FLOOD HAZARD ASSESSMENT FOR DAGANA DZONGKHAG

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

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Acknowledgment

The Flood Engineering and Management Division, DES, would like to acknowledge and thank all those who have contributed towards the preparation of the Flood Hazard Assessment of Dagana Dzongkhag:

1. Dagana Dzongkhag Administration and Dagana Local Government
2. National Centre for Hydrology and Meteorology (NCHM), 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

Acronyms

FEMD	Flood Engineering Management Division.
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	Gewographical Information System is a computer based method for analyzing Geographical information and maps.
FHM	Flood Hazard Map
AoMI	Areas for Mitigation Interest
DDM	Department of Disaster Management.
DES	Department of Engineering Services
MoWHS	Ministry of Works and Human Settlement

Executive Summary

The most prominent river that causes flooding in Dagana Dzongkhag is the Sunkosh River. Sunkosh River flowing north to south, passes by the northeast side of Daragaon, Hawajhori, Lhamoizingkha and Majigaon and is also the border river with India in the downstream reach. Due to high velocity and non-cohesive bank materials, the degree of erosion of bank, especially along the right bank villages is very high. Over the last decades, the area has been losing hundreds of acres of fertile agricultural land.

The objective of the study was to conduct a detailed flood assessment of critical rivers in Dagana Dzongkhag. And after analysing the AoMI, prioritize critical flood prone areas, recommend appropriate flood protection measures along the identified flood prone areas.

The prioritized area for flood management works is as follows:

1. Critical area along Sunkosh River under Lhamoizingkha Gewog
2. Critical areas along the Paireni stream Kholsi under Karmaling Gewog
3. Critical areas along the Sunkosh River under Nichula Gewog

Through the study, it was recommended to adopt revetment along with spurs at critical locations along the right bank of Sunkosh River where there is erosion due to the concentration of the flow. And in the 11th FYP, the Department of Engineering Services, MoWHS, Royal Government of Bhutan have invested Nu. 110,641,623 in Dagana Dzongkhag. A combination of gabion revetment and spurs were designed by FEMD, DES and implemented by Lhamoizingkhag Dungkhag along right bank of Sunkosh River.

Introduction

Background

Dagana Dzongkhag is located in the southern part of the country adjacent to Indian border as shown in Figure 1. It covers an area of approximately 1,719.13 sq km with elevation ranging from 100 m to 4,720m above the sea level. There are flood hazard risks including inundation and river channel erosion caused by two main rivers (Wang river and Sunkosh river) flowing through the study area, and also monsoon rivers (Kalikhola etc.). Figure 1 shows the study area of this tour including critical areas (Lhamoizingkha Gewog, Nichula Gewog, Karmaling Gewog).

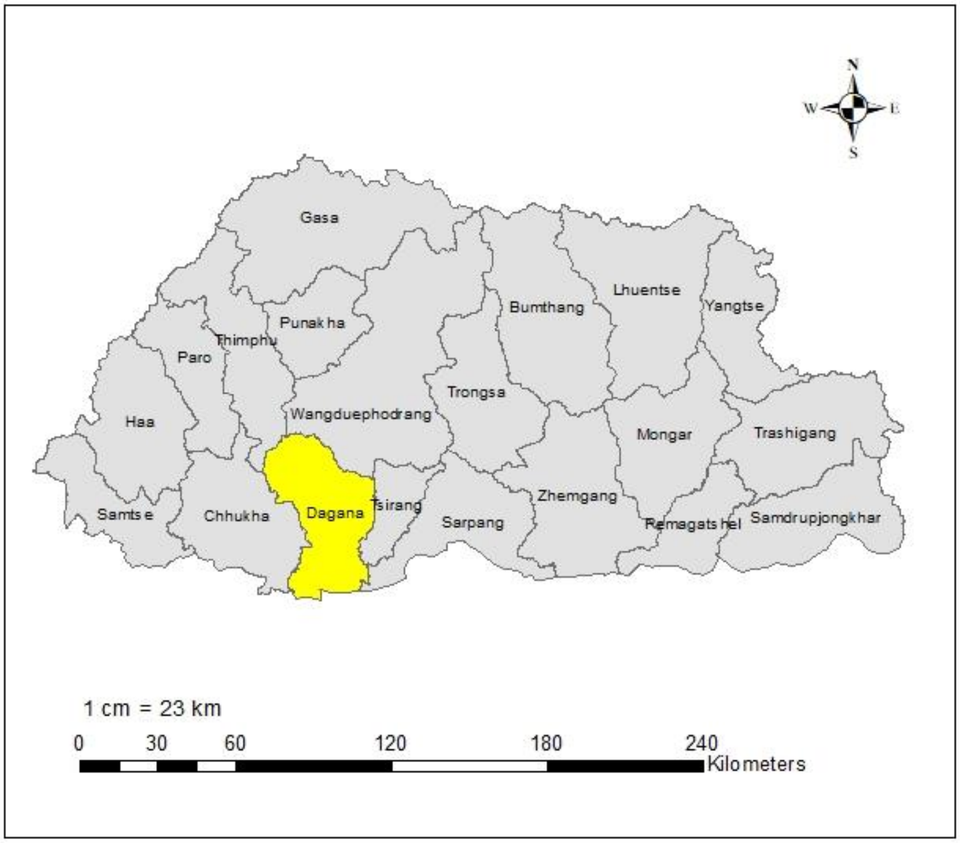

Figure 1: Location of the study area

Objective

Objective 1: Detailed flood assessment of critical rivers in Dagana Dzongkhag.

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

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

Study Area

Sunkosh River is one of the major rivers of Bhutan that flows through Dagana Dzongkhag. The study area lies near the Indo-Bhutan border with approximately 4 km stretch of the Sunkosh River.

Basic Hydrology of Sunkosh River

- Catchment Area at Kerabari: 9,569 km^2
- Average annual rainfall: 1,619 mm
- Average annual yield: 15,220 M cum
- Maximum observed flow: 3,939 m^3/s
- Minimum observed flow: 87 m^3/s
- Probable Maximum Flood (PMF): 17,455 m^3/s
- Annual Sediment Load: 0.6 mm/year

Three Gewogs namely, Lhamoizingkha, Nichula, Karmaling under Dagana Dzongkhag were identified for the detail flood assessment study. These Gewogs were identified as the flood prone areas in the Dzongkhag after the preliminary assessment. The location of the rivers flowing through the identified Gewogs is shown in Figure 2.

