FLOOD HAZARD ASSESSMENT FOR SAMTSE 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, Bhutan
2. National Land Commission, Ministry of Home and Cultural Affairs, Bhutan
3. Department of Geology and Mines, Ministry of Economic Affairs, Bhutan
4. National Statistical Bureau, Bhutan

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Acronyms

FEMD	Flood Engineering Management Division
Dipu,Diana and Dhamdum Khola	River flowing through Samtse Dzongkhag
HEC-RAS	The Hydrologic Engineering Centre, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modelling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defence, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995
GIS	Geographical Information System is a computer based method for analysing Geographical information and maps
FHM	Flood Hazard Map
FHA	Flood Hazard Assessment.
NCHM	National Centre for Hydrology and Meteorology
AFA	Areas for Further Assessment
MoWHS	Ministry of Works and Human Settlement
DDM	Department of Disaster Management

Executive Summary

This flood hazard assessment study focuses only for Samtse Dzongkhag and flood hazard map have been prepared for Dipu, Diana and Dhamdum River under Samtse Dzongkhag. Most of the agricultural land and few houses are located along these Rivers in the flood plains which expose them to high risk of flooding.

The main objective of the study is as follows:

- Flood hazard assessment of Samtse Dzongkhag.
- Identify and prioritize critical flood prone areas within Samtse Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

A hydrodynamic model was developed for Dipu, Diana and Dhamdum River in GIS software. Digital Elevation Model with 10 meter resolution ALOS is used for this project. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

The reliability of the maps has been affected by the inadequate spatial rainfall data for the study area. There is no hydrological discharge data for these rivers. Land cover data and soil data has not been used for modelling purpose resulting in unrealistic ground condition.

Introduction

Background

Samtse Dzongkhag is bordered by Chukha Dzongkhag in the east, Haa dzongkhag in the north and the Indian state of west Bengal and Sikkim in the south and west respectively. It has an elevation of 200-4400 m above sea-level and lies in the sub-tropical monsoon climate zone with good forest cover. The monthly temperature ranges between 15 degree Celsius in winter to 30 degree Celsius in summer and receives an annual rainfall between 1500-4000 mm. The summer is hot and humid and winter is dry and moderately cool.

About 77% of the total area is under forest cover and only 8% is under agricultural cultivation. Around 15% of the total area is under the category of others, which includes snow glaciers, eroded lands, water spreads and marshy areas.

In the foothill of Yoeseltse, Ugentse, Chengmari, Samtse, Sipsu and Tendu Gewogs, wetland cultivation is an important activity and rice is the staple diet along with mustard as the main oil crop. In the northern Gewogs such as Denchukha, Dungtoe and Dorokha, apart from paddy cultivation, the people also depend on dry land cultivation. Maize, Orange and cardamom are also grown extensively. Presently Samtse Dzongkhag has an area of approximately 1309.1 square kilometers and has two Drungkhags (Dorokha and Tashicholing) and 15 Gewogs.

The main cash crops of dzongkhag are arecanut, ginger, orange and cardamom. (Source: www.samtse.gov.bt)

Figure 1: Study Area

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

Sl. No.	Name of Village	Name of Gewog	Name of river/stream	Type of threat(Agriculture/Resident	Estimated Population	Past flooding record
1	Majuwa(Tharpaling)	Ugyentse	Chungpatang river	Slope		
2	Bhoteykharka (Nyimalung)		Sisnay & chungpatang river	Slope		
3	Thakurigoan(Lhendupling)		Kharkhola stream	Slope		
4	Ngatshang		kadoo khola river	Slope		
5	Raigoan		Gagunay stream & chungpatang river	Slope		
6	Malbasey-Noonpani	Namgay choling	Jitti Khola	Between Tirshulay and Jitti bridge		
7	Malbasey-Noonpani		Tirshulay khola	Between Tirshulay and Malbasey		
8	Malbasey-Noonpani		Gadi khola	Between kholgari and Noonpani		
9	Malbasey-Noonpani		Bagay khola	Between noonpani and kholakharka		
10	Malbasey-Noonpani		Tshang Tshangay khola	Between noonpani B and C		
11	Malbasey-Noonpani		Khari Khaini Khola	Between Tirshulay and Kholgari		
12	Rajaruk-Majuwa		Rajaruk Khola	Gairi Kharka		
13	Rajaruk-Majuwa		Jitti Khola	Majuwa Pakha		
14	Choksa-Kalikhola		Choksa Khola	Choksa Gairi		

15	Dipujhora	Norbugang	Kharkhola stream	1)Irrigation channel 2) Cultivated wet land 4 acres 3) Jorilic Area/ Kelabari(locality)		
16	Dipujhora		Dipu river	1)Wet and dry land 50 acres		
17				2)Irrigation channel damage		
18				3) Diana bridge		
19	Dipujhora		Bbararay khola	1)Farm road 2) Bhatitar-13 acre(locality)		
20	Dipujhoran A		Shibu khola	wetland 15 acres		
21	Kirney		Diana river	1)wetland 20 acres 2) Bhutan Mines		
22	Kopchey Area			1)Dry & wetland 15 acres 2) Dhappar wetland 20 acres		
23	Nangladang		Suparay khola(stream)	wetland		
24	Denchukha(Sukithang & Lasa village)	Denchukha	Somchukhola	Land, settlements & human life		
25	Gabjee A		Gabji stream/Rainfall	Denchukha school settlements		
26	Bhalukhola		Rainfall & streams	Lands & settlements		
27	Demjee		Lomji stream	Lands & settlements		
28	Baseni		stream Baseni	Lands & settlements		
29	Kaduri		Bhalukhola (stream)	Lands & settlements		
30	Bangalay		stream Bangalay	Land, settlements & human life		
31	Budeney	Samtse	Dhamdhum river	Flash flood		last monsoon (bridge damagaed)

Objective

Objective 1: Flood hazard assessment of Samtse Dzongkhag.

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

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

Study Area

Samtse Gewog: Samtse Gewog is located to the south west of the Samtse Dzongkhag. It is bordered by Phuntshopelri Gewog in the south, Dophuchen Gewog in the northeast, Tading Gewog in the east, Norbugang gewog in the west and Indian State of West Bengal in the southwest. It has approximate area of 105.48 km2. The Gewog has mostly sandy and clayey type of soils. Samtse Gewog has four critical rivers affecting settlements, Agricultural land and infrastructures. The rivers are:

1. Buduney River
2. Dhamdum River
3. Sukriti River
4. Bukey Khola

Norbugang Gewog: Norboogang (Chengmari) Gewog is located to the west of Samtse Dzongkhag. It has an approximate area of 115.09km2. It is bordered by the Namgaychholing Gewog to the Northwest, Doongtoed to the northeast and Sangngachholing and Ugyentse Gewogs to the west and Samtse and Dophuchen Gewogs to the east and West Bengal to the south. The Gewog experience subtropical type of climate. The annual rainfall ranges from 1500mm to 4000m. The rivers are:

1. Diana River
2. Dipu River
3. Chumpatang River

Yoeseltse Gewog: Yoeseltse Gewog lies on a road head and about 28 kms from the Dzongkhag Headquarters. It is one of the smallest Gewog covering about 22.95 square kilometres of area. The Gewog is bordered by Ugyentse and Norbugang Gewogs to east, Sangngachholing Gewog to the west and the Indian state of West Bengal to the south and west. The Gewog experiences mostly heavy shower with annual rainfall ranging from 1500mm to 4000 mm. summer is hot and humid; winter is dry and cold with the mean annual temperature of 19.2 degree Celsius. Gewog falls in sub-tropical monsoon zone.

