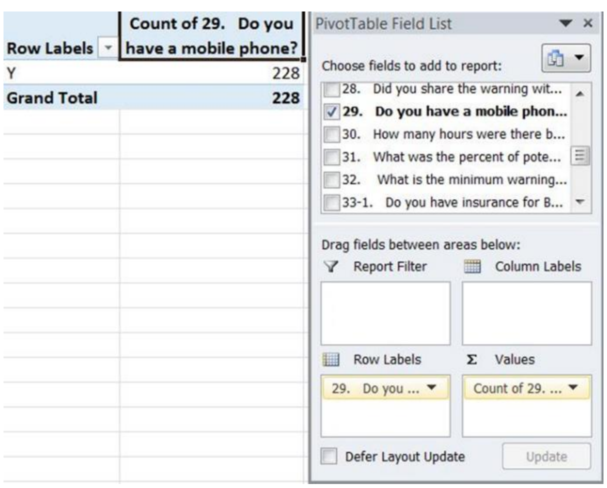
The survey questionnaires contain questions related to the four vulnerability indices (social, economic, physical and exposure) for four categories of land uses such as residential, commercial, infrastructure and institutional. Therefore, it was very critical to select the best variables to prepare the vulnerability map. Firstly, the questions were compiled in the excel format and analyzed as illustrated in Figure 20.



Row Labels	Count of 13. Construction material
Concrete Structure	2
Concrete structures	147
Concrete Structures	9
Mix Structures	11
Mix Structures	2
Mix Structures	6
Mix strucutures(Load Bearing	2
Mix strucutures(Load Bearing)	23
Wood Structures	15
Wood Structures	10
WS	1
Grand Total	**228**

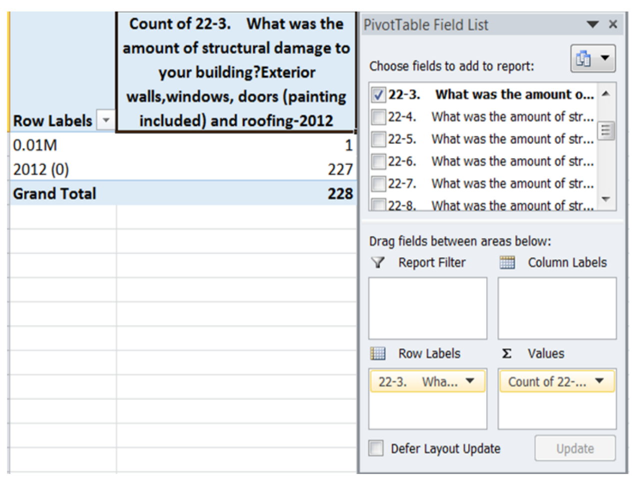
Figure 20: Analysing the questions in excel.

Then, the variables were selected based on the availability of quality and quantity responses from the respondents. For example, after the questionnaire survey has been compiled, the questions which have the same responses for a question as shown in Figure 21 or which do not have any answers or enough answers have been eliminated as given in Figure 22. These types of responses do not have any impact on vulnerability.



Row Labels	Count of 29. Do you have a mobile phone?
Y	228
Grand Total	**228**

Figure 21: Question with the same response.



Row Labels	Count of 22-3. What was the amount of structural damage to your building?Exterior walls,windows, doors (painting included) and roofing-2012
0.01M	1
2012 (0)	227
Grand Total	**228**

Figure 22: Question with insufficient response

Further for this study, the infrastructure land use questions have been removed since it does not have enough number of answers. Out of four survey samples, only one sample has answer and therefore, it was eliminated. Further, some variables conveyed the same meaning and therefore, it was also eliminated from all the four land uses.

Variable Classification and scoring

After finalizing the variables from the questionnaires, it was classified into four vulnerability indices (social, economic, physical and exposure). The classes and score for the variables were finalized based on previous studies and also after discussion amongst the engineers. The variables have been defined with class and score for four vulnerability indices.

In residential land uses, there are 3 variables for social vulnerability index, 7 for physical vulnerability index, 4 for economy vulnerability index and 5 for exposure vulnerability index. For residential land uses, Table 6, Table 7, Table 8 and Table 9 give the information on classes, scoring and source.

Table 6: Residential-Social Variables.

Variables		Classes	Score	Remark	Source
1	How long have you been living here?	>15	25	Living for longer time in a community develops a good bond resulting in less vulnerability during flood.	Morin et al., (2016)
		11-15	50		
		6-10	75		
		<=5	100		
2	Total No. of families	<=5	33	Large family needs more resource and facility.	Saqib et al., (2016) Rana and Routray (2016)
		6-10	67		
		>10	100		
3	Do you have any disabled family members with you?	0	0	The presence of disabled family members increases the vulnerability.	Ahsan and Warner, (2014)
		1	50		
		>1	100		

Table 7: Residential-Physical Variables.

Variables		Classes	Score	Remark	Source
1	Construction material & Age of the building	Concrete <=50	0	As per the Bhutan Schedule of Rates (BSR) valuation, the concrete structure over 50 years is more vulnerable. Similarly, other structure above 25 years is more vulnerable.	FEMD
		Concrete >50	100		
		Mix/Wood/ Temporary<=25	0		
		Mix/Wood/ Temporary>25	100		
2	Door plinth level	<=0.45m	100	This is from the building standard.	FEMD
		>0.45m	0		

3	No. of stories	1	100	Higher the story, less vulnerable.	FEMD
		>1	0		
4	What was the maximum water level and duration of flood that entered your building? Depth-2015	<=0.5m	33	Higher the water level, more the destruction.	FEMD
		0.5-1m	67		
		>1m	100		
5	What was the maximum water level and duration of flood that entered your building? Duration-2015	<=6hrs	33	Longer the duration, more the destruction.	FEMD
		6-12hrs	67		
		>12hrs	100		
6	What is the minimum warning time would you need to move all your transportable contents to a safe location?	<=0.5hrs	0	The classes for this variable are decided for flash floods. More warning time needed means more vulnerable.	FEMD
		0.5-1hrs	50		
		>1hrs	100		
7	What is the shortest distance between your building and river?	<=30m	100	Shorter the distance, more vulnerable. The buffer distance is as per planning standard.	FEMD
		30-100m	50		
		>100m	0		

Table 8: Residential-Economy Variables.

