FLOOD HAZARD ASSESSMENT FOR HAA DZONGKHAG

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

YEAR 2019

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1. Haa Dzongkhag Administration and Haa Local Government
2. National Centre for Hydrometeorology, Bhutan
3. National Land Commission, Ministry of Home and Cultural Affairs, Bhutan
4. Department of Geology and Mines, Ministry of Economic Affairs, Bhutan
5. National Statistical Bureau, Bhutan

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Acronyms

FEMD	Flood Engineering Management Division.
Haa River	River flowing through Haa Dzongkhag
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 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 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
AoMI	Areas for Mitigation Interest

Executive Summary

The Haa valley lies southwest of the Paro valley, hidden behind the high ridge of the Chelala. For this study Haa Dzongkhag was assessed and the flood prone areas were analysed. The objectives for the study are as follows:

Objective 1: Detailed flood assessment of Haa River and its critical tributaries in Haa Dzongkhag.
Objective 2: Analyze the AoMI (Areas of Mitigation Interest) assessment in Haa Dzongkhag. Furthermore, identify and prioritize critical flood prone areas within Haa Dzongkhag.
Objective 3: Recommend appropriate flood protection measures along the identified flood prone areas.

The Haa River was identified as the most critical river that required detailed flood modelling. Haa River was modelled using HEC RAS software in 1D steady flow analysis and with boundary condition of 100 years return period. The flood hazard maps for the areas along Haa River is mapped and assessed.

The Area of interest (AoMI) are further prioritized for flood protection measures. Following are the prioritized areas:

1. Yangthang Village, Bji Gewog
2. Haa Town, Katsho Gewog
3. Fishery Pond and Helipad, Eusu Gewog
4. Tsaphel Lower Secondary School, Eusu Gewog
5. Jyenkana Primary School, Samar Gewog

The flood intervention along Haa River was prioritized based on the number of population affected by the flood. The first priority area was Yangthang Village under Bji Gewog with 62 households at risk. The FEMD, DES in the year 2016 (11^{th} FYP) constructed gabion revetment along the left bank of Haa River near Yangthang village to protect the residents from flooding risk. A total amount of Nu. 42 million was invested for the flood protection works.

It is highly recommended to implement flood protection works in other prioritized areas especially the Tsaphel Lower Secondary School and Jyenana Primary School. The Dzongkhag administration is recommended to carry out the flood protection works with technical support from the Flood Engineering and Management Division, DES, MoWHS, The Department of Disaster Management, Ministry of Home and Cultural Affairs, is recommended to carry out the pre-disaster activities in the identified flood prone areas.

Introduction

Background

The Haa valley lies southwest of the Paro valley, hidden behind the high ridge of the Chelala as shown in Figure 1. There are two roads into Haa. One climbs from Paro, crossing the 3810m Chelala. The other diverges from the Thimphu–Phuentsholing road at Riverzom and travels south, high above the Wang River. Haa Dzongkhag is comprised of 6 Gewogs, namely, Bjee, Katsho, Eusu, Samar, Gakiling, Sombaykha.

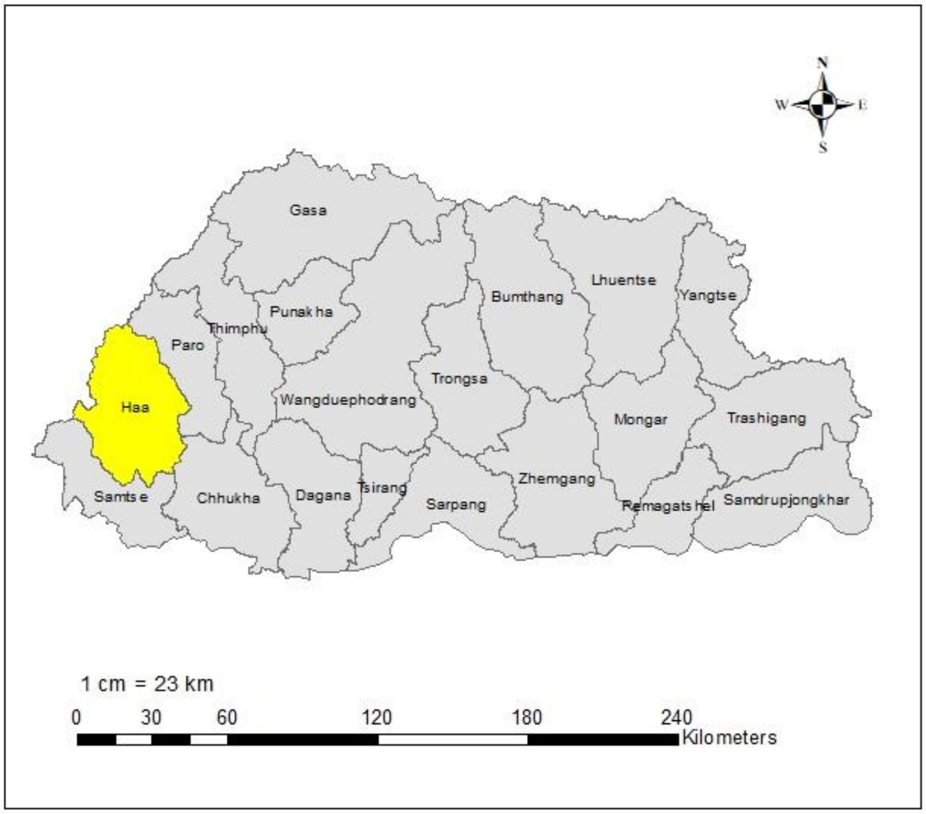

Figure 1: Location of the study area

Sl. No.	Services	Number	Sl. No.	Services	Number
1	Hospital	1	6	Local cattle	9702
2	BHU I	1	7	Yak	5857
3	BHU	3	8	Horse	1937
4	Indigenous Unit	1	9	Wet land	88.5 Hectares
5	Total Number of Schools	13	10	Dry land	2067.8 Hectares

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

Sl. No.	Name of Village	Name of Geog	Name of river/stream	Type of threat(Agriculture /Resident	Estimated Population	Past flooding record
1	Pharikha	katsho	Haa River	Both	10	26th. May 2009
2	Yangthang	Bji	Haa River	Resident	150 (62 households)	26th. May 2009
3	Hatey	Bji	Yak River	Resident	70	2009
4	Nagtsho	Katsho	Haa River	Agriculture		26th. May 2009
5	Kana	Issu	Haa River	Agriculture		26th. May 2009
6	Jenkana School	Samar	Haa River	School	200	26th. May 2009
7	Tshaphel School	Issu	Haa River	School	200	26th. May 2009
8	Gensa	Bji	Haa River	Agriculture		Every Monsoon season
9	Tokey	Bji	Haa River	Both	100	Every Monsoon season

Table 2: Historic flooding events reported by the Media

Sl. No.	Place of incident	Name of river/stream	Types of threat	Reported Date	Flooding record	Remarks
1	Haa Town	Haa River	Workshop and residential area.	27th May, 2009	26th May, 2009	Washed away 4 labour camp and workshop. Flooded Haa town forcing evacuation.
2	Damthang	Yak River	Residential and Cattle	19th July, 2008	18th July, 2008	Washed away cattle in nearby sheds and damaged 2 traditional buildings.
3	Yangthang	Haa River	Residential and Agriculture		26th May, 2009	A house was washed away, several houses were submerged, bridges were swept away and many farmers have lost their entire crop.

Objective

Objective 1: Detailed flood assessment of Haa River and its critical tributaries in Haa Dzongkhag.