Tashicholing Gewog: Tashichhoeling (Sipsu) Gewog under Tashichholing Dungkhag is where the Dungkhag Headquarters is located. It located to the west of Samtse Dzongkhag and lies towards the south of Pemaling and Namgaychholing Gewogs and the Indian state of West Bengal to the southeast and west. It has around 27.67 km2 in area. The Gewog experience hot and humid summer, pleasant winter with annual rainfall ranges from 1200mm to 3000 mm. The altitude of the Gewog ranges from 400 to 1400 meters above the sea level. The rivers are:

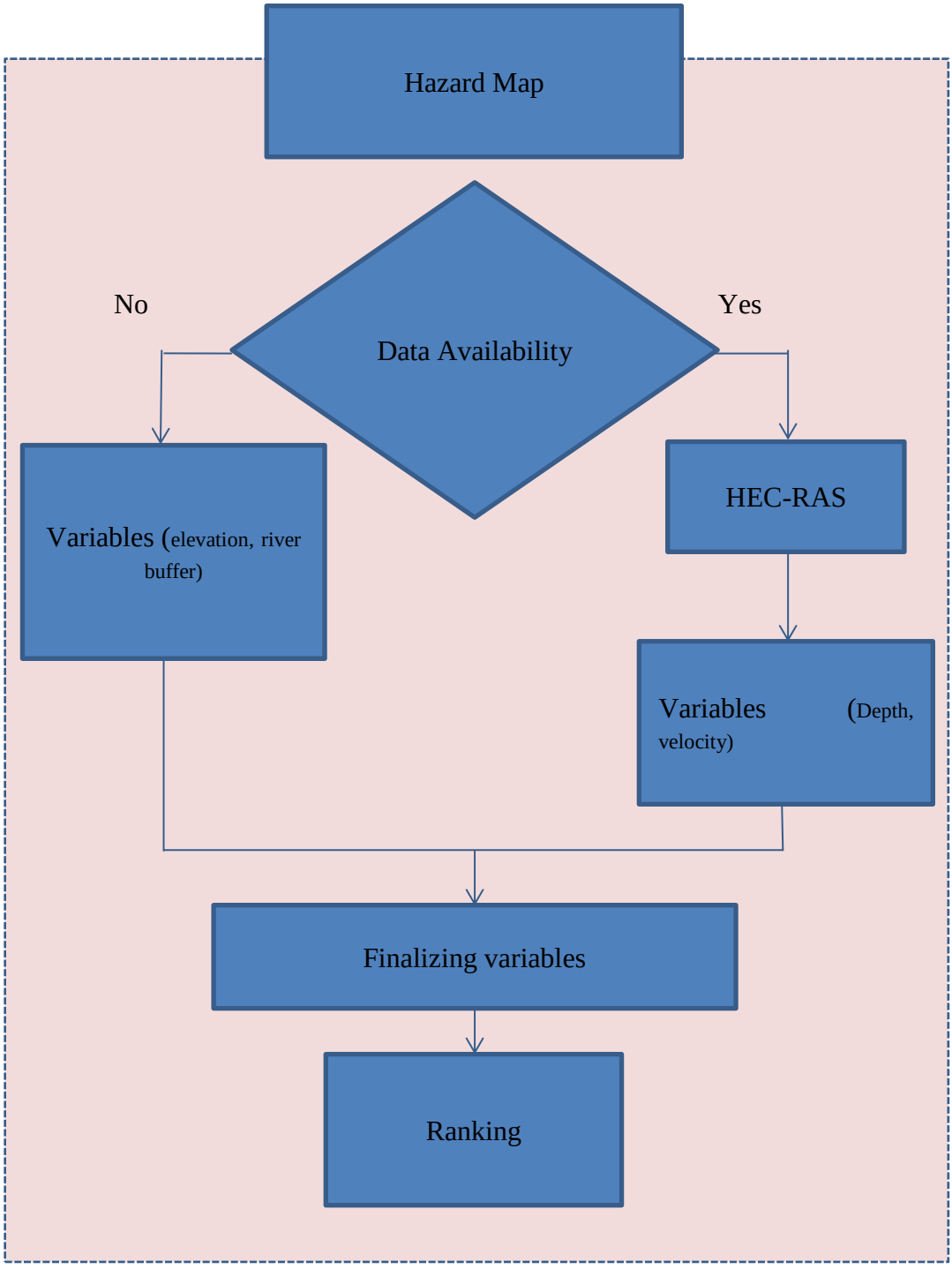
1. Sipsoo Khola
2. Jiti Khola
3. Jaldhaka Khola

Tendruk Gewog: Tendruk Gewog under Tashichholing Dungkhag is located to the north-west of the Samtse Dzongkhag and is bordered by Norgaygang Gewog in the northwest, Namgaychholing Gewog in the east, Haa Dzongkhag in the north and Indian State of West Bengal in the southwest. It has a total area of 132.52 km2. The Gewog falls in the sub-tropical zone with warm summer and cold winter with snowfall in the northern regions of the Gewog. The annual rainfall of the Gewog ranges from 1200 mm to 3000mm. The rivers are:

1. Bindu Khola
2. Tendu Khola

Phuntshopelri Gewog: Phuentshogpelri (Pagli) Gewog is located to the south-west of Samtse Dzongkhag. Gewog is bordered by Tading Gewog in the east and northeast, Samtse Gewog in the north and Indian State of West Bengal in the south and west. It covers around 116.02 square kilometers with elevations ranging from 600 – 1400 meters above sea level. The Gewog experiences annual rainfall ranging from 1500mm to 4000 mm. The northern part of the Gewog experiences cool temperate climate and the southern part of the Gewog experiences sub-tropical type of climate.

Methodology



Data Collection and Assessment

Hydrological and Meteorological Data

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

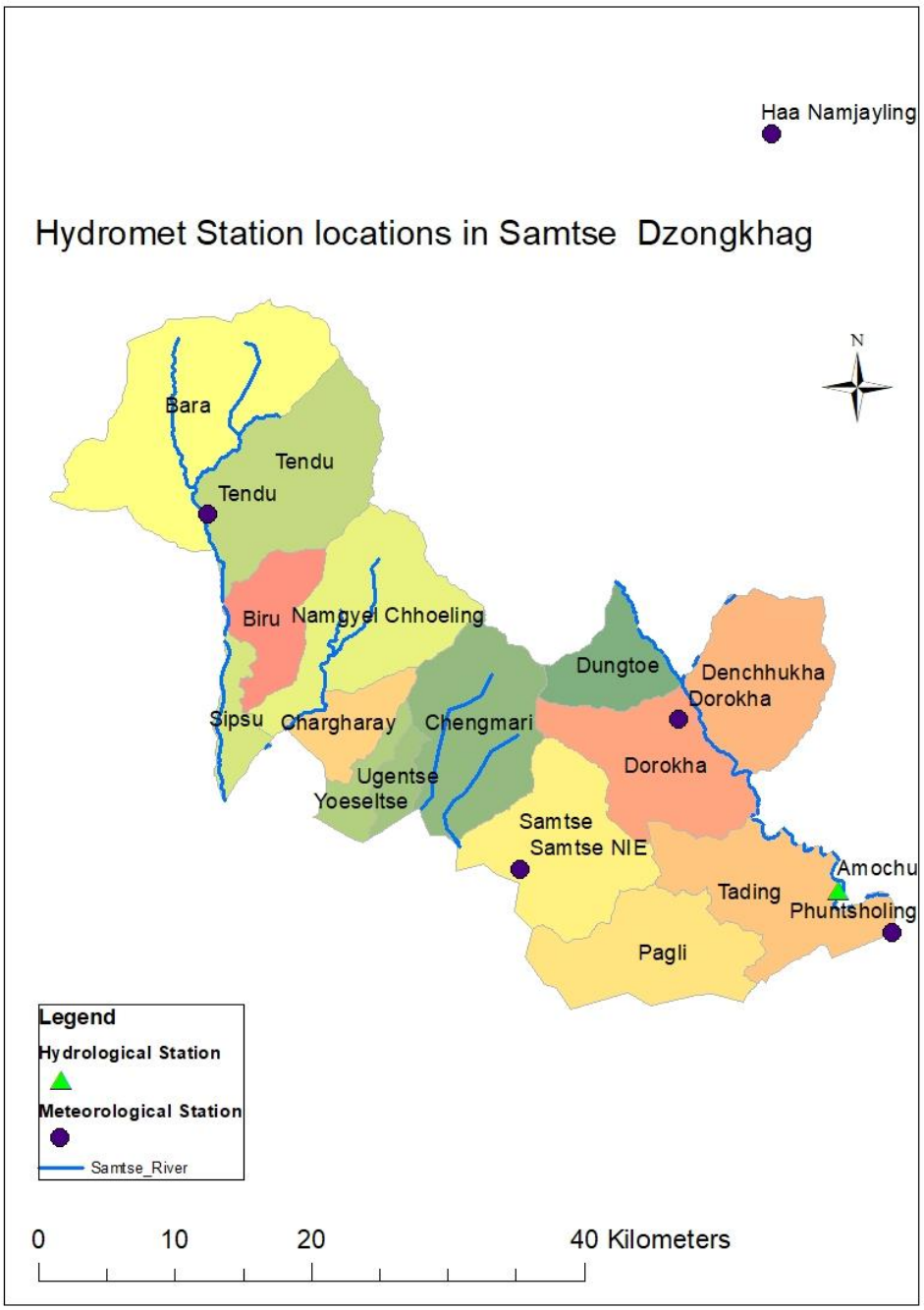


Figure 2: The location of the Hydro-met station in the study area

Meteorological Data

There are 3 meteorological stations available in the watershed study area. Only Sipsu met station has temporal daily data from 1996 to 2013.

