FLOOD HAZARD ASSESSMENT FOR PEMA GATSHEL DZONGKHAG

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

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Acknowledgement

Flood Engineering and Management Division under Department of Engineering Services, Ministry of Works and Human Settlement have taken immense initiative and efforts in carrying out flood hazard assessment for Pema Gatshel Dzongkhag and preparation of the Flood Hazard Map for Kerong Chhu in Nganglam Dungkhag, under Pema Gatshel Dzongkhag. The Division has successfully completed this project on time. However, it would not have been possible without the valuable support, guidance and help of many individuals and organizations. Therefore, we would like to extend our sincere thanks and appreciation to all of them:

1. National Center for Hydrology and Meteorology, Ministry of Economic Affairs, Bhutan
2. National Statistical Bureau, Bhutan
3. Dzongkhag Administration, Pema Gatshel Dzongkhag
4. Dungkhag Administration, Nganglam

The Flood Engineering and Management Division would also like to acknowledge and thank all those who have contributed and willingly helped us with their abilities towards carrying out the flood hazard assessment studies for Pema Gatshel Dzongkhag.

Acronyms

FEMD	Flood Engineering Management Division.
HEC-RAS	The Hydrologic Engineering Centre, River Analysis System is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modelling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. The program was developed by the US Department of Defence, Army Corps of Engineers in order to manage the rivers, harbours, and other public works under their jurisdiction; it has found wide acceptance by many others since its public release in 1995.
GIS	Geographical Information System is a computer-based method for analysing geographical information and maps.
FHM	Flood Hazard Map
FRA	Flood Risk Assessment.
AoMI	Areas of Mitigation Interest
MoAF	Ministry of Agriculture and Forest.
DDM	Department of Disaster Management.
GLOF	Glacial Lake Outburst Flood.
SWAT	Soil and Water Analysis Tool

Executive Summary

Kerong Chhu flows past Nganglam town, under the Nganglam Dungkhag, Pema Gatshel Dzonkhag. There are no recorded past flood events, that had affected the settlements along the River. However, with increasing unpredictable rainfall intensities and patterns attributed to the climate change around the World, it has become crucial to take heed of impending natural disasters, especially in this context caused by Floods, and thus take pre-emptive measures to avert any disasters caused by it.

Therefore, the FEMD had initiated to undertake Flood Hazard Assessment for Pema Gatshel Dzongkhag with the main objective to achieve as follows:

- Flood hazard assessment in Pema Gatshel Dzongkhag and identify areas vulnerable to flooding in the face of climate change and variability.
- Analyse the AoMI (Areas of Mitigation Interest) assessment in Pema Gatshel Dzongkhag and identify and prioritize critical flood prone areas within Pema Gatshel Dzongkhag.
- Recommend appropriate flood protection measures along the identified flood prone areas.

Before commencement of field assessment, as per the desktop studies, it was found that only one River imposed significant threat to settlements under Pema Gatshel Dzongkhag, namely Kerong Chhu, flowing through the Nganglam Town. Therefore, FEMD officials visited only Kerong Chhu under Nganglam Dungkhag for flood hazard site investigation purposes.

The Flood Hazard Map obtained by carrying out Hydrological and Hydrodynamic modeling using SWAT and HECRAS applications respectively, depicts certain critical areas like RBA colony, area downstream of Bridge in Nganglam Town and few stretches in the DCCL area vulnerable to Flooding. Therefore, intervention like Gabion Revetments are recommended to be provided at those Areas of Mitigation Interest.

Introduction

Background

Pema Gatshel District is located in the southeastern part of Bhutan. The Dzongkhag covers an area of about 1023 square km with elevation ranging from 1000 to 3,500 meters above sea level and experiences an average annual rainfall of 1500mm to 3000mm. It shares its border with Trashigang Dzongkhag in the north and north- east, Mongar Dzongkhag in the north and north-west, Zhemgang Dzongkhag in the west, Samdrup Jongkhar Dzongkhag in the east and the Indian state of Assam in the south. 87.65% of the total area is under forest cover, comprising mainly of coniferous and broadleaf species. The climate of the Dzongkhag is hot and humid during the wet season and moderate cold during the dry season. Land holdings are dominated by Kamzhing with negligible wetland.

Divided into 11 gewogs namely; i) Choekhorling Gewog, ii) Dechenling Gewog, iii) Norbugang Gewog (These three Gewogs are under Nganglam Dungkhag), iv) Chhimung Gewog, v) Chongshing Gewog, vi) Dungmin Gewog, vii) Khar Gewog, viii) Nanong Gewog, ix) Shumar Gewog, x) Yurung Gewog and xi) Zobel Gewog.

The Dzongkhag has a population of around 25000 people from 4486 households. All the gewog centers are connected with roads making it easier to transport goods and communicate with service centers especially Dzongkhag and Dungkhag administration. Catering to their services are 772 civil servants providing different services – health, education, census, land, etc. Similarly, there are also service delivering corporate bodies like BPC, BTL, Tashi Cell, Bhutan Post, BoBL, BDBL and so on. The basic health service needs are catered from 12 BHUs, five subpost and 35 ORCs. When these health centers are not able to cater, the patients are referred to Pema Gatshel district hospital.

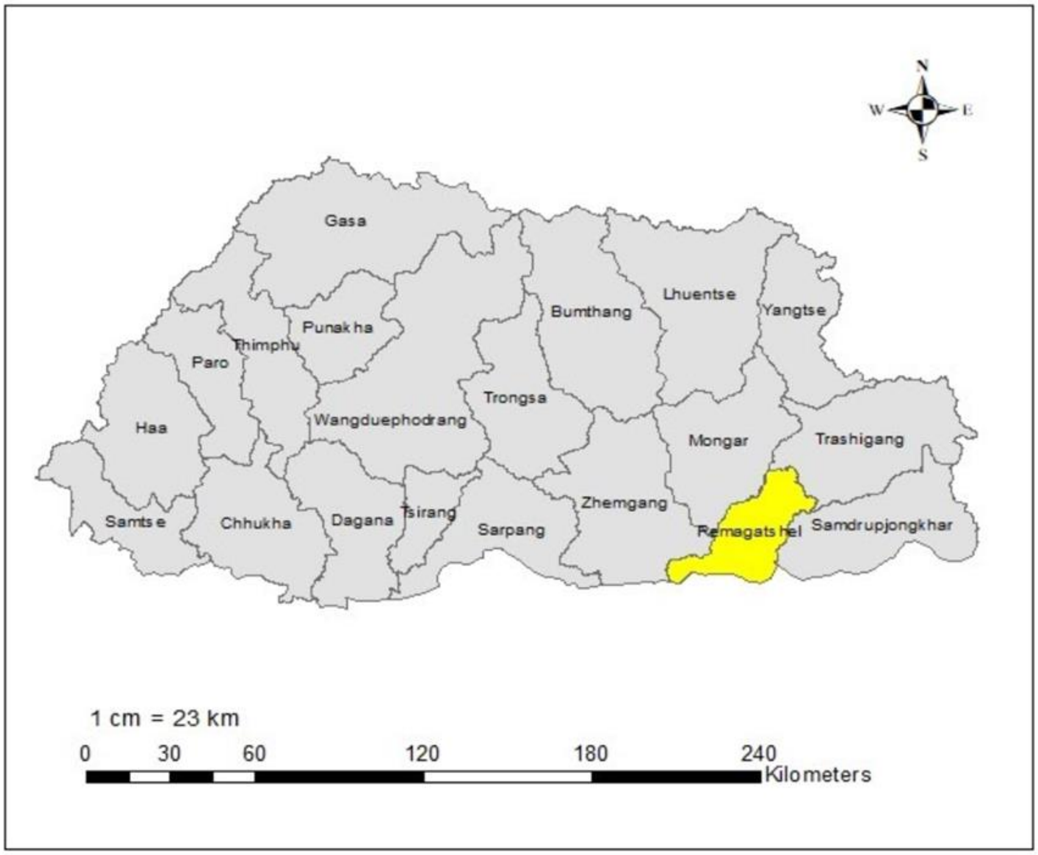

Figure 1: Bhutan Map showing the area of Interest (Pema Gatshel Dzongkhag).

Objective of the Study

Objective 1: Flood hazard assessment in Pema Gatshel Dzongkhag and identify areas vulnerable to flooding in the face of climate change and variability.

Objective 2: Analyse the AoMI (Areas of Mitigation Interest) assessment in Pema Gatshel Dzongkhag and identify and prioritize critical flood prone areas within Dzongkhag.

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

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Flood Hazard Assessment

Floods are natural processes occurring throughout the world, difficult to prevent but can be managed in a proper way to reduce its impacts. Flooding is a threat to life, properties and the environment in the face of climate change. It is therefore, very important that flooding hazards be accessed to identify any flood risk to the area and accordingly plan mitigation measures to reduce its impacts on the most vulnerable.

The Flood Hazard Assessment is intended to identify communities (i.e. village settlements, educational and health facilities, commercial buildings) around the country where the risk due to flooding might potentially be significant and thus, need further study and interventions. Different techniques, methods and their combinations can be used to do the assessment. The factors that will determine the adoption of suitable methods are as follows:

1. The nature of the Flood Hazard.
2. Availability of data like the hydro-met data and topographic data.
3. Feasibility of collecting additional data.
4. Resources available for analysis.
5. Technical capacity of the engineers.

The main objective of the flood hazard assessment is to identify the area which is more prone to flood by site investigations, interactions with the people living in the locality, modelling using different river analysis system etc. The localities are asked on the past flooding events, areas affected, inundated areas, infrastructure constructed in the past for flood protections, etc. The assessment will also include pictographic evidences of the affected areas, the existing infrastructures in the flood prone areas, the gauging stations for rainfall and discharge etc.

Based on the field observations and the past damage reports, the high-risk flood prone area is identified. After identifying the high-risk area, cross-sectional survey of the critical river is conducted for modelling purposes. Subsequently, hydrological and meteorological data such as discharge, rainfall etc. are also collected from the relevant agency for the most critical flood prone area. Flood Hazard Map is prepared based on the availability of data. The Flood Hazard Map showing the inundated area is validated by comparing the inundated area with the recorded past flood event.

