FLOOD HAZARD ASSESSMENT FOR TSIRANG DZONGKHAG

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

YEAR 2019

Reviewed By: Kedhar Kumar Adhikari, GIS Officer, FEMD, DES, MoWHS

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Acknowledgement

Flood Engineering and Management Division under Department of Engineering Services, Ministry of Works and Human Settlement have taken immense initiative and efforts in carrying out preliminary flood hazard assessment for Tsirang Dzongkhag and preparation of the Preliminary Flood Hazard Map for Burichhu in Tsirang 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. Department of Hydro-met Services, Ministry of Economic Affairs, Bhutan
2. National Statistical Bureau, Bhutan
3. Dzongkhag Administration, Tsirang 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 Tsirang Dzongkhag.

Acronyms

FEMD	Flood Engineering and Management Division.
Bhurichhu	River flowing through Patalay village,Sergithang Gewog
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.
FHM	Flood Hazard Map.
FHA	Flood Hazard Assessment.
DHSM	Department of Hydro-Met Services.
MoWHS	Ministry of Works and Human Settlement.
DHS	Department of Human Settlement.
NSB	National Statistical Bureau.

Executive Summary

Tsirang Dzongkhag is located in the southern part of Bhutan and shares the border with Dagana in the west, Sarpang in the south and Trongsa and Wangduephodrang in the north. Tsirang Dzongkhag, encompassing a total area of 638.8 Sq. Km has twelve Gewogs, namely Barshong, Patshaling, Dunglagang, Gosaling, kikorthang, Mendrelgang, Sergithang, Phuentenchu, Rangthangling, Semjong, Tsholingkhar and Tsirangtoe. All twelve (12) Gewogs are connected with farm roads.

The main objectives of the studies are listed below.

- Detailed flood assessment of Burichu river in Tsirang Dzongkhag.
- Analyze the AoMI (Areas of Mitigation Interest) assessment in Tsirang Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Tsirang 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.

Burichu 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 1D**.

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 Bhurichu 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.

Tsirang Dzongkhag is located in the southern part of Bhutan and shares the border with Dagana in the west, Sarpang in the south and Trongsa and Wangduephodrang in the north. Tsirang Dzongkhag, encompassing a total area of 638.8 Sq. Km has twelve Gewogs, namely Barshong, Patshaling, Dunglagang, Gosaling, kikorthang, Mendrelgang, Sergithang, Phuentenchu, Rangthangling, Semjong, Tsholingkhar and Tsirangtoe. All twelve (12) Gewogs are connected with farm roads.

As per the PHCB 2005, Tsirang has 3,651 households and a total population of 18,667 out of which, 17,001 live in the rural areas. The estimated population for the Tsirang Dzongkhagas of 22 December, 2016, based on PHCB 2005. People are mostly depended on agriculture and livestock. Paddy, maize and millet are the major cereal crops grown while orange, cardamom and vegetables are the principal cash crops. Vegetable and cardamom are an important source of cash income for most of the farmers. Livestock rearing is also an important economic activity with poultry, piggery and fisheries contributing to income generation. The climate in Tsirang Dzongkhag is warm and temperate with elevations ranging from 400-2000 meters above the mean sea level. The Dzongkhag experiences warm summers and cool, dry winters. The summers here have a good deal of rainfall, while the winters have very little rain. The average temperature of Tsirang Dzongkhag is about 22.4° C with a minimum of 18.6°C and maximum of 26.2°C.

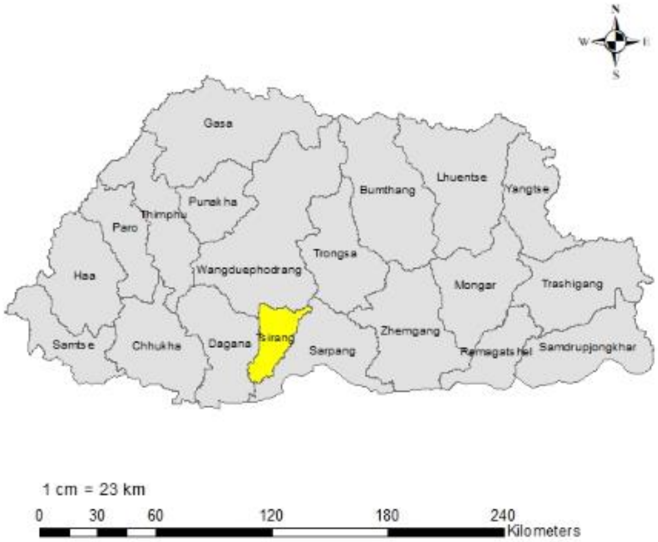


Figure 1: Bhutan map showing the study area.