Variables		Classes	Score	Remark	Source
1	What is the approximate total present replacement value of your properties? (Ngultrum)	<=0.5M	33	More property, more vulnerable.	FEMD
		0.5-1M	67		
		>1M	100		
2	Do you have insurance for Building?	Yes	0	Insured building will be less vulnerable.	FEMD
		No	100		
3	Do you have any savings in case of an emergency?	Yes	0	More savings, less vulnerable.	FEMD
		No	100		
4	What is the average income of your family per month? (Ngultrum)	<=1000	100	Less income, more vulnerable.	FEMD
		1000-5000	85		
		5000-10000	70		
		10000-15000	55		
		15000-20000	40		
		>20000	25		

Table 9: Residential-Exposure Variables.

Variables		Classes	Score	Remark	Source
1	How many times did you experience flood while living at this address?	0	0	The classes are based on the responses in survey. More number of flooding, more vulnerable.	FEMD
		1	20		
		2	40		
		3	60		
		4	80		
		>4	100		
2	Did you share the warning with others?	Yes	0	Warning not shared is more vulnerable.	FEMD
		No	100		
3	How many hours were there between the time you became aware that flooding might reach your home until the water actually reached to your property?	<=5minutes	100	Shorter the time, more vulnerable.	FEMD
		5-10minutes	75		
		10-60minutes	50		
		>60minutes	25		
4	For how many hours water supply was interrupted? (Hours)2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		
5	For how many hours electrical supply was interrupted? (Hours)2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		

In commercial land uses, there are 2 variables for social vulnerability index, 7 for physical vulnerability index, 4 for economy vulnerability index and 5 for exposure vulnerability index. For commercial land uses, Table 10, Table 11, Table 12 and Table 13 give the information on classes, scoring and source.

Table 10: Commercial-Exposure Variables.

Variables		Classes	Score	Remark	Source
1	How many times did you experience flood while working in this address?	0	0	The classes are based on the responses in survey. More number of flooding, more vulnerable.	FEMD
		1	20		
		2	40		
		3	60		
		4	80		
		>4	100		
2	Did you share the warning with others?	Yes	0	Warning not shared is more vulnerable.	FEMD
		No	100		
3	How many hours were there between the time you became aware that flooding might reach your company/shop/industry until the water actually reached to your company/shop/industry?	<=5minutes	100	Shorter the time, more vulnerable.	FEMD
		5-10minutes	75		
		10-60minutes	50		
		>60minutes	25		
4	For how many hours water supply was interrupted? (Hours)-2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		
5	For how many hours electric supply was interrupted? (Hours)-2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		

Table 11: Commercial-Physical Variables.

Variables		Classes	Score	Remark	Source
1	Construction material & Age of the building	Concrete <=50	0	As per the Bhutan Schedule of Rates (BSR) valuation, the concrete structure over 50 years is more vulnerable.	FEMD
		Concrete >50	100		
		Mix/Wood/ Temporary<=25	0		

		Mix/Wood/ Temporary> 25	100	Similarly, other structure above 25 years is more vulnerable.	
2	Door plinth level	<=0.45m	100	This is from the building standard.	FEMD
		>0.45m	0		
3	No. of stories	1	100	Higher the story, less vulnerable.	FEMD
		>1	0		
4	What is the minimum warning time would you need to move all your transportable contents to a safe location?	<=0.5hrs	0	The classes for this variable are decided for flash floods. More warning time needed means more vulnerable.	FEMD
		0.5-1hrs	50		
		>1hrs	100		
5	What is the shortest distance between your building and river?	<=30m	100	Shorter the distance, more vulnerable. The buffer distance is as per planning standard.	FEMD
		30-100m	50		
		>100m	0		
6	What was the maximum water level and duration of flood that entered your building? Depth-2015	<=0.5m	33	Higher the water level, more the destruction.	FEMD
		0.5-1m	67		
		>1m	100		
7	What was the maximum water level and duration of flood that entered your building? Duration-2015	<=6hrs	33	Longer the duration, more the destruction.	FEMD

Table 12: Commercial-Social Variables.

Variables		Classes	Score	Remark	Source
1	How many workers are working there? (including full time and part time)	<=5	33	Large number of workers needs more resource and facility.	Saqib et al., (2016) Rana and Routray (2016)
		6-10	67		
		>10	100		
2	How long they are settled in this current building?	>15	25	Living for longer time in a community develops a good bond resulting in less vulnerability during flood.	Morin et al., (2016)
		11-15	50		
		6-10	75		
		<=5	100		

Table 13: Commercial-Economy Variables.

Variables		Classes	Score	Remark	Source
1	How many buildings are there at this facility?	<=5	33	More the number of buildings, more vulnerable.	FEMD
		5-10	67		
		>10	100		
2	What is the approximate total present replacement value of your company/shop/industry properties?	<=0.5M	33	More property, more vulnerable.	FEMD
		0.5-1M	67		
		>1M	100		
3	Does your company/shop/industry have insurance for Building?	Yes	0	Insured building will be less vulnerable.	FEMD
		No	100		
4	Does your company/shop/industry have insurance for Contents?	Yes	0	Insured contents will be less vulnerable.	FEMD
		No	100		

In institutional land uses, there are 1 variable for social vulnerability index, 7 for physical vulnerability index, 4 for economy vulnerability index and 5 for exposure vulnerability index. For the institutional land uses, Table 14, Table 15, Table 16 and Table 17give the information on classes, scoring and source.

Table 14: Institutional-Social Variables.

Variables		Classes	Score	Remark	Source
1	How many workers are working there? (including full time and part time)	<=5	33	Large number of workers needs more resource and facility.	Saqib et al., (2016) Rana and Routray (2016)

Table 15: Institutional-Economy Variables.

Variables		Classes	Score	Remark	Source
1	How many buildings are there at this facility (If several estimate the damage for whole)?	<=5	33	More the number of buildings, more vulnerable.	FEMD
		5-10	67		
		>10	100		
2	What is the approximate total present replacement value of your institution properties? (Ngultrum)	<=0.5M	33	More property, more vulnerable.	FEMD
		0.5-1M	67		
		>1M	100		
3	Does your institution have insurance for Building?	Yes	0	Insured building will be less vulnerable.	FEMD
		No	100		
4	Does your institution have insurance for Contents?	Yes	0	Insured contents will be less vulnerable.	FEMD
		No	100		

Table 16: Institutional-Physical Variables.