Study area

After carrying out desktop studies, it was found that only one river poses significant threat to settlements under Pema Gatshel Dzongkhag, namely Kerong Chhu, flowing through the Nganglam Town. Therefore, FEMD officials had visited only Kerong Chhu under Nganglam Dungkhag for flood hazard site investigation purposes.

Nganglam under Pema Gatshel is located in the south-eastern part of the country. Being in the south, Nganglam area has a warm winter with hot and humid summer. Nganglam Dungkhang is categorized as a satellite town and shares its border with Indian state of Assam. At an elevation of 145m, it receives an annual rainfall of 3400mm and more than 130mm a day during monsoon season. It is expected to be one of the major border town in future connecting the central and eastern Bhutan.

The Kerong Chhu flows through the Nganglam town and Dungsam Cement Corporation Ltd. Factory. Flowing from Kerong and Dazema village, it has a total catchment area of 88Sq.km until it joins Manas River. Settlements along the river have increased over the years with many structures being constructed.

A major flooding event can be of great threat to these exposed buildings and other infrastructures in the area. Minor flooding is quite recurrent during every summer season while major ones have occurred in 1996 and 2006 when there were not many settlements.

With technical backstopping from FEMD, Nganglam Dungkhag administration had also constructed gabion walls and revetment embankments at certain critical reaches of the Kerong Chhu.. One of the biggest Cement Factory in Bhutan, Dungsum Cement Corporation Limited (DCCL) had been established, which lies along the river course and is thus exposed to flooding, if no proper interventions are taken.

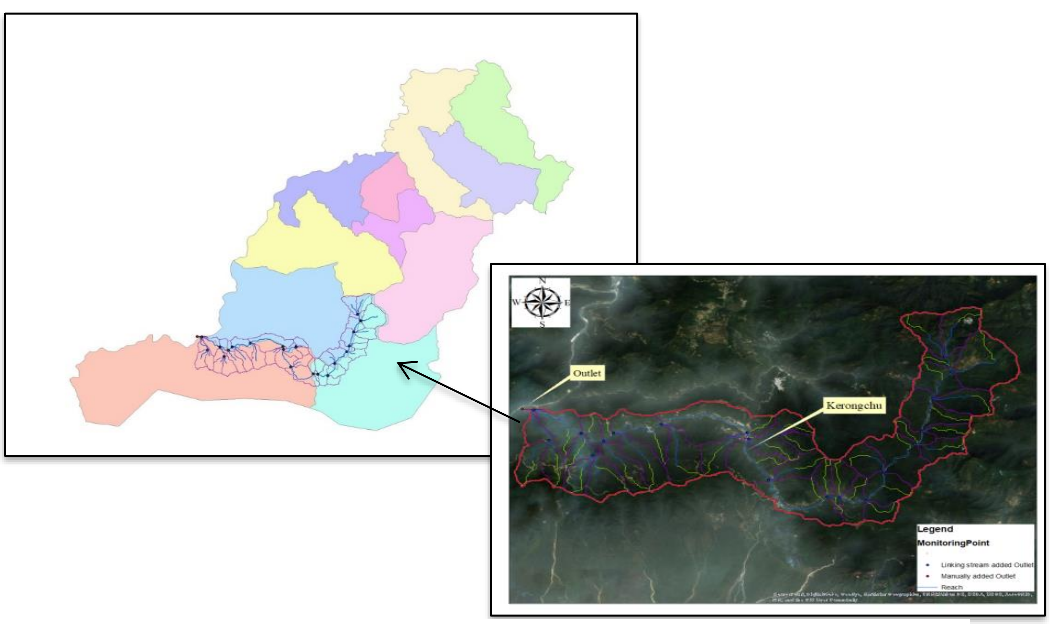


Figure 2: Catchment area of Kerong Chhu under Nganglam Dungkhag

The Kerong river is sourced from the Kerong village and through Dazema, it flows over a steeply gradient topographic profile until it reaches the flat area of Nganlam Dungkhag.

Figure 3: Armed force colony at the right bank of Kerong river and is under risk of inundations during monsoons.

The river flows through the center of the Nganglam town whereby the Royal Bhutan Army camp and some Settlements are very close to the river.

Figure 4: Automobile workshop area and below the Bridge area

The Dungkhag Administration with the technical support from FEMD had carried out the Flood Protection works in the Fiscal year 2017-2018. The structures mainly of RCC walls and Gabion Revetments were constructed at the automobile workshop and around the downstream of bridge area.

Figure 5: Near DoR office area

After the town area, it also flows along the Dungsam Cement Corporation Limited (DCCL) factory and offices. The DCCL authority has also constructed a series of flood protection walls at the critically risky locations.

Figure 6: Kerong river flowing adjacent to DCCL area and boulders stacked along the river

Except for some river boulders stacked along the river course, there are no proper flood protection works being carried out along the river course as of now.

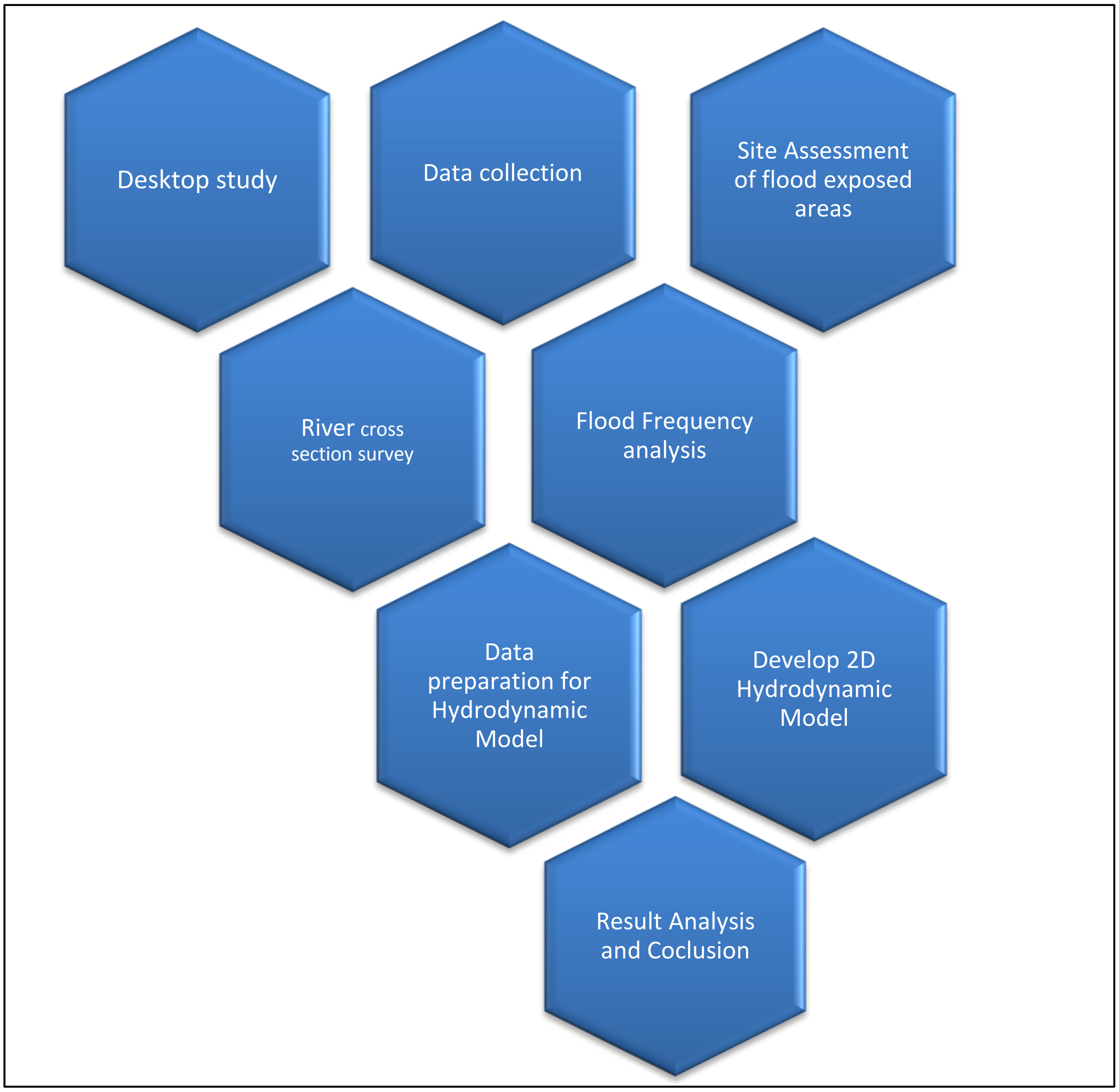

Figure 7: DCCL Factory areas

The table below shows the areas vulnerable to flooding by Kerong River as per visual inspection.

Table 1: Areas vulnerable to Flooding

Sl.No	Vulnerable Areas	Existing Intervention	Remarks
1.	Royal Bhutan Army camp	Gabion Boundary Wall	Right bank
2.	Workshop Area (upstream) near the bridge in town	RCC & Gabion wall constructed along the bank	Left Bank
3.	Houses downstream of bridge	Gabion revetment constructed	Right and Left bank
4.	DoR office area	Gabion wall constructed	Right bank
5.	Private land opposite to DoR office area	N/A	Left bank
6.	DCCL factory area	Boulder Ripraps	Left bank

Methodology



The above Chart shows the various steps and procedures carried out for the preparation of the Kerong river flood hazard map. The steps involve desktop study, collection of data required for running the models till the final output of flood hazard map prepared. The whole step is divided into two processes – hydrological analysis (discharge calculation) and hydrodynamic modeling (preparation of hazard map) performed using the software SWAT and HEC-RAS software respectively. The steps are explained in the following sections.

Data Collection and Assessment

Hydrological and Meteorological Data

The hydromet data which mainly refers to rainfall, discharge and temperature are one of the main data for the preparation of the hazard map. The models and the maps produced are directly depended on the quality of such data used. It follows the concept of “garbage in – garbage out”. An erroneous or limited data will not be able to give the correct results or maps and affect the whole procedures.