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

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

Study Area

Bji Gewog is one of the largest among six Gewogs under Haa Dzongkhag and has 23 villages with 278 households. The total area of the Gewog is 802.2Sq.Kms and is bordered by Tibet Autonomous Region of China to the north and Katsho Gewog in the south. The Gewog falls within pure alpine region and altitude ranges from 2750 to 3300 metre above sea level. Since it falls within the pure alpine region, it experiences cold and dry winter and wet and warm summer. Temperature in winter drops as low as minus seven degree Celsius and receives snowfall several times in a year starting from late October till April.

Most populations of the Gewog are nomadic and are yak herders. Main income sources are livestock and they are economically better off. Almost all villages have improved accessibility with well-connected farm roads. *(Haa Dzongkhag Administration)*

Katsho Gewog is located at an altitude of 2850 to 3100 above sea level about 1 km from the main town, Haa Dzongkhag, Kartsho Gewog administration caters its services to five *Chiwogs* namely Wangtsa, Bali(Bali & Mombitshokha), Yatam(Yatam & Kargoen), Ingo(Ingo & Pharakha), and Kajana-Drading(Kajana, Gangkha, Naktshang and NamRiver). The Gewog comprises of 289 households and 1875 population. It’s also one of the smallest Gewog among six Gewogs of Haa, with an area of 42.8sq.kms.

People of these Chiwogs largely depend their livelihoods on dairy products of their cattle and yaks. The nomadic culture, migrating to higher altitude during summer and descending to lower altitude during winter, is still widely being practiced today. Thus, raising of livestock is inevitable and soul to the people of Katsho Gewog. They also cultivate barley, buckwheat and Wheat but Apple, Potatoes, Peas and other vegetables are presently the main cash crops grown for both cash income and personal consumption.

The general public of Kartsho Gewog is also privileged to have public services such as education, health and RNR extension services. They have easy excess to all the public facilities both from the Gewog and the Dzongkhag. In addition, the Gewog has Six Lhakhangs/Goenpas namely Wangtsa Lhakhang, Bali Lhakhang, Katsho Goenpa, Lungkha Lhakhang, Jung nay Drag and Dradhing Lhakhang.

Eusu Gewog has a total area of approx. 67.7sq.km

Total lhakhangs: 9

Total households: 243

Total population: 1752

Total area: approx. 67.7sq.km

No of chiwogs: five

No of tshogpas: five

Main source of income: apple, potatoes and livestock.

No of schools: One (Tshaphel Lower Secondary School)

No of BHUs: NIL

No of ORCs: Two

Gakiling Gewog falls under South of Haa Dzongkhag which is separated by *Tergola* (Door to hidden treasure) and *Selala* pass. The Gewog is encompassed with total area of 192.22 Sq.Km and population little over 1100(1124 appro.) with an altitude ranging from 1000-2750 meters above sea level. The vegetation ranges from broad-leafed forest and mixed coniferous towards north. The Gewog is administratively divided into four *Demkhongs (Constituencies)* namely:

1. Dorithasa Kowkha Yangtsena Demkhong
2. Sertena Fentena Demkhong
3. Rangtse Yowkha Tagna Demkhong
4. Ngatsena Dremeakha Phootsena Demkhong

Among the four Demkhongs, Sertena Fentena Demkhong is the furthest from Cewog Center with three official days on foot. The Gewog is comprised of 19 villages with 212 households and the it shares border with Dumtoe and DenRiverkha Gewogs under Samtse Dzongkhag in the south and Sombaykha and Samar Gewogs in the north.

The Gewog population mostly depends on livestock rearing for their livelihood and cardamom as their sources of cash income. *(Haa Dzongkhag Administration)*

Sombaykha Gewog located south of the Dzongkhag Administration and it is a half day drive and another full day walk from the Dzongkhag. The Gewog has an area of about 432.8 Sq.Km approximately with 6 Chiwogs (*Shaba Shabjee, Sangbay Ama, Nakha, Yaba, Bebji and MoRiver)* consisting of 12 villages and 230 registered household with the population of 2306. The Chiwogs are geographically scattered and not connected to farm roads. However, the Haa-Samtse National highway which is under construction is expected to benefit some of the villages in the Gewog.

The altitude of Sangbay Gewog ranges from 1400m to 2100m above the sea level. The climatic condition of Sangbay Gewog varies from warm in summer with heavy rainfall and hailstorms and cold dry in winter. It is surrounded by Sama Gewog in the Northeast and Gakiling Gewog in the South**.**

The Gewog has 100% coverage of telecommunication by both B mobile and T cell. All the settlements are electrified. The Gewog has one Primary School, 2 extended classroom (ECR), 1 basic health unit, 5 outreach clinics and 3 non formal education centers taking initiatives to assure basic wholesome education to the community.

Methodology

The methodology adopted for the study is as shown in Figure 2 . A thorough desktop study was followed by data collation from different agencies. A detailed site assessment was conducted in the flood prone Gewogs and analysed. A hydrodynamic model was developed for Haa River and the flood hazard maps were developed. After analysing the results, areas of Mitigation Interest (AoMI) were identified and prioritized.

Figure 2: Methodology adopted for the study

Data Collection and Assessment

Hydrological and Meteorological Data

The hydro-meteorological data was acquired from the National Centre for Hydrology and Meteorology (NCHM). As per the data from NCHM, there is only one meteorological station and one hydrological station as shown in Figure 3.

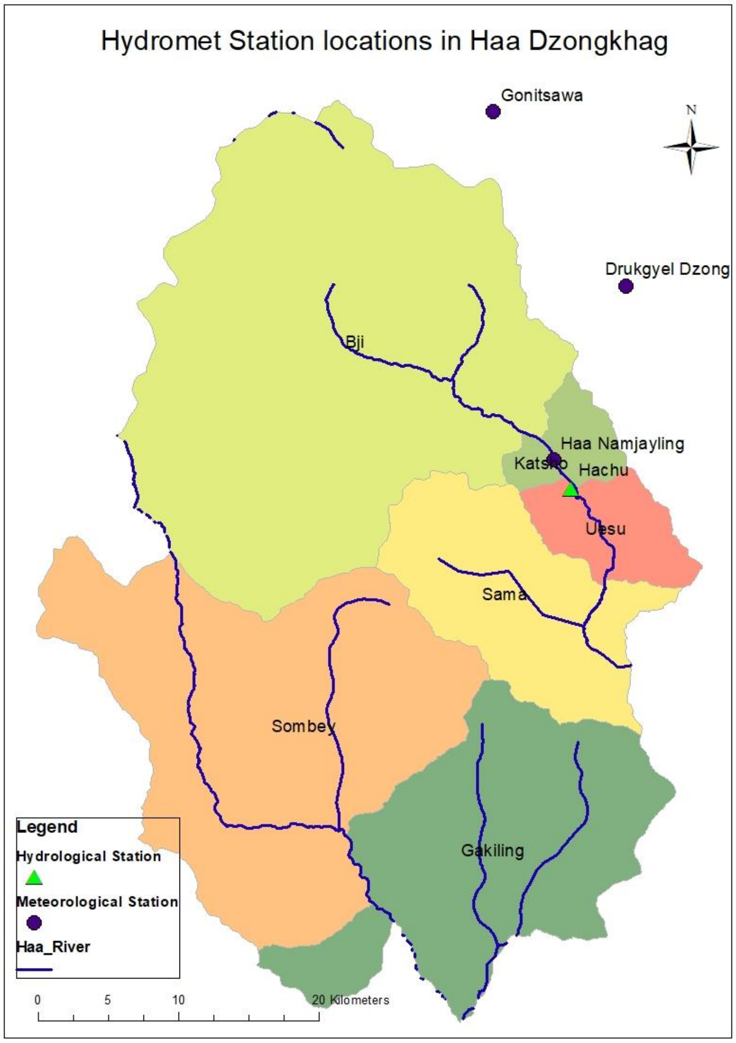

Figure 3: Hydro-Meteorological station in the study area

Scientific Data

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

Item	Data Source	Model
DEM	SRTM 30m and 90m (USGS, EarthExplorer)	Hydrodynamic Model
DEM	ALOS 10m DEM	Hydrodynamic Model

Site Assessment of the Study Area

A Team of relevant officials from FEMD carried out site investigation of the flood prone areas in Haa Dzongkhag in the month of February, 2015. The Local Government leaders also accompanied the team to verify the flood prone areas. During the meet, the local authorities provided information on area known or suspected to be risk from flooding. It should be noted that the public consultation was undertaken in parallel with site based validation of the areas. After the assessment of the site investigation and taking into account the outcome of the public consultation meet, the following areas have been identified as AoMIs (Areas for Mitigation Interest).