Scientific Data

DEM (Digital Elevation Model)

Digital Elevation Model with 10 meter resolution ALOS is used for this project. The Digital Elevation Model (DEM) represents the natural topography and manmade feature such as roads, embankments and buildings.

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.

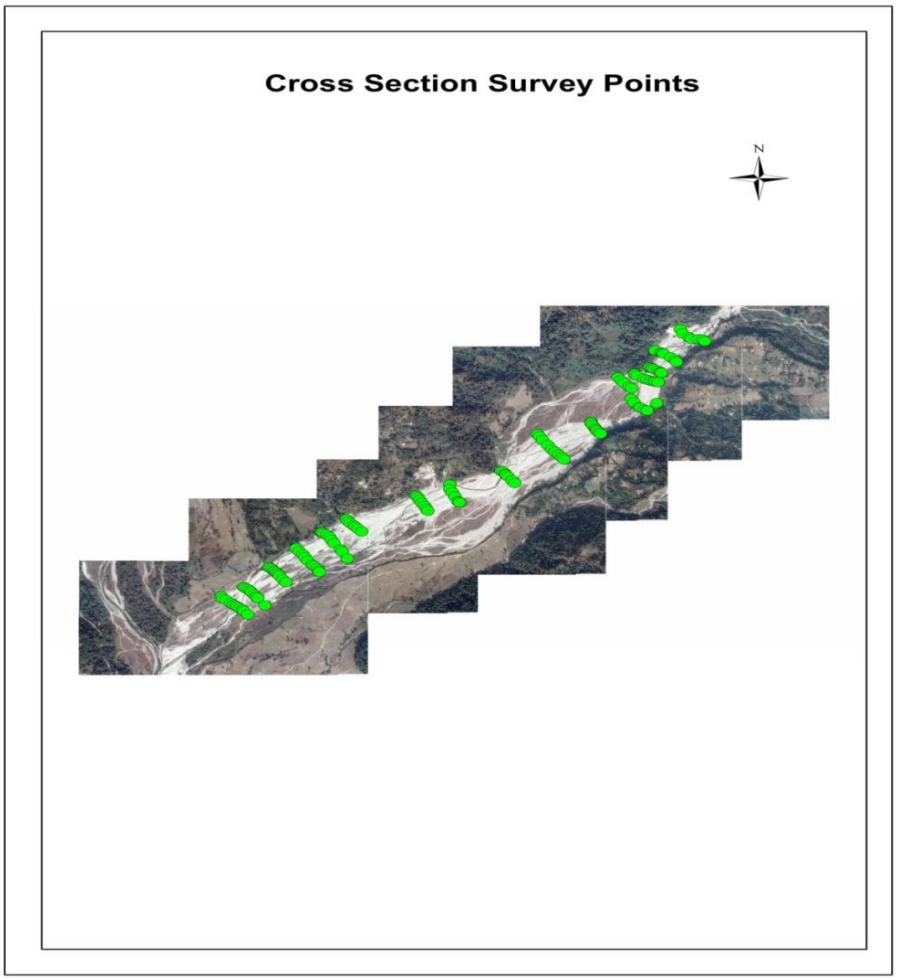


Figure 3: Cross section survey points of Dipu River

Site Assessment at Gewog Level

The field surveys have been carried out in 6 Gewogs (Samtse, Norbugang, Yoeseltse, Tashicholing, Tendu and Phuntshopelri) under Samtse Dzongkhag in order to create corner stone data for future project formulation. During the survey, the team inspected the potential flood risk sites and collected basic land Geographical data, demographic data (the number of households under the risk etc.) and past flood event records with the cooperation of local Gewog and Dzongkhag officials.

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

Samtse Gewog:

Buduney River: The FEMD team met with the Mangmis and the Tshogpas of Samtse Gewog and discussed about the threat caused by the Budeney River. All the representatives present shared their concern over the increased flooding risk caused by the diversion of the Dhamdum stream to Budeney stream. The diversion was done by the Department of Roads, Ministry of Works and Human Settlement through dredging works and construction of AB mattress which is still under construction as of date. The total cost for the dredging works and AB mattress can come up to Nu. 42 million. As per the Mangmi and the Tshogpas, the DoR had diverted the river since the Budeney Bridge was unstable. DoR hopes that the Budeney Bridge can accommodate both the discharge from Dhamdum and Budeney streams during monsoon. However, the Gewog representatives fear for the worse during the coming monsoon with the added discharge from Dhamdum stream. The Gewog representatives also claimed that the DoR did not acquire any public clearance before the diversion works took place.

Figure 4: Google image of Dhamdum and Buduney

Figure 5: Budeney Riverbed filled with heavy sediment deposits

Figure 6: Ongoing flood protection works carried out by DoR

Dhamdum River: The FEMD team met with the Mangmis and the Tshogpas of samtse Gewog and discussed about the threat caused by the Dhamdum stream. Dhamdum stream floods during monsoon season and dries up completely during dry season. The catchment of Dhamdum is very prone to landslides since the geology is composed mostly of loose Phyllite and Talc.

Figure 7: sediment deposit in the floodplain of Dhamdum River

Figure 8: AB Mattress under construction for diversion of Dhamdum river to Budeney river flowpath

Sukriti River: The FEMD met the Dzongkhag Engineer, Samtse to discuss about the flood management works under planning process for Samtse Dzongkhag. The Dzongkhag has requested for a budget of Nu. 20 million in the 12th FYP for flood protection works along Sukriti stream. The Dzongkhag administration has prioritized the left bank of Sukriti stream since there are already gabion revetments (1.5 Km length constructed with Nu. 16 million) on the right bank. Important infrastructures falling at right bank of Sukriti includes the Dzong, NIE institutions, Schools, Forest office, army colony and future 15-20 acres of sport complex. The Sukriti stream has caused inconvenience to settlements on the left bank especially the school children who study in Samtse Lower and High Schools. This new Sukriti Bridge under construction which connects to Gomtu town will hopefully reduce the problems faced during monsoon season.

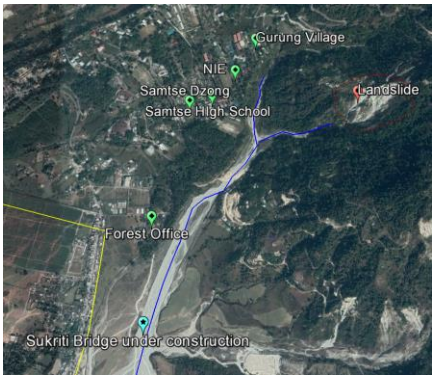


Figure 9: Location of critical infrastructures along Sukriti River

Figure 10: Sukriti Bridge abutment protection works

Figure 11: gabion revetment along right bank of Sukriti River during construction in June, 2017.

Figure 12: Agricultural lands on the left bank of Sukriti River being eroded

Bukey Khola: Bukey khola runs through 3 villages, Bukey A, Bukey B and Khalingtar respectively. There are 12 households, 2 shops, a scholl and lhakhag along the Bukey River. During 1993 flooding, 6 Acres of wet land in Khalingtar and 3 Acres of Dry land in Bukey village washed away. Every year landslide occurs washing away agricultural land.

Figure 13: Settlement along Bukey Khola

Norbugang Gewog.

Diana Khola: In the year 2000, Heavy Flash flood occurred washing away suspension bridge (Restored in 2005), Motor able bridge (Restored in 2002), Irrigation channel (Restored in 2012) and about 50 Acres of wet land. Diana Khola Bridge is longest Motor able bridge in Bhutan.

In the year 2012- 2013, 1.6 M budget is used for construction of Flood protection Structures (Gabion wall) along Diana Khola.

