FLOOD HAZARD ASSESSMENT OF THIMPHU DZONGKHAG

A detailed assessment of flooding problems in Thimphu Dzongkhag, Bhutan

[Pick the date]
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CONTENTS

INTRODUCTION

Flood as defined by Chow*et al*., (1988) is a relatively high flow that overflows natural channels. Floods compromises socio-economic development and have significant impacts on human lives, their property, and the environment. The occurrences of floods around the world has increased significantly during the years 1999-2000 and 2005-2006. In 2006 and 2007, more than half of all natural disasters were floods. The damages reported due to floods all over the world in the last two decades have been estimated at 556 billion Euros.

Cyclone Aila in 2009 was one of the most disastrous events causing flooding in South Asian countries such as Bangladesh, India, and Bhutan.In Bhutan a record high rainfall of 72.5 mm was recorded and a hydrological station in the capital, Thimphu, recorded an unprecedented high flow of 661 m³/s. Riverine flooding caused by this unprecedented rainfall event resulted in the loss of 12 lives and a total economic damage of 9.6 million Euros (DDM, 2014).

Flash floods and glacial lake outburst floods are other types of flooding that are common during the monsoon seasons (June-September) in Bhutan. The location of the flood-prone areas to monsoon flooding in Bhutan is shown in Figure 1(NEC, 2016). A detailed flood damage of some recent flooding events in Bhutan is shown Table 1. As depicted in the table, riverine flooding has affected most number of districts as compared to other types of flooding.

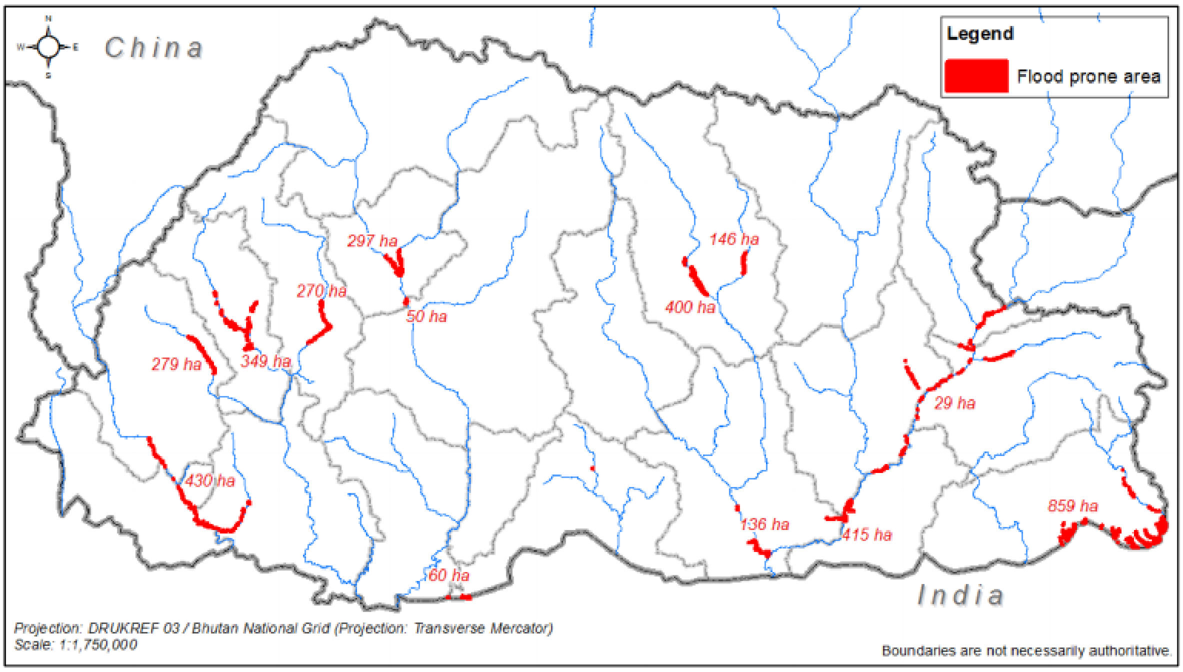


Figure 1: Map showing floodprone areas in Bhutan to monsoon flooding (NEC, 2016)

The most disastrous glacial lake outburst occurred on 7th October 1994 when a glacial lake named Lake Luggy in Lunanabursted with flood volume of 18 Million m³ along the Punakha-Wangdi valley. This event resulted in 21 casualties affecting 91 households. A total of 1700 acres of land comprising of agricultural and pasture areas, and infrastructures were damaged including 12 houses and 4 bridges. (DDM, 2014). There has been extensive studies (Watanbe and Rothacher, 1996;Bajracharya, Maharjan, & Shrestha, 2014; Bajracharya, 2007) carried out on glacial lake outburst floods in Bhutan. However, GLOF in Bhutan is outside the scope of this present study. The present study will focus on riverine flooding in Bhutan with a particular focus on Thimphu Dzongkhag.

Table 1: Flood damage report of recent floods in Bhutan (DDM, 2014)

Year	Flood event	Affected area	Impact/consequences
2000	Flash flood	2 districts affected	49 lives lost, 17 huts washed away: BOD fuel station, the market, 1 saw mill, 2 main water supplies and the city's sewage system destroyed and several vehicles submerged.
2004	Flash flood	6 districts were affected.	9 lives lost, 29 houses completely washed away, 26 houses collapsed and about 107 houses collapsed and about 107 houses partially damaged; 161 acres of wetland and 503 acres of dry land washed away; many tons of crops and fruits lost. Damages to infrastructure and services facilities: 39 irrigation channels damaged, 22 bridges of different types damaged or washed away
May 2009	Riverine Flooding caused by Cyclone *Aila*	17 districts were affected.	Damages estimated at 9.6 *million Euros.* Rivers and streams reached record levels of the past forty years. The floods resulted in the loss of 12 lives and impact everything such as agriculture properties, bridges, roads, livestock, irrigation and drinking water systems.
4th June 2013	Riverine flooding	1 district affected	The flood due to incessant heavy rains damaged a a lot of agriculture land (2.4 acres), crops, an irrigation channel, farm roads, and culvert bridge.
29th July 2016	Riverine flooding	4 district affected	4 lives lost and affected 125 households, 6.79 million Euro worth of construction material damaged.

Managing flood is a challenge and one of the first steps to managing flood is mapping the hazard and risk areas. According to Mertz *et al.* (2007), a flood map is a visual representation of the spatial distribution of flood hazard, vulnerability or risk which effectively relays information to end users. The maps are categorized into flood hazard maps which are associated with the intensity of flood, vulnerability maps with the effect of the flood on socio-economy and environment and risk maps with the hazard multiplied by the vulnerability

(Merz, Thieken, &Gocht, 2007). A visual description of the flood hazard, vulnerability and risk is shown in Figure 2(Merz, Thieken, & Gocht, 2007)

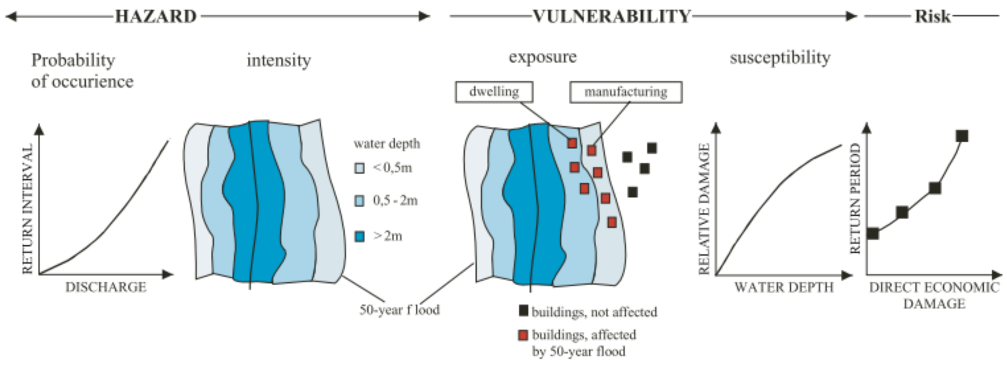
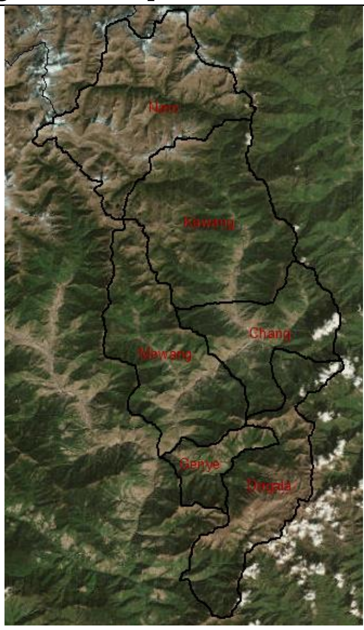


Figure 2: Visual description of flood hazard, vulnerability and risk map (Merzet al., 2007)

The most recent numerical tools used for flood mapping are one-dimensional and two-dimensional hydraulic models (Horritt, 2002). These models are able to simulate floodplain inundation and river hydraulics in many studies done by many researchers although conducting hydraulic modelling in study areas with fewer data available has always been a challenge.

Study Area

Thimphu is the capital of Bhutan. It shares boundaries with Gasa and Punakha Dzongkhags in the east, Chukha and Dagana in the south, Paro Dzongkhag in the west and Tibet (China) in the north. The Dzongkhag has one Dungkhag and 8 Gewogs viz; Chang, Dagala, Genyekha, Kawang, Mewang, Lingzhi, Naro and Soe. Mewang, Chang, Dagala, Geneykha and kawang Gewogs falls directly under the Dzongkhag Administration while the 3 Gewogs of Lingzhi, Naro and Soe are under the Lingzhi Dungkhag Administration. It has many important historical, cultural and religious heritage sites.

Sl.No.	**Gewog**	**Past flooding**	**Gewog location map**
1	Naro	Not flooding reported	
2	Kawang	Thimphu River, Chubachu	
3	Chang	Olarongchu	
4	Mewang	Namseling area along Thimphu River : below the flood protection works : Construction by Dzongkhag, designed by FEMD, DES, MoWHS Jabmisa -Jemina area near Minihydel	
5	Lingzhi	No flooding reported	
6	Genyekha	No flooding reported	
7	Dagala	No flooding reported	
			Figure 3: Location of Gewogs under Thimphu Dzongkhag

Objective

The general objective of the study is to reduce the flooding risk along flood prone areas in Thimphu Dzongkhag through flood hazard mapping and detailed field investigation.