As mentioned, Kerong river flows from the village of Kerong. The catchment area of the river is 88 sq.km. The rainfall station is located above the Nganglam town but within the Kerong river catchment area. The rainfall data of the station was obtained from the National Centre for Hydrology and Meteorology (NCHM). The daily rainfall data is available from the year 1985 – 2017 during the time.

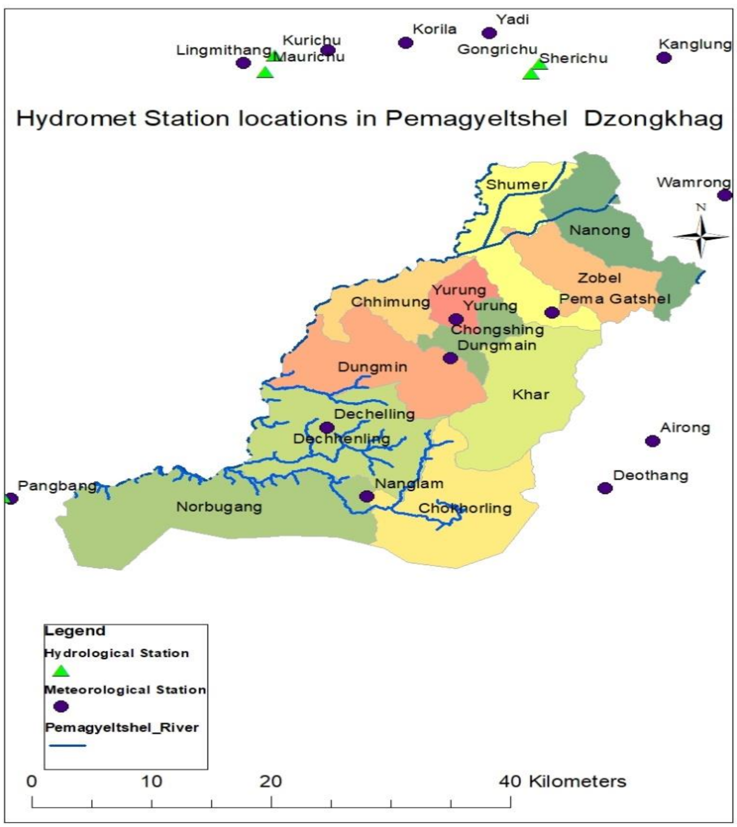


Figure 8: The Location of the Hydro-met stations in Pema Gatshel

Scientific Data

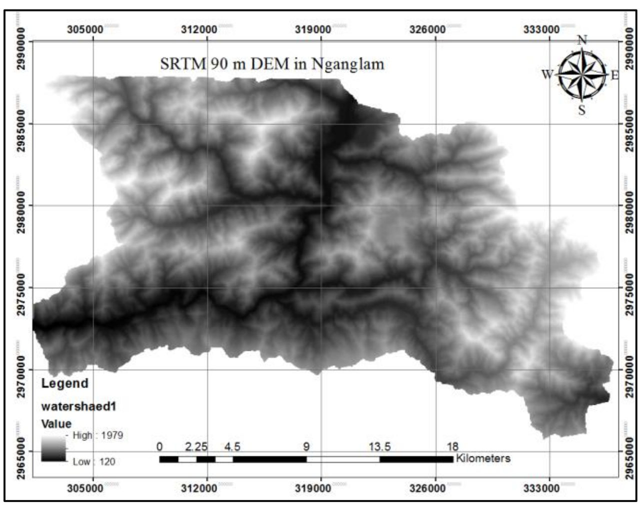
Digital Elevation Model

Digital Elevation Model (DEM) is another important data for the flood hazard map preparation and its resolution quality will hugely influence in performing the modelling and generating the discharge and hazard map. Although correction of DEM can be done, it is always better to use the best resolution DEMs. In case of Kerong Chhu, the following DEMs were being used.

1. 90m SRTM DEM

2. 10m ALOS DSM

Different sourced DEMS have been tested for the task and the best have been selected considering the study area. The 5m SRTM DEM received from National Land Commission of Bhutan (NLCS) contains lots of error as it has been prepared from topography suvey data. The 30m SRTM DEM downloaded from USGS, earthexplorer site viz. https://earthexplorer.usgs.gov/ also gives the similar errors. It contains same values beyond its cell size. Some values are same even beyond 280m and many vertical and lateral errors are also encountered. However, the SRTM 90m DEM from the same source has been used in the hydrological analysis in the SWAT model. It has been corrected by USGS and is found to be less erroneous. Sub-basin parameters such as slope gradient, slope length of the terrain, and the stream network characteristics such as channel slope, length, and width are derived from the DEM.



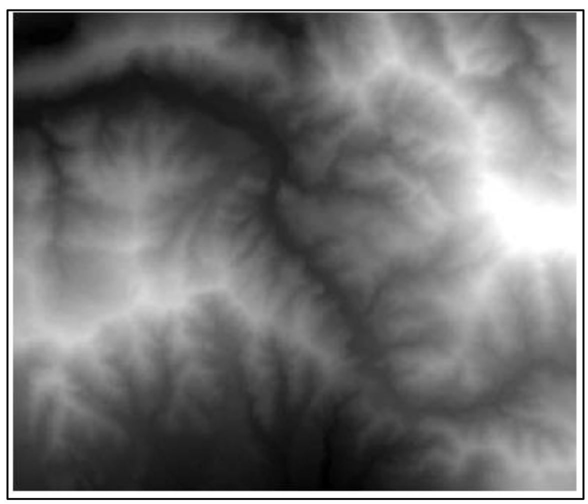


Figure 9: SRTM 30m DEM (left) and 10m ALOS DSM (right)

Since the 30m SRTM cannot describe the river course and overbanks properly, ALOS 10m Digital Surface Model (DSM) has been used in the hydrodynamic model in HEC-RAS for generating the flood hazard map.

Soil and Land use Data

Hydrology models like SWAT and HSPF require land use and soil data to determine the area and the hydrologic parameters of each land-soil category simulated within each sub-watershed. Land use is one of the most important factors that affect runoff and evapotranspiration in a watershed. Parameters like infiltration and Manning's coefficient are derived from the land use map. Use of site specific land use and soil type data is recommended in order to get good result. Hence, request to collect the data has been sought from Forest Resource Management Division (FRMD) and National Soil Service Center (NSSC) under Ministry of Agriculture and Forest (MoAF) for land use and soil data respectively. The land use data of Kerong river basin has been received but the soil data for the region has not been developed.

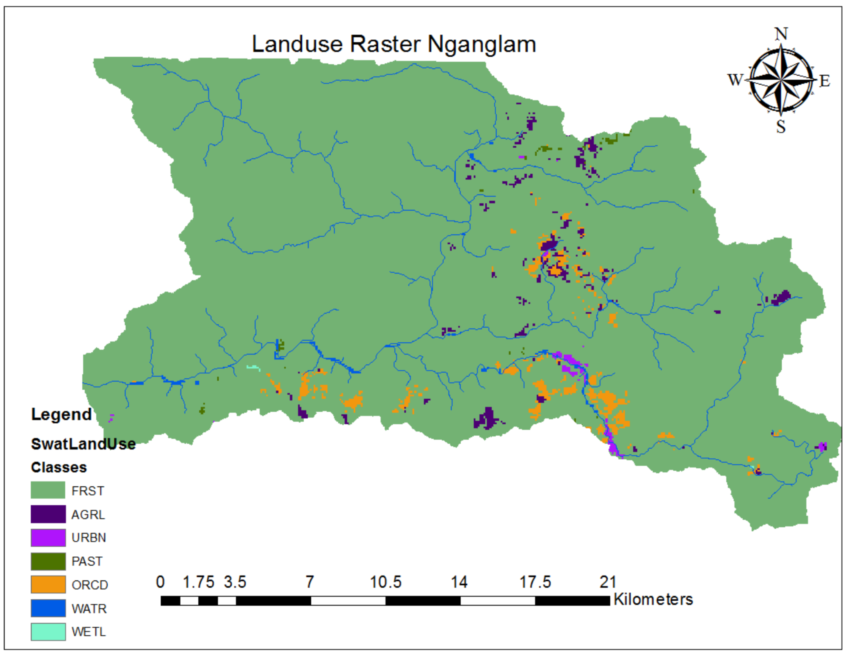


Figure 10: Landuse map of Nganglam

Land use and soil data (1 KM resolution, 2009) of the area is also freely available in the global data. Land use map of this study area has been collected from Global Land Cover Characterization Land use (GLCC). GLCC is a land use data with 1km mesh created by U.S. Geology Survey (USGS), University of Nebraska-Lincoln (UNL), and European Commission for environmental research. Land use is classified to 24 divisions.

The soil data required for the study has been downloaded from Food and Agriculture Organization global dataset generally referred as FAO. Hence, these data were used for the FHM of Kerong river.

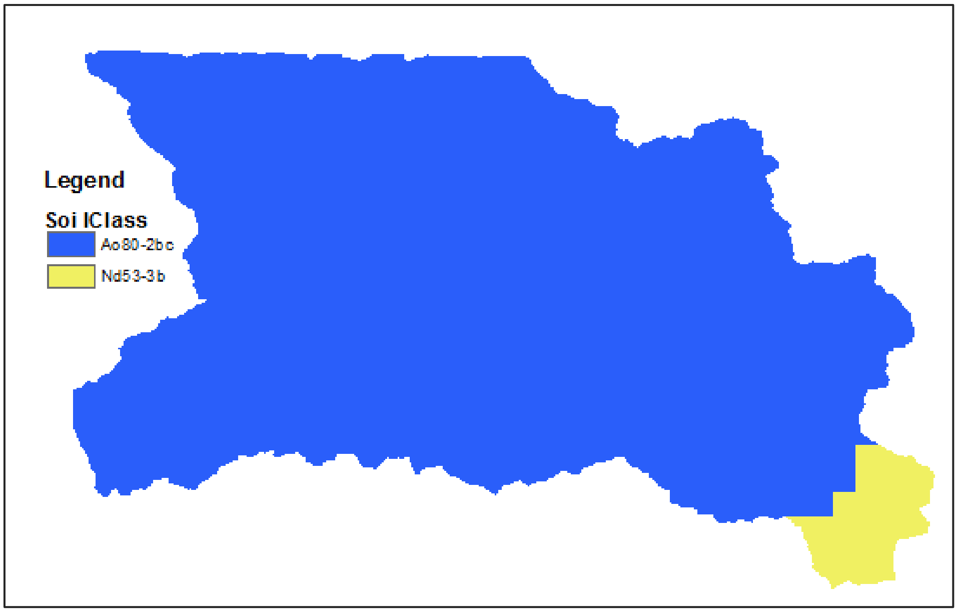


Figure 11: Soil map of **Nganglam**

River Cross Section Data

The Cross section survey of the Kerong Chhu was done by the FEMD in two parts; a) Nganglam town area and b) DCCL factory area.