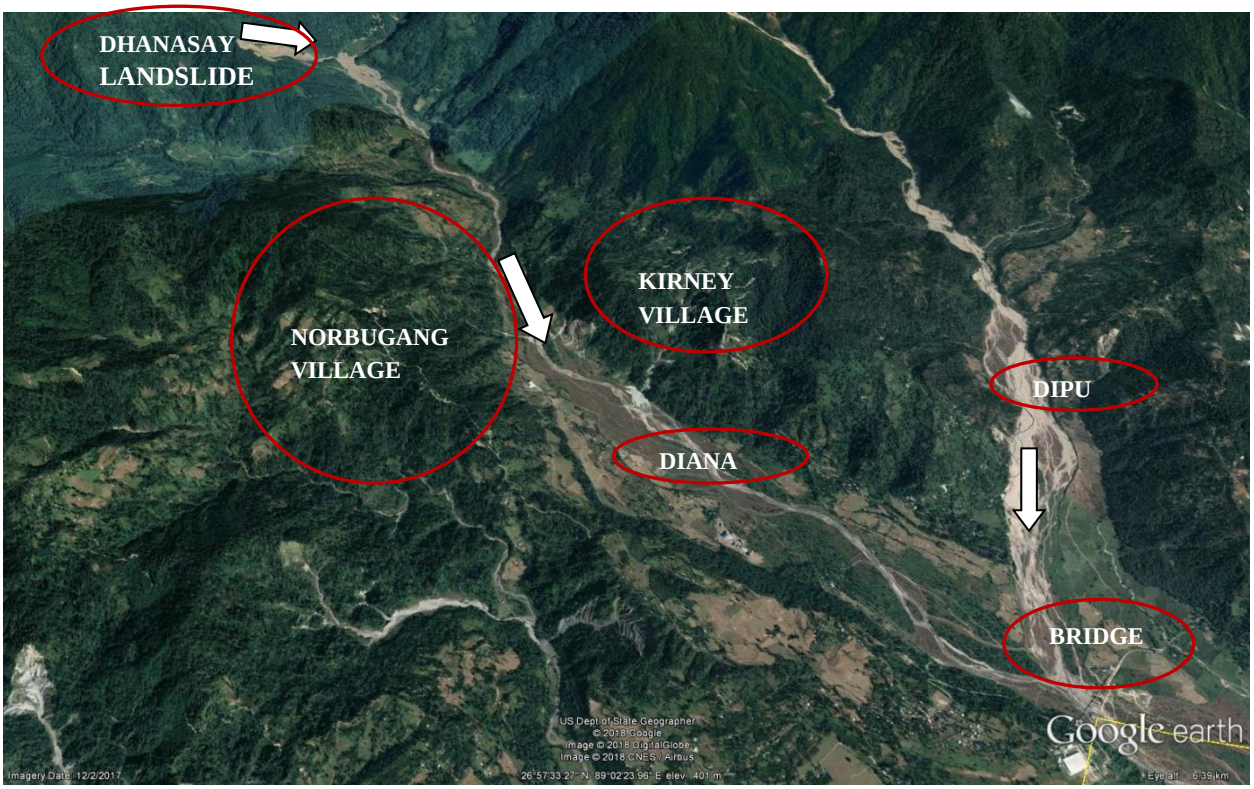


Figure 14: Google Image of Diana and Dipu khola

Dipu Khola: The bed of Dipu river is dominated by debris deposit such as boulders, clay and sand.The main source of debris is due to Noonpani slide at the source.This slide is the biggest land slide in Norbugang Gewog which existed since long time.Other source of debris is due to mining at the upstream of Kirney and Dipujhora village.

Following points were discussed by the Gewog Administration:

1) Till now 8 people have been washed away by Dipu River including 1 student in 2001.
2) Few numbers of livestock being washed away annually.
3) Till now approximately 100 acres (wet land and dry land) destroyed belonging to 40 households of Kirney village.
4) Prior to year 2000, present river bank was paddy field with small flow path.
5) Flowpath is moving towards Kirney village at right bank increasing vulnerability of land slide and loss of beetle nut trees and wet lands.
6) In 2017, 70 metres of RCC wall intervention constructed by Gewog administration is functioning well and reduced landslide at left bank.

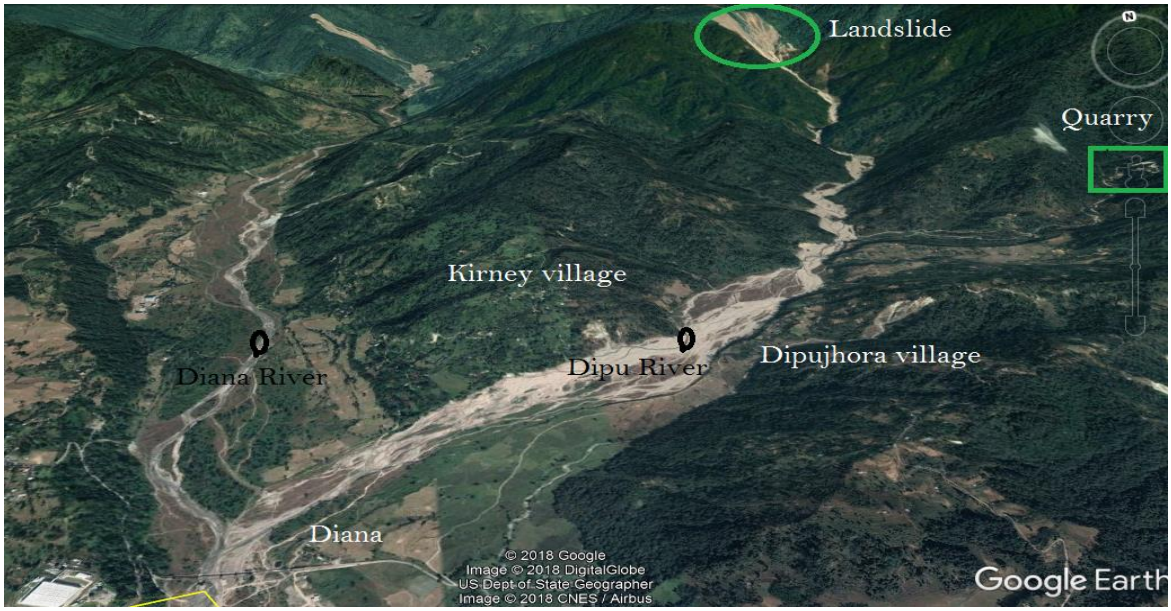


Figure 15: Google Image of Dipu Khola

Chumpatang: It is a seasonal stream with high flow during summer and little or no flow during dry season. During summer, stream swells up with lots of debris flow from hillside towards downstream. Mass slope failure occur every monsoon. In 2002 about 1.5 Acres of wet land and dry land was washed away

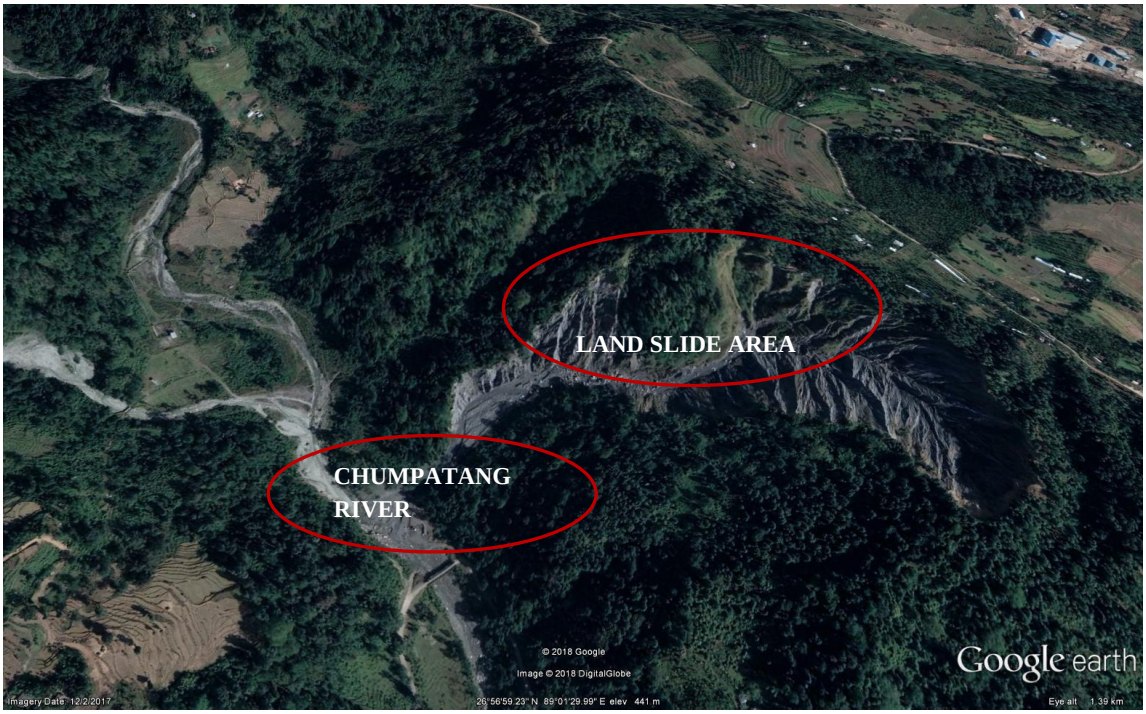


Figure 16: Google Image of Chumpatang slide Area.