Variables		Classes	Score	Remark	Source
1	Construction material & Age of the building	Concrete <=50	0	As per the Bhutan Schedule of Rates (BSR) valuation, the concrete structure over 50 years is more vulnerable. Similarly, other structure above 25 years is more vulnerable.	FEMD
		Concrete >50	100		
		Mix/Wood/ Temporary<=25	0		
		Mix/Wood/ Temporary>25	100		
2	Door plinth level	<=0.45m	100	This is from the building standard.	Building Standard
		>0.45m	0		
3	No. of stories	1	100	Higher the story, less vulnerable.	FEMD
		>1	0		
4	What is the minimum warning time would you need to move all your transportable contents to a safe location?	<=0.5hrs	0	The classes for this variable are decided for flash floods. More warning time needed means more vulnerable.	FEMD
		0.5-1hrs	50		
		>1hrs	100		
5	What is the shortest distance between your building and river?	<=30m	100	Shorter the distance, more vulnerable. The buffer distance is as per planning standard.	DHS
		30-100m	50		
		>100m	0		
6	What was the maximum water level and duration of flood that entered your building? Depth-2015	<=0.5m	33	Higher the water level, more the destruction.	FEMD
		0.5-1m	67		
		>1m	100		
7	What was the maximum water level and duration of flood that entered your building? Duration-2015	<=6hrs	33	Longer the duration, more the destruction.	FEMD

Table 17: Institutional-Exposure Variables.

Variables		Classes	Score	Remark	Source
1	How many times did you experience flood while working in this address?	0	0	The classes are based on the responses in survey. More number of flooding, more vulnerable.	FEMD
		1	20		
		2	40		
		3	60		
		4	80		
		>4	100		
2	Did you share the warning with others?	Yes	0	Warning not shared is more vulnerable.	FEMD
		No	100		
3	How many hours were there between the time you became aware that flooding might reach your company/shop/industry until the water actually reached to your institution?	<=5minutes	100	Shorter the time, more vulnerable.	FEMD
		5-10minutes	75		
		10-60minutes	50		
		>60minutes	25		
4	For how many hours water supply was interrupted? (Hours)-2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		
5	For how many hours electric supply was interrupted? (Hours)-2015	<=6hrs	0	More hours means more vulnerable.	FEMD
		6-24hrs	50		
		>24hrs	100		

Regional Division

The vulnerability assessment can be done at the regional level and also in more detail at the household level. For regional flood damage assessment, information on population and asset in the region are required. Similarly, for household assessment, the information on the four vulnerability indices such as social, physical, economic and exposure is required and thus, collected through the questionnaires survey.

However, due to lack of information on population density and asset information as mentioned earlier for Samdrupjongkhar Municipality, only a vulnerability assessment at household level is done on the households located in the two new regions classified as developed areas and undeveloped areas.

The information provided by the Municipality shows the existing land use map as given in Figure 23, without any information on the population density, assets and area. Therefore, for these assessments, the existing land use is classified into two regions (developed and undeveloped) as given in Table 18Table 18: Classified land use.. The Figure 24 shows the new land use map used in the assessment study.

Table 18: Classified land use.

EXISTING LAND USE	NEW LAND USE
Commercial	Developed
Heavy Vegetation	Undeveloped
Industrial Land	Developed
Institute	Developed
Institute Residential	Developed
Mix Land Use	Developed
Organized Open	Undeveloped
Residential	Developed
River	Undeveloped
Road	Developed
Transport	Developed
Vacant	Undeveloped

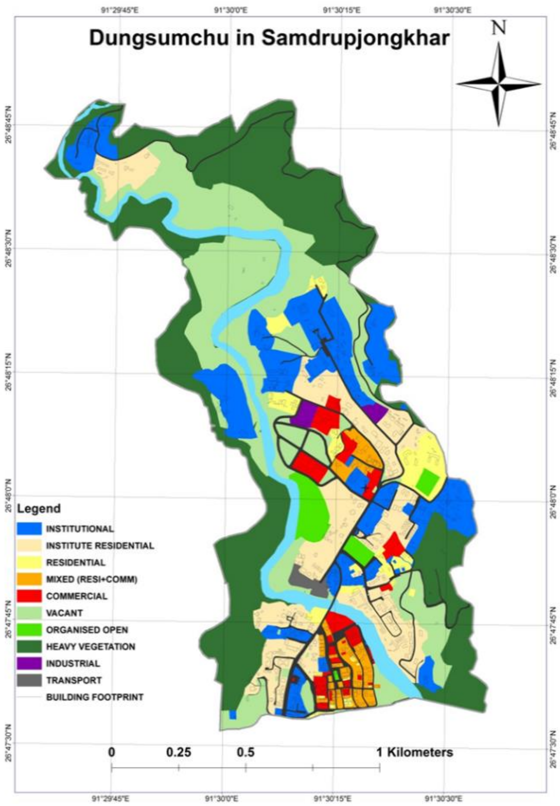


Figure 23: Existing land use plan (Original).

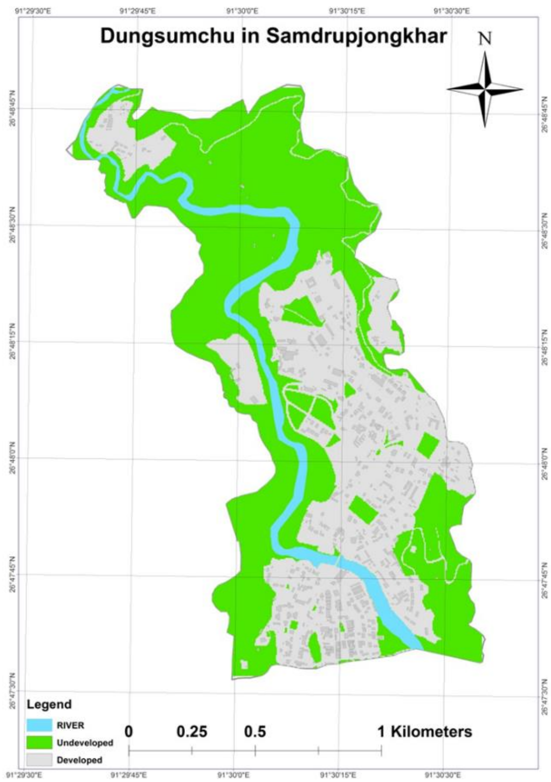


Figure 24: Classified Land use area (Undeveloped and Developed).

Vulnerability index calculation

Based on the two classes of land use (Developed and Undeveloped), the households were projected on the land use map using GIS software. However, it was found out that some of the household were not getting projected in the land use map, rendering it useless. Therefore, in this process, some of the questionnaires had to be discarded because of the incorrectness in the location information (Latitude and Longitude) collected during the survey. The Table 19 gives the information on the number of survey samples discarded.

Table 19: Samples discarded after the projection.