Scope of Study

The scope of current study is limited to flood prone areas along Thimphu River and critical tributaries of Thimphu River falling under Thimphu Dzongkhag.

Output of the study

- Flood hazard areas along Thimphu River and critical streams under Thimphu Dzongkhag identified.
- Recommend possible structural and non-structural interventions along the flood prone areas to reduce the flooding risk.

METHODOLOGY

For the stream, a hazard map was created using buffer zone of 30m on both sides of the streams and elevation of the area. Areas closer to streams with lower elevation are ranked with higher hazard. And areas further away from stream with higher elevation are ranked with lower hazard.

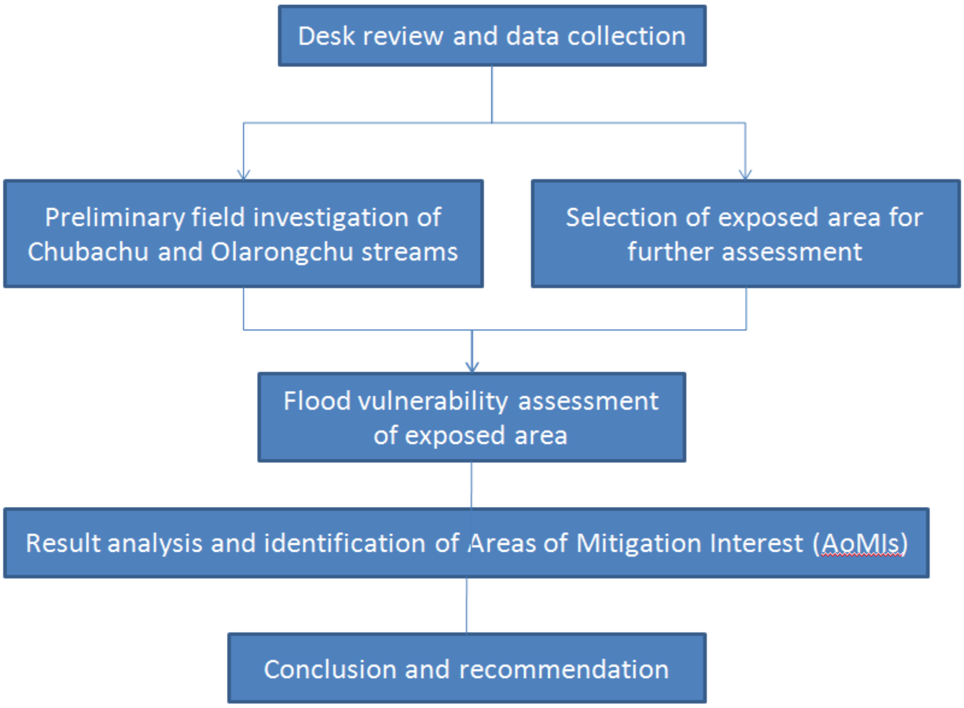


Figure 4:Methodology adopted for assessing critical stream

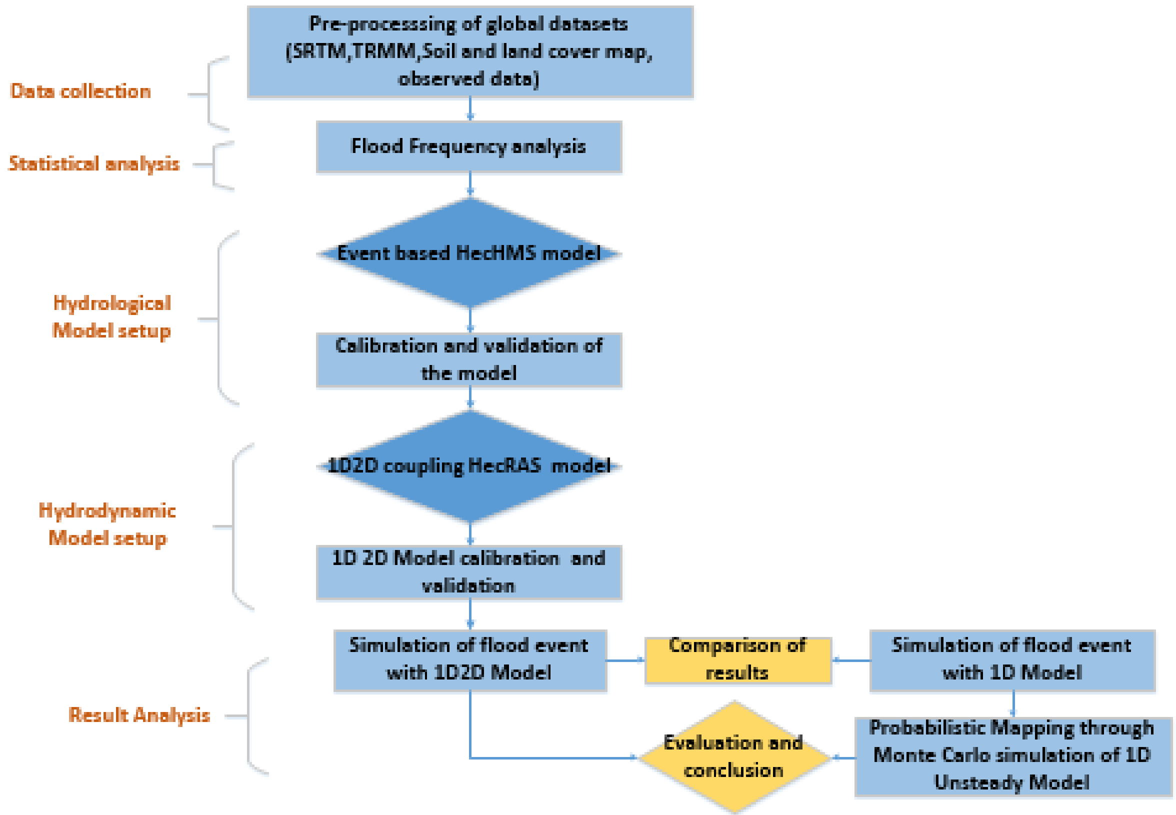


Figure 5: Methodology adopted for flood hazard mapping of Thimphu River

Data used for the study

The data required for the study was acquired from the relevant agencies and according to the data availability, a suitable methodology was adopted for the past flood assessment of the two streams. The data used for the study is listed in Table 2.

Table 2: List of data used for the study

Data type	Details	Source	Application
SRTM DEM	90m and 30m resolution	NASA through Earth explorer website	Catchment delineation
Image	High resolution Thimphu Image (2004)	Thimphu Thromdey	For mapping
DEM	5m resolution	Thimphu Municipality, Bhutan	1D and combined 1D-2D hydraulic modelling
Rainfall data	Daily temporal scale	Department of Hydro-met Station, Ministry of Economic Affairs	Hydrological Modelling
Discharge data	Daily temporal scale	Department of Hydro-met Station, Ministry of Economic Affairs	Flood frequency analysis and hydrological modelling

TRMM	3 Hourly Temporal scale	NASA	To disintegrate the daily rainfall data to 3 Hourly data
Land cover data	30m	GlobCover	Computation of Curve Number for sub basins
Soil cover data	30m	National Soil Service Centre, Bhutan	Computation of Curve Number for sub basins
Flood Assessment forms	Preliminary filed investigation survey	Flood Engineering and Management Division, DES, MoWHS	Assessment
Flood Assessment forms	Flood vulnerability questionnaire survey	Flood Engineering and Management Division, DES, MoWHS	Assessment

FLOOD FREQUENCY ANALYSIS

Flood hazard is the potential to cause harm to a vulnerable society that is exposed to the hazard. So therefore, a vulnerable society that is not exposed to any flood hazard is not under any flood risk. Flood risk is also defined mathematically as the probability of flood which is the likelihood of a flood occurrence and the consequences caused by the flood to the vulnerable society exposed to flood.

Therefore, in order to understand and manage flood risk, there is a need to establish a relationship between flood magnitude and its annual exceedance probability. The Flood Frequency Analysis (FFA) of hydrological data at Lungtenphu station was carried out by Gumbel distribution and Log-Pearson Type III distribution.