Yoeseltse Gewog.

Kuchi Diana River: Irrigation channel intake structure was constructed in 2016, but it is not well protected.There is chances of breakdown of structure incase of severe flooding in future.This is also the concern for the Gewog administration too.

Figure 17: Google image of Irrigation channel in Kuchi Diana River.

Figure 18: Irrigation channel in Kuchi Diana River.

Tashicholing Gewog.

Sipsoo Khola: During 2005 flooding, there is creation of artificial pond on upstream washing away approximately 9 acres of wet land. There is no settlement along the river; however, there are approximately 68 Acres of wet land along the river. The ground level is at minimal height about the river bed level.

Gabion wall of 120 m is constructed last year from Gewog budget of Nu.0.8M

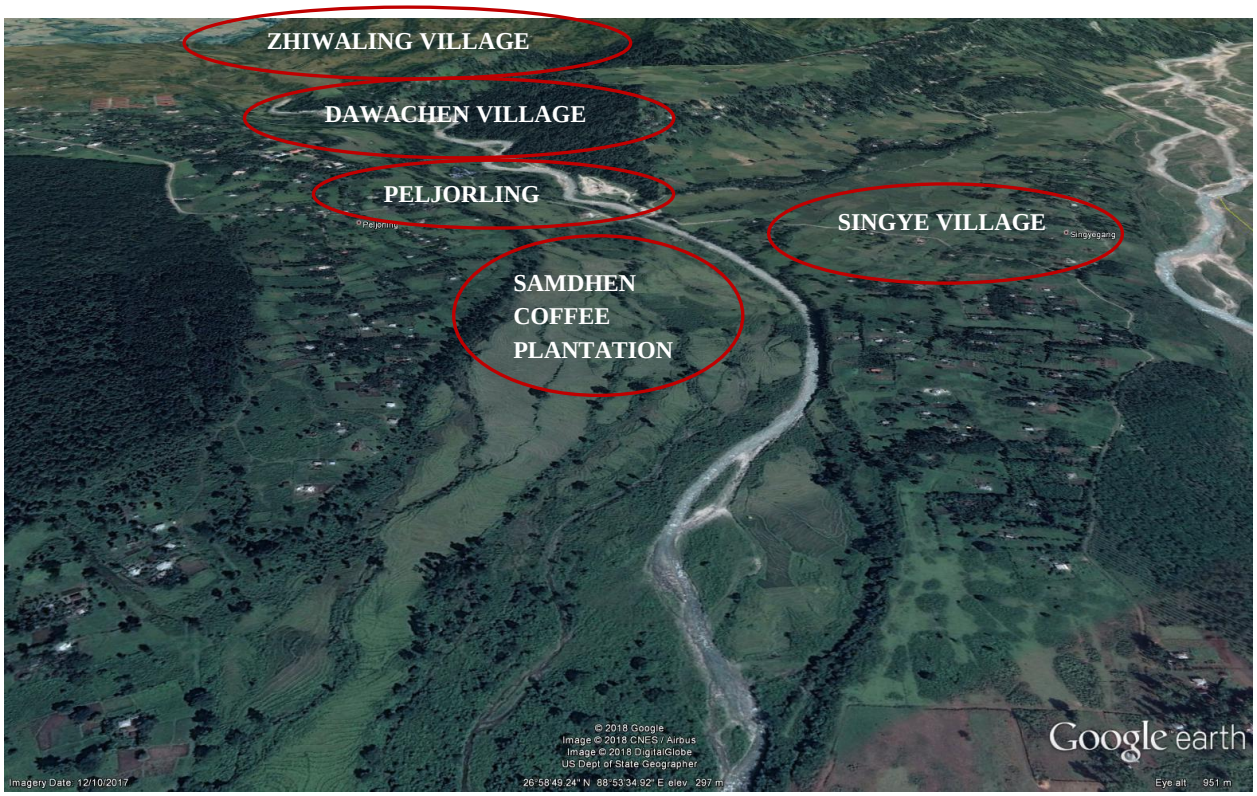


Figure 19: Google Image of Sipsoo Khola.

Figure 20: Image of Gabion protection wall constructed using Gewog budget.

Jiti Khola. Jiti Khola affects Singye gang village. There are 106 households, approximately 500 people and 424 cattles in Singyegang village. There are also 11 cars, 36 acres of wet

land and 400 acres of dry land in Singyegang village. Lift irrigation pump house is also located at river bed.

Previously river was diverted to its original course using gabion wall. But river changed its course every year affecting agricultural land on downstream. The motor able bridge was washed away for two consecutive years 2005 & 2006 respectively.

Figure 21: Image of Singye village and pump station along Jiti Khola

Jaldhaka Khola: There is no human settlement or infrastructure along this river. There are agricultural land along the river which are left uncultivated due to fear of wild animals (Elephant & wild boar).Hence protection may not be required along Jaldakha river.

Tendruk Gewog.

Bindu Khola: In 2009, about 5 acres wet land and 3 acres orange orchard washed away by Bindu River. As per Gewog Mangmi, there is a proposal of hydropower construction at the upstream of Bindu River in the future. After the construction of hydropower dam at upstream, flood threat to the wet land will be reduced at the downstream.

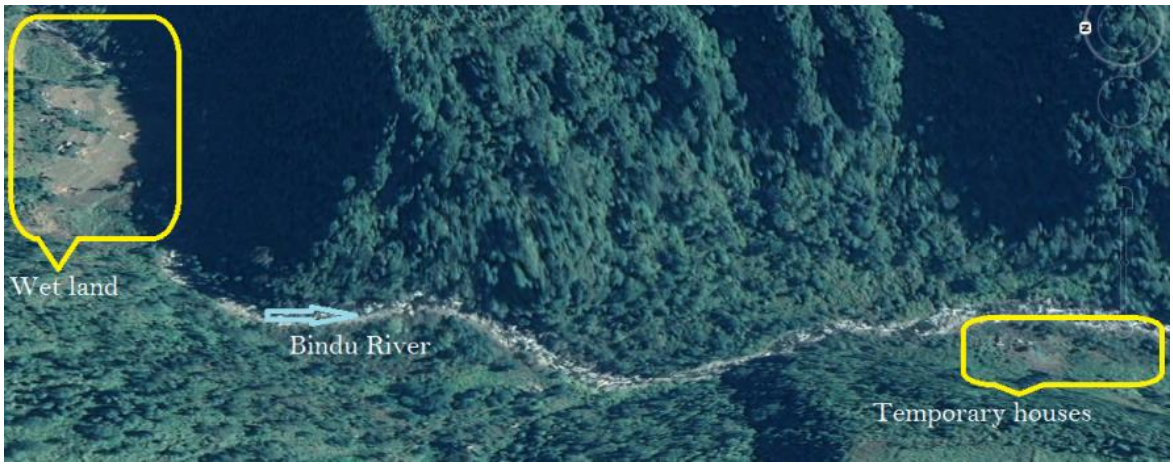


Figure 22: Image of wet land and temporary houses along Bindu khola

Tendu Khola: Along Tendruk stream, there is no human settlement.The only structure constructed from the river is irrigation channel intake.Annually during monsoon season landslide takes place near the intake structure and causes frequent disruptions to the flow in the channel.Therefore, proper intake protection is required by constructing 50 metres flood protection structure.

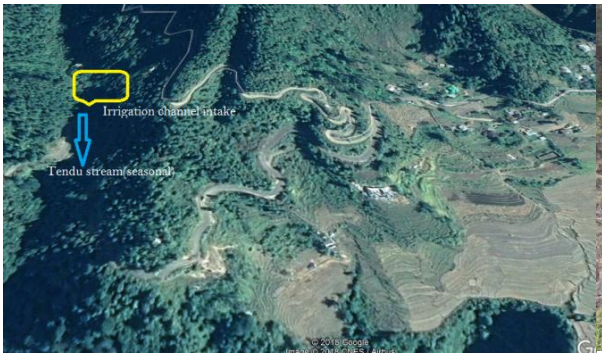


Figure 23: Google Image showing location of irrigation channel along Tendu khola

Figure 24: Image of Tendu Khola

Phuntshopelri Gewog.

Pugli Khola: Existing river bed of Pugli Khola used to Agricultural land before 1993 flooding. During 1993 flooding, approximately 11 acres of wetland was washed away leading to the expansion of river bed. Today river bed level is as high as ground level and approximately 1500 metres in width. Mining in upstream leads to large deposition of river river bed materials on downstream. There is about 200 Acres of wet land along the river.