Objective

Objective 1: Detailed flood assessment of Burichu River in Tsirang Dzongkhag.

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

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

Study Area

Barshong Gewog is located in western part of Tsirang Dzongkhag with an area of 21.2 sq. km with altitude ranging from 700 to 1500 meters above the mean sea level. Barshong Gewog consists of 5 chiwogs (Barshong Toed, Barshong Maed, Gangtokha, Chunnykhang and Toisang) and 330 households. The Gewog has a total of 575.24 acres of dry land, 254.6 acres of wet land, 57.25 acres of orchards and 9.8 acres of cardamom. The favorable diverse agro-ecological features provide the Gewog with a high potential for the cultivation of many different types of cereal grains as well as horticulture crops. Livestock rearing is also an important activity contributing to required food nutrition as well as cash income from the sale of surplus dairy products.

Doonglagang Gewog is one of the least developed Gewogs in Tsirang Dzongkhag with an area of 45.9 sq. km with altitude ranging from 900 to 1500 meters above the mean sea level. The Gewog has one community school and it has one Basic Health Unit (BHU) and one outreach clinic (ORC). The Gewog has agriculture, forestry and one livestock extension centre which provide the RNR extension services in the Gewog. The people of the Gewog mainly grow maize, wheat and rice. The Gewog has 365 households, with total population of 3180.

Gosarling Gewog has altitude ranging from 700 to 1300 meters above the mean sea level. Gosarling Gewog consists of 5 chiwogs and 267 households. The people of the Gewog mainly grow maize, wheat and rice.

Kikhorthang Gewog is the most developed Gewogs in Tsirang Dzongkhag with an area of 17.80 sq. km with altitude ranging from 900 to 1600 meters above the mean sea level. Kikhorthang Gewog consists of 5 chiwogs (Dekiling, Satshangma, Nyzergang, Tashiyangong and Menchuna) and 479 households. The people of the Gewog mainly grow maize, wheat and rice.

Mendrelgang Gewog is located in south east part of the Tsirang Dzongkhag with an area of 15.50 sq. km with altitude ranging from 700 to 1400 meters above the mean sea level. Mendrelgang Gewog consists of 5 chiwogs and 376 households. The Gewog has two (one primary and one middle secondary) schools, Gewog office, RNR Centre, BHU, ORC, 2 Non-Formal Education Centre and a Lhakhang established at different places. The people of the Gewog mainly grow maize, wheat and rice.

Patshaling Gewog is located in western part of the Tsirang Dzongkhag with an area of 170.9 sq. km with altitude ranging from 600 to 1900 meters above the mean sea level. Patshaling Gewog consists of 5 chiwogs and 277 households. The people of the Gewog mainly grow maize, wheat and rice.

Phuentenchu Gewog is located in north-east part of the Tsirang Dzongkhag with an area of 132.32 sq. km with altitude ranging from 700 to 1300 meters above the mean sea level. Phuentenchu Gewog consists of 5 chiwogs and 313 households. The people of the Gewog mainly grow maize, wheat and rice.

Rangthangling Gewog is located in south-west part of the Tsirang Dzongkhag with an area of 24.5 sq. km with altitude ranging from 00 to 1600 meters above the mean sea level. Rangthangling Gewog consists of 5 chiwogs and 423 households. The people of the Gewog mainly grow maize, wheat and rice.