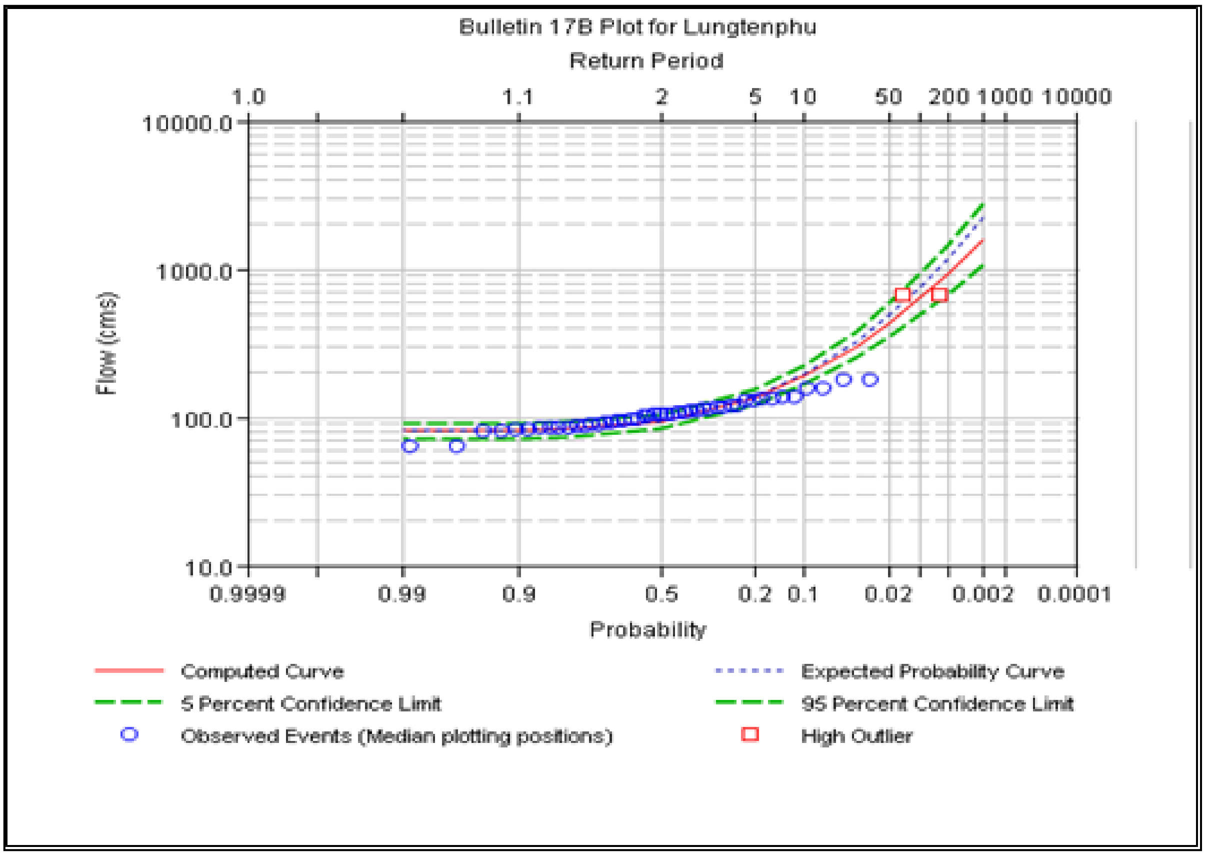


Figure 6:Graphical result from Log Pearson III distribution for Lungtenphu station

Table 3Tabular result from Log Pearson III distribution for Lungtenphu station

Flood Frequency for Lungtenphu station					
Return Period	Probability	Discharge (m³/s)	Expected Probability flow in m³/s	Confidence limits flow in m³/s	
				0.05	0.95
100	0.01	643	758	935	490
50	0.02	440	492	595	353

25	0.04	304	325	384	255
10	0.1	190	196	222	168
5	0.2	137	138	154	123
2	0.5	95	95	105	84

HYDROLOGICAL MODEL

Hydrologic models represent the hydrologic cycle in a catchment in a simplified and conceptual manner. The impact of land use or climate change is also studied with hydrological modelling. Another application of hydrological model is the generation of synthetic hydrographs for ungauged rivers and also used for flood forecasting.

A hydrological model is broadly classified into conceptual and physically based. And according to the spatial description of catchment, it can either be lumped, semi-distributed or distributed models. Lumped model considers the whole basin as homogenous, semi-distributed model computes flow contribution from homogenous sub basins, while distributed models considers the basin as a grid. Hydrologic routing of flood uses the continuity equation and one of the most commonly used routing method is the Muskingum routing. A lumped or semi distributed rainfall runoff model can be developed by delineating a catchment and using land use and soil data as input. There are a number of rainfall runoff modelling tools, HEC-HMS, NAM, HBV, SWAT, etc.

A semi-distributed hydrological model was adopted for the current study and HEC-HMS tool was used. The HEC Hydrological Modelling system is a simple and freely available modelling tool. Since Wangchu basin is a small and reasonably simple catchment to model, HEC HMS tool was selected for its simplicity. The rainfall-runoff model consists of a loss component, transfer component and base flow component. This chapters explains all the components in detail.

- ## Basin Model

The freely available DEMs were explored among which SRTM 90m was downloaded from CGIAR CSI[1] website and SRTM 30m was downloaded from USGS Earth Explorer[2] website. The DEMs were pre-processed and analysed. The 90m (3-arc second) resolution DEM proved to represent the drainage lines better with complete data in the study area as shown in Figure 7. Whereas, the 30m (1-arc second) resolution DEM had many voids which led to poor representation for the drainage lines as shown in Figure 8. The 90m DEM was therefore used for the study to delineate the catchment and was further reconditioned using river network for the basin which was acquired from the Watershed Management Division, Ministry of Agriculture and Forestry, Bhutan. The reconditioned DEM was used for catchment delineation and pre-processing of input data required for the hydrological modelling.

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[1]http://www.cgiar-csi.org/data/srtm-90m-digital-elevation-database-v4-1 (last accessed date: October, 2016)

[2]https://earthexplorer.usgs.gov/ (last accessed date: October, 2016)

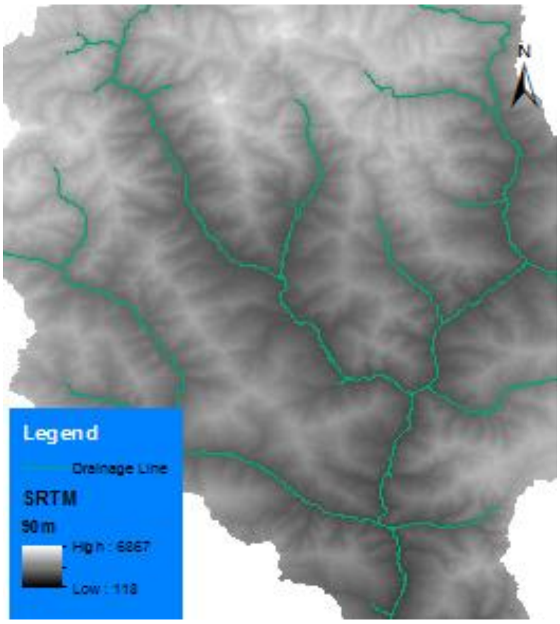

Figure 7: SRTM 90m with well represented drainage

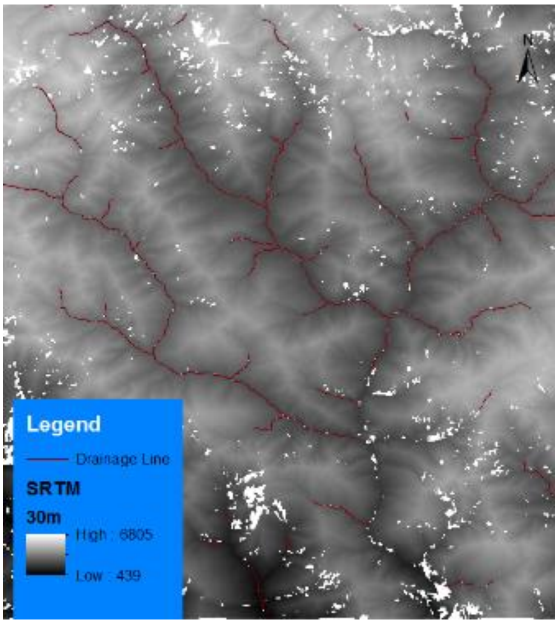

Figure 8: SRTM 30m data with voids and poorly represented drainage

HEC-HMS software was used to build the event based rainfall runoff model for Wangchu Basin. The model was used to simulate the flood corresponding to a short duration of rainfall. There are three different models, namely, basin model, meteorological mode and the control model. In the basin model, there are important processes such as loss, transform and baseflow. Figure 9 shows a schematic view of the basin model for Wangchu basin.

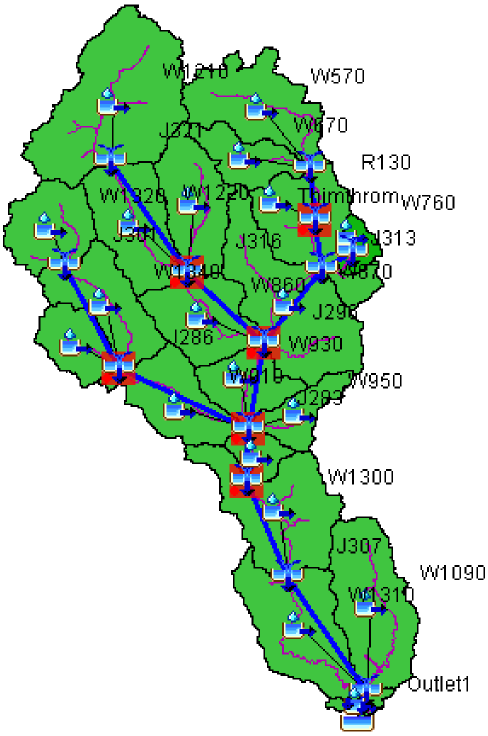

Figure 9: Basin model used for the hydrological modelling

The methods adopted for Loss, Transform and Baseflow are the SCS Curve number, Snyder Unit Hydrograph and Recession method respectively. The parameters required for the adopted processes are listed in Table 4.

Table 4: Methods adopted for basin processes

Basin Processes	Method	Computation	Parameters required	Reason for the choice
Loss	SCS Curve Number	Computed from land cover and soil type.	Initial loss Curve number Percentage of impervious zones in the basin	It is an event based model
Transform	Snyder Unit Hydrograph	Uses clark unit hydrograph methods to compute ordinates	Standard lag in hours Peaking coefficient	HEC-GeoHMS was used to calculate the longest flow path and average slope determination, then the time of concentration was calculated using Kirpich formulas
Baseflow	Recession method	Estimated for each sub basin from observed minimum flow	Initial discharge Recession constant Ratio to peak	Suitable for catchments where the volume and timing of baseflow is strongly influenced by precipitation.

Meteorological Input

There are 14 metrological stations, namely, Paro, Haa, DrugyelDzong, Betikha, Chapcha, Lingshi, Chukha, MoEA, Semtokha, Begana, Gedu, Tala, Dochula and Gunistawa located in Wangchu basin as shown in Figure 10. From the 14 stations, 2 stations namely, Dochula and Gunistawa were neglected for the study due to the lack of data.