Figure 25: Images of Pugli khola

Teite Khola: Two mining are located on the upstream of Teite Khola. Mining produces lots of gravels and sand which creates artificial pond in upstream which on breaking leads to flooding in downstream.

Figure 26: Image showing location of Teite village

Kalapani Khola: It has been observed that vast area of agricultural land was lost during previous floods due to deposition of landslide debris and sediments.Kalapani river is the ultimate drainage basin for various seasonal streams. Huge quantity of sediment deposited was caused by landslide of an entire hillock, two kilometers upstream of the village. According to the local people, in 1993 there was a big flood with landslide sediments which entered towards Kalapani village and destroyed wet and dry lands.

To protect the river entering towards settlement and agricultural land, Dzongkhag administration have constructed 500 metres of RRM flood defense wall.It was found by the team that, the wall is in good condition and functioning well.Sediment deposit have reached more than half of wall height.

According to the Tshogpa, a private contractor have approached Gewog administration for seeking approval for dredging works along Kalapani river and sought public clearance.However,clearance from NRDCL is awaited.

Figure 27: Images of Kalapani khola

Kharkara Khola: It has been observed that 2 acres of agricultural land was lost during 2017flood.River bed level has increased due to deposition of landslide debris and sediments.This river is the ultimate drainage basin for various seasonal streams. Huge quantity of sediment deposited was caused by dolomite mining at the upstream. People have to cross this river to reach Gomtu.During monsoon season, school children, workers of cement factory are affected by this river.Most of the settlement are located at its left bank.

According to the Tshogpa, a private contractor have approached Gewog administration for seeking approval for dredging works along Khakara river and sought public clearance. However, clearance from NRDCL is awaited.

Figure 28: Image of Kharkara khola

Khana Verti Khola: There is large quantity of sediment deposit and river bed level is increasing yearly. Land slide of Agricultural land occurs every year.

Sukti Khola: It has been reported by the Tshogpa that there are 4 Chiwogs located along Sukti river.They are Pendenling, Ghisingma, Dolomthang and Dumshigang Chiwogs.To

reach these Chiwogs people have to cross this river.In case of flash flood,road gets block. There is no mining along this river. According to the Tshogpa, severe increase in river bed level was caused during 1993 flood due to land slide at upstream and yearly during rainfall bed level keeps on increasing

It has been observed that, the soil in the catchment area is very susceptible to erosion.During monsoon season, the eroded material is deposited along this river which leads to unpredictable shifting in the flow of the streams.In Sukti river, it is observed that due to excessive deposit of eroded materials, the bed level of the river is as high as the surrounding land.The agricultural land is getting destroyed by the deposition of eroded materials.

Figure 29: Image of Sukti khola

Identifying Critical River: Budeney River has been identified as most critical river because, there is increased flooding risk caused by the diversion of the Dhamdum stream to Budeney stream. The diversion was done by the Department of Roads, Ministry of Works and Human Settlement through dredging works and construction of AB mattress which is still under construction as of date. The total cost for the dredging works and AB mattress can come up to Nu. 42 million. As per the Mangmi and the Tshogpas, the DoR had diverted the river since the Dhamdum Bridge was unstable. DoR hopes that the Budeney Bridge can accommodate both the discharge from Dhamdum and Budeney streams during monsoon. However, the Gewog representatives fear for the worse during the coming monsoon with the added discharge from Dhamdum stream.

Development of Model

Flood Hazard Map

The flood hazard map can be prepared based on different variables such as flood depth, flood duration, velocity, rainfall, elevation, soil and distance from the river. The variables to be used for flood hazard map were based on the availability of the data for Dipu, Diana and Dhamdum Khola

The variables such as flood depth, flood duration and velocity are to be gathered after running HEC-RAS model. The input for the model is the discharge, river cross-section survey, DEM (Digital Elevation Model), dimension and location of the flood protection structures. Therefore, cross-section survey for river was conducted. Due to lack of discharge data for Dipu, Diana and Dhamdum Khola, HEC-RAS could not be used. Hence, the variables such as flood duration, flood depth and velocity could not be taken into consideration for preparation of flood hazard map.

Table 2: 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 to 2013 for Sipsu Meteorological station, it could not be used as it was not giving information on rainfall variability across Dipu, Diana and Dhamdum area.
5.	Elevation	This variable is being considered.
6.	Soil	Couldn't be considered due to lack of soil data.
7.	Distance from the river	This variable is being considered as planners use a standard buffer zone near water bodies (river, stream etc.)

For preparation of flood hazard map, two variables such as elevation and distance from the river have been considered important in this study. The ranking and weighting for the two variables has been discussed thoroughly amongst the engineers in the Division. The Table 3 gives the detail of the ranking and weighting:

Table 3: Classes and ranking of variables

Variable	Classes	Ranking	Weighting	Remarks
Main rivers (River buffer)	0 – 30 m 30-100m >100m	2 1 0	25	As per the standard use by planners.
Elevation	<= 175 175-250m 250-325 m >325 m	3 2 1 0	75	The elevation is used from the ALOS 10m DEM.