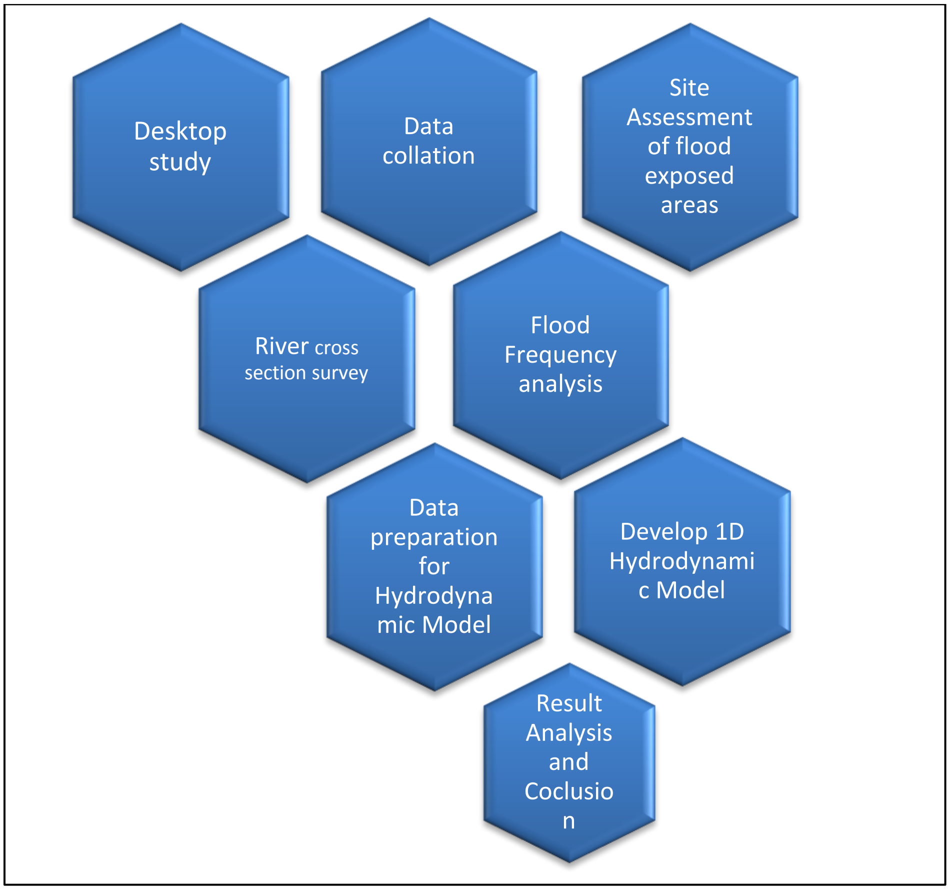
Semjong Gewog has an area of 14.5 sq. km with altitude ranging from 900 to 1600 meters above the mean sea level. Semjong Gewog consists of 5 chiwogs (Tashiling Teod, Tashiling mead, Dzomling, Drangreygang and dekidling). The people of the Gewog mainly grow maize, wheat and rice.

Sergithang Gewog has an area of 45.93 sq. km with altitude ranging from 900 to 1600 meters above the mean sea level. Sergithang Gewog consists of 5 chiwogs (Tashithang, Sergithang toed,Sergithang maed, Norboogang and Samdendzong). The people of the Gewog mainly grow maize, wheat and rice.

Tsholingkhar Gewog is connected by Wangdue-Tsirang highway. Tsholingkhar Gewog consists of 5 chiwogs and 353 households. The people of the Gewog mainly grow maize, wheat and rice.

Tsirangtoed Gewog has an area of 30.3 sq. km with altitude ranging from 800 to 1300 meters above the mean sea level. Tsirangtoed Gewog consists of 5 chiwogs (Tsirangtoed, Soentabsa, Kabelshing, Wongphu and Tongshina). The people of the Gewog mainly grow maize, wheat and rice.

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 **Error! Reference ource not found.**.

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

Meteorological Data

There is only one meteorological station available in the Dzongkhag. 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 1.

Table 1: Meteorological station in the Dzongkhag.

Sl. No	Met station name	Temporal data available
1	Damphu	1996/01/01 to 31-10-17

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	30 m 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 0.03km resolution Digital Elevation Model (SRTM30) has been used to create a basin model. SRTM 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

Site investigation is required to gather the information on the ground reality (e.g. settlements along the rivers, existing flood protection structures, river hydraulics, hazards it pose on the community etc.). The whole site is walked thoroughly to see any particular points of interest while carrying out the preliminary flood hazard assessment studies.

- Burichhu, Sergithang Gewog.
- Larichu, Sergathang Gewog.
- Ratay khola& Changchay Khola, Semgong Gewog.
- Rati khola, Rangthangling Gewog.
- Gangtray khola, Kikhorthang Gewog

Kikhorthang Gewog

Trashiyangjong village is under Kikhorthang Gewog and it is located at 27°01'17.9" northing and 90°09'22.8" easting having elevation 1016 m. Before five (5) years some portion has been taken away by landslide at edge of wet land. Around three (3) household and approximately fifteen (15) people are residing in Trashiyangjong village. The main threats was agricultural land.The areas were stabilized and trees were grown up. There has no risk to settlement more less no attention requires in this vicinity

Table 2: Location of river and affected under Kikhorthang Gewog

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Trashiyangjong	Kikhorthang	27°01'17.9"	90°09'22.8"	1016	Left bank
2	Gangtray Khola	Kikhorthang	27°01'11.8"	90°09'05"	1044	

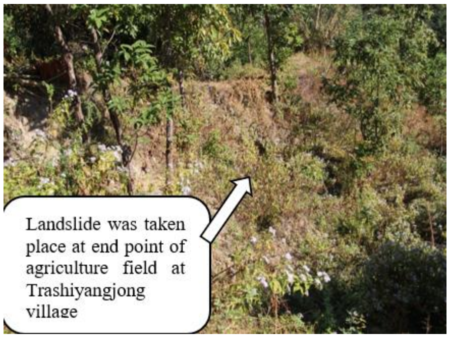


Figure 3: Landslide area below the Trashiyangjong village

Figure 4: Small stream at Trashiyangjong village

Rangthangling Gewog

Rati khola flows between Mendrelgang Gewog and Rangthangling Gewog and it is located at 26°57'29.2"northing and 90°07'10.3"easting having elevation 970 m. This river seems to erode base of the right bank and caused landslide. It is fresh landslide but not able to bring it control. In future it may pull down settlement because water comes out middle of landslide and landslide will continue. Over their around two (2) household and approximately ten (10) people are residing in that village. The main threats were orange orchard and need to take some attention.