1. Jenkana School, Samar Gewog

Figure 4: Jyenkana School Area, Samar Gewog

Figure 5: Kana Village farm land, Eusu Gewog

Figure 4 illustrates the football ground and the pig shed inside the Jyenkana School colony that was flooded in the 2009 flood. The flash flood lasted for 2 days and the area was flooded for a week. The Dzongkhag Administrations have constructed gabion walls to mitigate flash flood in year 2010. The structures are still protecting the affected areas.

2. Kana Village, Eusu Gewog

The farmlands in Kana Village under Eusu Gewog are located in the flood plain area while the settlements are located above the floodplain areas. The Dzongkhag Administration has carried out dredging works to divert the water away from the farmlands.

3. Tsaphel School, Eusu Gewog

Figure 6: Tsaphel School, Eusu Gewog

During the 2009 Flash flood in Haa, Tsaphel School which is located at the flood plain was protected by the concrete boundary wall. If not for the boundary wall, the loss would have been devastating.

4. Pharikha Village, Katsho Village

Figure 7: Pharikha Village, Katsho Gewog

There are 5 households affected by flash floods every monsoon in Pharikha Village.

5. Haa Town, Katsho Gewog

The flash flood in 2009 has flooded the Haa Town caused major damage to the private and government infrastructures. The Government intervened in year 2010 and constructed a 1.35 Km length AB mattress at the left bank of Haa River and in year 2012, a 3.5 Km length AM Mattress was constructed at the right bank of Haa River.


Figure 8: AB Mattress along Haa Town

6. Hatey, Bji Gewog


Figure 9: Upstream of YakRiver


Figure 10: Downstream of YakRiver

7. Tokey Village, Bji Gewog

The small stream that flows to the Haa River through Tokey Village floods the whole village during monsoon season.


Figure 11: Stream in Tokey Village

8. Yangthang Village, Bji Gewog

Yangthang Village is rated as the highest risk area for Flood in Haa Dzongkhag. The village is located in the floodplain with the 62 households which is the highest in the Dzongkhag. During the 2009 flash flood, 2 houses and a saw-mill was washed away from this village. The Dzongkhag Administration has been constantly constructing gabion walls to protect the village but due to lack of budget and proper design, the structures have failed time and again. The Dzongkhag Administration has requested the Ministry of works and Human Settlement to design an appropriate mitigation structure that will sustain for a longer period and protect the village.

Figure 12: Yangthang Village at the left bank of Haa River

River cross section survey

The cross section survey for Haa River was conducted by a team from FEMD, DES. The survey was conducted from upstream to the downstream from left bank towards right bank. The cross section survey of the Haa River was carried out as per the SoP for conducting river cross section survey. The location of the cross section survey for Haa River is shown in Figure 13.

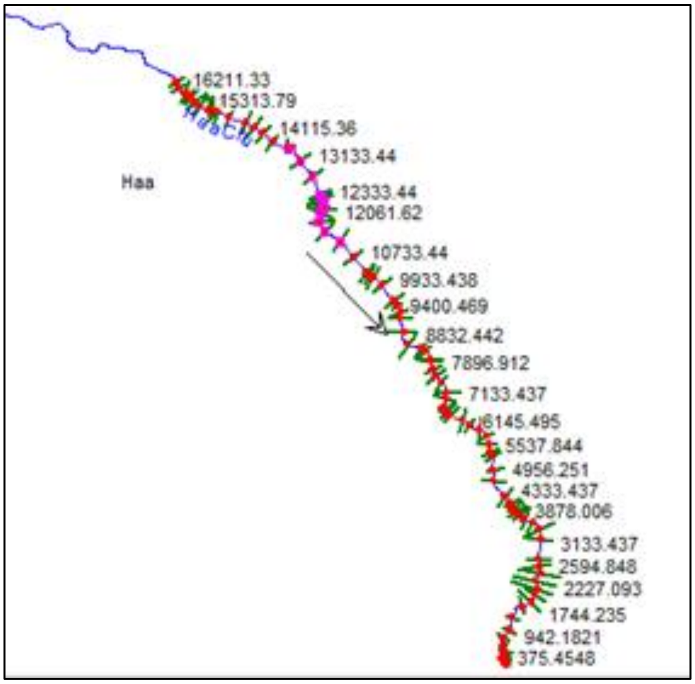

Figure 13: The cross section survey data for Haa River

Flood Frequency Analysis

Gumbel distribution

Gumbel is an Extreme Value distribution (EV Type I) (Emil Julius Gumbel, 1941) used to analyse extreme maximum or minimum of a number of sample of distribution. The parameter for the distribution is as follows. The mean (μ) and the standard deviation (σ) of the annual maximum time series is computed along with values of 'a' and 'c' which is given by Eqn.5.1 and Eqn.5.2.

$$a = \sqrt{\frac{6\sigma^2}{\pi^2}} = 0.7797\sigma \qquad \text{Equation 1}$$

$$c = \mu - 0.5772a \qquad \text{Equation 2}$$

And for each return period of (T), the standard variate is computed using Eqn.3 and the return period discharge is computed using Eqn.4.

$$Y_T = -\ln\left[-\ln\left(1 - \frac{1}{T}\right)\right] \qquad \text{Equation 3}$$

$$Q_T = c + Y_T a \qquad \text{Equation 4}$$

The results from the Gumbel distribution for Haa River is detailed in Table 3.

Return Period	Return Period Discharge in cumecs (Peak Method)
2	28
5	37
10	43
25	50
50	55
100	61
500	73
1000	78
10000	96

Table 3: Flood frequency result using Gumble probability method for Haa Rive

Log Pearson III distribution

The Log Pearson III (Pearson, 1895) was the second statistical technique used to fit the flood frequency for the river. The distribution is computed by a general equation, Equation 5. The annual peak discharge data were ranked from largest to smallest and the $\log_{10}$ value for each data was computed.

$\log_{10} Q_T = K_T \sigma + \mu$ Equation 5

Where Mean, $\mu = \frac{1}{n} \sum_{i=1}^{n} (\log_{10}(x_i))$

Standard deviation, $\sigma = \frac{1}{n-1} \sum_{i=1}^{n} (\log_{10}(x_i) - \mu)^2$

Probability of occurrence, $P_T = \frac{1}{T}$

Intermediate variable w for each return period, $w_T = \left[\ln\left(\frac{1}{P_T^2} \right) \right]^{\frac{1}{2}}$ *for* $(0 < P_T \leq 0.5)$

Frequency factor $K_T = Z_T + (Z^2{}_T - 1)k + \frac{1}{3}(Z^3{}_T - 6Z_T)k^2 - (Z^2 - 1)k^3 + Z_T k^3 + Z_T k^4 + \frac{1}{3} k^5$

$k = \frac{C_s}{6}$; $C_s = \frac{n \sum_{i=1}^{n} (\log_{10}(x_i) - \mu)^3}{(n-1)(n-2)\sigma^3}$

$Z_T = w - \frac{2.515517 + 0.0802853w + 0.010328w^2}{1 + 1.432788w + 0.189269w^2 + 0.001308w^3}$

The results from the Log Pearson III distribution for Haa River is detailed in Table 4.