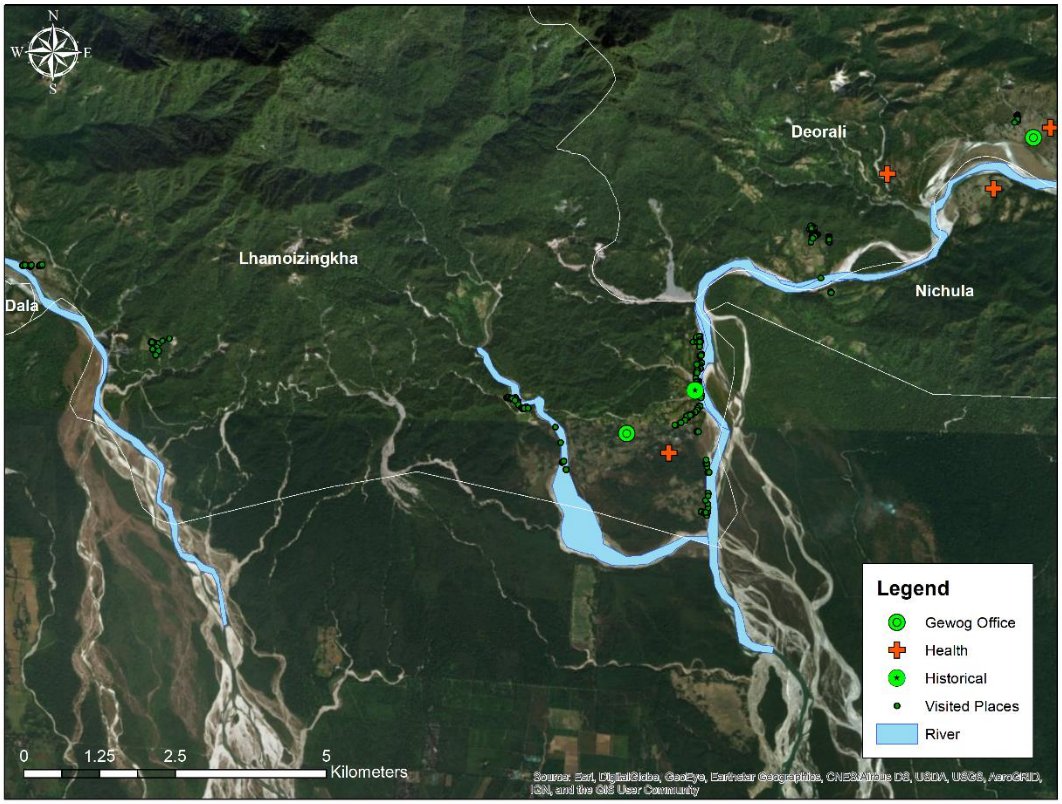

Figure 2: The location of the critical rivers in Dagana Dzongkhag

Table 1: The list of rivers/streams assessed in the three Gewogs

Lhamoizingkha Gewog	Karmaling Gewog	Nichula Gewog
Sunkosh	Homa River	Sunkosh
Paneh	Sunkosh	Nichula
Men dir kholsi	Pairini	
Kalikhola	Manpuri	
Sunkosh	Charmile	
Paneh	Laprang/Saprang	

Methodology

The methodology adopted for the study is as shown in

Figure 3. A thorough desktop study was followed by data collation from different agencies. A detailed site assessment was conducted for Dagana Dzongkhag and the results were analysed. A hydrodynamic model was developed for Sunkosh River the flood hazard maps were developed. After analysing the results, areas of Mitigation Interest (AoMI) were identified and prioritized.

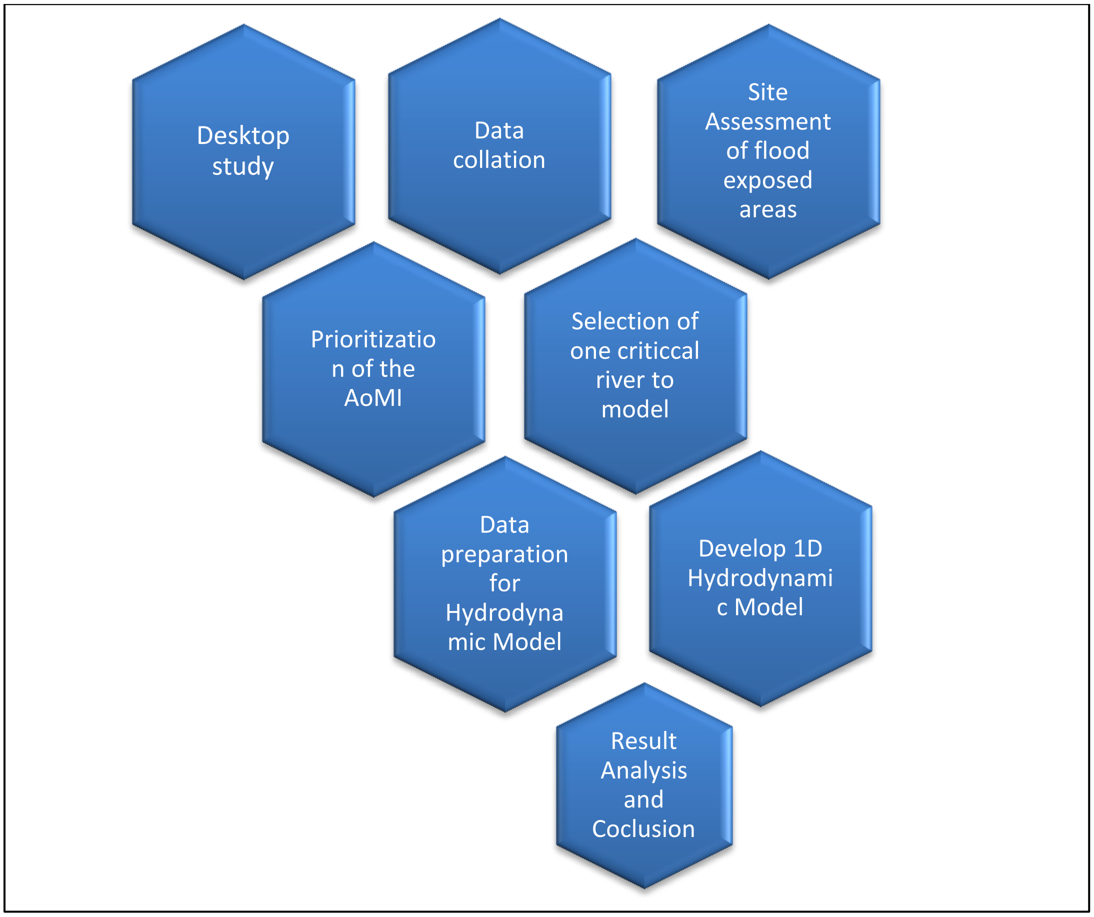

Figure 3: Methodology adopted for the study

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 six meteorological stations and two hydrological station as shown in Figure 4.

Average annual rainfall in the project area is 1455.10 mm. About 80% of the rain is received during the summer months from June to September. The spring months of April (55.4 mm) and May (107.6 mm) also receive considerable rainfall. The maximum rainfall is observed in the month of July (393.9 mm) and accounts for almost 27% of the total annual rainfall.

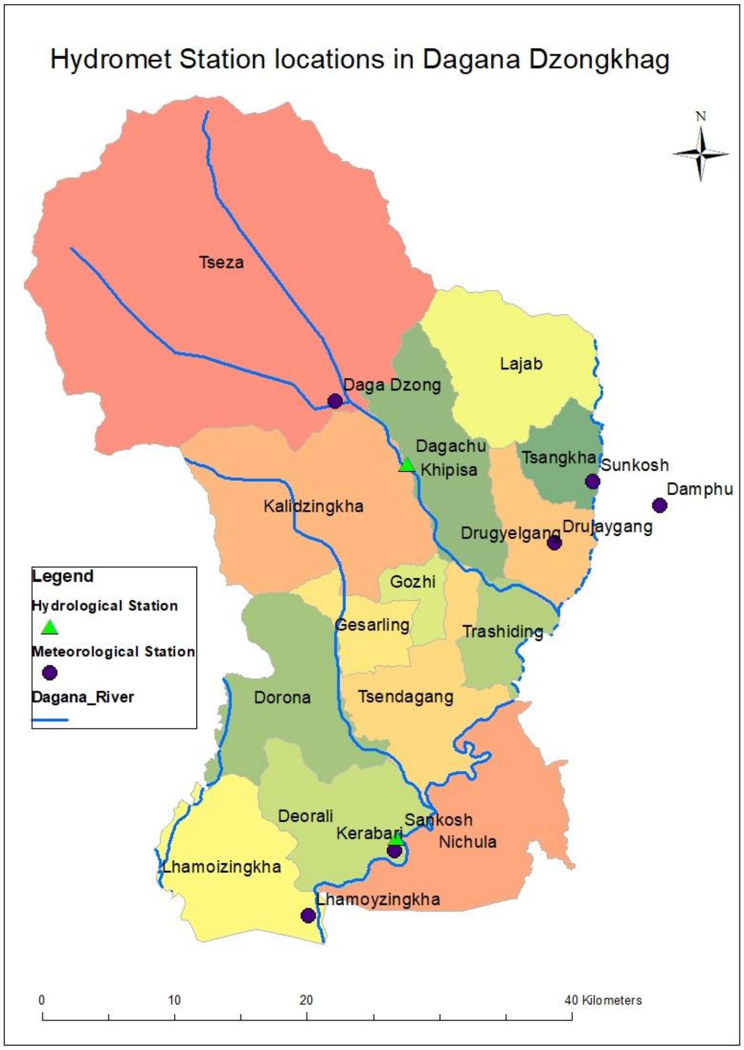

Figure 4: Hydro-Meteorological station in the study area

Scientific Data

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

1. ALOS DSM : 10 meter resolution (courtesy: SATREPSE PROJECT, Nagoya University, Japan)
2. Project site image: 10 meter resolution (courtesy: SATREPSE PROJECT, Nagoya University, Japan)
3. Settlement Data of Dagana Dzongkhag (courtesy: National Land Commission, Ministry of Home and Cultural Affairs, Bhutan)

Site Assessment at Gewog Level

A detailed Gewog level flood assessment was conducted for the 3 Gewogs using the flood assessment forms. 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's officials.