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

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

Result Analysis and Conclusion

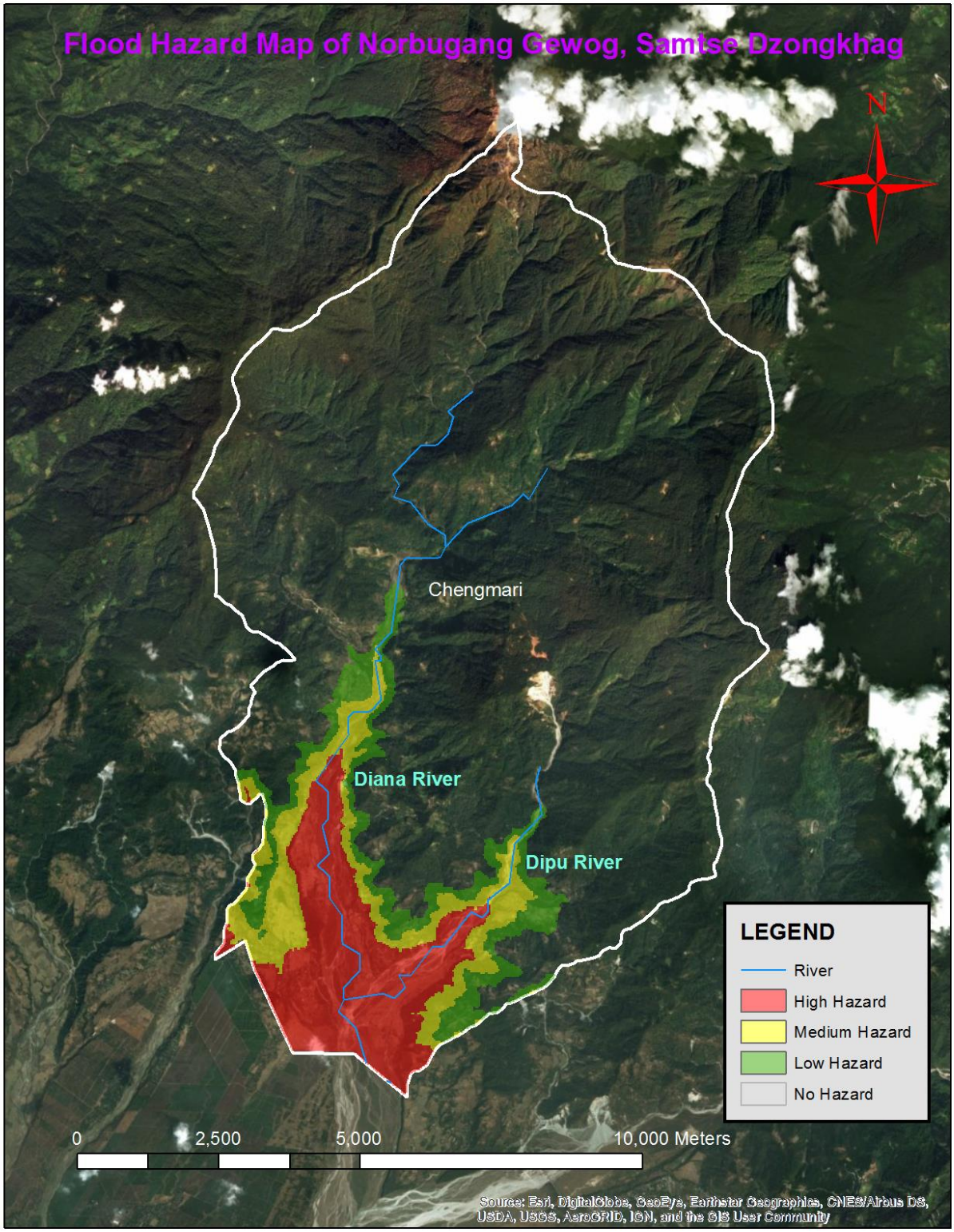


Figure 30: Preliminary Flood Hazard Map for Dipu and Diana River

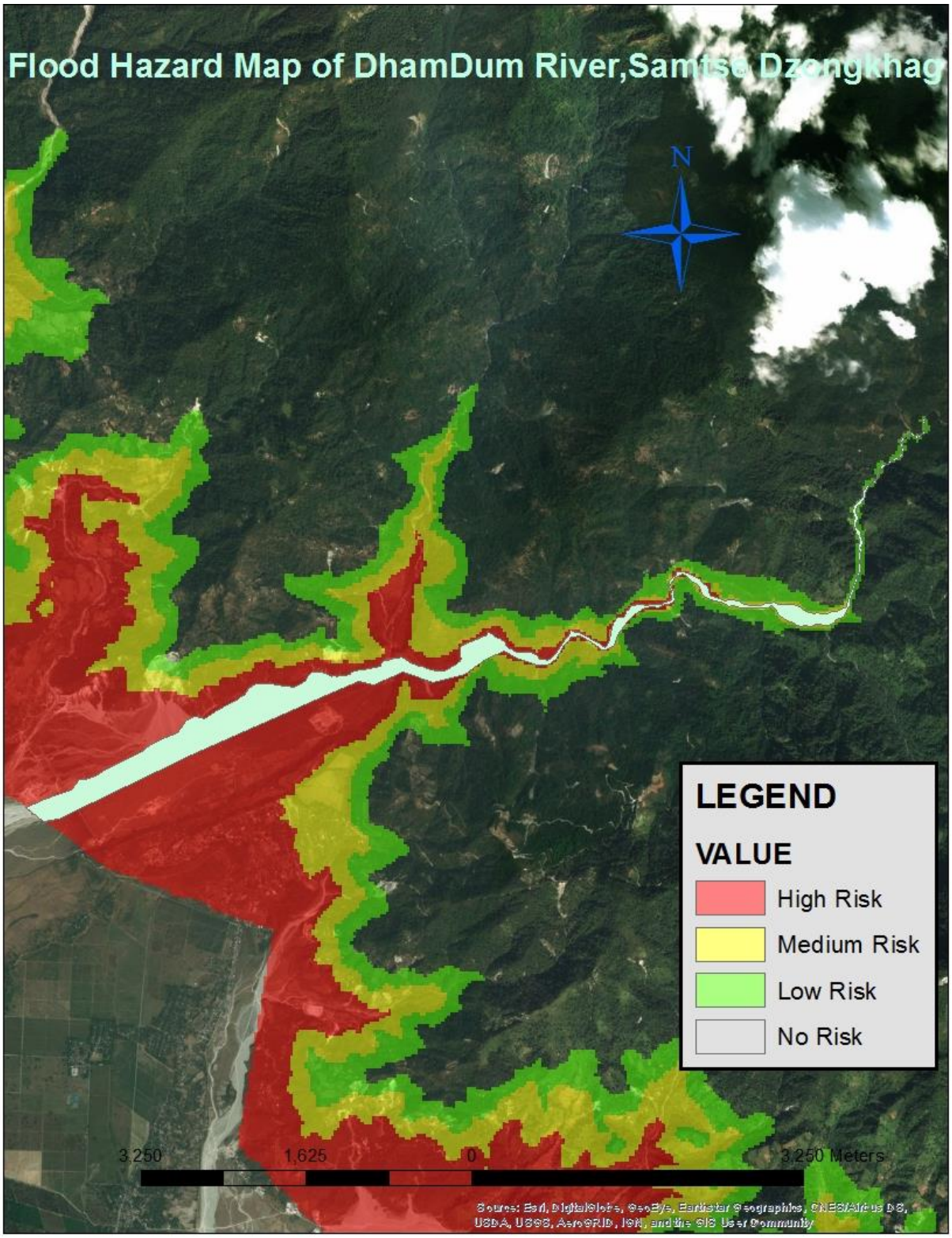


Figure 31: Preliminary Flood Hazard Map for Dhamdum River

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).

The Department of Engineering Services and Department of Roads, MoWHS, Royal Government of Bhutan have invested Nu.16M and 42M respectively in the 11th FYP for Samtse Dzongkhag. Gabion revetment along Sukreti River was designed by FEMD, DES and implemented by Samtse Dzongkhag.

Sukreti River:

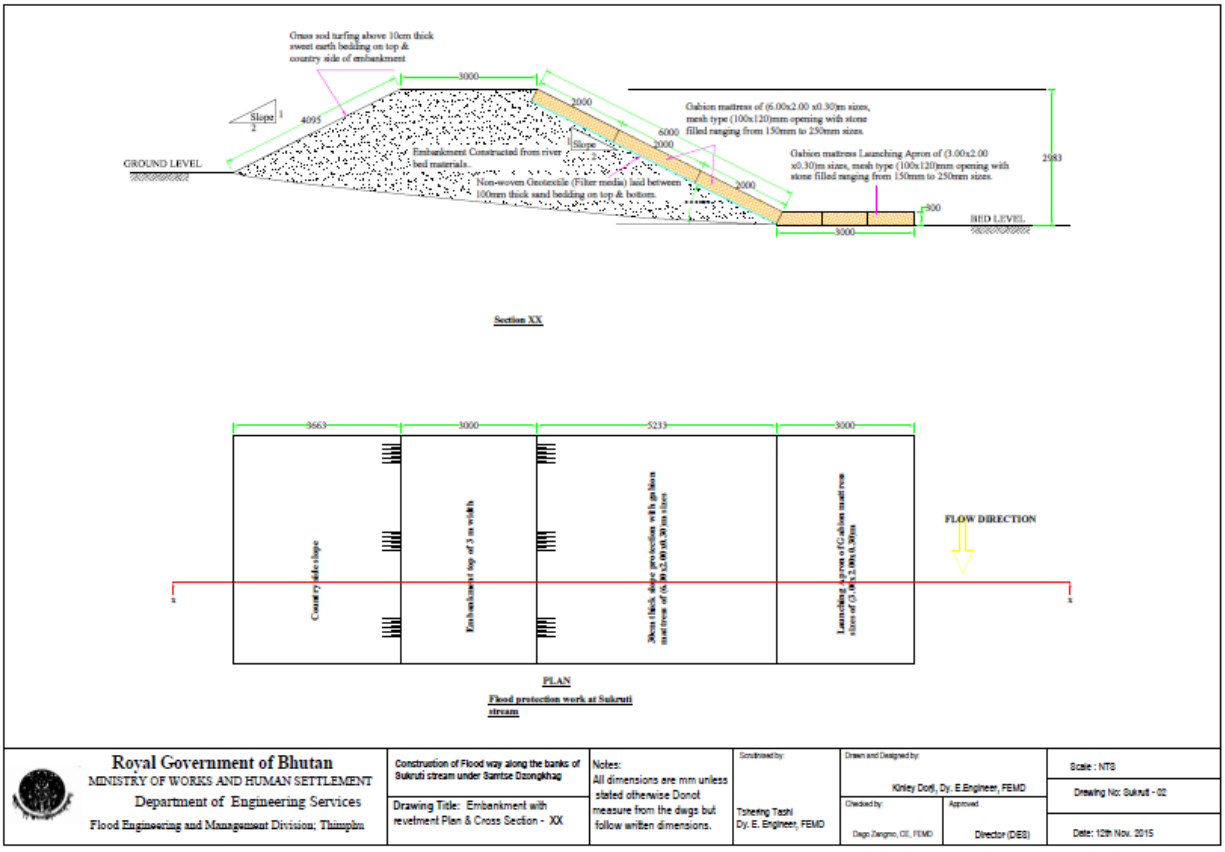


Figure 32: Plan and cross section of flood way along right bank of Sukreti River.