Sl.No	Description	Survey Sample	No. of Samples discarded
1.	Residential	228	63
2.	Commercial	26	0
3.	Institutional	10	0

Then, the vulnerability index is calculated for the different indices using the formula from Table 20**Error! Reference source not found.**. In case of Table 20, the variable used is Household size. The classes represent the family size. N gives the number of households in that particular location with various family sizes. It is assumed that more the number of people, more vulnerable. The classes and scores for the formula is fixed based on the past studies and also in discussion amongst technical experts. The weighted score is calculated by multiplying the percentage of household with particular family sizes and the score. Subsequently, the final weighted score is calculated by dividing the weighted sum by 100.

Table 20: Weighted score for vulnerability index.

Variables	Classes	Location A		Score	Weighted Score
		N	%		
Household size	<=5	44	88.0	33	2904
	6-10	5	10.0	67	670
	>10	1	2.0	100	200
			Sum(100)		**Weight Sum/100= 37.74**

Flood Hazard Map

The elevation map in Figure 25 is generated from Digital Elevation Model (DEM) of 4-meter resolution provided by the Municipality. Similarly, the river buffer in Figure 26 is calculated using Euclidean distance in spatial analyst tools.

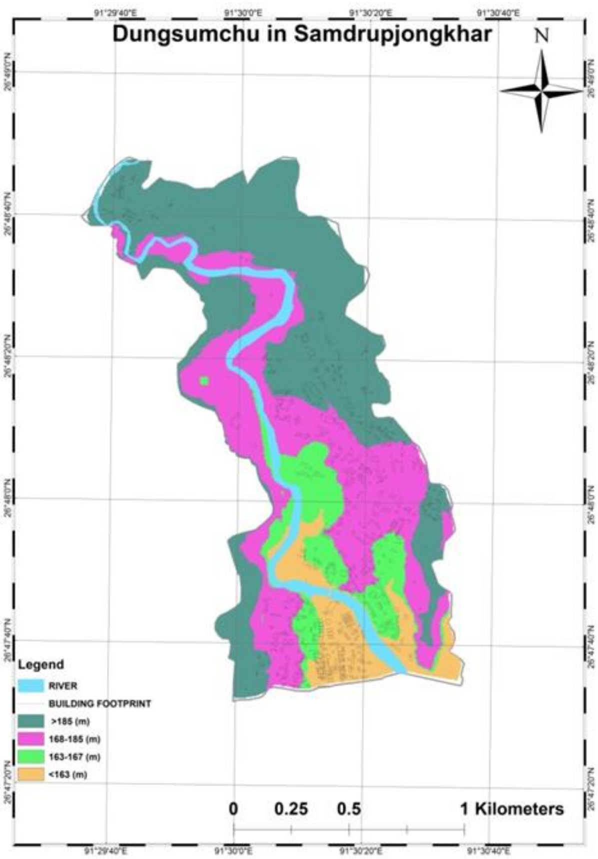


Figure 25: Elevation Map for Dungsumchu.

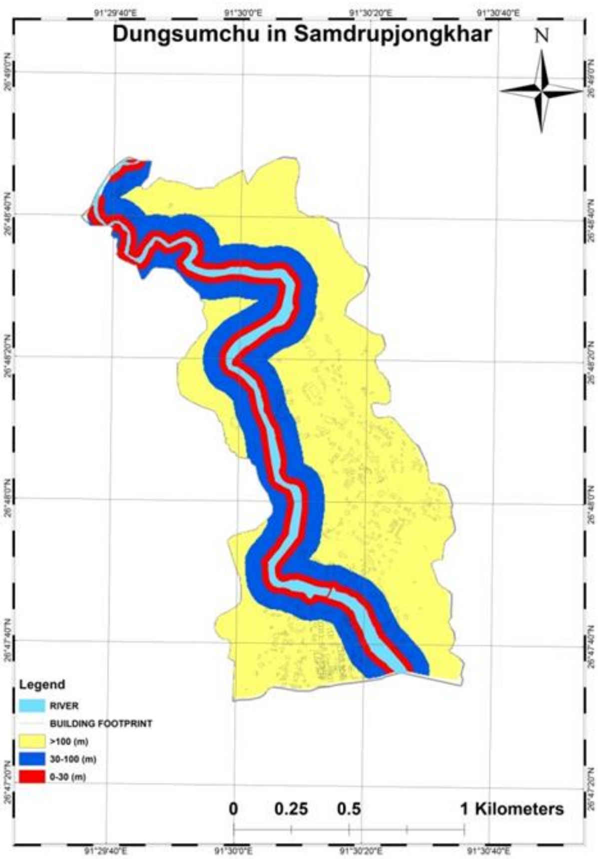


Figure 26: River Buffer for Dungsumchu.

The flood hazard map as shown in Figure 27 has been prepared based on the given weights for river buffer and elevation using raster calculator in GIS. The weight of 75 is given to the elevation data and 25 are given to the river buffer. Both the maps are then overlaid to prepare flood hazard map for Dungsumchu using the equation in raster calculator as follows:
(***River Buffer *25+Elevation *75***)

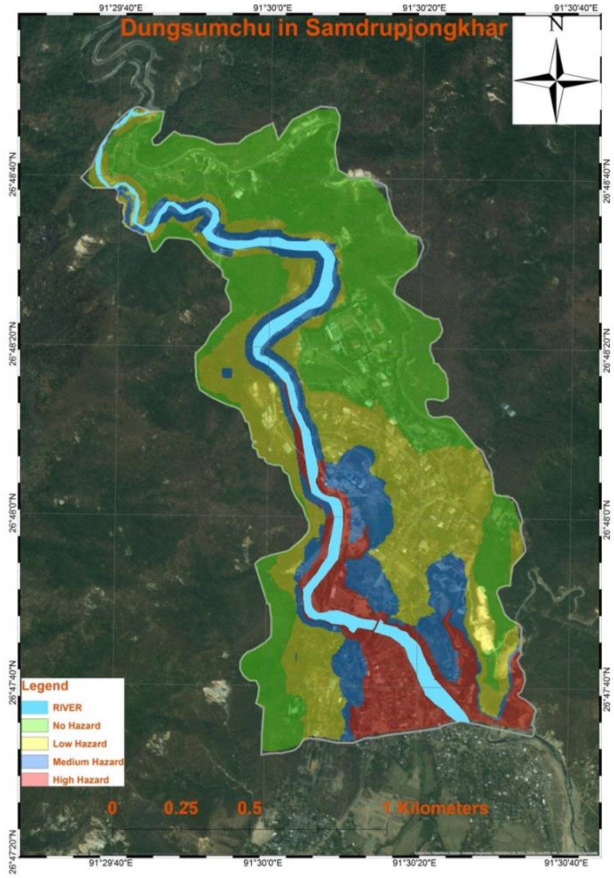


Figure 27: Flood Hazard Map for Dungsumchu.