The data which has been collected during the site investigation are listed from Table 2: The site investigation data (1/3) to Table 4: The site investigation data (3/3) including demographic (households and population), economy (Livestock, vehicle, important infrastructure and past intervention work), agriculture (land, annual yield and crop value) and meteorological (past flood observation) information. The listed data are selected for data analysis.

Table 2: The site investigation data (1/3)

Gewog	River	Number of households affected in the Gewog being assessed (along the river)	Human population in the area	Livestock population	Number of vehicles in the area	Any important infrastructure in the area (Lhakhangs, hospitals, institutional buildings)	Existing intervention	What kind of protection works were built in the past?
Karmaling	1 (Homa Chu/Om Chu)	8 household	33	100	1 bike	-	no	-
	2 (Sunkosh)	5 household	15	25	1 bike	-	-	-
	3 (Pairini)	13 Household	43	50	3 cars	School, Gup office, RNR, ORC.	no	-
	4 (Manpuri)					-	gabion wall in 2013 RCC wal in 2013 (Fail)	RCC wall is constructed on the upstream of Manpuri to divert the stream for irrigation purpose. However, it has failed.
	5 (Charmile)	3 Household	11	14		-	same as the above	About 50m length of Gabion wall constructed in the year 2013 was washed away. The existing gabion walls on the right bank of Charmile stream are hand-woven and without apron. It has failed.
	6(Laprang/Saprang)	1 Household				-	-	-
Nichula	1 (Nichula)	15 Household	60	30 cows	5 bike, 1 tractor	1 lhakhang, farm road (2.5 Km)	-	-
	2 (Sunkosh)	26 Household	120	50 cows	15 bike, 4 cars	Gewog office, Extended classroom, RNR, Park Office, FEB, GC road (6 KM)	-	-
Lhamoizing kha	1. Kalikhola	16 H/H (160Nos), 31H/H(310Nos)	160+310	in total 420	in total 42	-	-	-
	2. Sunkosh	Hawajori, 11H/H (552 Nos), Majagong -85 H/H (335Nos)	552+335			-	-	-
	3. Mandhir khosli	49 H/H (490Nos)	490			BOBL, BDBL, RICBL, Lhakhang, Shiv Mandir, BPC, Lhakhang, Shive mender, FMCL, Dungkhag court, Workshop	-	-
	4. Raidak	16 H/H (160Nos)	160			-	-	-

The total value of agriculture (Unit: Ngultrum) are calculated as per the local government's data like as below:

$$Total\ value\ of\ agriculture = \sum_{i=1}^{n} A_i \times Y_i \times P_i$$

Where;

A_i is the area of agriculture land by the type of crops (Acre)

Y_i is the annual yields of the crop (Kilogram per Acre)

P_i is the market price of the crop (Ngultrum per Kilogram)

Table 3: The site investigation data (2/3)

Gewog	River	Crops	Agricultural land at risk (Acre)	Kg/acre, year	Nu./kg	total value of agriculture (Nu.) *Calculated
Karmaling	1 (Homa Chu/Om Chu)	Paddy, Betel Nut	19	85 muri from 16 acres, 35 kg/1 muri (2975 kg) 10 kg/tree, 700 trees/acre, 3 acres betel nut (21,000 kg)	Nu 25-35 per kg (Rice), Nu 25/kg.	614,250
	2 (Sunkosh)	Paddy, Betel Nut	28.75	10 muri/acre, 16 acre, (5600 Kg) 12.75 acres (89250 Kg)	Nu 25-35 per kg (Rice) Nu 30/kg (Near road point)	2,845,500
	3 (Pairini)	Paddy, Betel Nut	62	600 muri from 60 acres (21,000 kg) 2 acres(14,000 kg)	Nu 25-35 per kg (Rice), Nu 30/kg (Near road point)	1,050,000
	4 (Manpuri)	-	0	-	-	-
	5 (Charmile)	-	0	-	-	-
	6(Laprang/Saprang)	-	0	-	-	-
Nichula	1 (Nichula)	-	20	-	-	-
	2 (Sunkosh)	-	40	-	-	-
Lhamoizing kha	1. Kalikhola	Paddy Betel nut	20	91600kg 100760kg	(whole)=Nu.20 @kg (whole)=Nu.25 @kg	183,200 2,519,000
	2. Sunkosh		40			
	3. Mandhir khosli		18			
	4. Raidak		13			

Table 4: The site investigation data (3/3)

Gewog	River	Past damage record	When did the last flooding occur?	How many times has the flooding occur?	How long did the last flooding occur?
Karmaling	1 (Homa Chu/Om Chu)	1994 (High- washed away 9 acres of orchard and agricultural field, 1 life lost, animals affected) Every season (Low- affecting agricultural fields since the river bed level and settlements are on the same level).	1-3 years ago (2017)	Floods during every heavy rainfall	More than 2 day(2017, 3 days)
	2 (Sunkosh)	Low	4-10 years ago (1960, 1964,1994 and 2009)	Flood in 1960,1964,1994 and 2009	Not recorded
	3 (Pairini)	2017(Medium- 50 decimal wetland washed away and covered with debris)	1-3 years ago (2017)	Floods during every heavy rainfall	1-2 day(2017, 1 day)
	4 (Manpuri)	None	Not recorded	Not record of flooding	Not recorded
	5 (Charmile)	2017(High-agricultural land affected)	1-3 years ago (2017)	Floods during every heavy rainfall	Not recorded
	6(Laprang/Saprang)	2017(Low-Only one Household is located at the confluence of Laprang and Saprang with about 8 acres of agricultural land)	1-3 years ago (2017)	Flood in 2017	Not recorded
Nichula	1 (Nichula)	Medium(2009- washed away 10 acres of land, applied for re-location belonging to 2 Household in Barang Village, Damchina Chiwog)	1-3 years ago	Floods during every heavy rainfall	1-2 day(2009)
	2 (Sunkosh)	Medium(2009)	1-3 years ago	Floods during every heavy rainfall	1-2 day(2009)
Lhamoizing kha	1. Kalikhola	-	1-3 years ago	Floods during every heavy rainfall	0-3 hours
	2. Sunkosh	High	-	-	-
	3. Mandhir khosli	-	1 year ago	Floods during every heavy rainfall	0-3 hours
	4. Raidak	-	-	-	-

The past flood event records have been collected during the site investigation from the local government officials in order to analyse the frequency of flood events as a factor of the flood risk in the Dzongkhag,. The past flood event records are listed in Table 5. Morphological change has to be considered, however no specific morphological change has been observed in Dagana Dzongkhag during the site investigation.

Table 5: Past flood events (verified) in the Dzongkhag

Gewog	River	Past damage record
Karmaling	1 (Homa Chu/Om Chu)	1994 (High- washed away 9 acres of orchard and agricultural field, 1 life lost, animals affected) Every season (Low- affecting agricultural fields since the river bed level and settlements are on the same level).
	2 (Sunkosh)	Low
	3 (Pairini)	2017(Medium- 50 decimal wetland washed away and covered with debris)
	4 (Manpuri)	None
	5 (Charmile)	2017(High-agricultural land affected)
	6(Laprang/Saprang)	2017(Low-Only one Household is located at the confluence of Laprang and Saprang with about 8 acres of agricultural land)
Nichula	1 (Nichula)	Medium(2009- washed away 10 acres of land, applied for re-location belonging to 2 Household in Barang Village, Damchina Chiwog)
	2 (Sunkosh)	Medium(2009)
Lhamoizing kha	1. Kalikhola	-
	2. Sunkosh	High
	3. Mandhir khosli	-
	4. Raidak	-

Prioritization of the Areas

To analyse the areas or hazards on the basis of the data collected during the site investigation, the risk priority factors are set as follows:

Households at risk: The number of households under the flood risk as per the local government.

Agricultural land at risk: The area of agricultural land under the flood risk as per the local government (Unit: Acre).