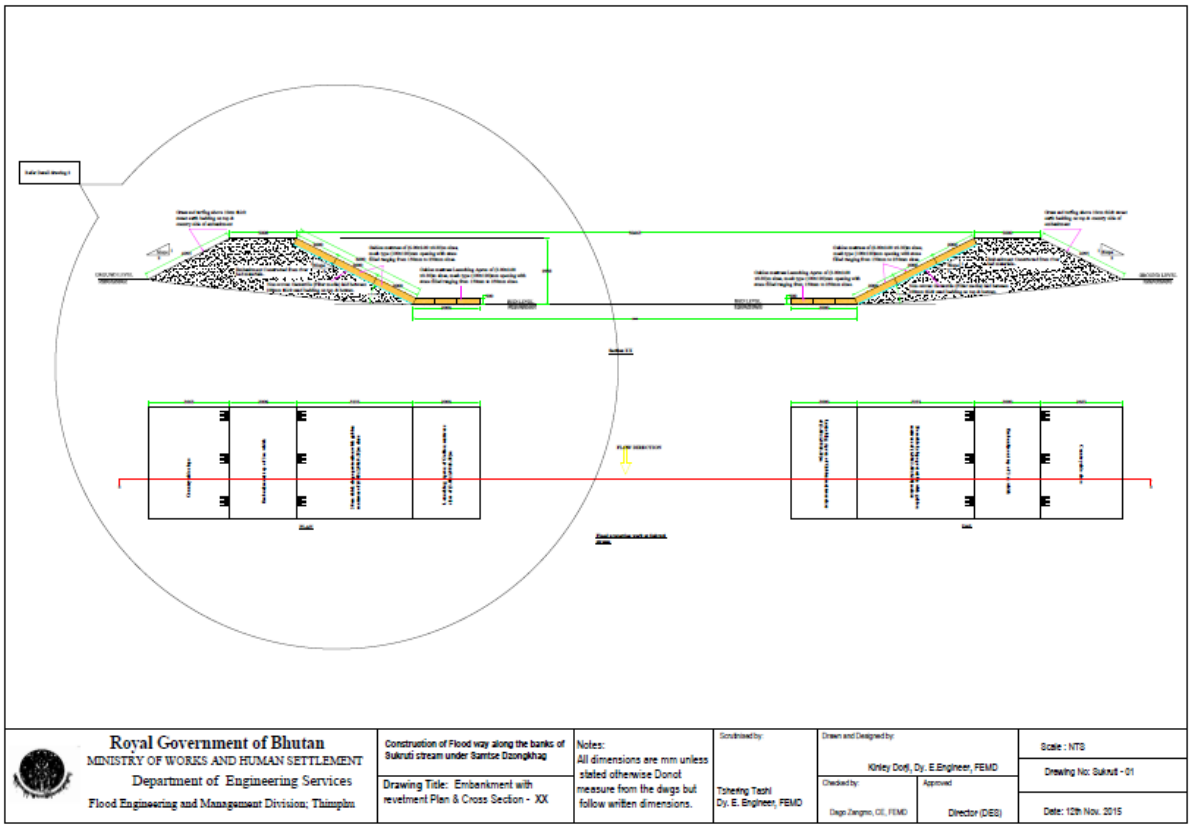


Figure 33: Plan and cross section of floodway along Sukreti banks.

Figure 34: Embankment with gabion crate revetment at right bank along Sukreti River.

Dhamdum River:

Figure 35:AB mattress construction along Dhamdum River

Figure 36:Debris flor towards Dhamdum River

Recommendation for Flood Management

Samtse Gewog.

Budeney and Dhamdum River: A detailed technical study should have been conducted before the diversion of the Dhamdum River to Budeney River. A proper study with pros and cons of the diversion could have led to a different solution other than diversion. It is highly recommended to study the catchment and implement proper catchment stabilization methods to reduce the sediment deposits which fill up the river bed during monsoon.

The diversion of the Dhamdum River will increase the discharge flowing through the Budeney River flow path thus exposing the residents at the right bank of Budeney and the Budeney Bridge itself under increased flooding risk in the coming monsoons. Therefore it is highly recommended to implement counter measures for the diversion work that is currently under process. It is also highly recommended to conduct geotechnical and watershed assessment of the Budeney and Dhamdum and catchment for sustainable watershed management.

Sukriti River: The Samtse Dzongkhag Administration has carried out ample flood protection works along the right bank of Sukriti River where all the critical infrastructures are located such as NIE, School, Dzong. However, no study has been conducted to manage the landslide located in the upper catchment of Sukriti River. Therefore it is highly recommended to conduct geotechnical and watershed assessment of the Sukriti catchment for sustainable watershed management practices.

Bukey Khola: No study has been conducted to manage the landslide. Gabion wall at selected location may be constructed to prevent the community from flooding. Further, bioengineering works could also protect landslide.

Norbugang Gewog.

Diana Khola: Dhanasay stream is the source of river loads in Diana River due to landslide in upstream. It is also the cause of year 2000 flooding. Dhanasay stream brought river loads (Landslide materials) to the confluence of Diana Khola and Dhanasay stream. These river loads created artificial pond at confluence, blocking the flow of Diana Khola. There are high chances that larger pond maybe created and on breaking of this pond, major destruction maybe caused.

Nothing much about soil stabilization can be done as there is large mass movement of slope. Control structures may be constructed to divert this debris flow along the flow of Diana Khola as to prevent the creation of artificial pond.

Dipu Khola: Due to continuous deposit of the land slide debris, river bed level have increased and reached almost equal to the ground level.The rate of sediment is very high which causes irregular flow path and erodes cultiviable land at both banks.To reduce the flooding effects,catchment areas should be managed properly. After monsoon season, dredging along the centre line of the flowpath would help to control river changing its direction and avoid further landslide at both the banks.

Chumpatang: Proper study about geology of catchment and methods for slope stabilization is to be carried out before implementation of any structures.

Yoeseltse Gewog.

Kuchi Diana River: Irrigation channel intake structure was constructed in 2016, but it is not well protected.There is chances of breakdown of structure incase of severe flooding in future.This is also the concern for the Gewog administration too. Therefore immediate flood protection structure at intake is highly recommended. To protect further destruction of wet land, there is a requirement of about 500 metres flood protection structures at the downstream of channel intake in critical areas along wet land.

Tashicholing Gewog.

Sipsoo Khola: Embankment with gabion revetment with apron may be constructed to protect wet land and infrastructures from destruction due to flooding for a length of 1200m on both bank of the river. Moreover, proper study is recommended before the construction of structures.

Jiti Khola: River maybe left with wider flow path and gabion protection maybe provided in settlement areas to prevent adverse effect on settlements and agricultural land.

Tendruk Gewog.

Tendu Khola: Proper intake protection is required by constructing 50 metres flood protection structure.

Phuntshopelri Gewog.

Pugli Khola: Study should be undertaken to see the effects of mining in upstream to the river in downstream. Moreover dredging may be carried out to maintain the river bed level below the ground level.

Teite Khola: Dredging may be carried out. Proper protection along Teite village maybe provided to save village from flooding.

Kalapani Khola: It has been observed that there is a requirement of additional 400 metres protection works at the downstream of existing RRM wall.Construction of embankment with gabion revetment in continuation to RRM wall would minimise threat of river entering towards settlement.To control diversion of flowpath due to sediment deposit, dredging along its centre line can reduce risk.Slope stabilization to control debris flow.

Kharkara Khola: To control diversion of flowpath due to sediment deposit, dredging along its centre line can reduce risk.Construction of gabion wall at suitable locations along settlement area can minimise further scouring and land slide and slope stabilization.
Khana Verti Khola: Flood protection structures along the settlement and agricultural land of approximately 1100m may be provided to protect settlement and agricultural land from flooding.
Sukti Khola: To control diversion of flowpath due to sediment deposit, dredging along its centre line can reduce risk. Construction of gabion wall embankment at suitable locations along settlement area can minimise further scouring and land slide. Geotechnical study should be conducted for slope stabilization and reducing debris flow.

Limitations of the study

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

Although the preliminary flood hazard map has been prepared for Dipu, Diana and Dhamdum River, there are some unavoidable limitations such as:

- The elevation data required for the map was extracted from ALOS DEM with 10 metre resolution. A major problem with using SRTM data for flood hazard modelling of a floodplain is that it is not “bare-earth” and contains information about vegetation and urban areas that block the water movement in the model.
- The reliability of the maps has been affected by the inadequate spatial rainfall data for the study area. Since there was only one rainfall station in the Sipsu town catchment.
- There is no discharge data for Dipu, Diana and Dhamdum River.
- Land cover data and soil data has not been used for modeling purpose resulting in unrealistic ground condition.

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5. Coursework book for Training in 'Flood Risk Assessment and Planning of Mitigation Measures' conducted by ADPC (Asian Disaster Preparedness Centre for FEMD staff and funded by UNDP- Climate Risk Management Project.
6. Flood control measures for effective flood management, FEMD, DES, MoWHS