Return Period	**Return Period Discharge (Peak Method)**
2	25.74
5	32.70
10	38.33
25	46.72
50	53.98
100	62.20
500	85.91
1000	98.58
10000	155.34

Table 4: Flood frequency result using Log Pearson III distribution method for Haa River

Development of Model

Hydrodynamic model

A 1D hydrodynamic model was developed for Haa River in freely available hydraulic mode HEC-RAS. The methodology followed for developing the model is shown in Figure 14.

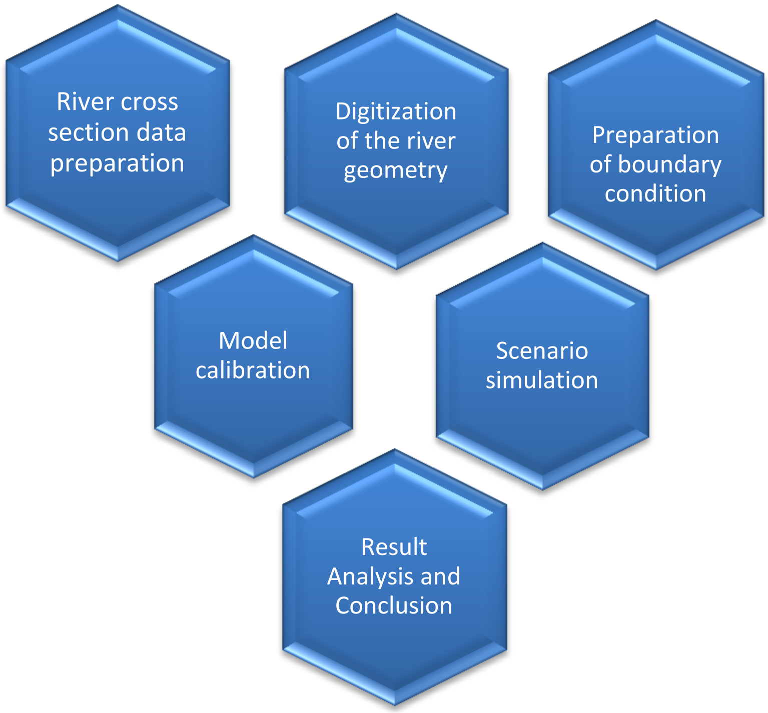

Figure 14: Methodology adopted for the developing the 1D Hydrodynamic Model

River geometry creation

River centreline is sketched with the help of given river network. The river cross-section data used in modelling are obtained from survey data which was conducted along Haa River.

The schematic of geometry in HEC-RAS for Haa River are shown in Figure 13.The cross-section consists of three parts: main channel, left bank and right bank.

Manning's value at main stream channel and overbank is assigned for each cross-section. A representative value of 0.07 is assigned for main stream and 0.07 for overbanks.

As the discharge for certain return period is fixed, steady flow option is selected. Subcritical flow regime is chosen. Due to the unavailability of other data, critical depth is assigned as downstream boundary condition, which is computed automatically by the model. The flow data assigned is the discharge of 100 year return periods.

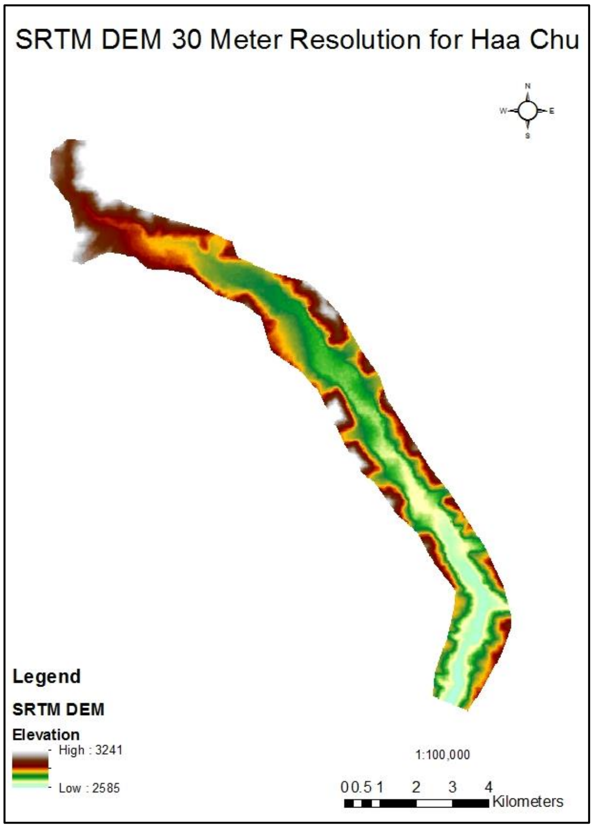

Figure 15: SRTM DEM for Haa River

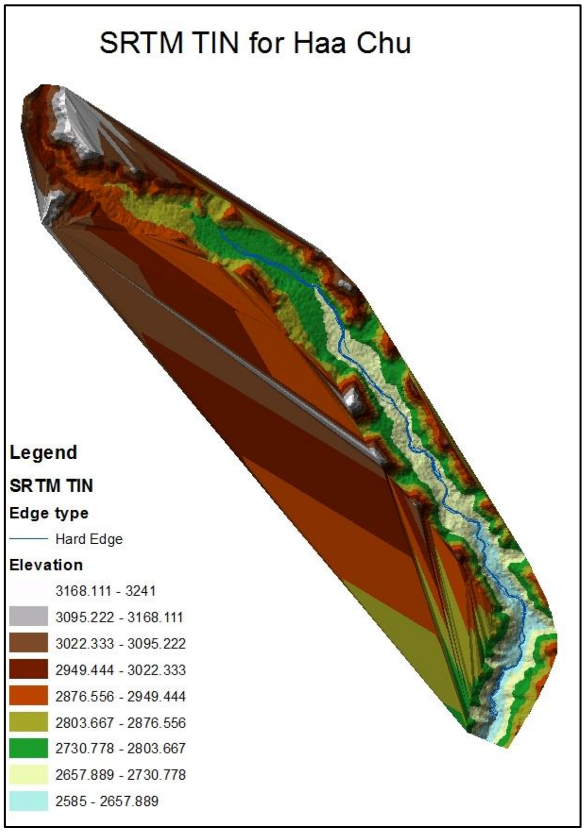

Figure 16: TIN Model for Haa River

Preparation of boundary condition

The steady flow discharge computed from frequency analysis for 100 years return period (61 m^3/s) was used as the upstream boundary conditions.

Scenario simulation

HEC-RAS gives cross-section wise output. Sample of output is shown in Figure 17.The plot shows the cross-section along with the water level for 100 years return periods.