Important infrastructure at risk: The number of important infrastructures under the flood risk which are counted by facilities (e.g. "Farm road", "School A" and "School B" are counted as three).

Past damage record: The severity of the past flood damage as per the local government. The extent of the subjective of the severity is weighted as high is 25, medium is 15 and low is 10 in light of the discussion.

Flood frequency (validated): The number of past flood events which has been recorded as medias in the area (e.g. News).

The weightage of each the risk priority factors are equally set as shown Table 6 in light of the discussion.

Table 6 The weightage of the risk priority factors

Weightage				
Houseolds at risk	**Flood frequency (validataed)**	**Agricultural land at risk**	**Important infrastructure at risk**	**Past damage record**
0.2	0.2	0.2	0.2	0.2

The marking of the areas or hazards is calculated as the equation below:

$$Total\ Marking = \sum_{i=1}^{n} F_i \times W_i$$

Where;

F_i is the value of the risk priority factor

W_i is the weightage of the risk priority factor

Table 7 show the result of the total marking calculation of each areas or hazards among the Dzongkhag.

The highest marking is 32.2 of the Sunkosh river area under Lhamoizingkha Gewog, the second is 19 of the Pairini river area under Karmaling Gewog and the third is 17.6 of the Sunkosh river area under Nichula Gewog

Table 7: The ranking of the risk prioritized areas or hazards in the Dzongkhag

Gewog	River	Parameter					Marking						Ranking
		Houseolds at risk	Agricultural land at risk (Acre)	Important infrastructure at risk	Past damage record	Flood frequency (validated)	Houseolds at risk	Agricultural land at risk	Important infrastructure at risk	Past damage record	Flood frequency (validated)	Total	
Karmaling	1 (Homa Chu/Om Chu)	8	19	0	25	1	1.6	3.8	0	5	0.2	10.6	6
	2 (Sunkosh)	5	28.75	0	10	4	1	5.75	0	2	0.8	9.55	8
	3 (Pairini)	13	62	4	15	1	2.6	12.4	0.8	3	0.2	19	2
	4 (Manpuri)	0	0	0	0	0	0	0	0	0	0	0	12
	5 (Charmile)	3	0	0	25	1	0.6	0	0	5	0.2	5.8	10
	6(Laprang/Saprang)	1	0	0	10	1	0.2	0	0	2	0.2	2.4	11
Nichula	1 (Nichula)	15	20	2	15	1	3	4	0.4	3	0.2	10.6	6
	2 (Sunkosh)	26	40	6	15	1	5.2	8	1.2	3	0.2	17.6	3
Lhamoizingkha	1. Kalikhola	47	20	0	0	0	9.4	4	0	0	0	13.4	5
	2. Sunkosh	96	40	0	25	0	19.2	8	0	5	0	32.2	1
	3. Mandhir khosli	49	18	11	0	0	9.8	3.6	2.2	0	0	15.6	4
	4. Raidak	16	13	0	0	0	3.2	2.6	0	0	0	5.8	9

Flood Frequency Analysis

Log Pearson Log Pearson III distribution

The Log Pearson III (Pearson, 1895) statistical technique was used to fit the flood frequency for the River. The distribution is computed by a general equation, Equation 1. The annual peak discharge data were ranked from largest to smallest and the $\log_{10}$ value for each data was computed.

$$\log_{10} Q_T = K_T \sigma + \mu \qquad \text{Equation 1}$$

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

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

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

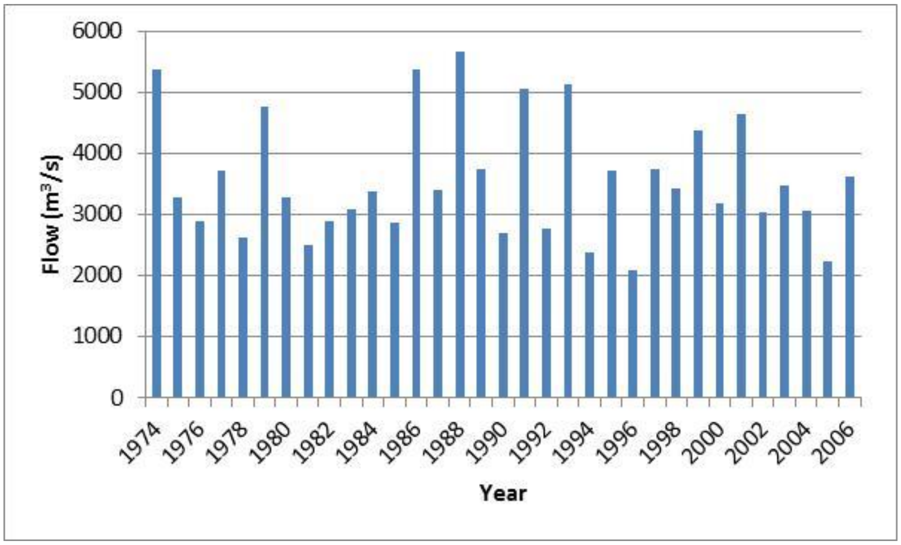

Figure 5: The annual peak discharge of Sunkosh River used for the study

Table 8: The result from the frequency analysis for Sunkosh River

Return Period	Return Period Discharge (Peak Method)
25	5520
50	6051
100	6579

Development of Model

Hydrodynamic model

HEC-RAS as a 1D hydrodynamic model was selected to obtain the flow profiles for flood of different return periods. Freely available ASTER DEM was used for obtaining cross-section data at different locations for Sunkosh River Steady flow option was selected for assigning flow of different return period. HEC-RAS was run in subcritical mode and various graphical and tabular outputs were obtained. The methodology followed for developing the model is shown in Figure 6.

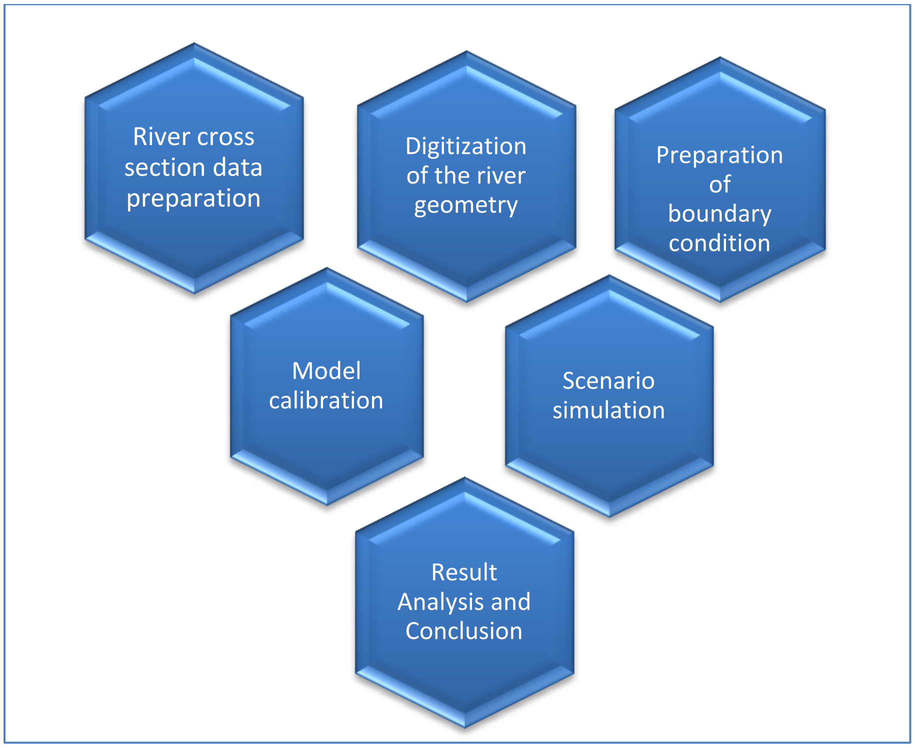

Figure 6: Methodology adopted for the developing the 1D Hydrodynamic Model

River geometry creation

The freely available ASTER DEM (30 m resolution) covering the study area was used for the hydrodynamic modelling. The DEM is shown for Figure 7 Sunkosh River. DEM in TIN format is required for HEC-RAS model. Raster DSM converted to TIN with the study stretch of river is shown in Figure 8 for the basin.