Table 3: Location of river and affected areas under Rangthangling Goweg

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Rati Khola	Rangthangling	26°57'29.2"	90°07'10.3"	970	Right bank

Figure 5: landslide area in Lower chanowtry village .

Semjong Gewog

Ratay Khola was flowing middle of samjong Gewog and it is located at 27°02'06.8"northing and 90°09'02"easting having elevation 911 m. This river seems to erode base of the right bank and eroded below the wet land. It is fresh scar were seen but does not require immediate action. It need to look some mitigation in future. Over their around 30 households and approximately 100 people are residing in that village. The main threats were orange agriculture land but found vegetation were intake.

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Ratay Khola	Semjong	27°02'06.8"	90°09'02"	911	Left bank

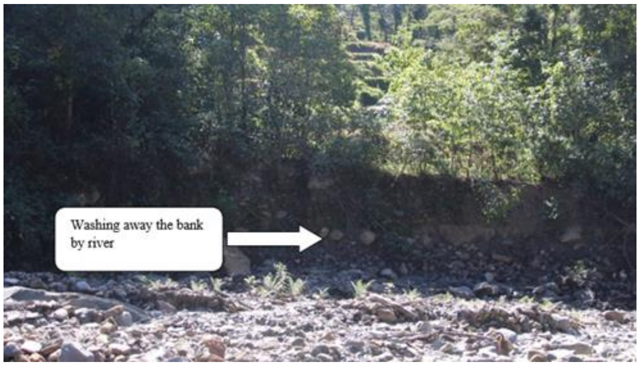


Figure 6: Erosion caused by Ratay khola


Figure 7: Threat by changchey khola on left bank

Sergithang Gewog

Burichhu and Larichhu were two river flowing middle of Sergithang Gewog and Burichhu is located at 27°05'08.9"northing and 90°07'43.2"easting having elevation 536 m. In similarly Larichhu is flowing middle of Patalay village which pose few areas of agriculture land. The team found it does not pose much critical threats to the settlement as well as agriculture lands. It is located at 27°05'52.9" northing and 90°07'42" easting having 652 m.

Besides Larichhu, the most critical river was Burichhu which had washed away few acres of wet land of lower patalay. This river had eroded at left bank where the wet land agriculture land exists. The fresh scar was seen and required imitate action to be taken in order to protect their lands by constructing gabion wall around 350 m. At particular area we observed 2 houses and wet land getting risk of flooding flood.

Entire Tsirang Dzongkhag team found this area was the most threats to flooding and team decided to carry out cross section survey for preparing flood hazard map. As per field investigation this area lies on flood plain and every year few stretches of agriculture were taken away by the river (Bhurichu). Therefore, the team concentrates that site and started picking up data as far as possible to develop the flood hazard map.

Sl. #	Name of the Villages/Rivers	Gewog	Coordinates		Elevations in m	Remarks
			Northing	Easting		
1	Larichu	Sergithang	27°05'52.9"	90°07'42"	652	Left bank

2	Larichu	Sergithang	27°05'43.9"	90°07'40"	641	Left bank
3	Larichu	Sergithang	27°05'19.7"	90°07'40.3"	553	Left bank
4	Burichhu	Sergithang	27°05'08.9"	90°07'43.2"	536	Left bank
5	Burichhu	Sergithang	27°05'14.6"	90°07'52.6"	559	Left bank
6	Burichhu	Sergithang	27°05'11.5"	90°08'09.4"	615	Left bank

Figure 8: Threat by larichhu and Burichu river in Sergithang Gewog.

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. 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.