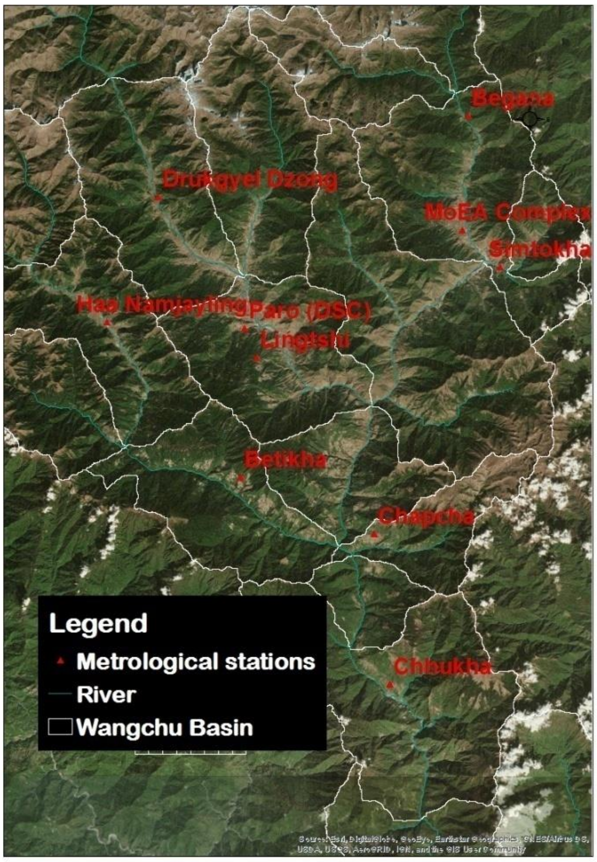

Figure 10: Map showing the location of Meteorological stations in Wangchu basin

The precipitation model used for the meteorological model is the User Gage Weighting method. The areal rainfall for each sub basin was computed using Thiessen Polygon method. The Thiessen polygons were created over the basin using HEC-GeoHMS as shown in Figure 11.

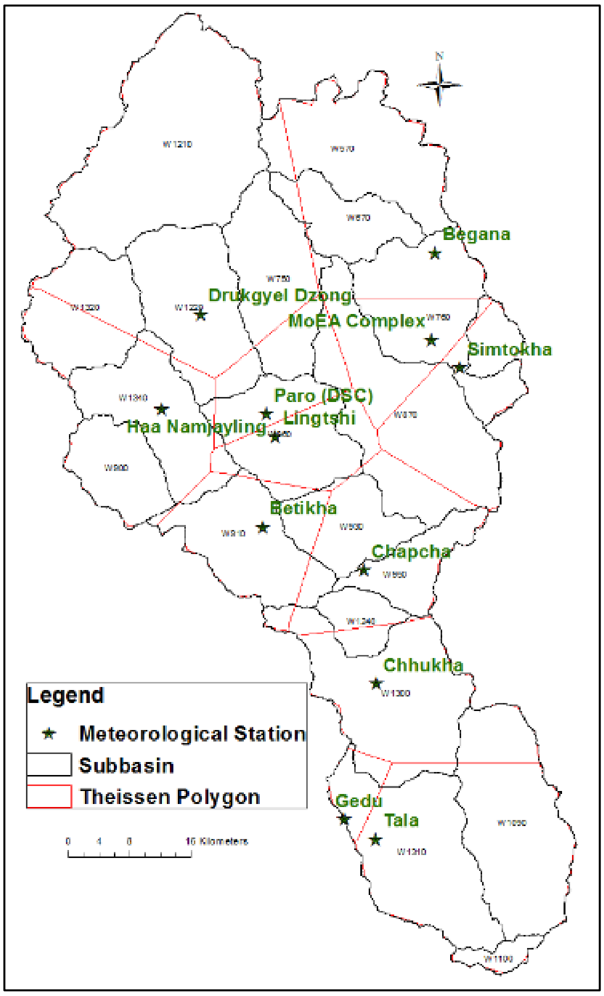

Figure 11: Thiessen polygon for Wangchu Basin

Calibration and Validation

The sensitive parameters for the hydrological model is listed in Table 5. The model was run to obtain the optimized parameter of these sensitive parameters in order to obtain the best fit for observed runoff and simulated runoff. There are two available search algorithms in Hec HMS, i.e. Nelder and Mead search algorithm and Univariate Gradient search algorithm that moves from the initial estimates to the final best estimates (Scharffenberg, 2013). For this study, the Univariant Gradient search algorithm was adopted.

Table 5: List of sensitive and insensitive parameters

Sensitive parameters	Insensitive Parameters
Recession - Initial Discharge	Recession - Ratio to Peak
SCS Curve Number - Curve Number	Recession - Recession Constant
SCS Curve Number - Initial Abstraction	Snyder Unit Hydrograph - Peaking Coefficient
	Snyder Unit Hydrograph - Standard lag

The calibration of the hydrological model at Chukha station was carried out a flood event from 25/05/2009-31/05/2009. The simulated and observed daily discharge is compared in Figure 12 and Table 6.

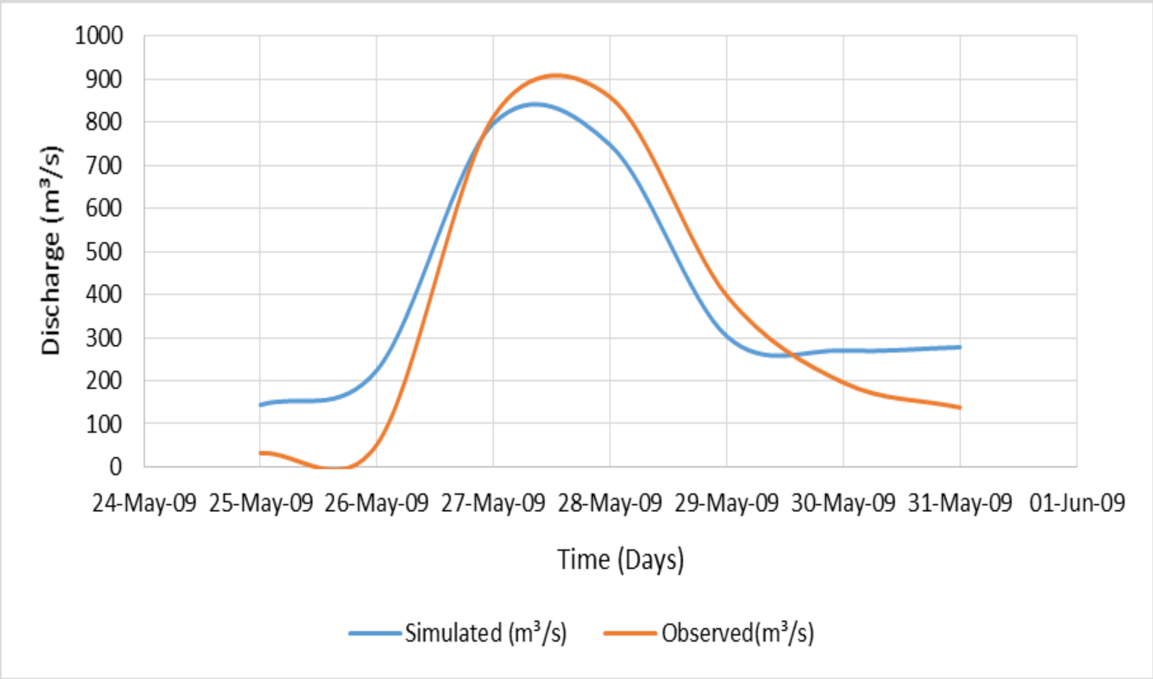

Figure 12: Graphical result of daily calibration at Chukha station

The validation of the hydrological model at Chukha station was carried out a flood event from 16/07/2008-24/07/2008. The simulated and observed daily discharge is compared in Figure 13-and Table 7.

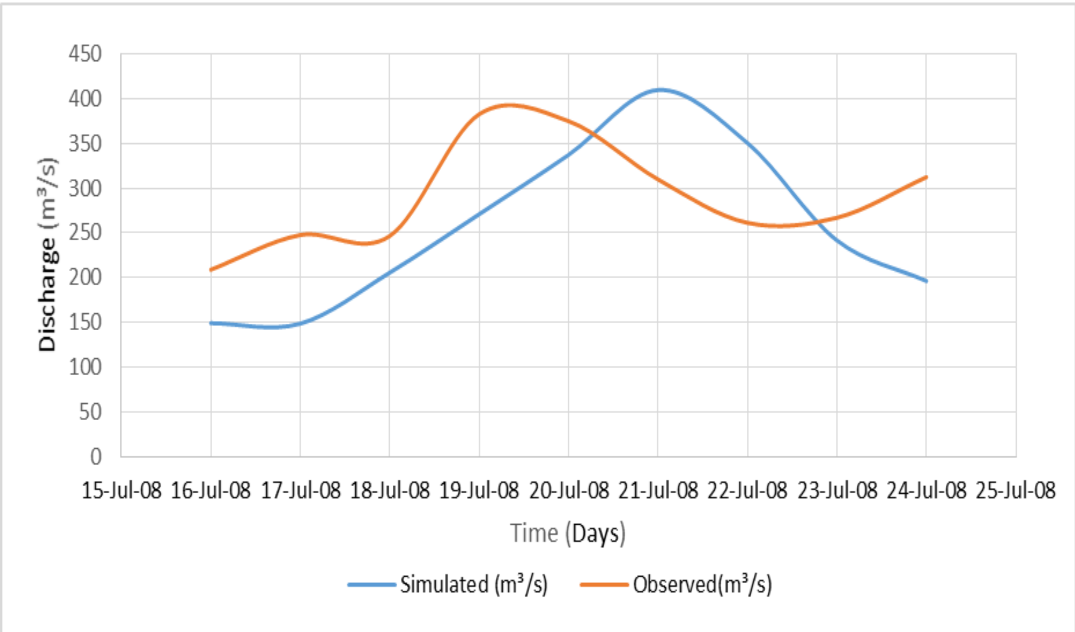

Figure 13: Graphical results of daily validation result at Chukha station

Table 6: Tabular result of model calibration

Time (Days)	Simulated discharge (m^3/s)	Observed Discharge (m^3/s)
25-May-09	144.2	32.2
26-May-09	225.2	52.7
27-May-09	798.3	814.3
28-May-09	747.7	858.8
29-May-09	303.2	397.4
30-May-09	270.4	195.8
31-May-09	278	138.1

Table 7: Tabular results of model validation

Time (Days)	Simulated discharge (m^3/s)	Observed discharge (m^3/s)
16-Jul-08	149.1	208.9
17-Jul-08	148.5	247.7
18-Jul-08	205.6	246.5
19-Jul-08	270.9	382.7
20-Jul-08	337.3	374.9
21-Jul-08	409.8	309.8
22-Jul-08	350.4	261.3
23-Jul-08	241.6	267
24-Jul-08	196.2	312.4

Table 8: Summary results from calibration and validation at Chukha station

Result	Peak Q, Sim (m^3/s)	Sim. Volume $(10^6 M^3)$	Peak Q, Obs (m^3/s)	Obs. Volume $(10^6 M^3)$	Volume Residual $(10^6 M^3)$	RMSE (m^3/s)	Mean Abs Error (m^3/s)
Calibration	798.3	220	858.8	207	13	112.7	102.9
Validation	409.8	184	382.7	203	-18	82.4	75.6

The summary results from the model calibration and validation at Chukha station is shown in Table 8.