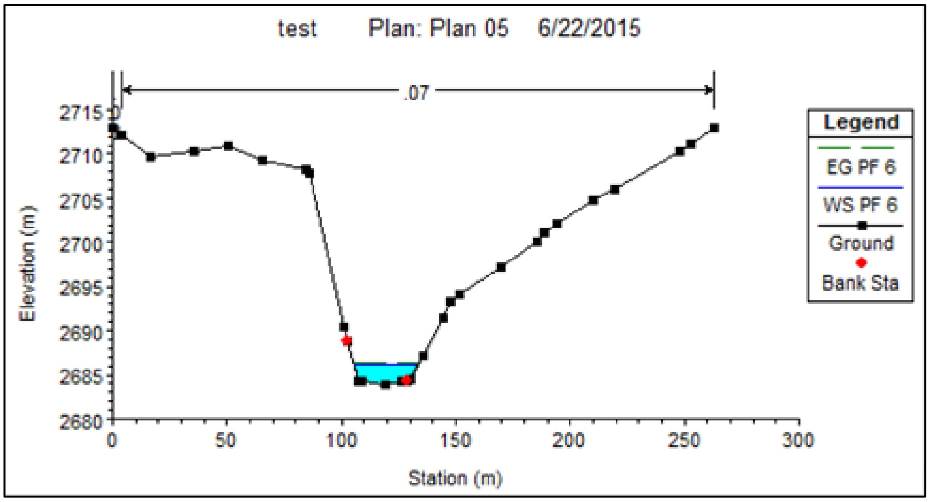

Figure 17: Sample Output of HEC-RAS for a cross-section of Haa River

The water surface profile obtained from HEC-RAS for Ha River River is given in Figure 18.

a

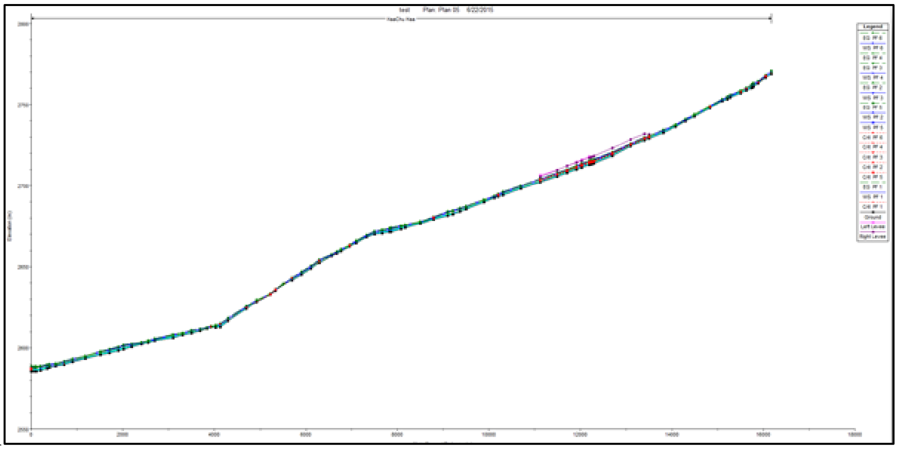

Figure 18: Plot of water surface profile of Haa River

Result Analysis and Conclusion

The flood hazard maps with 100 year return period for the flood prone areas is shown in Figure 19 Figure 20 Figure 21 Figure 22 and Figure 23.