HEC-RAS 1D Model setup

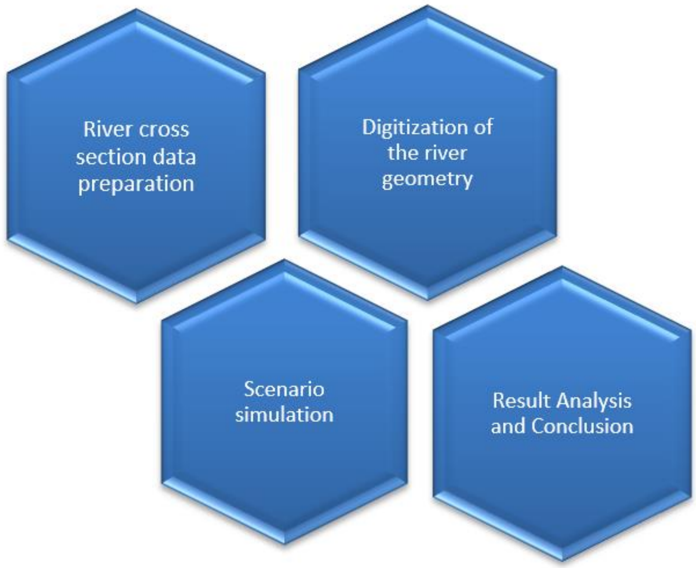


Figure 9: Methodology adopted for the developing the 1D Hydrodynamic Model

1. River cross section data preparation

Taking cross-section survey along the river study area is important for flood modeling and river analysis. Modeling of river helps to find out velocity, river profile etc. Cross-sections are required to represent channel geometry in a river hydraulic model. The accuracy of the simulated water levels and the floodplain delineation largely depends on the shape as well as extent of these cross-sections. For the assessment, the cross-section data was derived from DEM and also surveying using total station. The cross-section survey of Bhuri chu was carried out by FEMD, DES, MoWHS in December, 2016. About 25 numbers of cross-section data along Bhuri chu were collected.

2. Digitize the River geometry

First digitize river centreline (upstream to downstream), left bank and then right bank, after that the left flow path and the cross sections. The cross section line can be digitized in the same line as the survey point. The digitization can be done directly in HECRAS since Google earth can be loaded in HECRAS.

3. Hydro-Met Data

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

Burichu in Tsirang Dzongkhag is un gauged and hence there is no historical discharge data for the river at present. The only available data at Dumphu is the daily rainfall data collected at Dumphu Meteorological Station(DMS). As a result, preliminary flood hazard assessments based on damage reports and field observations are used to define the flood-prone areas along Bhuricu. Further, to validate the flood prone areas, rainfall-runoff model like HEC-HMS will be used to find the discharge for Bhurichu. We could collect at least (sixteen)16 years of rainfall from DMS from 1996 t0 20011.

Table 4: Maximum rainfall event from 1996-2011 in Damphu Metrology Station

Year	Maximum Daily Rainfall(mm)	Maximum 3-day Rainfall (mm)
1996	169.8	238.8
1997	73.00	142.2
1998	158.0	265.2
1999	127.2	202.8
2000	137.3	242.6
2001	68.00	95.40
2002	67.30	77.70
2003	106.0	189.8
2004	113.3	147.1
2005	145.5	220.9
2006	57.20	113.8
2007	149.8	241.8
2008	63.90	81.40
2009	190.4	289.6
2010	191.8	298.8
2011	140.6	290.0
Highest Rainfall	**169.8**	**298.8**

4. DEM (Digital Elevation Model)

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

5. Land cover Data

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

3. Rainfall Data (Average annual Rainfall)

While collecting rainfall data, it doesn’t have rainfall station with Bhurichu catchment area therefore, we took annual average rainfall from Damphu station then interpolated and calculated the amount of annual rain fall at study area by the method of isohyet. While calculating the annual rainfall we have found out maximum annual average rainfall is 2611.86mm and likewise minimum average rainfall is 2204.88 mm. As our above calculation based we model Bhurichu by using rational method.

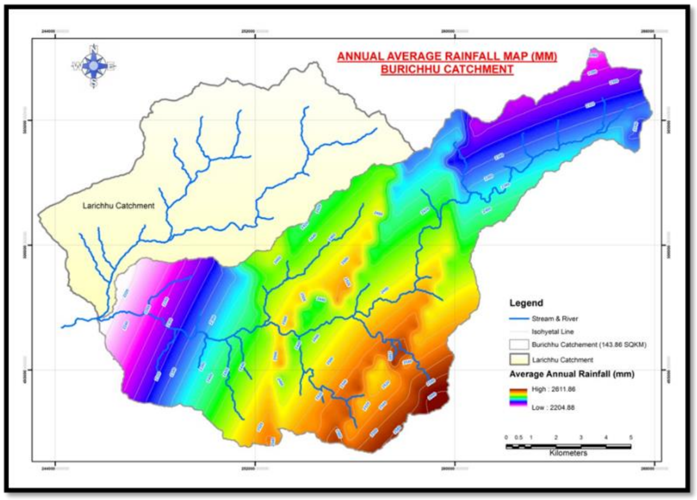


Figure 10: Annual average rain fall map for Bhurichu Catchment.