River centreline is sketched with the help of given river network. As observed cross-sections at different locations are not available for Sunkosh, the cross-section data is extracted from the ASTER DEM. Cross-section cut lines are assigned at appropriate locations from upstream to downstream for Sunkosh River. As the river is wide and the flow is large in Sunkosh River, cross-section data extracted from 30 m ASTER DEM will be applicable for hydrodynamic model. The schematic of geometry in HEC-RAS for Sunkosh is shown in Figure 9.

The cross-section station numbers increase from downstream to upstream. The cross-section consists of three parts: main channel, left bank and right bank. Manning's n value at main stream channel and overbank is assigned for each cross-section. A representative value of 0.03 is assigned for main stream and 0.05 for overbanks. Expansion and contraction coefficient is taken as default values (expansion = 0.3 and contraction = 0.1).

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 25, 50 and 100 year return periods.

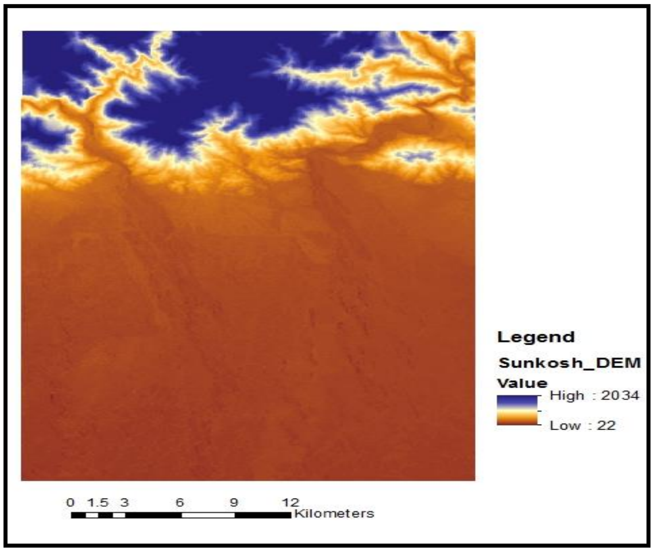

Figure 7: Aster DEM for the study area

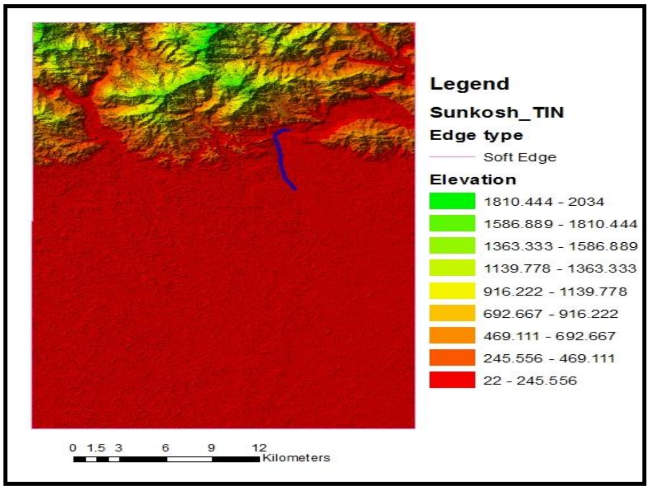

Figure 8: TIN for the study area

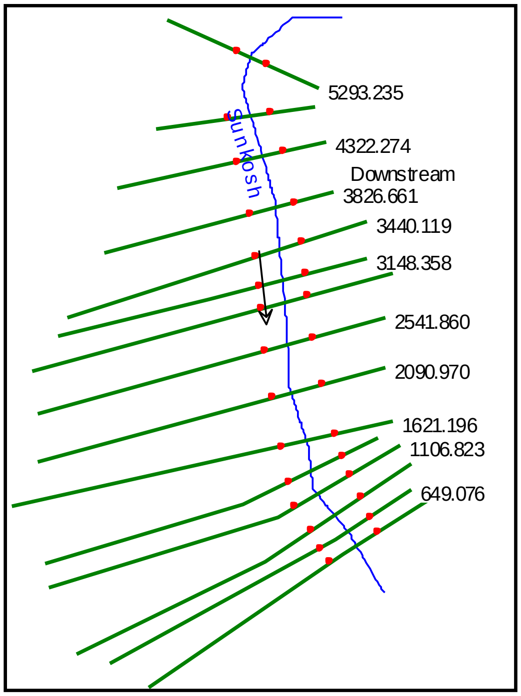

Figure 9: River system schematic for Sunkosh River

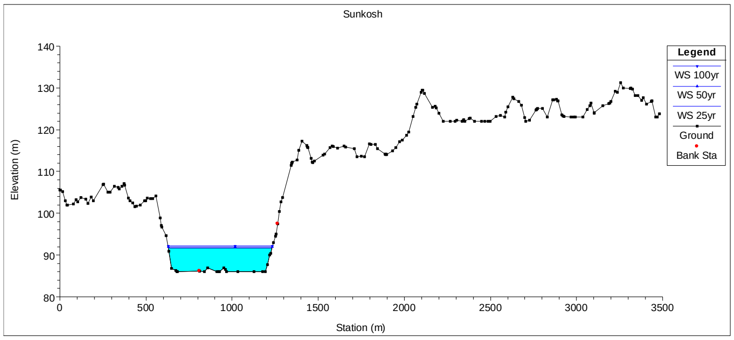

Figure 10: Sample Output of HEC-RAS for a cross-section of Sunkosh River

Scenario simulation

After setting up the HEC-RAS model, the model is run under steady flow condition for different return periods. HEC-RAS gives cross-section wise output. Sample of output is shown in Figure 10. The plot shows the cross-section along with the water level for 100 years return periods. The water surface profile obtained from HEC-RAS for Sunkosh River is given in Figure 11.

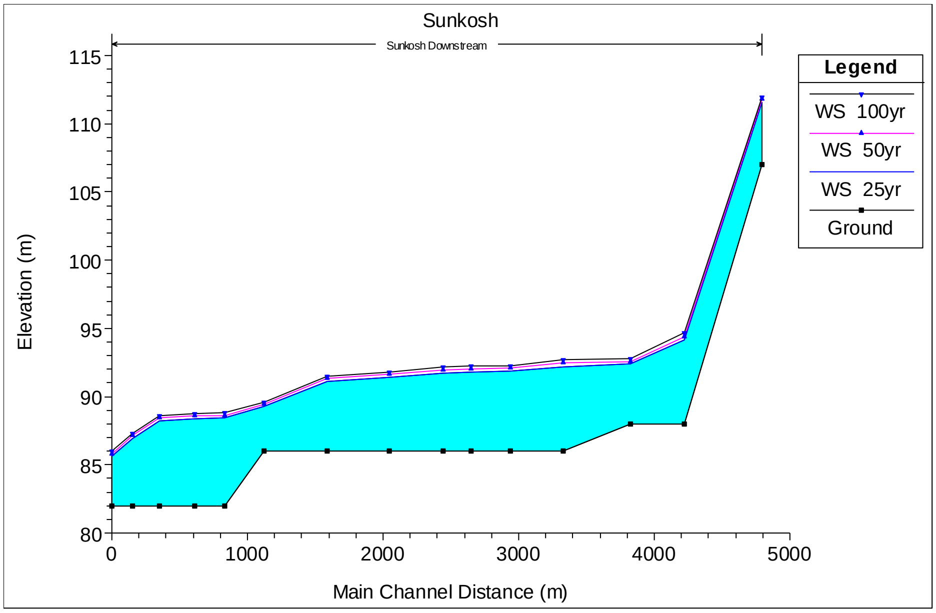

Figure 11: Plot of water surface profile of Sunkosh River

The maximum flow depth for the chosen cross-sections of Sunkosh River vary from 3.26 to 6.41 m for 25 year return period, 3.41 to 6.61 m for 50 year return period and 3.58 to 6.81 m for 100 year return period. The range of velocity for 25 year return period is 1.46 - 5.89 m/s, 50 year return period is 1.54 - 5.92 m/s and 100 year return period is 1.60 - 6.05 m/s.

Scenario: Assessment of change in river dynamics after the construction of river training structure at the right bank of Sunkosh River.