The **Error! Reference source not found.** shows that about 23 % of buildings out of 817 are located in high hazard zone. Only, about 21 % of the buildings are located in no hazard zone and rest is located in different hazard zones based on the prepared hazard map.

Table 21: Number of building in different hazard zones.

Sl.No	Hazard Zone	Number of Buildings	Percentage
1	No Hazard	174	21.30
2	Low Hazard	308	37.70
3	Medium Hazard	141	17.25
4	High Hazard	194	23.75
TOTAL		***817***	***100***

Flood Vulnerability Map

During the preparation of flood vulnerability map, the raster basemap for Samdrupjongkhar Municipality is reclassified 12 times using the reclassify tools under spatial analyst based on the ranking given for each vulnerability indices in the two land use categories. Some of the reclassifications output can be seen in Figure 28 and Figure 29.

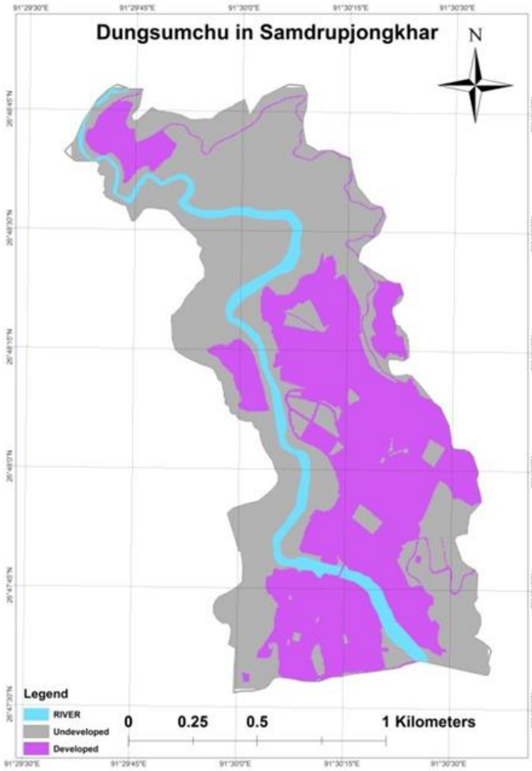


Figure 28: Reclassified map (Residential-social).

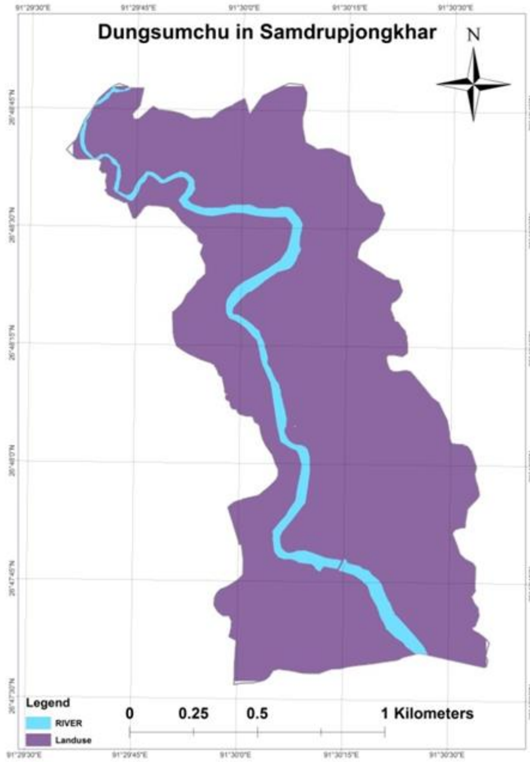


Figure 29: Reclassified map (Residential-physical).

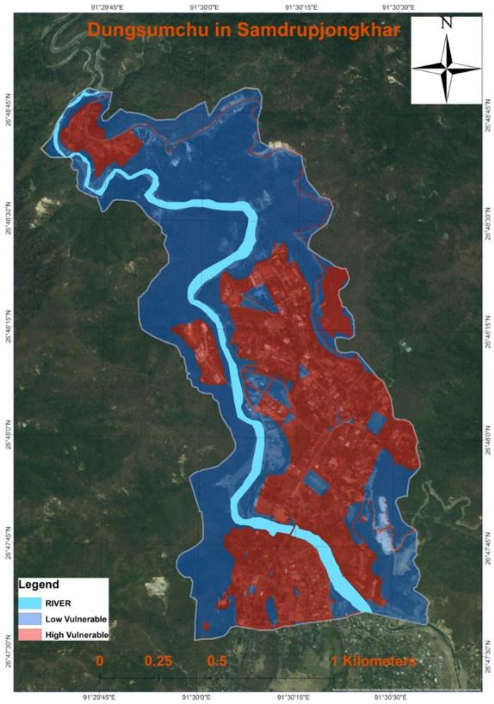


Figure 30: Vulnerability Map for Dungsumchu.

The Table 22 shows that about 2.69 % of buildings out of 817 are located in less vulnerable area and remaining 97.31 % are located in highly vulnerable area based on the prepared vulnerability map.

Table 22: Number of building in different vulnerable zones.

Sl.No	Vulnerable Zone	Number of Buildings	Percentage
1	Less Vulnerable	22	2.69
2	High Vulnerable	795	97.31
TOTAL		**817**	**100**

Flood Risk Map

The Hazard Map and Vulnerability Map is overlaid using raster calculator in spatial analyst tools to produce Flood Risk map. For both the raster layers, weightage of 50 each is given as follows:
(Flood Hazard Map *50+Flood Vulnerability Map *50).
The output flood risk map as given in **Error! Reference source not found.** is then reclassified into four classes as No Risk, Low Risk, Medium Risk and High Risk. The Table 23 gives the number of buildings in the different flood risk zone based on the prepared flood risk map. About 31% of the buildings out of 817 are located in high risk zone. Only about 1% of the buildings are located in no risk zone.

Table 23: Number of buildings in different flood risk zones.