4. Rational Method

Calculating runoff is very difficult since it depends on many factors such as ground permeability, rainfall duration, rainfall pattern, catchment area characteristics etc. However, rational method has been used to find out the maximum discharge to be used for different purposes.

The rational method is the simplest technique for estimating a design discharge from a small watershed. This method is suitable for small catchment only because the time of concentration of small catchment is small. The peak discharge is calculated in this method based on the assumptions that time of concentration is equal to the rainfall duration and rainfall intensity over the entire catchment remains constant during the entire storm duration. It was developed by Kuichling (1889) for small drainage basins in urban areas. The rational method only provides the peak discharge and it cannot produce a hydrograph. The accuracy of rational method also depends on the correct selection of runoff coefficient and delineation of catchment area.

Rational Equation: Q_p= 1/3.6. K.*I*.A

Where, Q: peak discharge in m^3/sec, K: runoff coefficient, *I*: mean rainfall intensity (mm/hr) within tp, tp: time of flow concentration (min), A: drainage area (km^2)

Here,

t_p : time of flow concentration (min)

$t_p = t_1 + t_2$

t_1 : traveling time to channel (min), t_2: flow traveling time along longest channel (min)

$t_1 = 30(A/2)^{1/2}$ …… (MLIT, Yamanashi, 2005)

$t_2 = 0.06\ L/\ (72\ (H/L)^{0.6})$ …….(Rziha formula) for channel slope >1/20

$t_2 = L/W/60$ ……..(Kraven formula) for channel slope ≤ 1/20

for W, W=3.5 (H/L ≥ 1/100), W=3.0 (1/100 >H/L>1/200), W=2.1 (1/200 ≥H/L)

where, L: Longest channel (m), H: difference of altitude between channel top and outlet (m), W: flow speed (m/sec)

here,

I: mean rainfall intensity (mm/h) within t_p

I : $R_{24}\ (5.3134/t_p^{2/3})$………..(Monobe formula)

I: $347.10\ .\ R_{24}/(t_p^{1.35+1502})$ …………(Iizuka formula)

Where, R_{24} :24 hours' rainfall (mm/day), t_p: time of flow concentration (min)

5. Result and conclusion

HEC-RAS (Hydrologic Engineering Center's River Analysis System) model, developed by the US Army Corps of Engineers, is selected in this study as a hydrodynamic model. This model is chosen for the study because it is available freely and easy to use. The model is applied to perform 1D analysis of steady flow water surface profile for preparing water surface profiles. The model performs 1D channel flow analysis and floodplain determination using discharge data, landcover data, DEM and river cross-section data.Bernoulli's energy equation is applied for the flow profile calculation in the steady flow. For unsteady non-uniform flow, 1D St. Venant equations are used, which represent the principle of conservation of mass and principle of conservation of momentum.

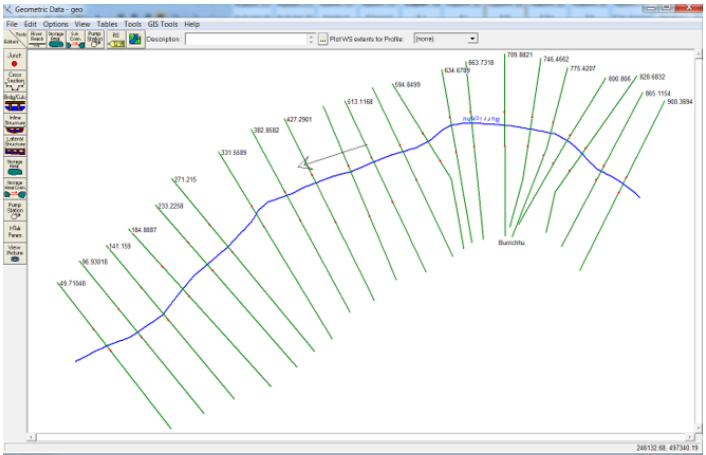


Figure 11: Geometric data used in the River Analysis of Bhurichu.

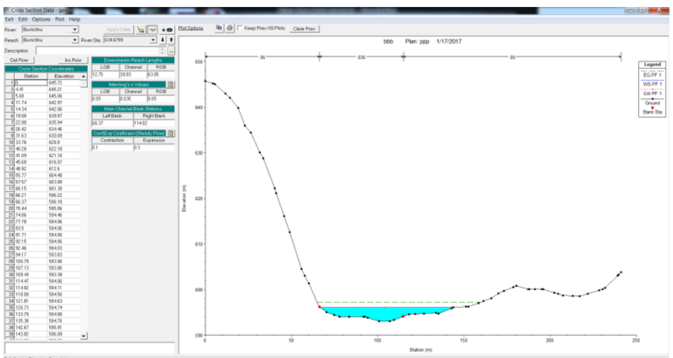


Figure 12: River cross-section showing the water level.