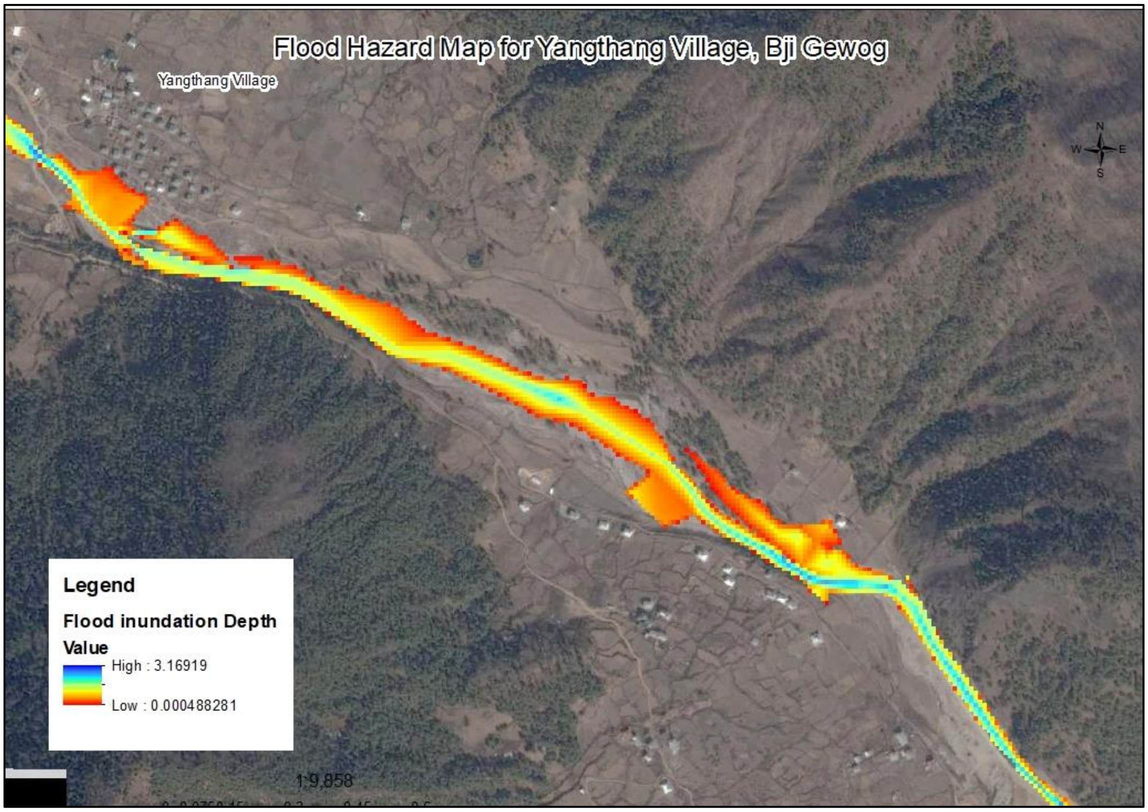

Figure 19: 100 year flood hazard map for Yangthang village, Bji Gewog

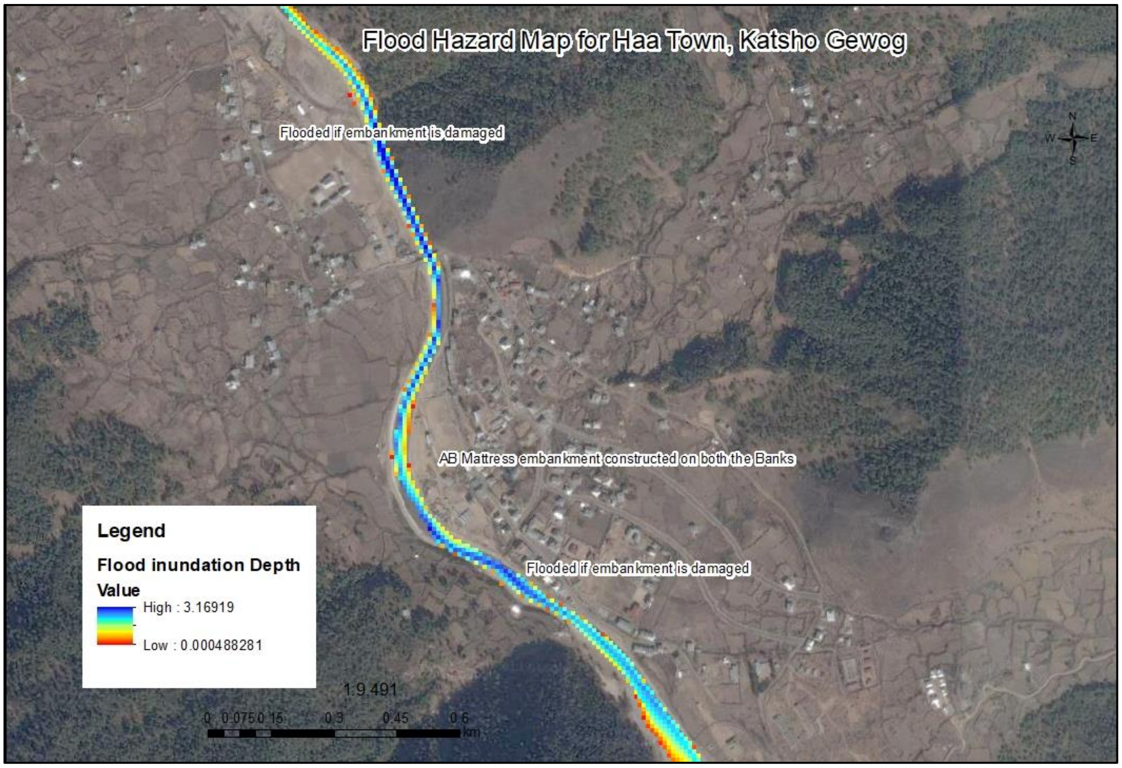

Figure 20: 100 year flood hazard map for Haa Town, Katsho Gewog

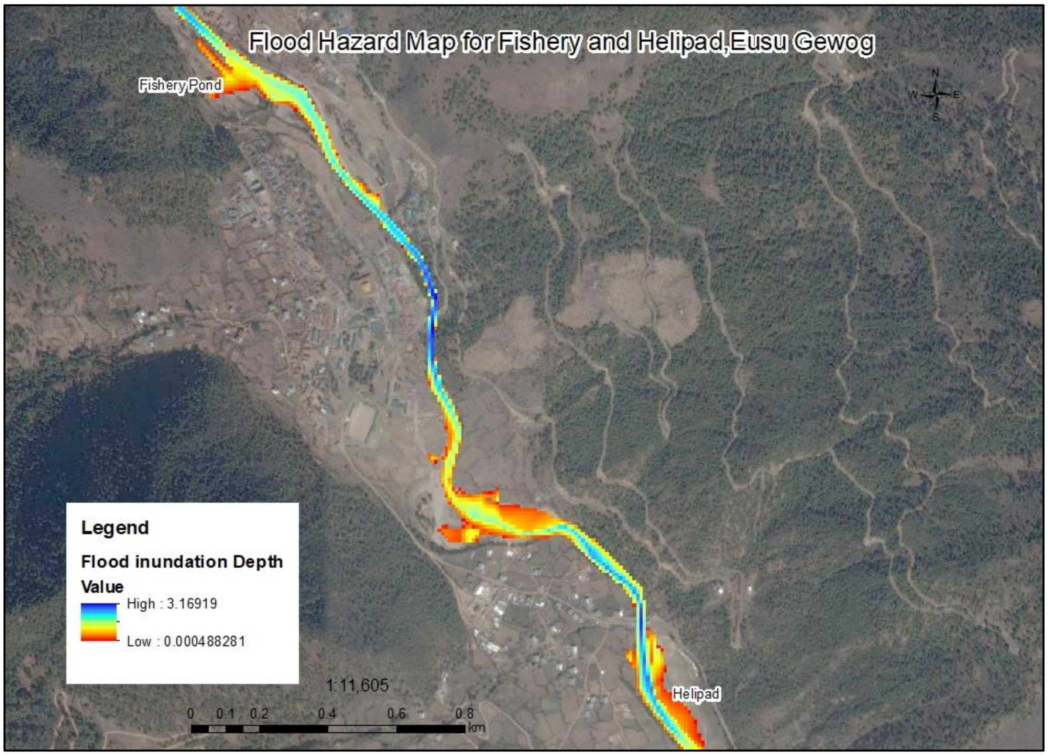

Figure 21: 100 year flood hazard map for Fishery and Helipad, Eusu Gewog

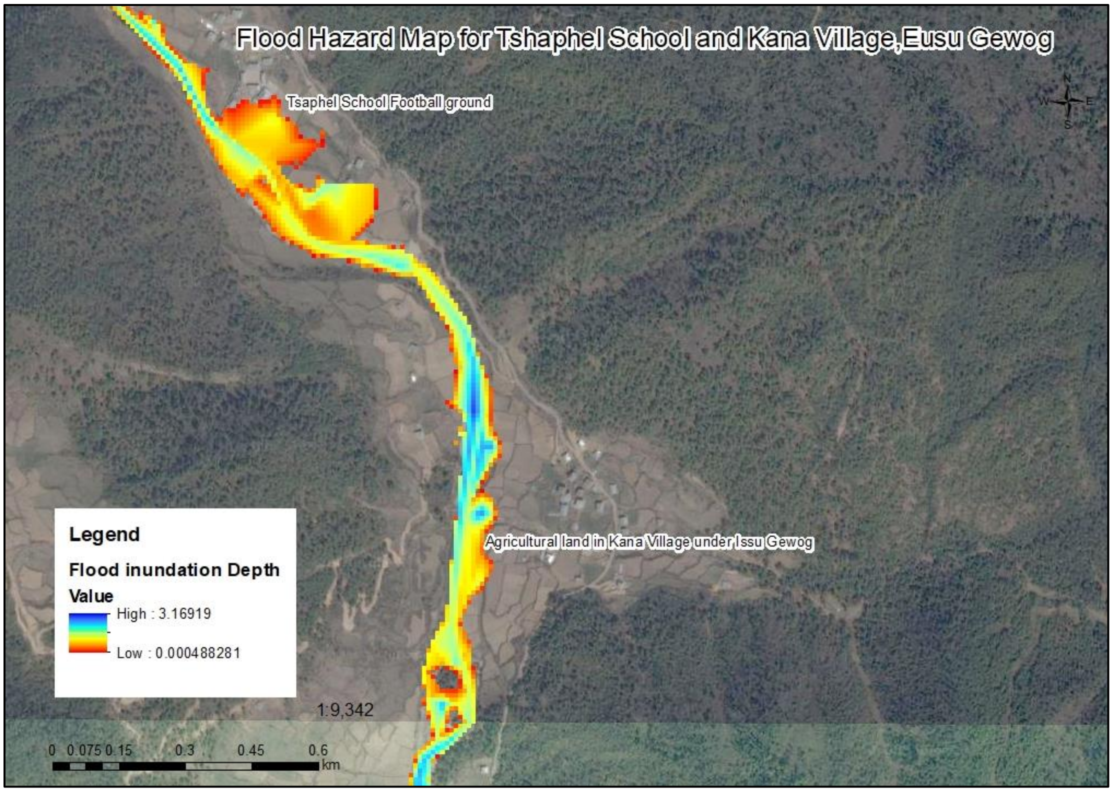

Figure 22: 100 year Flood Hazard Map for Tsaphel School and Kana Village, Eusu Gewog