The results from calibration indicate that the peak discharge is simulated 7% lower than the observed peak discharge while the simulated volume is 6.3% higher than the observed volume which is not significant. The difference between the RMSE and MAE is only 9.8 m^3/s which means that the error size is less inconsistent.

During validation, the peak discharge is simulated higher the observed peak discharge by 6.6% while the simulated volume is 9.3% lower than the observed volume. The difference between the RMSE and MAE is only 6.8m^3/s which means that the error size is less inconsistent.

It can thus be concluded that in both the cases of calibration and validation, the volume residual is not significant. And the peak observed discharge and peak simulated discharge differ by more or less 7%.

HYDRODYNAMIC MODEL

In a hydraulic routing or distributed routing, the flow is computed as a function of space and time. Hydraulic routing uses the continuity equation and the momentum equation or parts of it. A system formed by continuity equation and momentum equation does not have an analytical solution hence the requirement of numerical modelling. Some of the terms of a momentum equation are negligible depending on the problem it is solving. When the first two terms of the momentum equation is neglected, it becomes the diffusive wave approximation.(Price & Advisor, 1975). This approximation is applicable for slow propagating flood waves with mild backwater effects.(Popescu, 2014). Thus for the current study, the diffusive wave equation was adopted to solve the flood wave in the study area. And due to the limited available data, a simple numerical modelling tool was selected for the study. HEC-RAS is a very simple and freely available modelling tool requiring very less input data.

The combined 1D-2D Hydrodynamic model was developed for Thimphu River and the model was run for a 100 year return period discharge. The flood hazard map for Thimphu River is shown in Figure 14.

The hazard mapping for the critical tributaries for Thimphu River is also important for identification of flood prone areas. However due to the lack of the hydrological data for the streams, the hydrological model could not be calibrated. Thus a simpler approach was adopted in creating the flood hazard map for Chubachu stream and Olakha stream. The flooding hazard was based on the elevation and the proximity of the area to the stream. The flood hazard maps developed for upper Chubachu and lower Chubachu are shown in Figure 15 and Figure 16. The flood hazard maps developed for Olarongchu is shown in Figure 17. The flood risk areas for monsoon streams such as Jabjirongchu in Namseling village, Jemirongchu, Wangsisirongchu in Maedwang Gewog and Samtelingchu, Kawang Gewog are shown in Figure 18, Figure 19, Figure 20 and Figure 21.