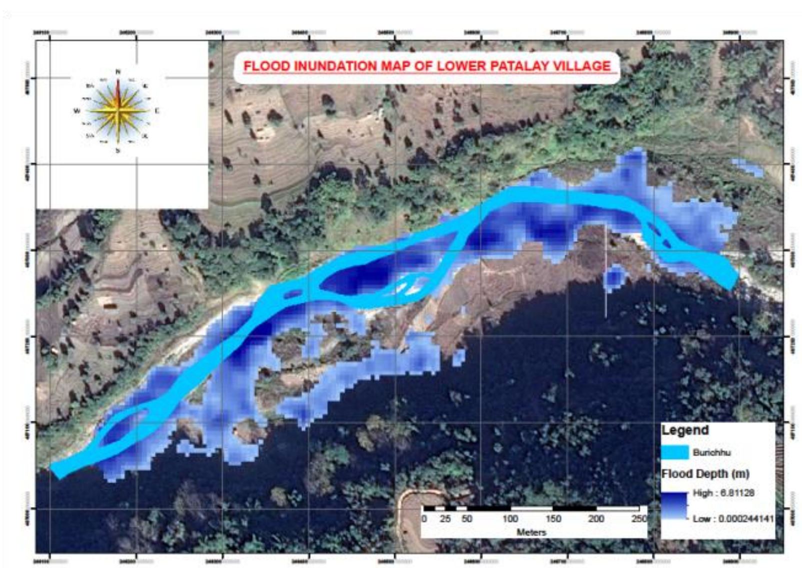


Figure 13: Flood hazard Map of Bhurichu river.

The flood maps show a clear snap shot of the flooding visualization along the river with elevation levels and areas susceptible to flooding for different scenarios. Generally, high water depth occurs along the main channel and spreads gradually to the flood plains. The preliminary flood hazard map only identifies the likely areas to be flooded due to extreme rainfall events and give a mean depth of floodwaters within each region. The maps are based on the general land characteristics and rainfall pattern over the Bhurichhu catchment.

Interventions

Design of the structures are required for effective and sustainable flood mitigation and bank protection of River to protect the lands, properties, human lives and infrastructures along the bank of the rivers. Sustainability of the flood and bank protection works in the river bed depends on sound design of the protection works. The protection will establish equilibrium flow regime and prevent the banks from eroding and overtopping. The design process is as follows:

- Interpreting the results of the mathematical model studies and field assessment studies.
- Design of river training works according to the type of flooding problem (erosion, overflow or sediment related problems).

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 inFigure 14. The stone fill should be of hard 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.