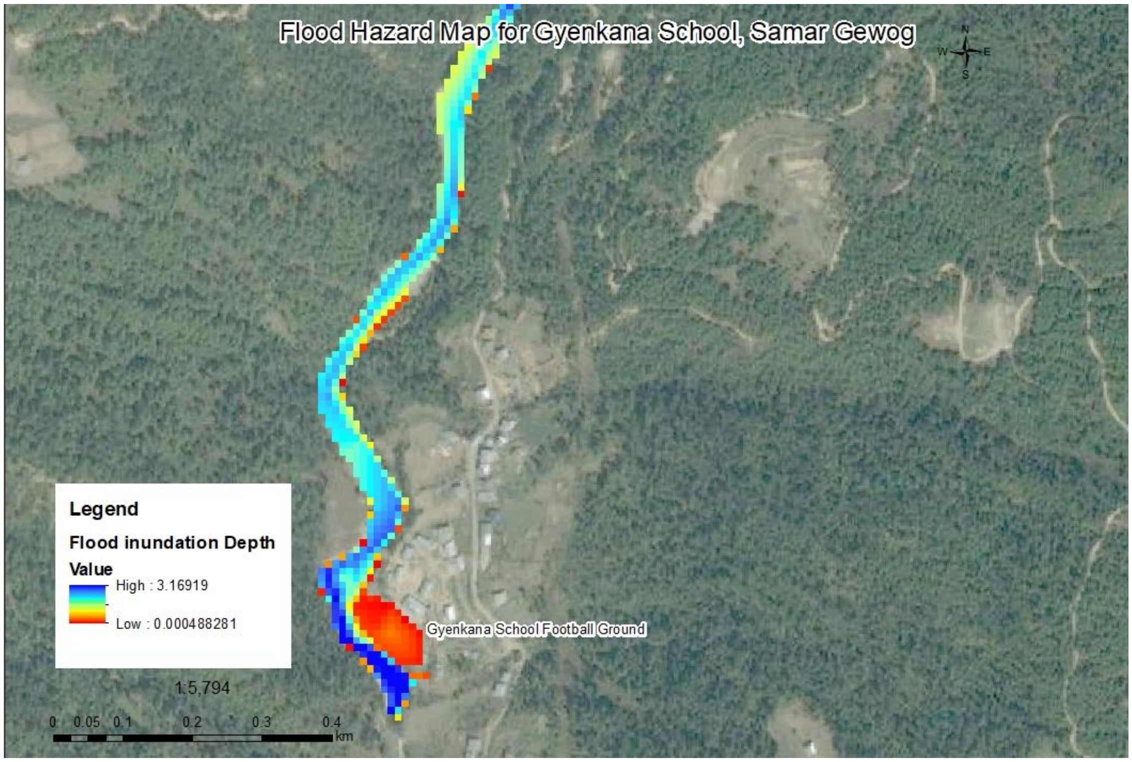

Figure 23: 100 year Flood Hazard Map for Gyenkana School, Samar Gewog

Recommendation for flood management

The Flood Hazard Maps for the following flood prone villages that were identified through flood hazard assessment are produced with the Report.

1. Yangthang Village, Bji Gewog
2. Haa Town, Katsho Gewog
3. Fishery Pond and Helipad, Eusu Gewog
4. Tsaphel Lower Secondary School, Eusu Gewog
5. Jyenkana Primary School, Samar Gewog

As per the outcome of the Flood Hazard Assessment of Haa Dzongkhag, the following flood prone areas are in need for immediate intervention inorder to minimize the impact of flooding.

1. Yangthang Village under Bji Gewog with 62 households at risk
2. Tsaphel Lower Secondary school under Eusu Gewog at risk
3. Jyenkana Primary School under Samar Gewog at risk

The flood interventions for the prioritised area are detailed in the next chapter of intervention. The Dzongkhag administration is recommended to carry out the flood protection works with technical support from the Flood Engineering and Management Division, DES, MoWHS,

The Department of Disaster Management, Ministry of Home and Cultural Affairs, is recommended to carry out the pre-disaster activities in the identified flood prone areas. The DDM can work in collaboration with the Local Government to locate the exact settlements from the FHM and plan the flood disaster awareness campaign in the areas. The settlements under red zone should be given the 1st priority, yellow zone as the 2nd priority and green zone as the 3rd priority. The areas that do not fall under any of the three zones can be identified by DDM as evacuation centres.

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 flood intervention along Haa River was prioritized based on the number of population affected by the flood. The first priority area was Yangthang Village under Bji Gewog with 62 households at risk. The FEMD, DES in the year 2016 (11^{th} FYP) constructed gabion revetment along the left bank of Haa River near Yangthang village to protect the residents from flooding risk. A total amount of approx. Nu. 42 million was invested for the flood protection works as shown in Figure 25. The Figure 26 Haa River along Yangthang Village in Haa Dzongkhag in year 2014 before intervention. And Figure 27 Haa River along Yangthang Village in Haa Dzongkhag in year 2016 after constructing gabion revetment to protect the nearby settlements.

The proposed flood protection measure at Gyenkana School in Samar Gewog is as shown in Figure 28. A similar proposal is also recommended for Tsaphel Schhol in Eusu Gewog.

Gabion revetment

The earthen embankments are constructed along the river banks within the flood plains of a river. The embankments are constructed to confine the river flood water within the cross- section available between the embankments preventing it from spilling over to the flood plains. This type of flood protection against flooding has been provided in some flood prone rivers with low banks in Bhutan. To prevent the erosion of the earthen embankments, it is further protected by constructing revetments on the riverside of the embankment. When the revetment is constructed with gabion mattress filled in with stones, it is called gabion revetment. A typical cross section of a gabion revetment is shown in Figure 24.

Advantages of gabion revetment

- Can be used as path by the pedestrian beside river.
- The construction materials for this type of flood protection structure are easy to transport and use at site. (Stones, soils and gabion mattresses)
- It can conform to subsidence as it can move with the earth and also dissipate energy from flowing water.
- Their permeability allows the gabion baskets to drain water easily reducing the pore pressure.
- They are environmentally friendly (green alternative) and requires no special masonry or skilled labour to construct it.

Disadvantages of gabion revetment

- Aesthetically not pleasing to sight.
- When the velocity of the streams and rivers are high, the gabion mesh baskets are at risk of getting torn by the transported boulders or debris.
- The gabion baskets are at risk of being damaged by corrosion if high quality gabion baskets are not used
- Upon failure of the gabion revetment, the earthen embankment can be easily eroded.