Sl.No	Risk Zone	Number of Buildings	Percentage
1	No Risk	11	1.35
2	Low Risk	180	22.03
3	Medium Risk	370	45.29
4	High Risk	256	31.33
TOTAL		**817**	**100**

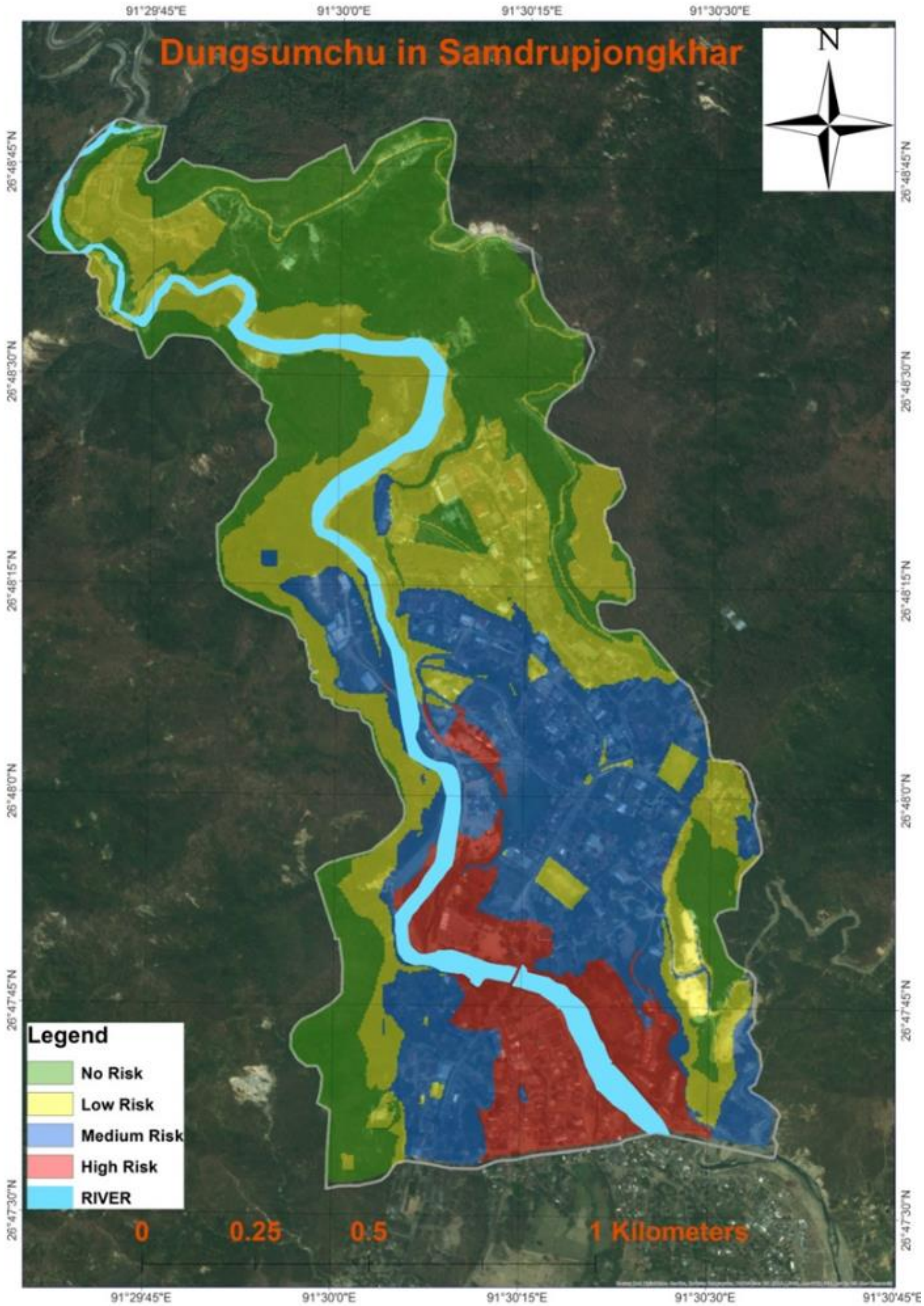


Figure 31: Flood Risk Map for Dungsumchu.

Interventions

In 2016, Design, drawing and detail specification for construction of flood protection structures along Chukarpo in Jomotsangkha was forward to dungkhag for implementation. The estimated cost of structure was **Nu. *5,382,763.00.*** The typical cross-section of Gabion revetment designed is shown in Figure 32.

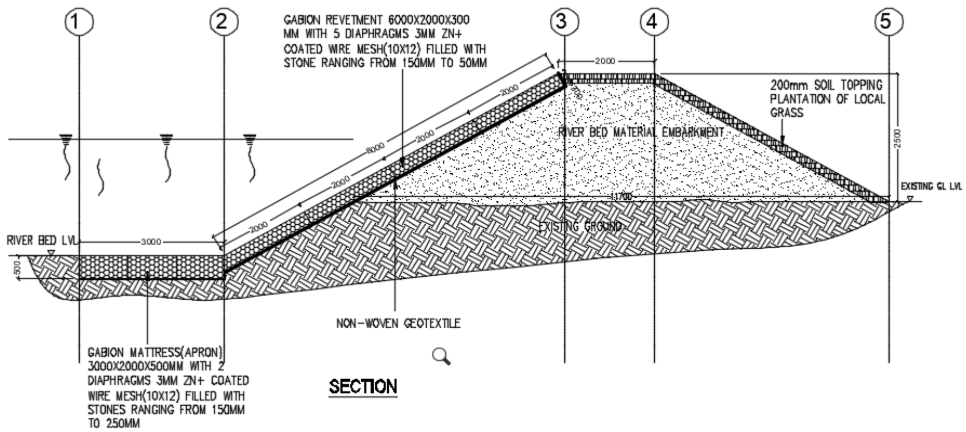


Figure 32: Typical section of gabion revetment designed for Chukarpo in jomotsangkha.

Similarly, in 2017, Design, drawing and detail specification for construction of flood protection structures along Rongchuthang river in Jomotsangkha was forward to dungkhag for implementation. The estimated cost of structure was **Nu. *14, 917,764.00.*** The typical cross-section of Gabion revetment designed is shown in Figure 33.