As left bank is in Indian side, embankment at only right bank side (Bhutan side) is considered for Sunkosh River while setting up HEC-RAS model as shown in Figure 12. The water surface profile for 25, 50 and 100 year return periods for Sunkosh is shown in Figure 13. The result shows that there will be no overtopping of right bank. Comparing the result it is found that there is change in water surface elevation and channel velocity as there is no any structure on the left bank and the width of the river is large.

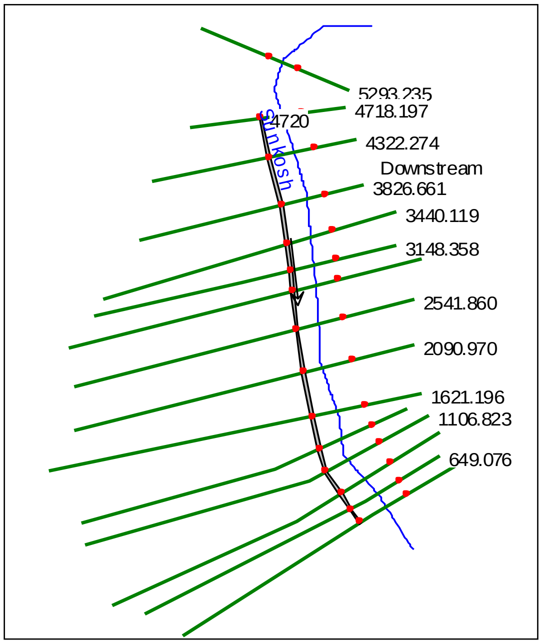

Figure 12: HEC-RAS model setup for the Sunkosh River with embankment at right bank

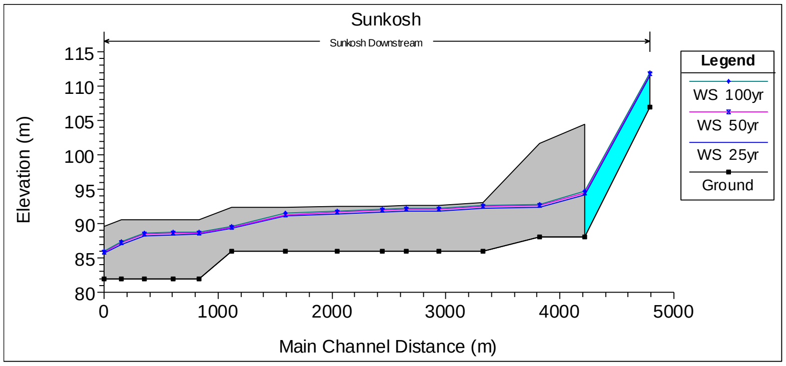

Figure 13: Water surface profile for Sunkosh River with embankment

Result Analysis and Conclusion

As per the prioritization of the flood prone areas the following AoMI (Areas of Mitigation Interest) are significantly considered in the Dzongkhag.

1. Critical area along Sunkosh River (At the base of Hawajorey, Kalikhola Town and Majagong village) under Lhamoizingkha Gewog

- Sunkosh River poses potential threats to the settlements and agricultural land of Hawajorey, Majagoan village and Kalikhola Town.
- As per the site investigation, it has been observed that the Sunkosh River has been washing away major Rivernk of land every year due to scouring.
- About 1 km of flood protection structures has been constructed till date. However, there are still some critical areas requiring immediate additional flood protection structures in the above-mentioned areas.
- Therefore, around 1200m of Flood protection structures is felt very essential along Sunkosh River.

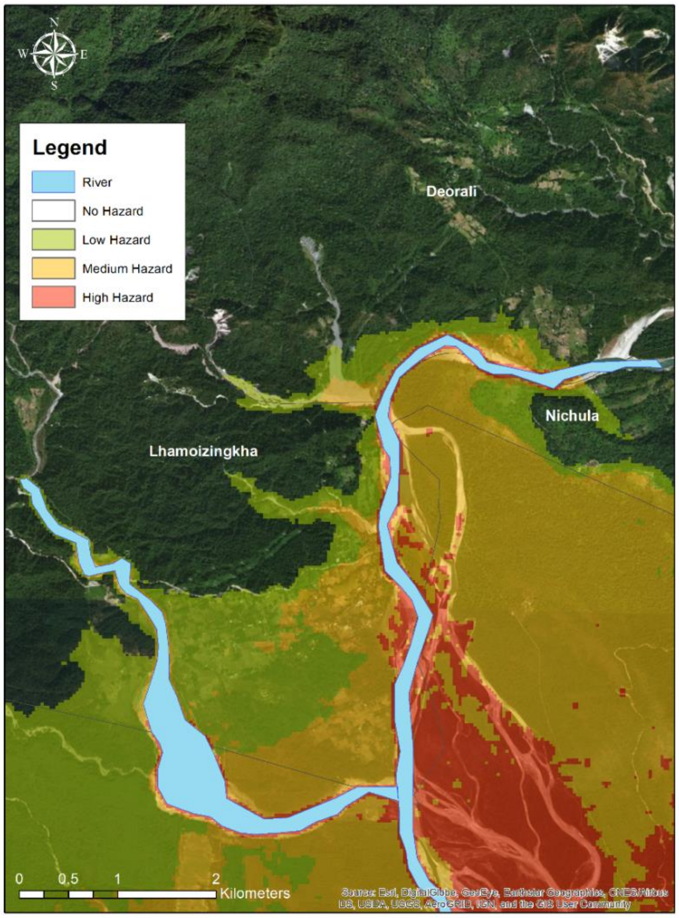

Figure 14: Flood Hazard Map along Sunkosh River in Lhamoizingkha Gewog

Figure 15: Scouring at the base of Hawajorey village by Sunkosh river

Figure 16: Agricultural land and settlement at risk along Sunkosh river

Figure 17: Scouring/Erosion by Sunkosh River at the base of Kalikhola

Figure 18: Scouring/Erosion by Sunkosh River in Majagoan village

2. Critical areas along the Paireni stream Kholsi under Karmaling Gewog

- Pairini Stream is seasonal in nature and it is completely dry during dry season. But during the monsoon, Pairini streams bring in large amount of debris and deposit it in the agriculture fields of karmaling village. It meanders as it passes through the settlement and does not have proper flow path. The river flow path and the settlement are at the same level.
- It also cut-offs the farm road leading to Homa village during the summer season.
- There were no past interventions carried out for the stream as it is formed from the runoffs during the rainy season.

- The team recommends check dam on the upstream portion of Pairini stream to trap the debris and prevent sedimentation in the agriculture field. Further, a flood way with enough flow path to divert the stream away from the settlement is also recommended at the downstream of Pairini stream.

Figure 19: Debris from Pairini stream affecting the electric pole in Karmaling village

Figure 20: Debris from Pairini stream affecting the Karmaling village

3. Critical areas along the Sunkosh River under Nichula Gewog

- ✓ Sunkosh River poses potential threats to the settlements and agricultural lands of both Bararey and Bichgoan village under Damchina Chiwog.
- ✓ The team observed that there is no single intervention carried out in the past to reduce the vulnerability of community to flooding.
- ✓ As per the local government, approximately more than 10 acres of wetland has been washed away at Bararey village due to scouring at the base by Sunkosh River. In addition, it also poses threats to the Bichgoan village located at the downstream portion of the river. Most of the institutions of Nichula Gewog such as Gewog office, school and RNR office are all located in Bichgoen. The village has around 26 households with more than 40 acres of wetland and 20 acres of dry land.
- ✓ Therefore, the team recommends around 300m of bank protection work along the left bank of Sunkosh at Bararey village. However, there is no immediate requirement of mitigation measures at Bichgoan village as the risk of flooding from Sunkosh River is low at the moment.