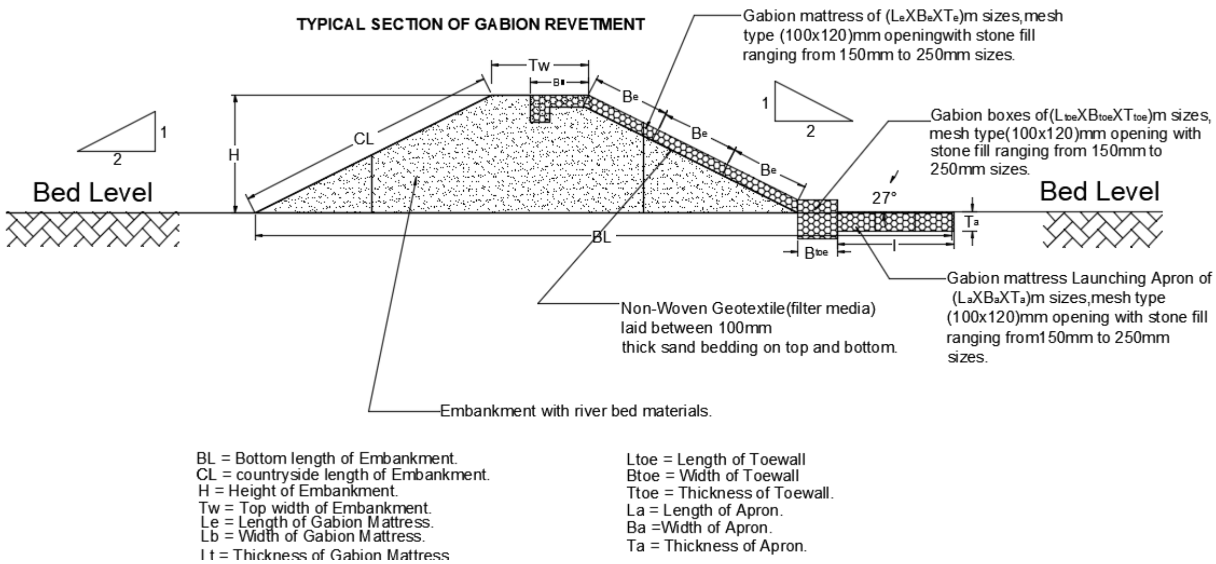

Figure 24: Typical cross section of a gabion revetment

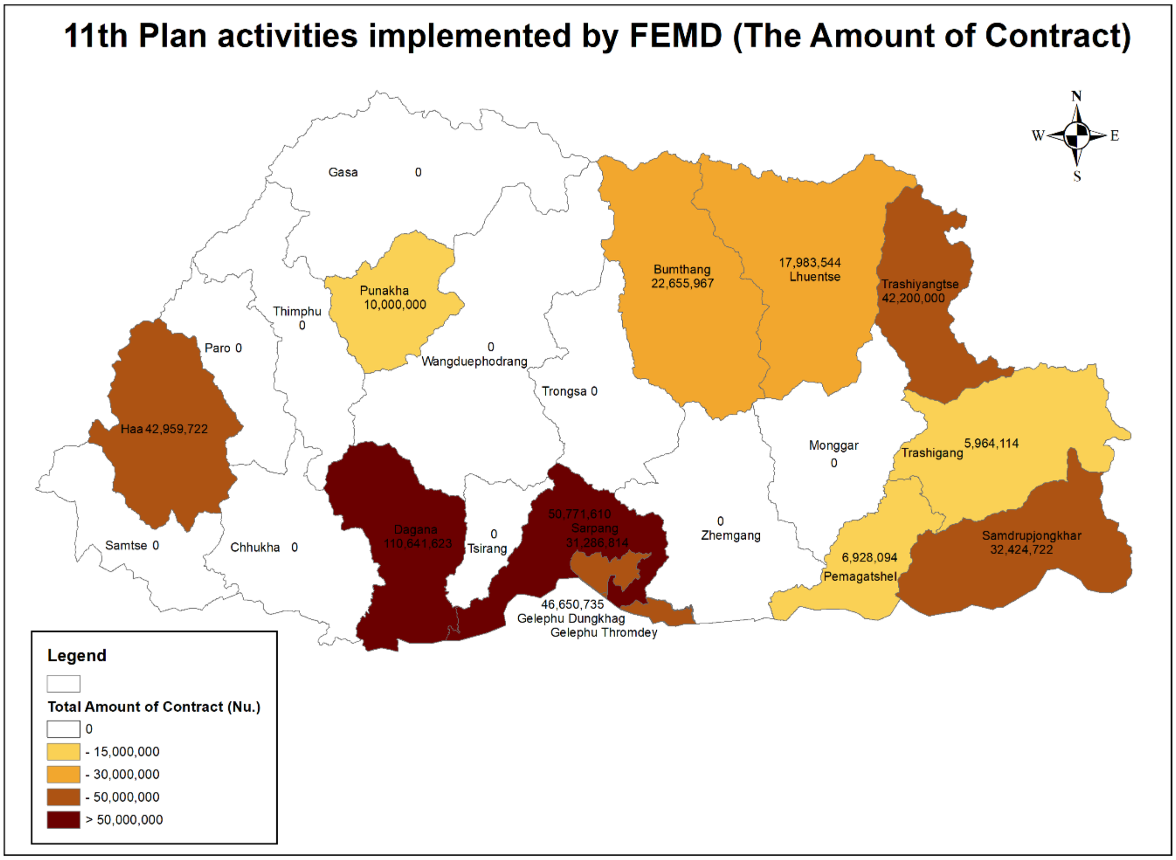

Figure 25: The cost of the flood intervention carried out by FEMD, DES, MoWHS in 11th FYP

Figure 26: Haa River along Yangthang Village in Haa Dzongkhag in year 2014 before intervention.

Figure 27: Haa River along Yangthang Village in Haa Dzongkhag in year 2016 after constructing gabion revetment to protect the nearby settlements.

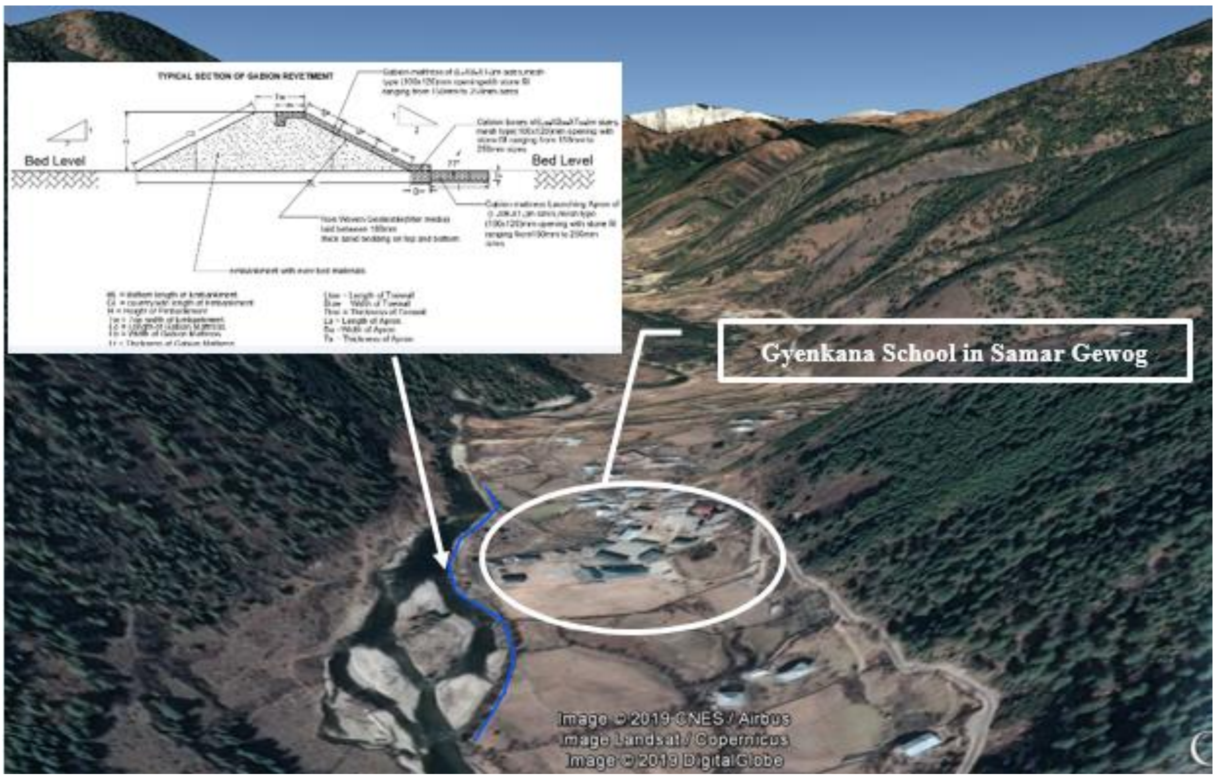

Figure 28: Proposed location of the gabion revetment along Gyenkana School in Samar Gewog.

Limitations of the study

All meteorological and hydrological analysis has been performed on the basis of collected available observed data from NCHM. And if any error remains in the primary data collection of respective agency cannot be resolved within this study.

The Digital Elevation Model used in this study was SRTM DEM with 30 meter resolution which is freely available. A more accurate Flood Hazard Map could have been produced if a high resolution DEM was used. Since a higher resolution DEM was not procured for this Project, it is highly recommended to procure it in the future and update the Flood Hazard Map.

For the Haa River, flood extents were derived based on hydrologic and hydraulic analysis. Hydrologic records were limited and so it is necessary to state how this might impact on using the map as is normally intended. The discharge at Haa River is measured by Wading Method which might be insufficient to derive with confidence the patterns of extreme rainfall events. The consequence is that there will be uncertainty in the estimated extreme rainfall amounts. If the Haa River was gauged with a Current Meter or an accurate discharge measurement gauge, the discharge data could have been more reliable.

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

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