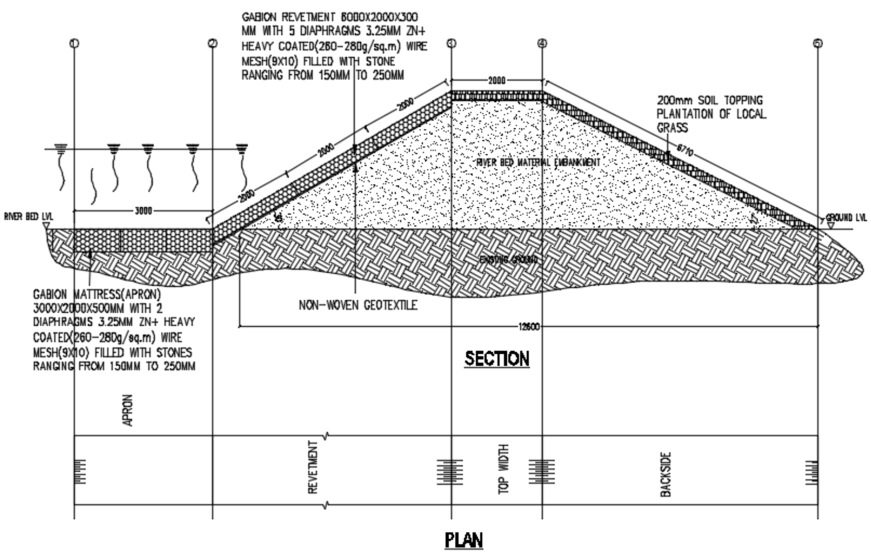


Figure 33: Typical section of gabion revetment designed for Rongchuthang River in jomotsangkha.

Long-Term measure for scour protection

The flood protection dikes along Dungsum Chu (River) in Samdrupjongkhar Dzongkhag have been designed by the engineers from Flood Engineering and Management Division and the

Municipality of Samdrupjongkhar. The river dikes stand high enough of about 5 m above the ground with a free board of about 1-1.5 m above the maximum flood level to the dike crest. It was reported that there was no dike overtopping in the past decades, but the toe and the base of the dike and the river banks are facing serious scouring problem at some locations. The causes of scouring are due to:

1. High flood flow velocity (which is likely to increase as a direct impact of climate change).
2. Lack of sufficient protection of loose river bank materials at the banks and base of the dikes.
3. Improper alignment of the dikes with respect to the flow.

Therefore, it is intended to provide methods and guidelines to protect the dikes and river banks at the toe and its base as follows:

1) The apron as shown in Figure 34 should be provided at the base of the toe wall (width of the launching apron= 1.5* maximum scour depth) to prevent scouring of the base under the toe wall. The bed scour should be measured at site by the designing engineer. Further, it is recommended that the base of the toe wall should be deeper for more efficiency.

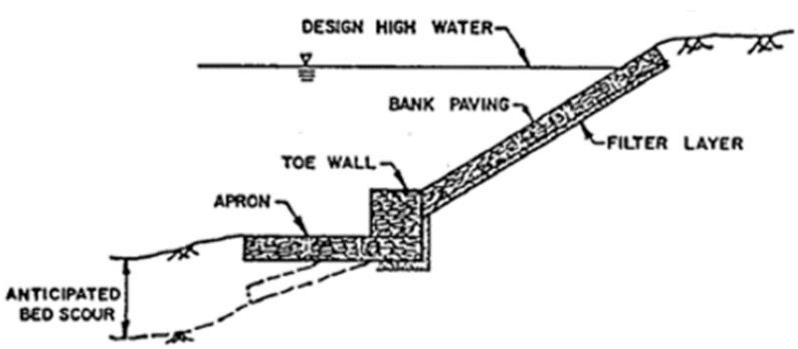


Figure 34: Requirement of apron for scour protection.

2) The toe mattress may be designed considering the maximum water level to protect the toe wall from failure due to scouring. It may be provided above the toe wall as depicted in **Error! Reference source not found.**.

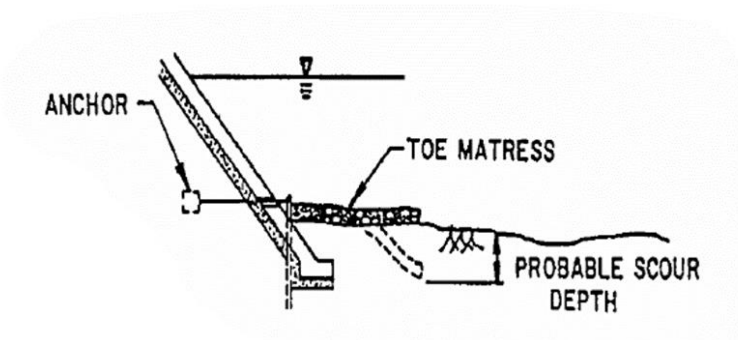
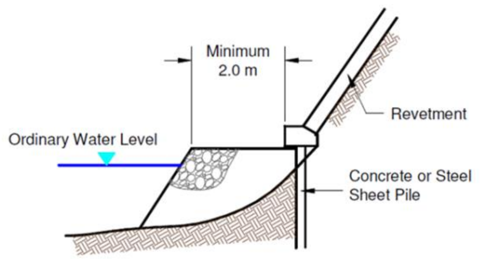


Figure 35: Requirement of toe mattress for toe protection.

3) Appropriate counter-measures such as concrete piles or sheet piles may be provided as given in Figure 36 and Figure 37 to protect the foundation of the revetments and walls during high velocity flow when it is subjected to direct water attack resulting in scouring of the deepest river bed. In addition, the foot protection works should also be placed in front of the revetment foundation to prevent scouring at the base of a loose soil.



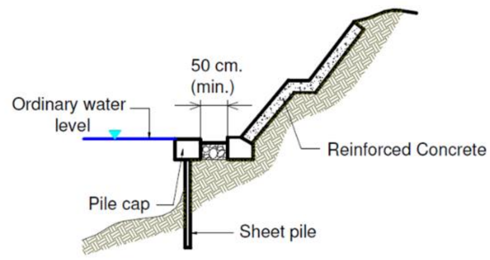


Figure 36: Concrete or steel sheet pile for scour protection.

Figure 37: Alternative sheet piling for scour protection

Short-Term/Interim measure for scour protection

The Municipality at present has constructed a lot of flood protection structures along Dungsumchu (River) to reduce the vulnerability of the people and infrastructure to flooding. Presently, the foundation of flood protection structures has weakened over years due to flash floods in the rainy season. However, they are still protecting the settlements along the banks of Dungsumchu. Therefore, there is a need to reinforce existing flood protection walls by providing interim measure on the base of the existing structures as follows;

1) **Error! Reference source not found.** and **Error! Reference source not found.** show an interim measure to re-strengthen the existing revetment, reinforced cement concrete (RCC) wall and Random Rubble Masonry (RRM) wall for flood protection. The diagram shows that three elements (first gabion panel, second gabion panel and apron) will be constructed in front of the existing walls. The function of the first panel gabion box (height X) provided in front of the toe wall is to prevent the revetment/RCC wall/RRM wall from sliding and it will also provide better stability. Further, the second panel placed below the first panel will make foundation stronger and it will also protect against erosion. The apron provided will be launched in due course of time due to scouring. However, the launching apron will cover the face of the scour and it will protect further scouring, thus retaining the strength of the base of structures.