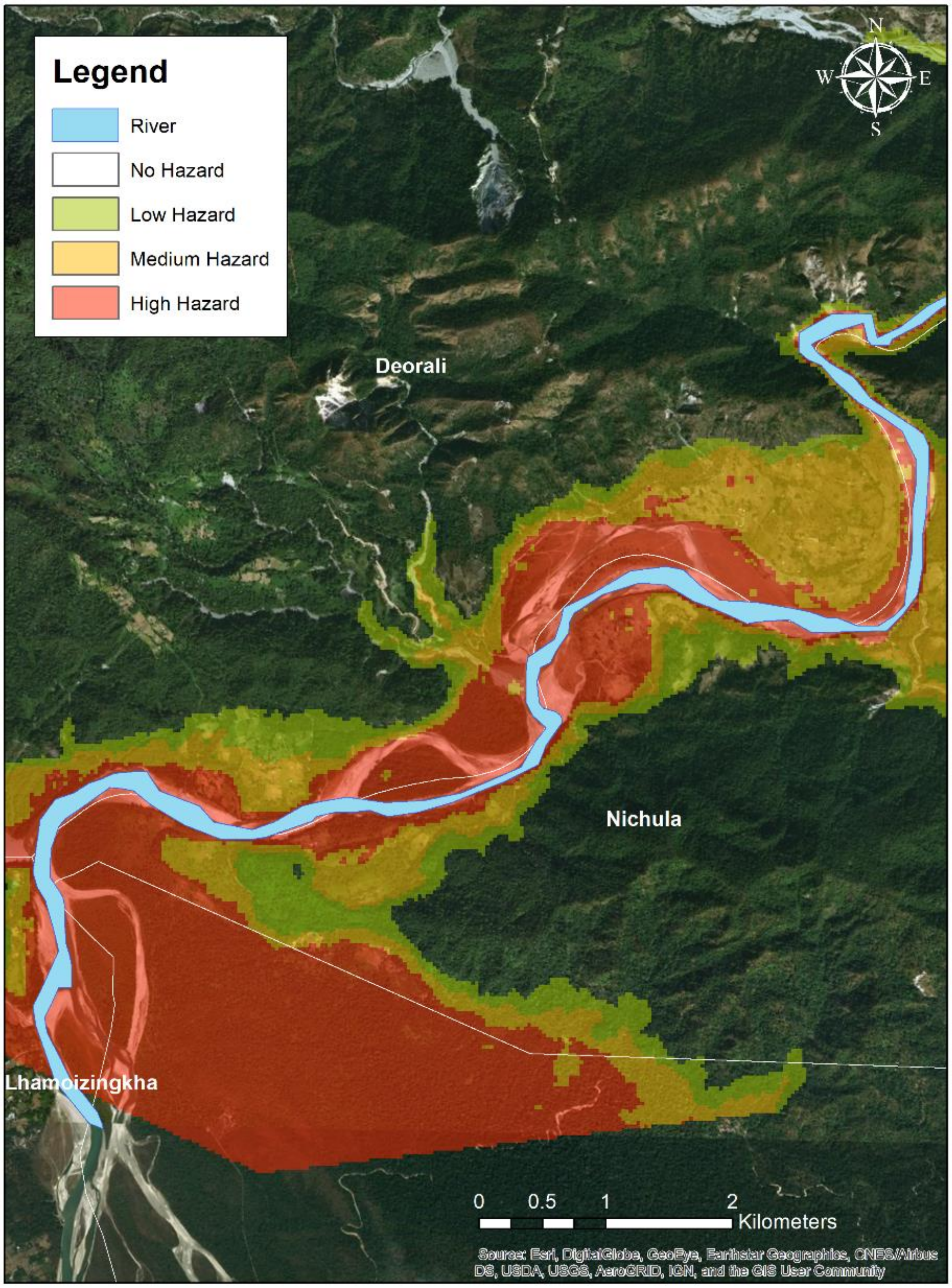

Figure 21: Flood Hazard Map along Sunkosh River in Nichula Gewog

Figure 22: Critical area at Barerey and Bichgoan under Damchena Chiwog

Figure 23: Critical area at Barerey and Bichgoan under Damchena Chiwog

Recommendation for flood management

Prioritization of the AoMI has been identified through the site investigation and the data analysis though the study. The detail of the prioritized areas is mentioned in the previous chapter. The following are the list of AoMI in order of priority:

4. Critical area along Sunkosh River (At the base of Hawajori, Kalikhola Town and Majagong village) under Lhamoizingkha Gewog
5. Critical areas along the Paireni stream Kholsi under Karmaling Gewog
6. Critical areas along the Sunkosh River under Nichula Gewog

The right bank of the Sunkosh River is being eroding at an alarming rate. So, the river training works are necessary along the right bank of the Sunkosh River to protect the four villages i.e.Kalikhola, Hawajhori, Lhamoizingkha and Majagaon in Bhutan. Based on the modelling results the design discharge recommended is 6,051 m^3/sec (50 year return period discharge) for Sunkosh River.

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.

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).

Layout of Flood Protection Works along Sunkosh river

For flood and bank protection of the constricted portion of the river, the following alternatives are considered:

- Construction of a series of spurs
- Construction of revetments along the river bank
- Combination of revetments and spurs

The three methods are discussed in the following sections.

1. Spurs

The spurs (groynes) are structures constructed transverse to the river bank to protect it from erosion. It is mainly used for river training and can have different function based on how they are constructed. It can be impermeable, permeable, deflecting, repelling and attracting spur. The spurs can be used singly or in series. It can be aligned either perpendicular to the bank or at an angle pointing upstream or downstream. Further, it can also be used in combination with other river training structures for flood protection. When the spur is constructed at an angle pointing upstream, it is called repelling spur. The spurs constructed in this way repel the river flow away from it and is usually used where major channel changes are required. The repelling spurs are usually constructed in a group to repel the water current. When the upstream angled spur is of short length and changes only the direction of flow without repelling it, it is called a deflecting spur. It gives local protection only.

Likewise, a spur inclined towards downstream reach, is called an attracting spur as it attracts the river flow towards it. The spur constructed perpendicular to the stream is usually the shortest possible and thus, most economic.

Advantages

- Spurs can be constructed using different materials as per the site conditions.
- Environmentally friendly spurs can be constructed using local materials.
- The construction of the spurs doesn’t require skilled personal.
- Very efficient in trapping sediments.

- It builds up beaches.

Disadvantages

- High river bank should be available to anchor (or tie) the spur back.
- Extra protection should be given to nose/head of the spur against anticipated scour.
- If river reach to be protected is long, spurs should be used in series.
- The first spur on the upstream portion of the river is more vulnerable and thus, should be given special care during design and construction.
- No single type of spur is suitable for all locations.
- The position, length and shape of spurs depend on site conditions.
- Single spurs are neither strong enough to deflect the current nor as effective in causing silt deposition upstream and downstream.

2. Revetments

The mathematical model studies show streamlined and smooth flow conditions along both banks. This has important advantages and disadvantages:

- Clear and unobstructed channel – as there are no projections, the smooth and streamlined flow will be maintained along the length.
- A deep channel can develop along the revetment causing high intensity flow during floods, increasing maintenance. This can be minimized in design.
- Uneven distribution of flow – development of channel along the revetment and corresponding high discharge intensity creates an uneven distribution of flow across the channel, with sedimentation in the slack flow region. The revetment is constructed along both banks with a uniform channel width and gradient. Sedimentation could occur in the centre of the river.

3. Combination of Revetments and Spurs

The disadvantages of spurs with the danger of overall instability and reduction of the potential land reclamation would not be avoided by combination with revetment. With both types of protection, attention has to be given to the transition between the protected hard bank and the natural soft bank upstream and downstream, otherwise severe erosion of the natural bank will result.

After weighing the qualitative advantages and disadvantages of the three methods discussed above, it is decided to adopt revetment along with spurs at critical locations along the right bank of Sunkosh River where there is erosion due to the concentration of the flow. A typical example of a combination of revetment and spur in Mahakali River, Nepal is shown in Figure 24.