Figure 12: Cross Section Survey being carried out (Left and Right)

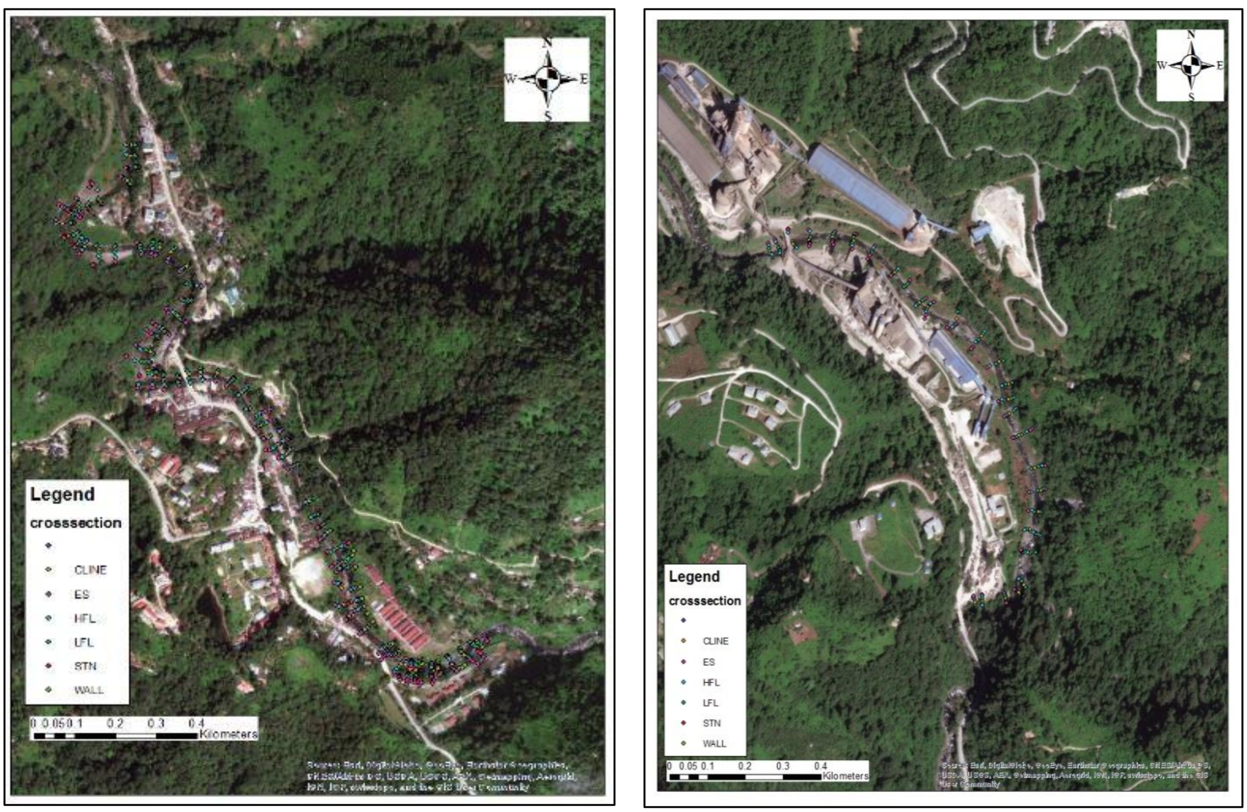


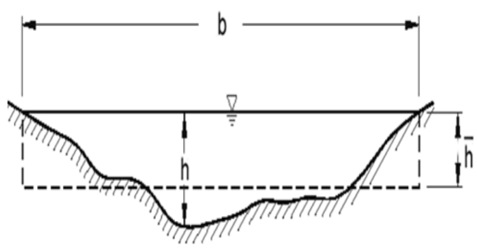
Figure 13: Cross Section Survey at Nganglam Town (left) and Cross Section Survey at DCCL area (right)

However, cross section survey details couldn't be applied, some areas were inaccessible due to rugged terrain and thus it didn't provide precise information. Such details of the area near the banks are required for getting proper flood inundation map. Hence, ALOS 10m DSM has been used in the hydrodynamic modeling.

Floating Method

Due to absence of Hydrological stations and thus Discharge data in the Kerong Chhu, the visiting team also conducted the floating method in order to determine the discharge through a rational method. It has been conducted at two locations – near Dezama village and at the bridge point. The bridge point measurements are all taken from the marks on the abutment of the flood level to calculate the peak discharge.

Table 2: Result of Floating Method

	***1. Dazema Village***	***2. Near Bridge point***	
River/Stream Name: Kerong river	**Lean season measurement**	**Peak season measurement**	
Date of discharge measurement: 5th Oct.2018			
Parameters	**Value**	**Value**	**Unit**
B = width of channel	13	24	m
H = Depth of the flow	0.85	2.66	m
L=Length of the velocity measurement taken	10	10	m
Time= Time taken for float object to cross the 'L'	7.455	5.44	s
V = velocity which is assumed constant across the section. (L/T)	1.34	1.83	m/s
A = cross sectional flow area (B*H)	11.05	62.4	m^2

Q = AV where Q = discharge;	14.807	114.192	m^3/s

The discharge during the lean season (during the time of experiment in October 2018) was found to be **14.807 cumecs** and the discharge taken from the highest flood level from the bridge point was calculated as **114.192 cumecs.** As the velocity of the lean season was considered for discharge calculation of the peak season, the actual peak season discharge is expected to be greater than **114.192 cumecs**. These discharges obtained by rational method would be helpful in validation and verification of the results from the hydrological model.

Development of Model

Hydrological Model

SWAT is used worldwide as it's a free software that supports readily available input data, can also be used in catchments that lack calibration data and is computationally efficient and can simulate for long terms (Neitsch et al.,2011). SWAT is a physically based, continuous time, watershed model, developed to predict the impacts of land use and soil management on water, water quality, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over a long period of time (Neitsch et al., 2011).

Catchments in the SWAT can be divided into sub-catchments to represent the heterogeneity of the soil, land use, slope properties that impacts the hydrology of each specific area (Neitsch et al., 2011). Each sub basin is composed of different elements such as climate, hydrologic response unit (HRU), wetlands, groundwater, reach and main channel which drains into the sub-basin (Neitsch et al., 2011).

HRUs are lumped land areas within the sub-basin which is a unique combination of land cover, soil type and slope class (Neitsch et al., 2011). HRU can be considered as the smallest unit in SWAT where components such as surface runoff, evapotranspiration, groundwater flow, sediment yield is estimated (Setegn et al., 2008b).

In SWAT model hydrological cycle is broadly divided into land phase and water or routing phase. Land phase controls the amount of water, sediment, nutrient and pesticide loading to the main channel in each sub basin and water or routing phase defines the movement of water and sediments through the channel network of the basin to the outlet. (Neitsch et al., 2011).

The land phase of the hydrologic cycle is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{t}(R_{Day} - Q_{Surf} - E_a - W_{seep} - Q_{qw})_i$$

Where, SW_t is the final soil water content (mm H2O), SW_o is the initial soil water (mm H2O), t is the time (days), R_{Day} is the amount of precipitation on day i (mm H2O), Q_{Surf} is the amount of surface runoff on day i (mm H2O), E_a is the amount of evapotranspiration on day i (mm H2O), W_{seep} is the amount of water entering the vadose zone from the soil profile on day i (mm H2O), and Q_{qw} is the amount of return flow on day i (mm H2O) (Neitsch et al., 2011).