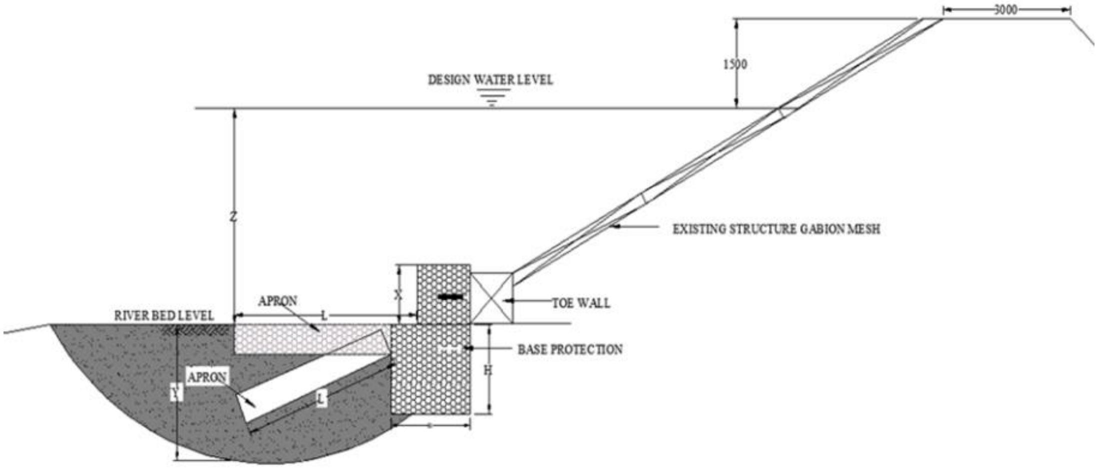


Figure 38: Apron for existing revetment.

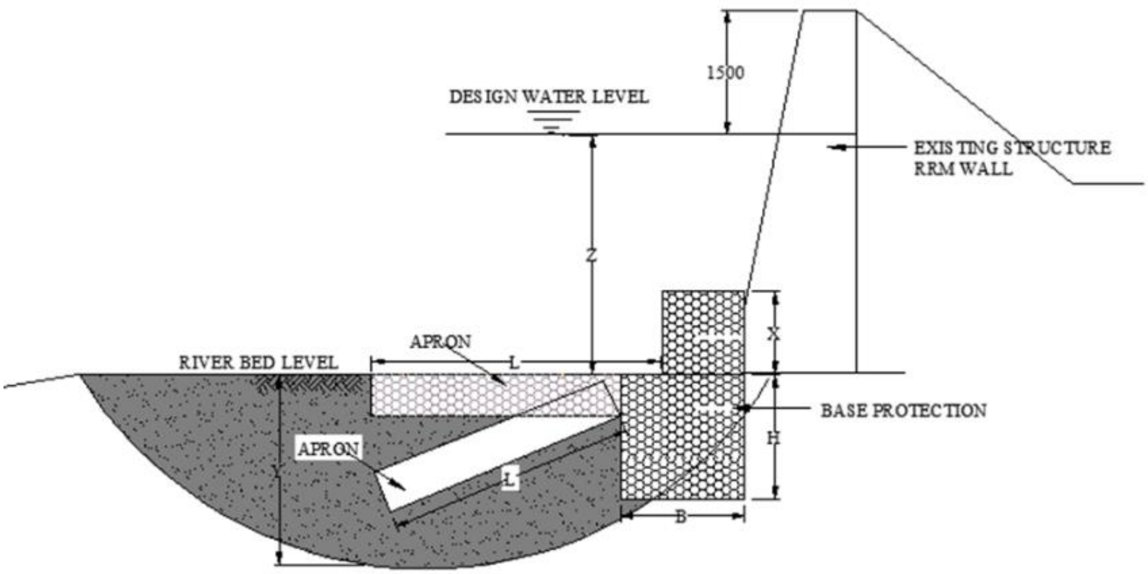


Figure 39: Apron for existing RRM/RCC wall.

Recommendation for flood management

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

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

- ✓ To improve the quality of flood hazard map, it is recommended that modeling (hydrologic and hydraulic) should be done using any relevant software.

- ✓ To produce more accurate Flood Hazard Map, it is recommended to use a high-resolution DEM for modeling purpose with updated land cover data and soil data for the region.
- ✓ Flood hazard maps are dynamic in nature and should be updated on a regular basis.

- ✓ The vulnerability map can also be improved by updating the actual landuse condition and also getting information on the population density region-wise.

- ✓ In future, the variables are to be fixed based on the local conditions and then only, vulnerability assessment should be done.

- ✓ The classes, scores and ranking for the variables in the vulnerability assessment should be fixed based on the proper past studies.

- ✓ The weightage for the flood hazard map, flood vulnerability map and flood risk map should be based on past studies and it should be also updated regularly.

Limitations of the study

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

- ✓ The Digital Elevation Model used in this study is 4 meter resolution provided by Samdrupjongkhar Thromde.
- ✓ There is no rainfall and discharge data for Dungsumchu resulting in using variables such as river buffer and elevation only for preparation of flood hazard map.
- ✓ The equation used in raster calculator for preparation of Flood Hazard Map is (***River Buffer *25+Elevation *75***) after discussion amongst the engineers in the Division.
- ✓ Due to lack of data on population density, assets etc. region wise, the Municipality is divided into two regions (Developed and Undeveloped) for vulnerability assessment.
- ✓ The questions for the vulnerability assessment survey were prepared before fixing the variables, thereby rendering some questions useless after the survey.
- ✓ The classes, score and ranking for the variables in this study were finalized based on previous studies and also after discussion amongst the engineers.
- ✓ The equation used in raster calculator for preparation of Flood Vulnerability Map is (***8.33 *Residential_social+8.33*Residential_physical+8.33*Residential_Economy+….)*** after discussion amongst the engineers in the Division.
- ✓ The equation used in raster calculator for preparation of Flood Risk Map is ***(Flood Hazard Map *50+Flood Vulnerability Map *50***) after discussion amongst the engineers in the Division.
- ✓ The proposed interventions can be recommended according to the actual site conditions, availability of the materials, equipment and fund.

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