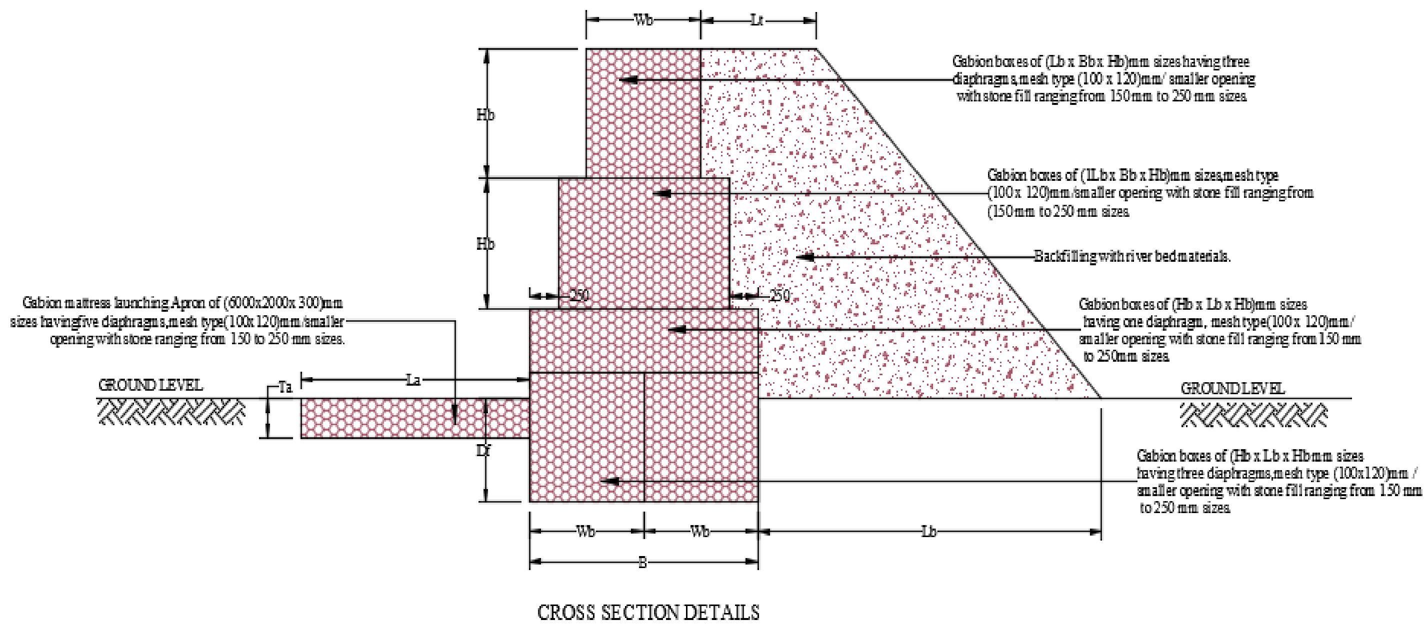


Figure 14: Typical cross-section of gabion wall

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 Figure 15 shows a gabion revetment used to reduce the impact of flood water during flooding in southern part of Bhutan

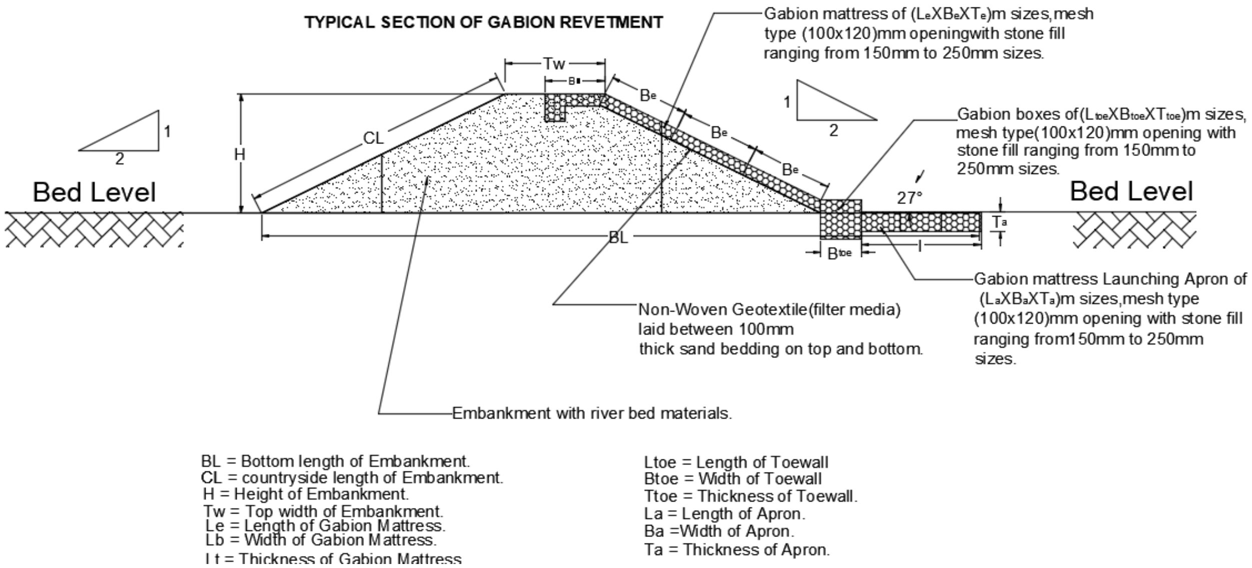


Figure 15: Typical cross-section of Gabion Revetment.

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.
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Disadvantages

1) The life expectancy of gabions depends on the lifespan of the wire, not on the contents of the basket.
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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 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 Bhurichu 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 at least at one small and one extreme flood event to improve the quality of the map.

- ✓ It is recommended that best fit method for discharge calculation be used for Bhurichu instead of directly using rational method till the discharge data acquisition is made possible by installing equipment.

- ✓ 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).

Limitations of the study

Although the preliminary flood hazard map has been prepared for Burichu, 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 is only one rainfall station in the Bhurichu catchment, Thiessen polygon method has been used to estimate the average rainfall over the catchment.
- ✓ There is no discharge data for Bhurichu resulting in the use of rainfall-runoff model such as HEC-HMS.
- ✓ During the study, the Manning's roughness is considered constant.
- ✓ One of the basic assumptions of the rational method is that the rainfall intensity must be constant for an interval at least equal to the time of concentration. For long duration of rainfall, this assumption may not hold true.
- ✓ 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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