Figure 24: : A typical combination of revetment and spur, Mahakali river, Nepal

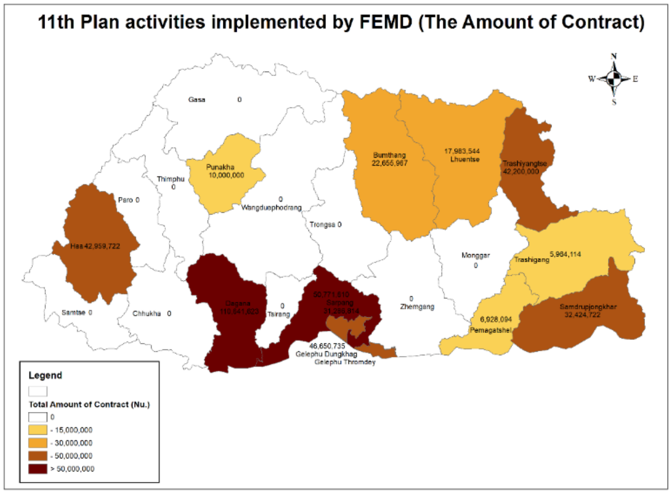

Figure 25: Map showing the structural intervention implemented by FEMD, DES, MoWHS

The Department of Engineering Services, MoWHS, Royal Government of Bhutan have invested Nu. 110,641,623 in the 11th FYP for Dagana Dzongkhag. A combination of gabion revetment and spurs were designed by FEMD (Figure 27 and Figure 28) DES and implemented by Lhamoizingkhag Dungkhag along right bank of Sunkosh River. The location of the flood protection works along Sunkosh River can be seen in Figure 30.The Sunkosh River in 2013 before intervention can be seen in Figure 29 and the Sunkosh River in 2017 after construction of gabion embankment with gabion spurs at the right bank of the river can be seen in Figure 30.

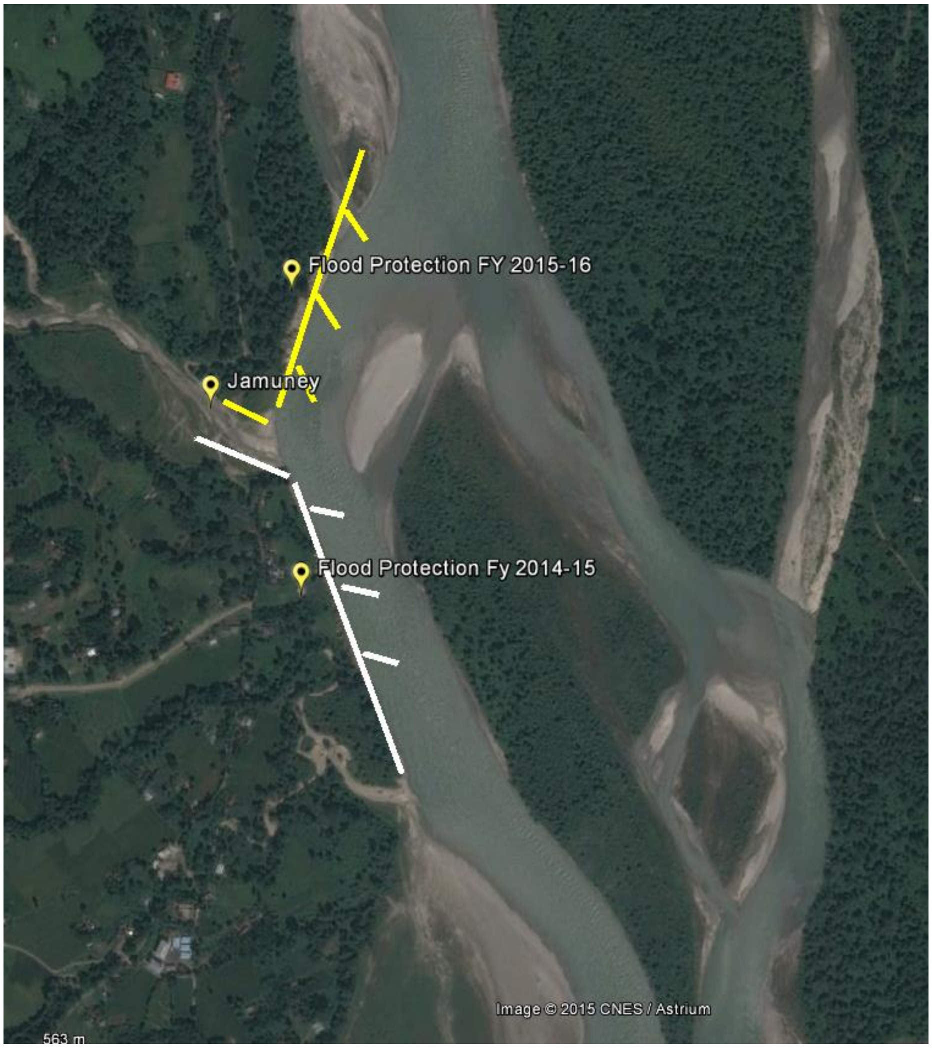

Figure 26: Location of the gabion revetment and spur along right bank of Sunkosh River

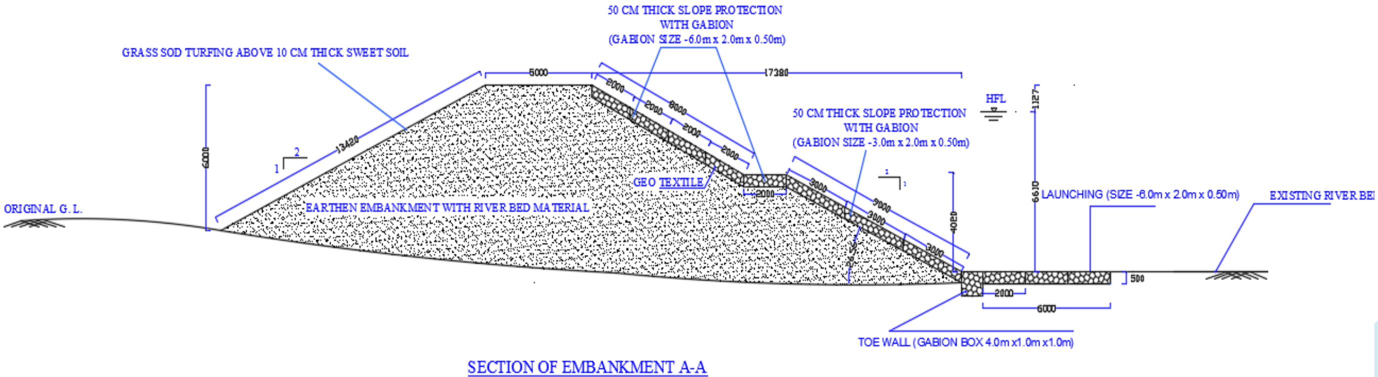

Figure 27: The sectional view of the designed gabion embankment for Sunkosh River

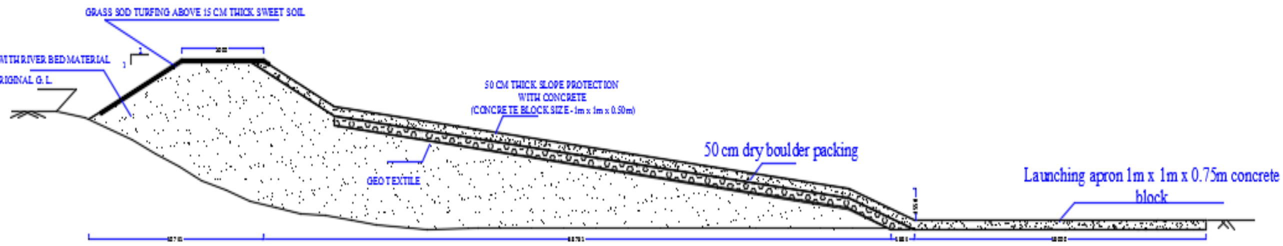

Figure 28: The sectional view of the designed gabion spur for Sunkosh River

Figure 29: Sunkosh River in 2013 before intervention

Figure 30: Sunkosh River in 2017 after the construction of gabion revetment and spur at the right bank of the river.

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 Models used in this study were ASTER DEM with 30 meter and SRTM DEM (30m and 90m) resolution which is freely available. A more accurate Flood Hazard Map could have been produced if a high resolution DEM was used.

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.

References

1. Detailed Engineering and feasibility study for Flood Protection work at Sunkosh river under Lhamoizingkha Dungkhag, Dagana, FEMD, DES, MoWHS
2. Dagana field assessment report, 2018, FEMD, DES, MoWHS
3. Flood inundation mapping using global datasets Thesis KC
4. Dagana Dzongkhag website
5. National Statistics Bureau website
6. Standard Operating Procedure for conducting river cross section survey, FEMD, DES, MoWHS
7. Detailed Sunkosh River assessment report, FEMD, DES, MoWHS.
8. Flood control measures for effective flood management, FEMD, DES, MoWHS.