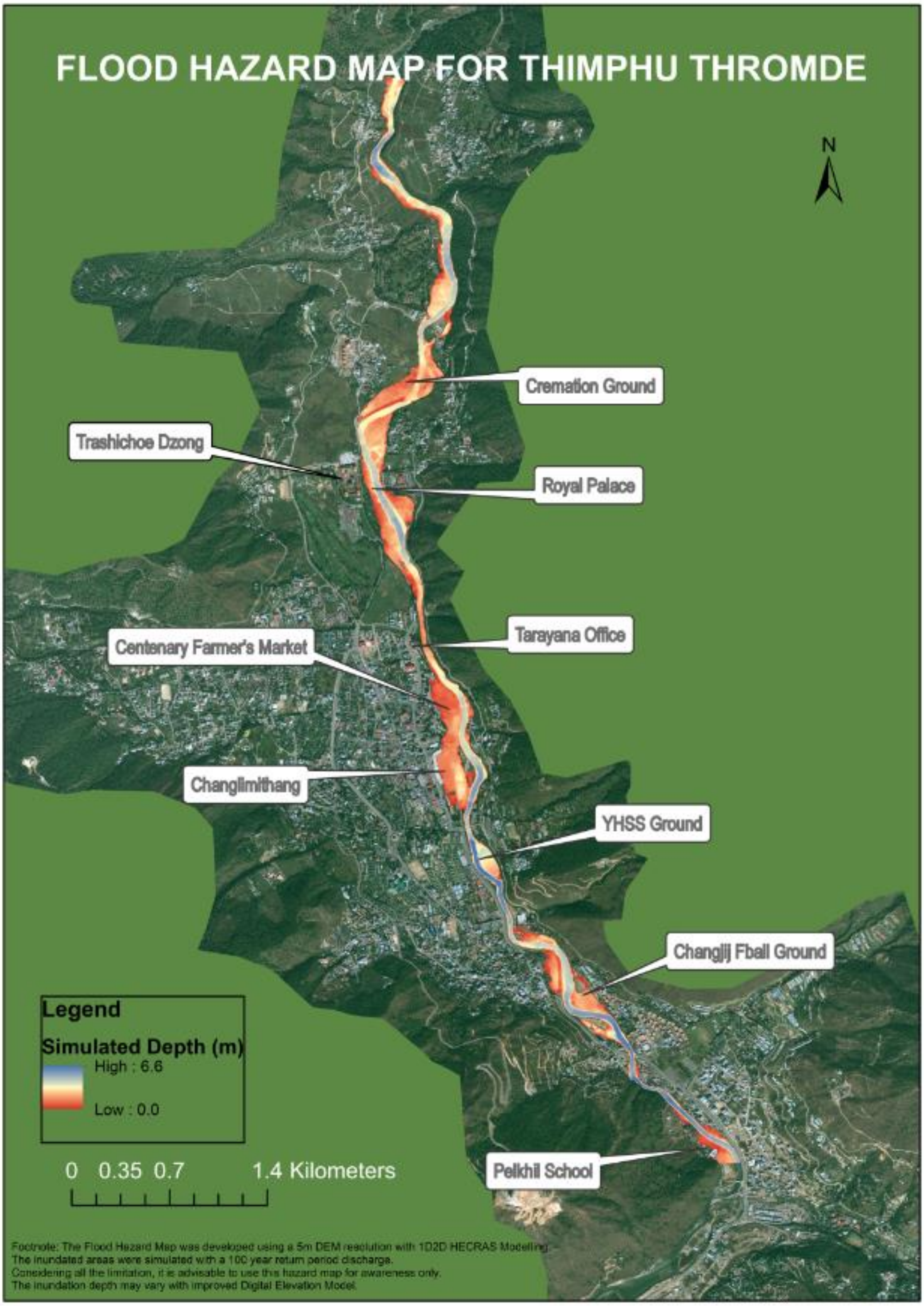

Figure 14: Flood Hazard Map for Thimphu Thromdey

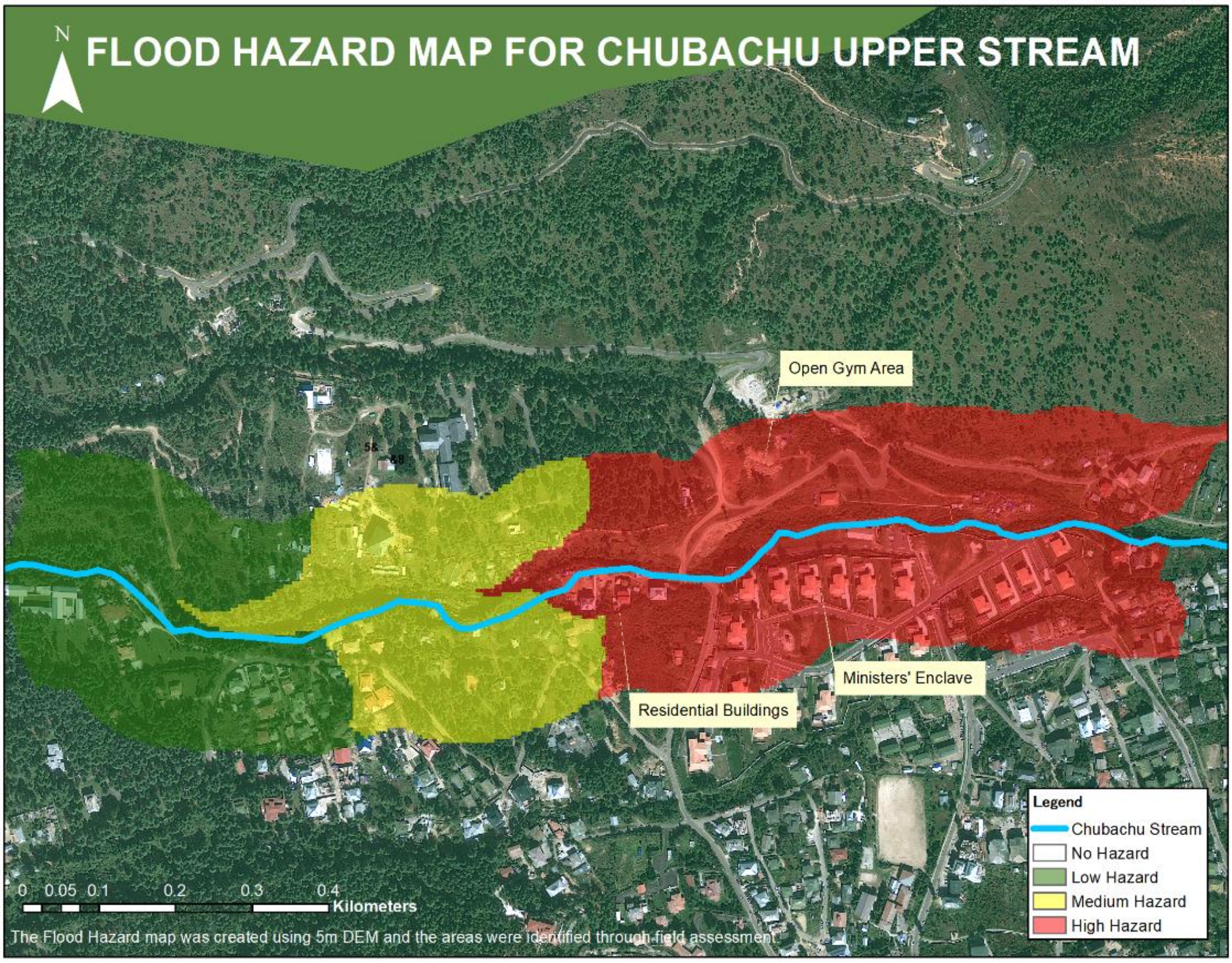

Figure 15: Flood Hazard Map for upper Chubachu stream

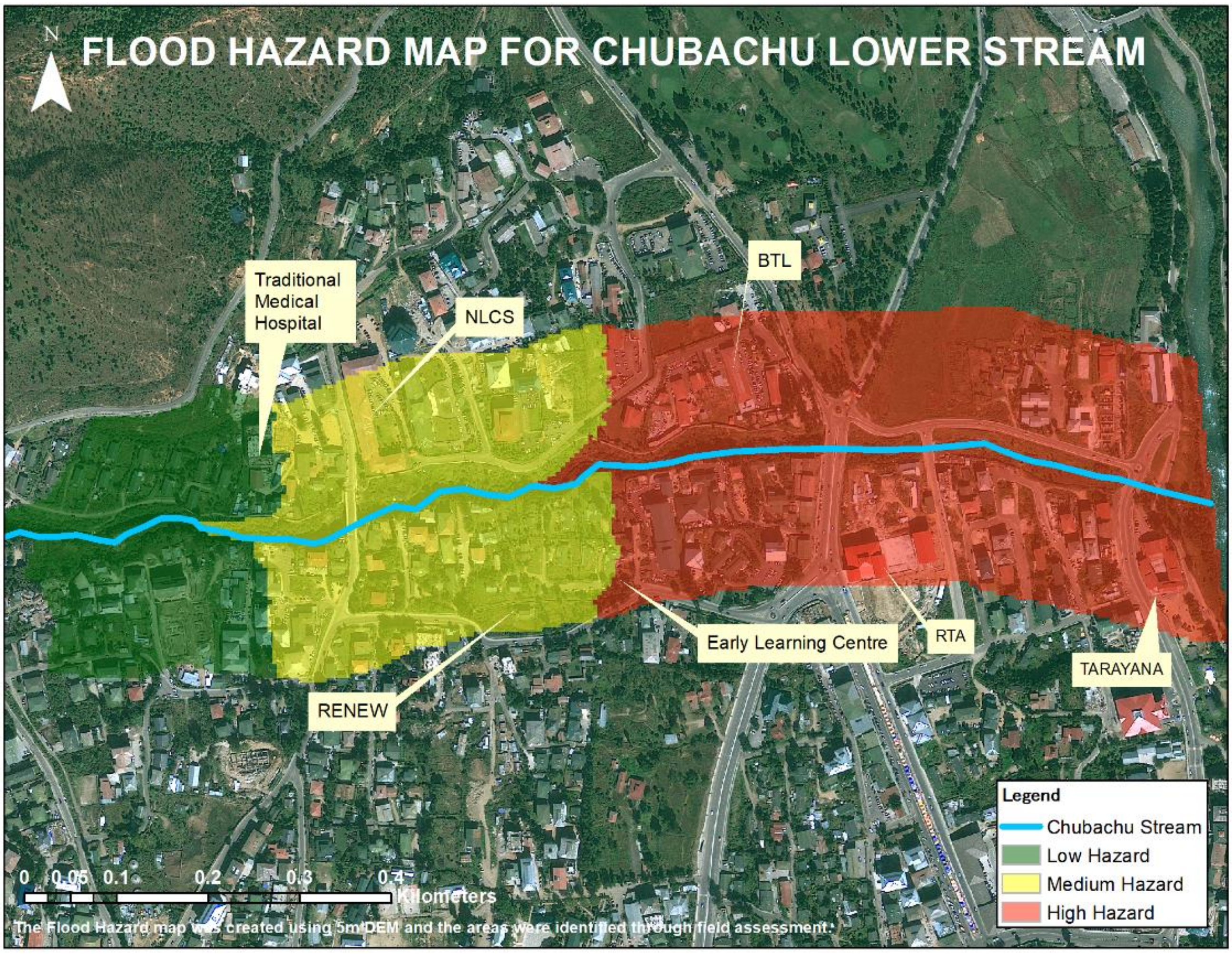

Figure 16: Flood Hazard Map for Lower Chubachu stream

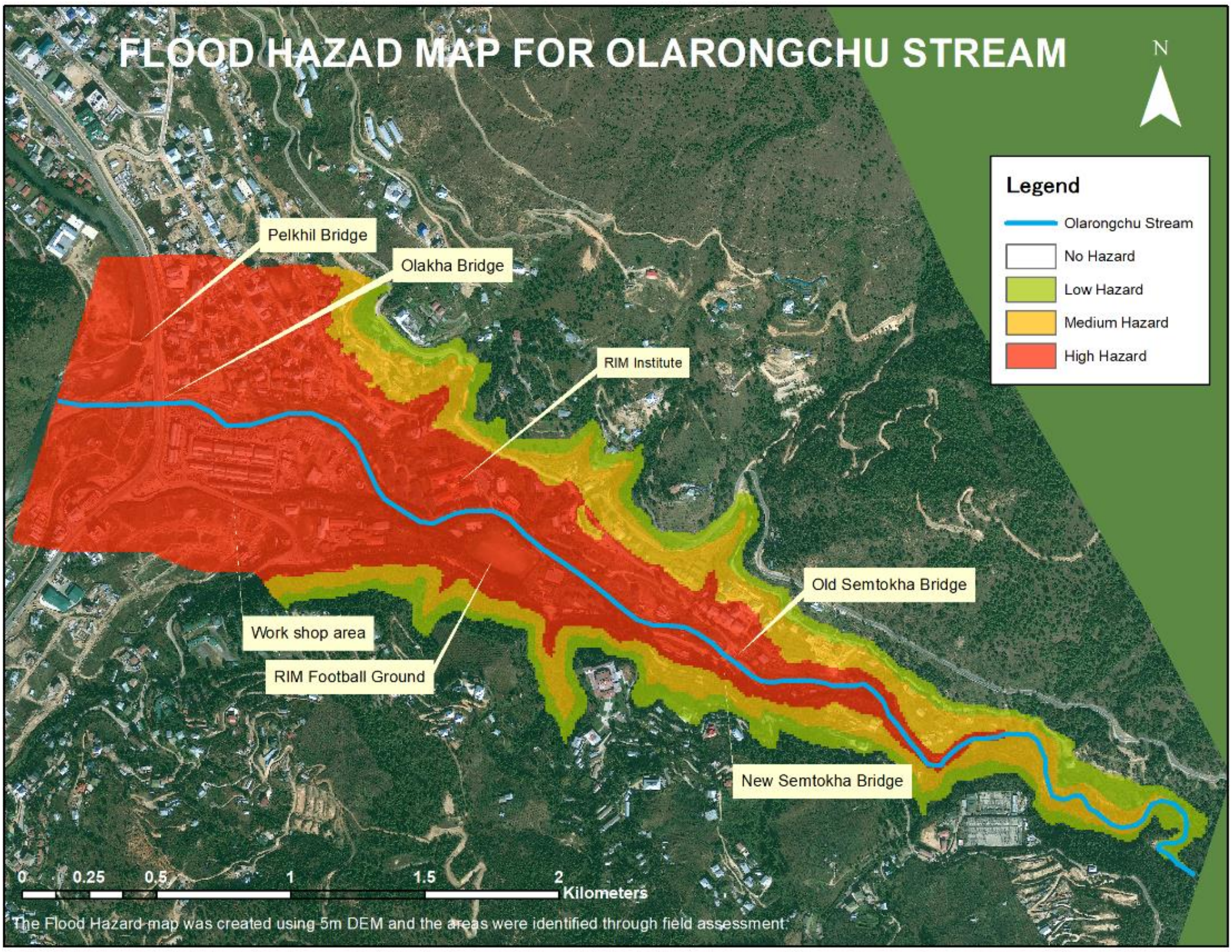

Figure 17: Flood Hazard Map for Olakha stream

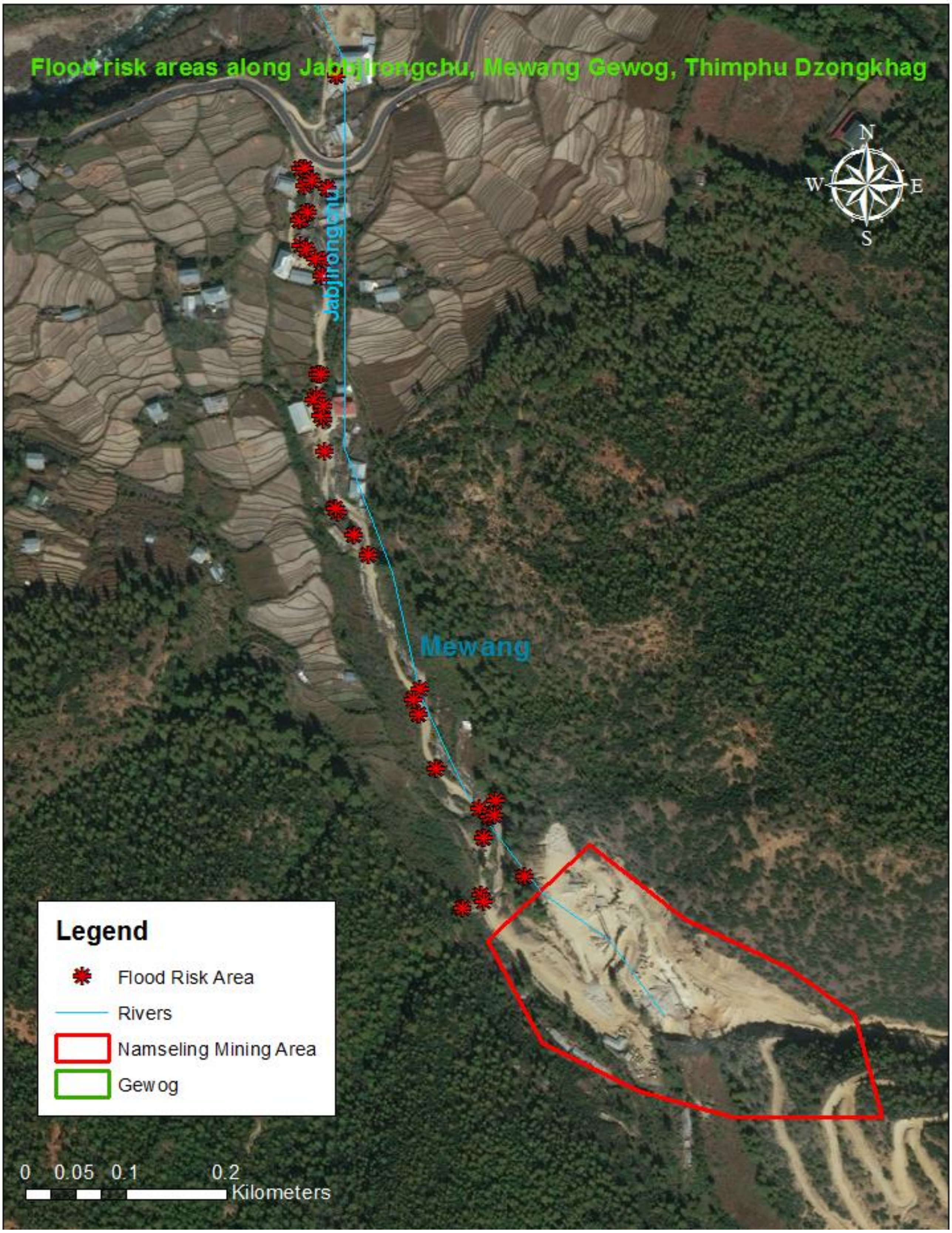

Figure 18: Flood risk areas along Jabjirongchu in Namseling village, Maedwang Gewog, Thimphu Dzongkhag.

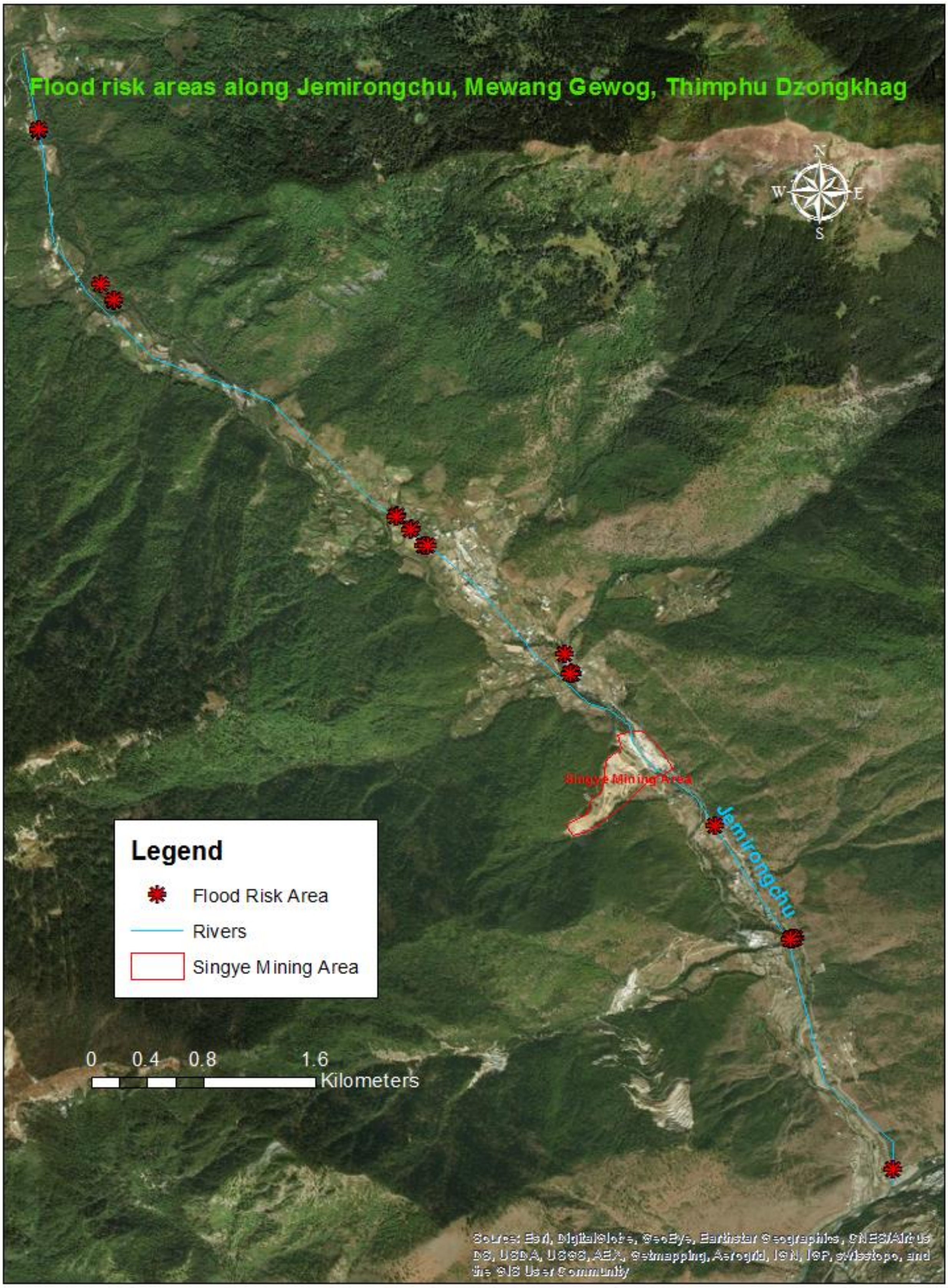

Figure 19: Flood risk areas along Jemirongchu, Maedwang Gewog, Thimphu Dzongkhag

Figure 20; Flood risk areas along wangsisirongchu, Maedwang Gewog, Thimphu Dzongkhag

Figure 21: Flood risk areas along Samtelingchu, Kawang Gewog, Thimphu Dzongkhag

AREAS OF MITIGATION INTEREST (AOMIS)

Areas of Mitigation Interest (AoMI) are important to define more comprehensive picture of flood risk and mitigation activity along the river or the watershed and in communicating how various mitigation activities can successfully reduce flooding risk. Identifying target areas for flood hazard mitigation can be done through hydrodynamic analyses or previous flood studies; site investigation of existing flood mitigation works and its functionality. The AoMIs identified can be communicated to the concerned agency Thimphu Thromdey since they are the implementing authority. The following section list the flood mitigation measures for the identified critical river and streams.

1. Thimphu River

Demkhong	Flood Prone Areas identified through Mapping
Hejo-Samteling	Pamtsho by the river
	Hejo near the Crematorium
	Langjophakha near Ludrong Garden opposite to the Dzong
Norzin	Part of the urban road after the Lingkana bridge/ royal garage
	Part of Centenary Farmers" Market and Changlimithang Stadium along with Coronation Park
	Chanjiji Football stadium
Babesa	Pelkhil School ground
	Lower part of Olakha workshop complex
	Hotel Terma Linca
	Parts of Ramtokto and some agricultural land in Kharsadrapchu area

2. Samteling Stream

Samtelingchu passes along Samteling and Jushina village. The river flows from a high gradient which mostly covers Samteling villages and descends to Jushina village. The upper part of Jushina village which is located above Smateling bridge is at a higher elevation with lower flooding risk. However, the areas located below Samteling Bridge are at a low gradient thus exposing it to a higher flooding risk. There are few lakes located at the upstream of the catchment, namely, Simkota Tsho, Jagatsho, Dungtsho. Although the residents have no proper record of a lake outburst before, the flow path of the river is quite wide and deep indicating the possibility of an outburst in the past decades.