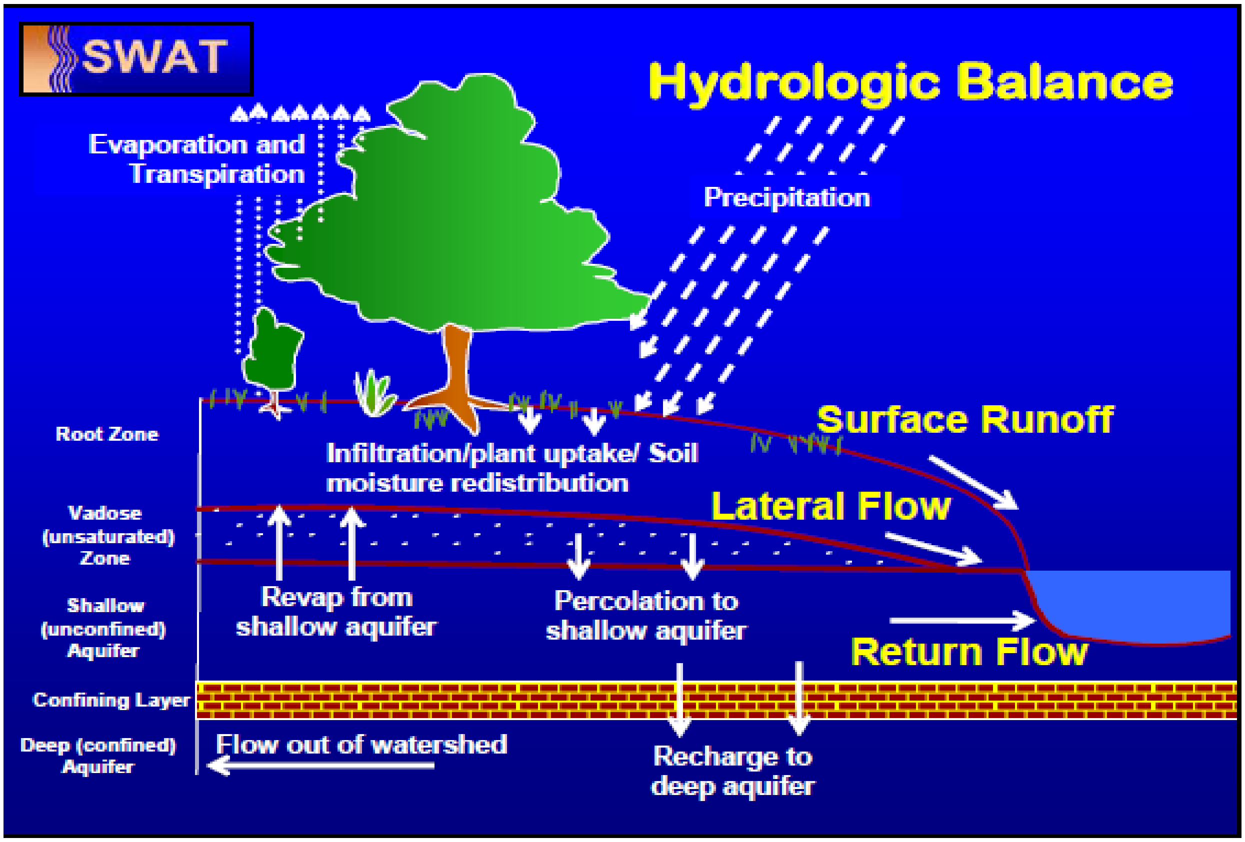


Figure 14: Schematic representation of the hydrological

Model setup

After data collection, the SWAT model was set up. The model was built in GIS environment and the software used was Arc-SWAT 2012 in Arc-GIS version 10.4. The steps followed in model setup are described under following sub headings.

Catchment Delineation and Sub-basin discretization

Catchment delineation is the first step towards the model setup in SWAT. The required tiles of the SRTM DEM of resolution 90x90 was used in creating a mosaic in Arc GIS environment, which was subsequently projected to WGS 1984 UTM Zone 46N and clipped before loading it into the "DEM Raster" tab in the watershed delineator toolbar in ArcSWAT. The outlet of the basin was chosen and then the catchment was delineated. The number of sub-basin division is strongly related to simulating sediments and nutrients in SWAT model (Jha et al., 2004). Hence, 132 sub basins were created and total Catchment area is 498 sq.km for Nganglam catchment. Further, the catchment for Kerong river was delineated with outlet near the confluence of Drangmechu. The total catchment area of Kerong river is found to be 88 sq.km. The large number of sub-basin division helps in representing the spatial variation of the variables such as precipitation, temperature, soil type, slope and land use. After sub basin delineation, sub basin parameters like minimum and maximum elevation, longest flow path and catchment area were also calculated.

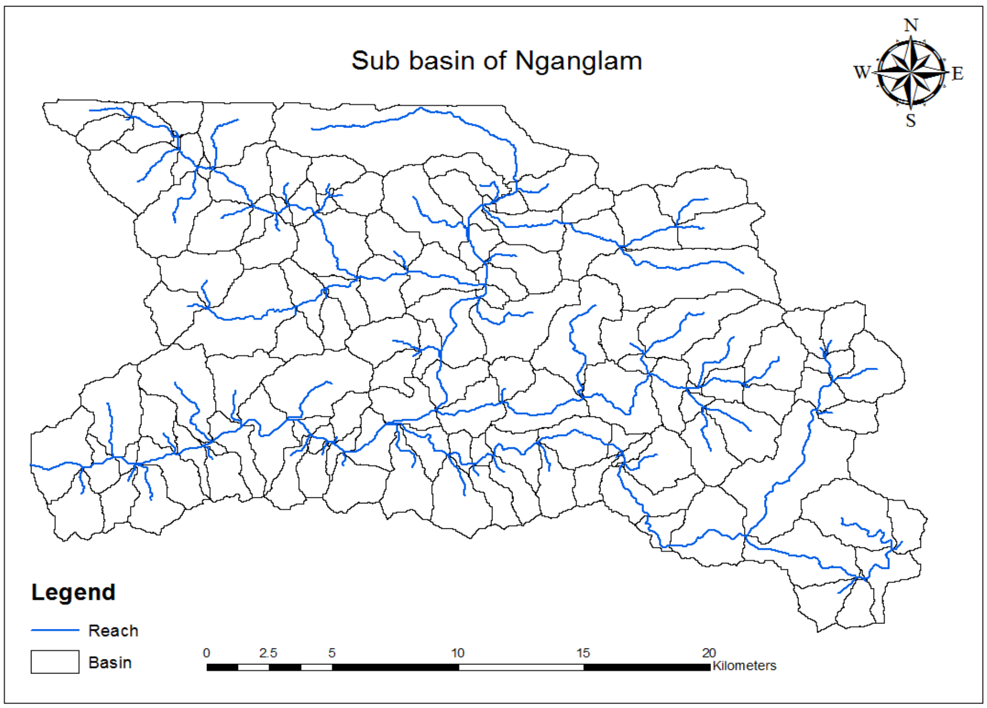


Figure 15: Kerong river Nganglam basin with its sub basins and river network.

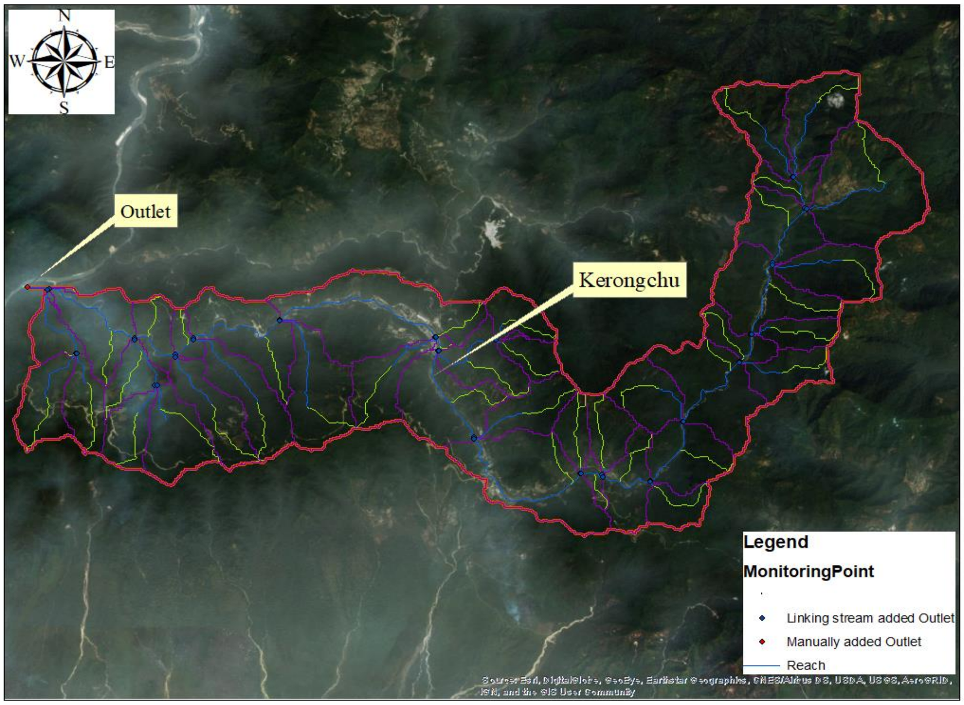


Figure 16: Kerong river sub-catchment

HRU definition

The sub-basins were further divided into multiple Hydrologic Response Unit (HRU). HRU is a unique combination of soil type, land use and slope which are the smallest unit in SWAT where calculation of the water balance, sediments and nutrients takes place.

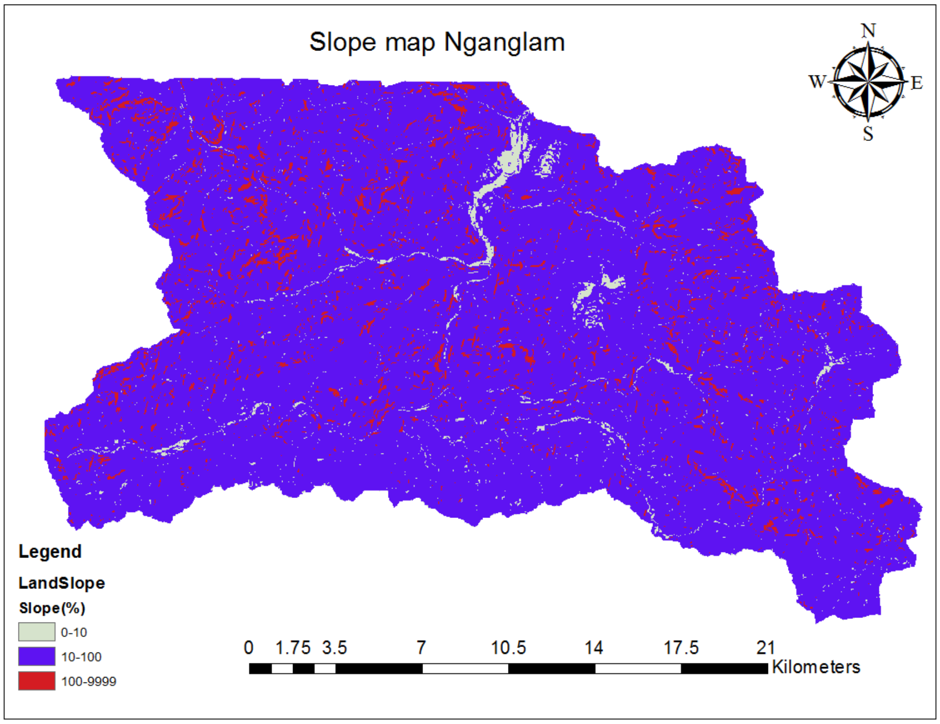


Figure 17: Slope distribution of Nganglam

To proceed with the HRU definition, the projected land use map and soil map were overlaid in the watershed. The land use classes of the Land use Bhutan had to be reclassified to the nearest matching land use category of the SWAT database. This was carried out by making a simple land use look-up table. The soil types and its corresponding parameters were also updated in the *user soil* database of the SWAT model. Next, the basin was divided into three slope categories with the criteria given by the FAO. Areas with slope 0-30% represented the undulating lands, 30 – 100% represented steep lands and >100% represented mountain areas as shown in Figure 17.