Figure 22: Flood risk areas above the Samteling bridge

Figure 23: Flood risk areas below the Samteling bridge

Figure 24: Flood risk areas near India House

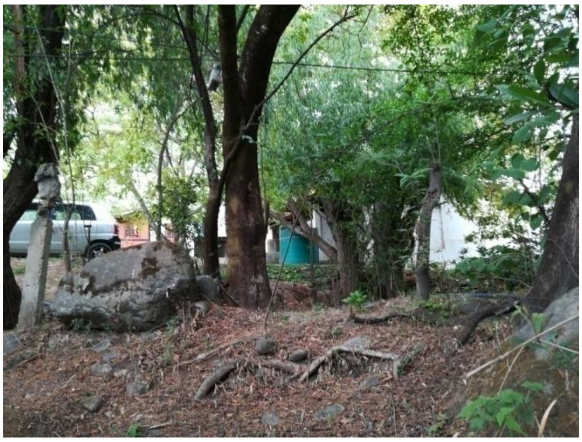

Figure 25: Flood risk areas located at a low gradient same as river.

It is recommended to conduct detailed assessment along the areas identified through the preliminary assessment for the design of the flood mitigation works. It is also highly recommended for the concerned agency to study the possibility of Lake Outburst in the future since there has been no study conducted so far. Since the area falls under the jurisdiction of Thimphu Thromdey, it is recommended for Thimphu Thromdey to carry out the flood mitigation works along the critical areas.

3. Chubachu Stream

- Relocation of water and sewerage pipes.

It is important to lay critical infrastructures such as water supply and sewerage pipes at locations where there is no risk of flooding or any other hazard. These infrastructures were however found to be laid on the stream bed and flood plain areas along Chubachu stream. It can be observed at Chubachu Bridge as shown in Figure 26 and Figure 27. Such improper laying water pipes can also be seen near Desi Zam as shown in Figure 28 and Figure 29.

- Landslide control measures along the two areas

Intense rainfall can trigger landslide and cause damming of flow path which can lead to flooding nearby areas. Two locations were identified along Chubachu for landslide mitigation works. An area below the Early Learning Centre and an area near RENEW office is prone to landslide as shown inFigure 30 and Figure 31. It is highly recommended to carry out slope stabilization works in these two areas.

- Clearing of Chubachu flow path

Leaving room for river is an important mitigation measure to reduce flooding risks in the area. It was observed during the field investigation at few locations, the flow path was narrowed with trees growing on the stream bed. Therefore, it is highly recommended to clear the trees growing along Chubachu stream. Few places where such measure can be taken are located near Desi Zam as shown in Figure 32.

Figure 26:Sewer pipe laid on the stream bed below Chubachu Zam

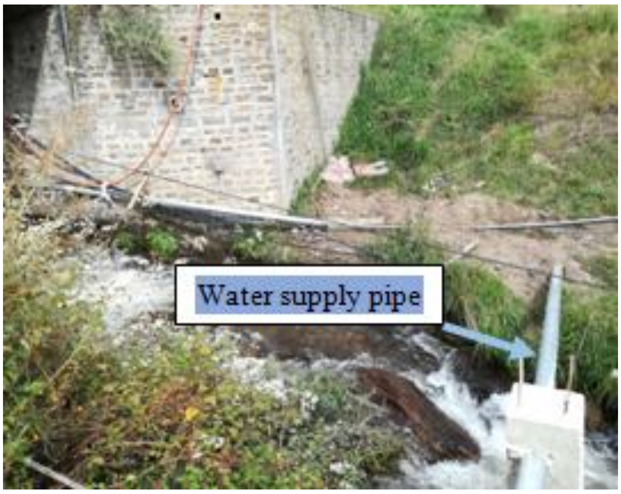

Figure 27: Water supply pipe laid across the stream on the floodplain area below Chubachu Zam

Figure 28: A water supply pipe running across the stream upstream of Desi Zam.

Figure 29: Water Pipes laid at the same level as Desi Zam

Figure 30: Need for slope stabilization downstream of ELC school.

Figure 31: Need for slope stabilization below RENEW office.

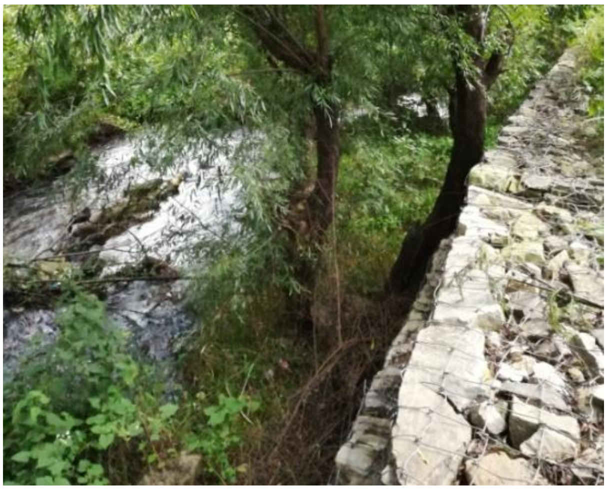

Figure 32: Trees obstructing the flow path of Chubachu stream

4. Olarongchu

- ### Protection near Living water company

The water bottling Company called 'Living water Company' which is located upstream of Olarongchu. The infrastructure for the company is located very close to the stream at the right bank. Although retaining walls were constructed with height ranging from 4m to 6m, the area was still observed to be of high risk. It can be observed fromFigure 33 and Figure 34 the high exposure of the structure to flooding. Such permanent infrastructures with high economic value need to be considered while managing flooding issues along the stream.

Figure 33: Living water company infrastructure under construction (October, 2017)

Figure 34: The distance between retaining wall crest and Olarongchu

- ### Removal of old Semtokha Bridge

The old Semtokha Bridge and new Semtokha are located only 5m apart. Although the old bridge has no more functional value, it was not dismantled till date. The old Semtokha Bridge has width of 10.5m and the new Semtokha Bridge with width 15.7m with waterway depth of 4m. However, the old Semtokha Bridge poses flooding risk to the nearby areas since the water way width is reduced by almost 3m compared to the new Bridge which is located 5m downstream of the old Bridge.

- ### Need for retaining wall upstream of Semtokha Bridge

The areas near hydraulic structure such as a bridge need extra attention to mitigate flooding disasters. An area above the Semtokha Bridge is being reclaimed with soil deposit for widening of road as shown inFigure 35.There is a need for a retaining wall to retain the reclaimed land in order to prevent any possible blockage of the flow path during monsoon season.

Figure 35: Need for a retaining wall upstream of Semtokha Bridge

Figure 36: Workshop area without the gabion wall

- Protection near Olakha workshop area

The workshop area located at the left bank of Olarongchu is located at a lower elevation thus exposing it to high flooding risk. The Thimphu Thromdey has constructed gabion wall of height 2m along the workshop area thus lowering the risk of the area from flooding. However, there is a short break on purpose along the continuous gabion wall which might expose some of the areas. The short break is located few metres in front of U.J. automobile workshop (Figure 36). Although the reason for the break is not known so it is recommended to close the gap and continue the wall till RIM Institute to fully reduce the flooding risk in the Olakha workshop area. The highly exposed area below the newly constructed Bailey Bridge (as shown in Figure 36) also needs to be protected with gabion walls.

Figure 37: Exposed workshop area without gabion wall protection

5. Jabmisa Rongchu

Jabmisa Rongchu flows through Namseling village in Maedwang Gewog. The village is exposed to very high risk of flash floods with heavy sediment content. The open air mining located in the upstream of the village has resulted in unstable slope thus causing huge sediment deposits along the Jabmisa Rongchu flow path. The sediment deposits along the flow path raises the bed level of the stream thereby exposing the nearby areas to increased flooding risks.

Figure 38: Settlements along Jabjirongchu under flooding risks

Figure 39: Settlements along Jabjirongchu under flooding risks

Figure 40: Settlements along Jabjirongchu under flooding risks

Figure 41: Sedimnt deposits at the source of Jabjirongchu

It is recommended to conduct detailed assessment along the critical areas identified through the preliminary assessment for the design of the flood mitigation works. It is also recommended to explore way to arrest the sediments with check dams or other technology.

6. Jemi Rongchu

Jemina village is under Maedwang Gewog under Thimphu Dzongkhag. The settlements in the village rely on agricultural products such as Potatoes, cabbage, carrot, beans, broccoli, cauliflower, sag, as their main income. Jimirongchu stream which flows through the village

The following areas were identified risky by the FEMD assessment team :

Areas along right bank of Jemirongchu at	**Areas along left bank of Jemirongchu at**

risk :	**risk:**
1. 4 households in Gidagom area	1. Workshop area
2. Jemina School	2. Gophel sawmill area
3. Lingzhiphakha agricultural land	3. Singye mining area
	4. Silidraphu area with one household under risk
	5. RNR and livestock centre under risk
	6. Yum Thugi Charity School with 147 students
	7. Sawmill and CDCL transmission line project under risk
	8. Rehabilitation centre with 1 building under risk.

The stream is flooding almost every monsoon season exposing the identified areas under risk. There is a lake named Jemilangtsho in the upstream of the village which will cause havoc downstream if it outburst.

It is recommended to conduct detailed assessment along the areas identified through the preliminary assessment for the design of the flood works.

Figure 42: Area near the Begana Mini Hydel project

Figure 43: Gidagom area with 4 HH under high risks

Figure 44: Singye Mininig area unde risk of flooding from Jemirongchu

Figure 45: sawmill under risk along Jemirongchu

Figure 46: CDCL transmission line project under risk along Jemirongchu

Figure 47: Rehab centre under flooding risk along Jemirongchu

7. Wangsisi Rongchu

Wangsisi rongchu is a very small stream which swells up during monsoon season. The stream passes through the settlements in Khariphu, Khariphu Lumnia and Kharibji villages exposing them to flooding risk during peak monsoon seasons. These villages are located at the same gradient as the stream thus under the risk of being inundated.

The following areas were identified as risk during the assessment:
1. Khariphu (4 households under risk) located at the right bank of Wangsisirongchu
2. Khariphu lumbina (6 households under risk) at the left bank of Wangsisirongchu
3. Kharibji village (4 households under risk) the left bank of Wangsisirongchu

Figure 48: Khariphu (4HH under risk) along wangsisirongchu

Figure 49: Khariphu Lumbina (6HH under risk) along wangsisirongchu

Figure 50: Kharibji (4HHunder risk) along Wangsisirongchu

Figure 51: : Kharibji (4HHunder risk) along Wangsisirongchu

It is recommended to conduct detailed assessment along the areas identified through the preliminary assessment for the design of the flood mitigation works.

CONCLUSION

Thimphu River flows through Thimphu valley and is joined by seven critical tributaries namely Kamrichu, Samtelingchu, Chubachu, Olarongchu, Jabmisarongchu, Jemirongchu, wangsisirongchu. The detailed flood assessment for the flood prone areas were conducted adopting different methodology for the main Thimphu River and its tributaries. Statistical analysis and hydrodynamic model was built for developing the flood hazard map for Thimphu River and critical areas were identified. A different methodology was adopted while assessing the tributaries due to lack of observed hydro-meteorological data. Flood assessment forms with field visits and interview of affected residents and local leaders were carried out for the identification of critical areas.

The areas along Chubachu stream is mainly dominated by institutional buildings thus having a high economic value. The southern part of Olarongchu stream is mostly commercial area with workshops dominating the business centre. The area along other streams such as Smatelingchu, Jabmisarongchu, Wangsisirongchu are mostly residential areas. And Jemina rongchu areas are mostly timber based business house, mining area in the upstream with a mini hydropower project at the downstream.

The areas located at the lower gradients were observed to be at a higher risk compared to areas with higher gradient. The results of the study were used by Thimphu Thromdey in drafting the Action Plan for flood disaster management. The Thromdey is planning for the mitigation works along the critical areas identified through this study.

RECOMMENDATION

- It is highly recommended to carry out flood mitigation measures along the areas identified under section: Areas of Mitigation Interests (AoMI) for Thimphu River and the critical tributaries namely, Samteling Chu, Chubachu, Olarongchu, Jabmisarongchu, Jemirongchu and Wangsisirongchu. It is important to create room for rivers by cutting trees that grow in on the river path, stabilize slopes near the rivers and clear other obstructions such as old bridges that are not in use anymore.

- It is highly recommended to install flood warning systems or discharge measurement gauge along Thimphu River for timely and accurate public warning of a flooding event.

- It is recommended to install hydrological station for Olarongchu, Chubachu and Samtelingchu for timely monitoring of the streams and to enable detailed hydrodynamic analysis in future.

- The flood hazard areas developed through this study can be used by different agencies such as Department of Disaster Management for awareness campaigns and for identification of evacuation areas.

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