Model Simulated Result

Figure 18 shows the simulated annual maximum daily discharge from 1988 to 2017.

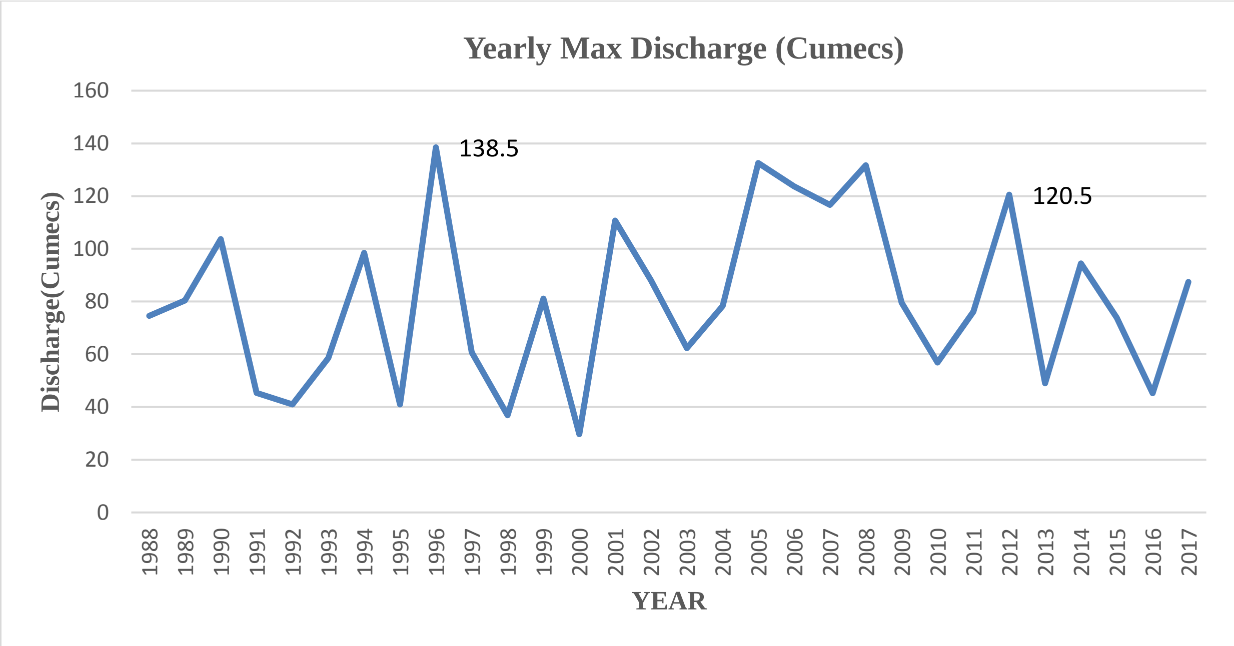


Figure 18: Simulated annual maximum daily discharge

During the site visit in October 2018, Floating method was carried out at the Bridge point and the peak discharge was calculated as **114 Cumecs** (this discharge should be higher since the river velocity during the monsoon season is greater than the assumed one in lean season).

Therefore, after comparing with the simulated discharges of past years (1988 to 2017), the simulated discharge in the year 2012 with **120.5 Cumecs** is found to be corresponding to the floating method discharge.

Therefore this simulated discharge can be found to be more or less reliable and thus the past maximum discharge of 1996 was considered to produce hydrograph for 100 year return period as input data for hydrodynamic model.

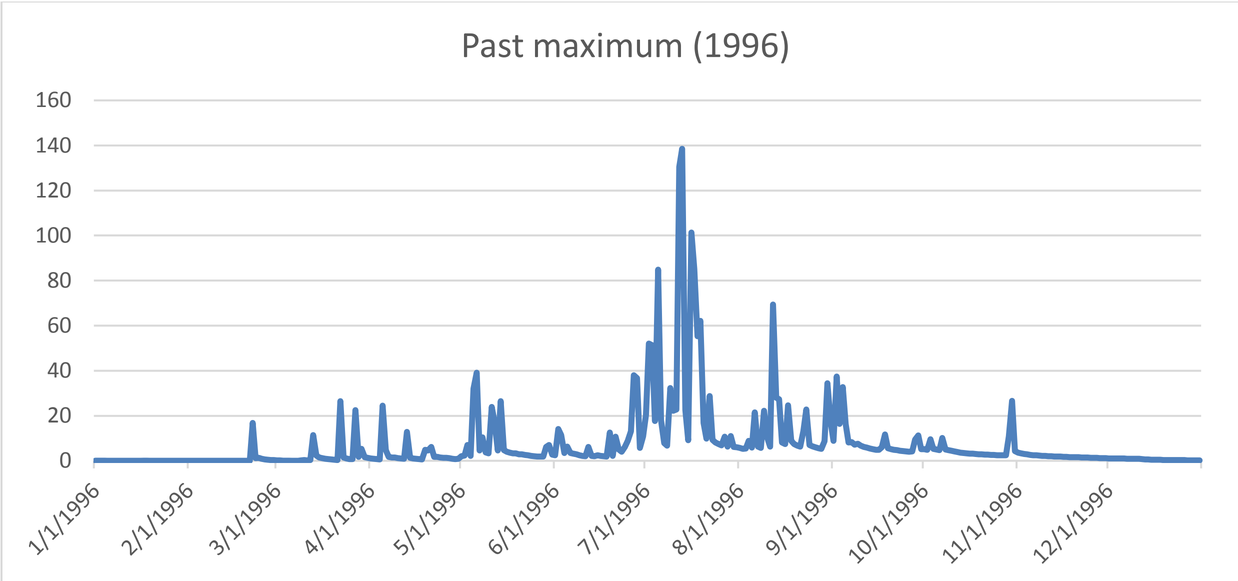


Figure 19: Hydrograph showing past maximum daily discharge in 1996.

*The peak daily discharge of the past maximum was simulated as 138.5 Cumecs in 1996.

Flood Frequency Analysis

Hydrologic systems are sometimes impacted by extreme events, such as severe storms, floods and droughts. The magnitude of an extreme event is inversely related to its frequency of occurrence, very severe events occurring less frequently than more moderate events. The objective of frequency analysis of hydrologic data is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions.

Frequency analysis using frequency factors is calculating the magnitudes of extreme events by the methods that are the probability distribution function. The frequency factor equation was proposed by Chow (1952), and it is applicable to many probability distributions used in hydrologic frequency analysis. Flood frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. Two of the common forms are:

1. Gumbel Distribution
2. Log-Pearson Type III Distribution

According two methods, because these methods are used to predict design floods, to identify proper method for this study, probability plotting is a probability distribution fits a set of hydrologic data that was used to compare with that two method.

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 parameters 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.

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

$$c = \mu - 0.5772a$$ 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.

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

$$Q_T = c + Y_T a$$ Equation 4

The results from the Gumbel distribution for Kerong river is detailed in the Table below.

Table 3: Result of frequency analysis in Gumbel distribution

Sl.No.	Return Period	Return Period Discharge (Peak Method)
1	2	75.42
2	5	103.12
3	10	121.46
4	20	139.05
5	30	149.16
6	50	161.81
7	100	178.88
8	200	195.87
9	1000	235.25

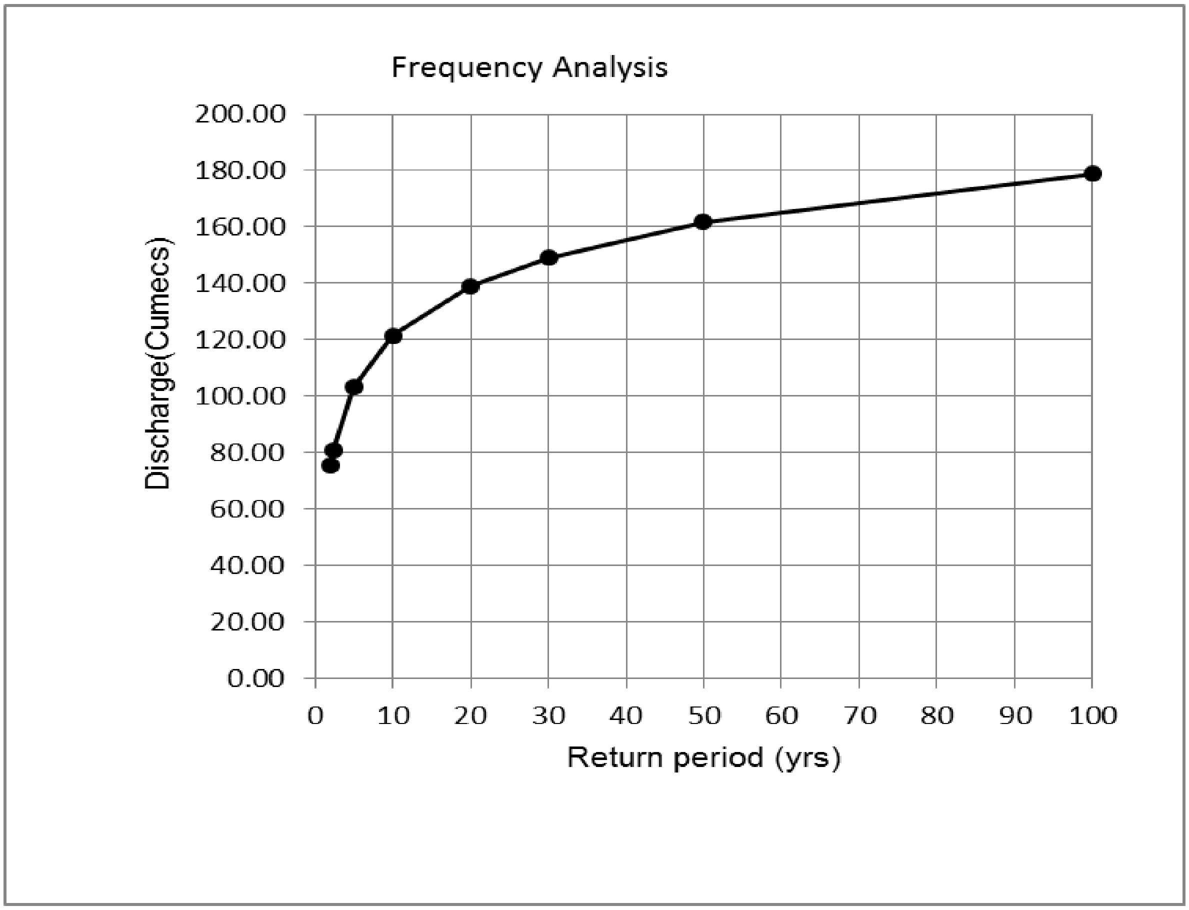


Figure 20: Result of frequency analysis in Gumbel distribution

Log Pearson III distribution

The Log Pearson III (Pearson, 1895) was the second statistical technique used to fit the flood frequency for the 5 rivers in the basin. 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.

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

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 result from the Log Pearson distribution for Kerong River is detailed in the following Table and figure.

Table 4: Result of frequency analysis in log-Pearson distribution

Sl.No.	Return Period (T)	Return Period Discharge
1	2	76.44
2	5	106.51
3	10	124.82
4	20	141.24
5	30	150.23
6	50	161.04
7	100	174.98
8	200	188.20
9	1000	216.76

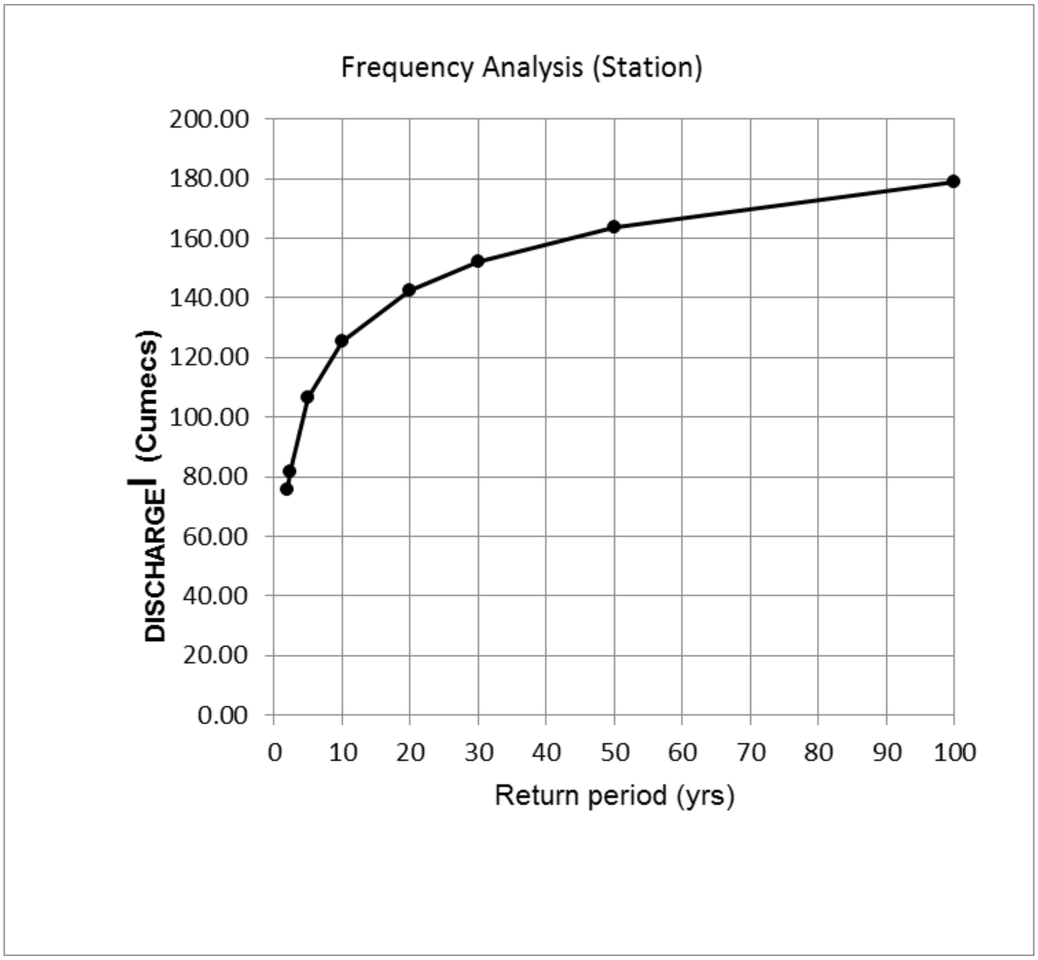


Figure 21: Frequency analysis in Log-Pearson distribution

Best fit analysis

Chi square tests have been carried out to the two frequency analysis and the result found Gumbel 0.968598 and Log pearson 0.999858. While comparing the Gumbel method and Log Pearson method, it was found that Gumble method shows better result as the frequency analysis model fitness (lower Chi square test value) as shown in **Figure 22**. Therefore, Gumble's method has been adopted to predict the discharge in return year periods.

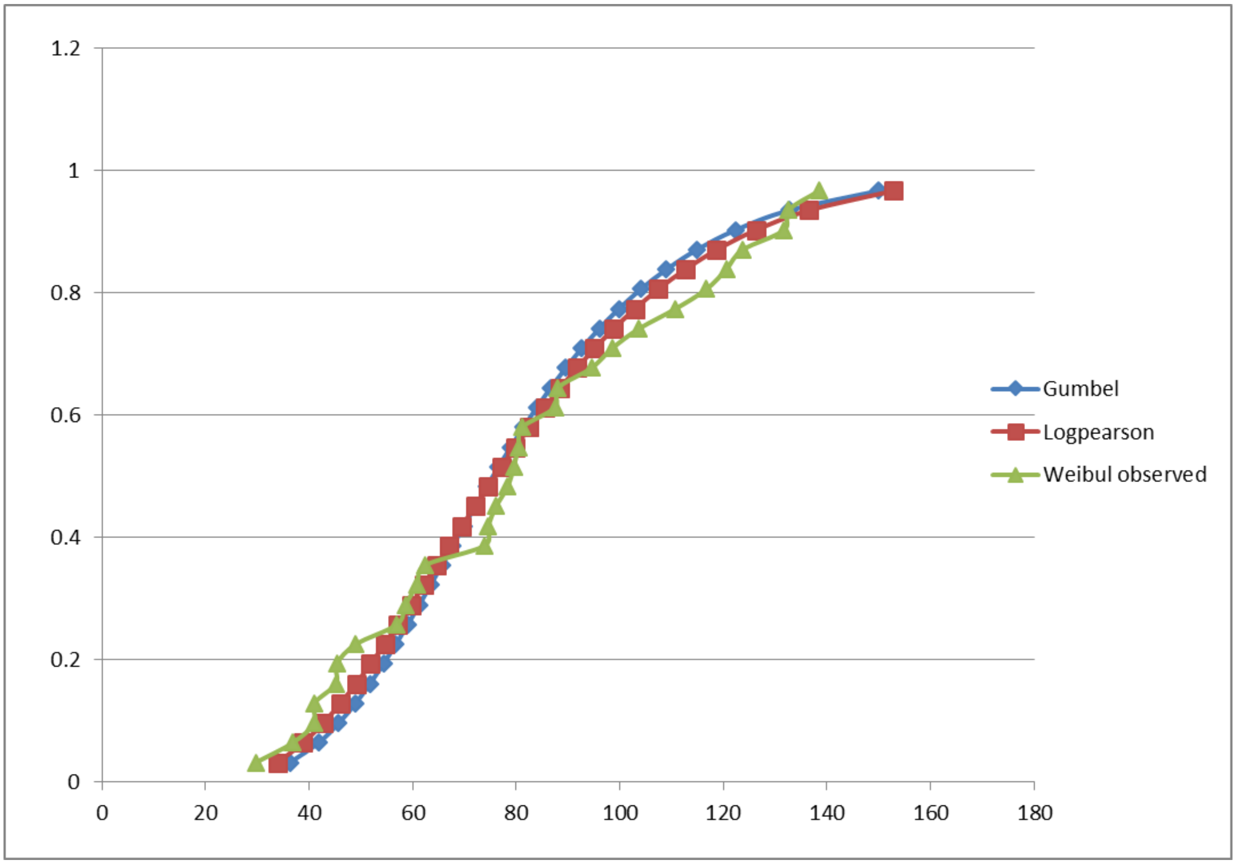


Figure 22: Result of the best fit analysis of frequency analysis method

*Weibul observed : Here it is simulated discharge from the observed rainfall.

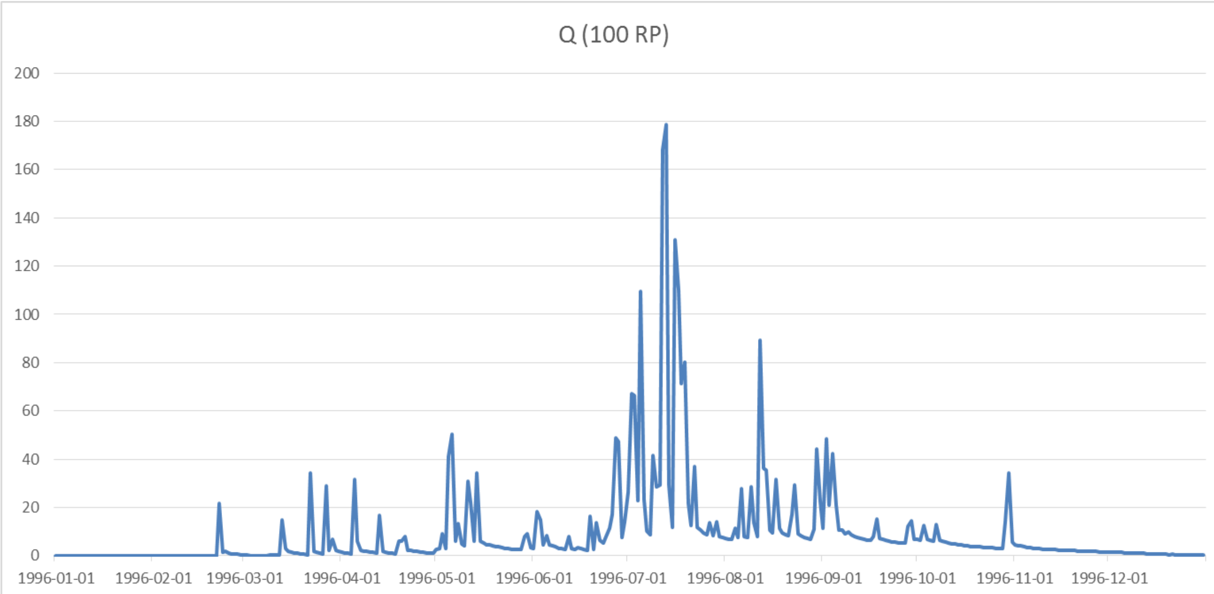


Figure 23: Hydrograph for 100 year return period at Kerong river

The Peak discharge for 100 years return period is obtained as **178.88 Cumecs** which will be used as input for upstream boundary for HECRAS modelling. Past maximum discharge (year 1996) was considered for creating the hydrograph in the 100 year return period and added 29% (=the peak discharge of 100 years return period/the peak discharge of the past maximum=178.88/138.5) to the maximum hydrograph.

Hydrodynamic model

Since SRTM 30 DEM and the Cross sections taken were significantly differing in terms of elevations and couldn't be superimposed, the ALOS 10m DSM was found most suitable for the study area and thus it was used to create a terrain for the 2D hydrodynamic model.

Hydrodynamic model setup, calibration-validation and simulation are the major steps for Hydrodynamic modeling. HEC-RAS software has been used to develop this hydrodynamic model for Kerong river. The Hydrologic Engineering Center's (HEC) River Analysis System (HEC-RAS) software allows the user to perform one-dimensional (1D) steady and 1D and two-dimensional (2D) unsteady flow river hydraulics calculations. HEC RAS is developed by US Army Corps of Engineers.

2D modelling has been selected because DSM can be suitable to develop hydrodynamic model in this study area. Since 1D modelling couldn't be applied due to cross section data limitation.

HEC-RAS 2D Model setup

The following figure shows workflow of HEC-RAS modeling for Kerong river.

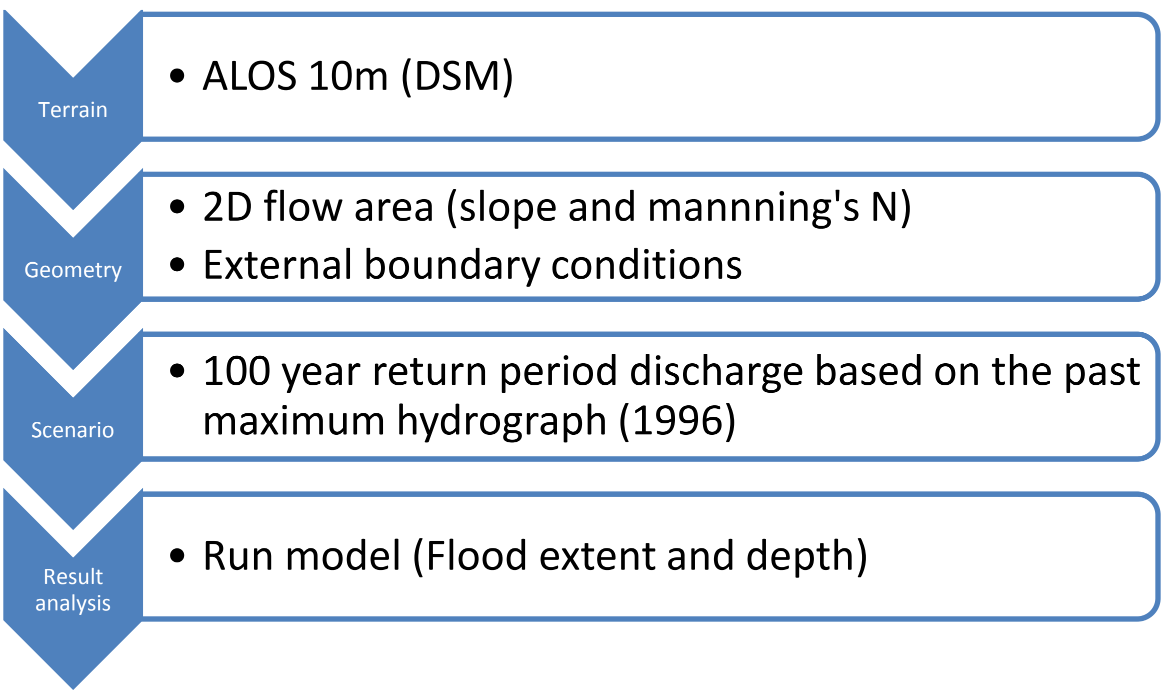


Figure 24: Methodology adopted for the developing the 2D Hydrodynamic Model

Terrain creation

The ALOS DSM was used to create the terrain in RAS Mapper. And since ALOS DSM takes into consideration the surface elevation, the building elevation at some location was represented. Therefore, this would lead to some unreasonable flood extent. The terrain was used for creating the 2D hydrodynamic model for Kerong Chhu.

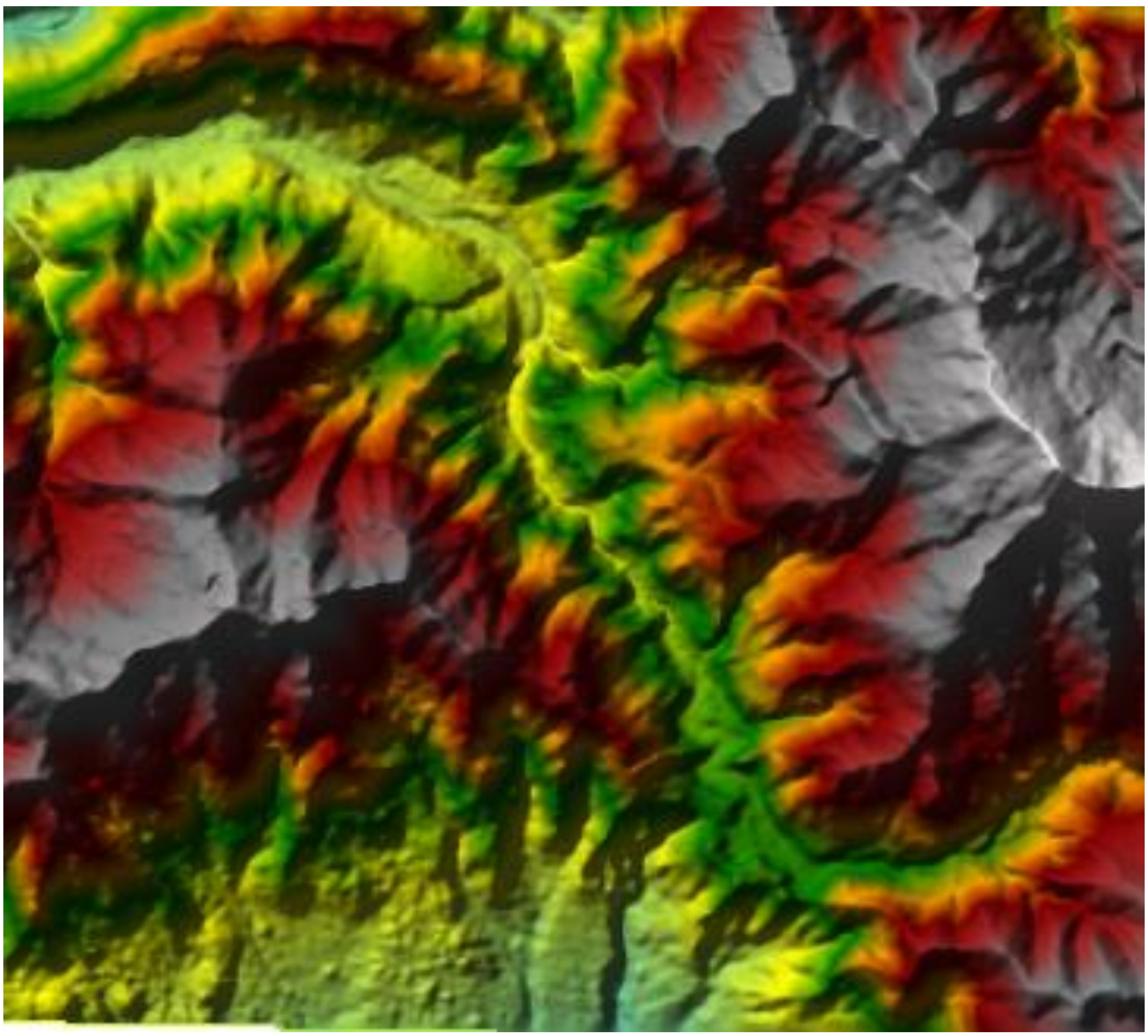


Figure 25: Kerong river terrain (ALOS 10m DSM)

Geometry (2D flow area)

Flexible mesh capability of HEC RAS 2D has been used to automatically generate mesh for the model domain. Central to the concept of 2D floodplain modeling is to use a computational mesh. HEC-RAS uses a combination of a finite-difference and a finite volume method to compute water elevation at the center of each computational grid cell for each computational time step. 2D modeling features in HEC-RAS allow a user to create computational mesh.

The 2D area for Kerong Chhu was created in RAS Mapper encircling the channel geometry. The mesh was refined by creating another polygon close to channel and refining it to 10m and perimeter spacing of 25m.

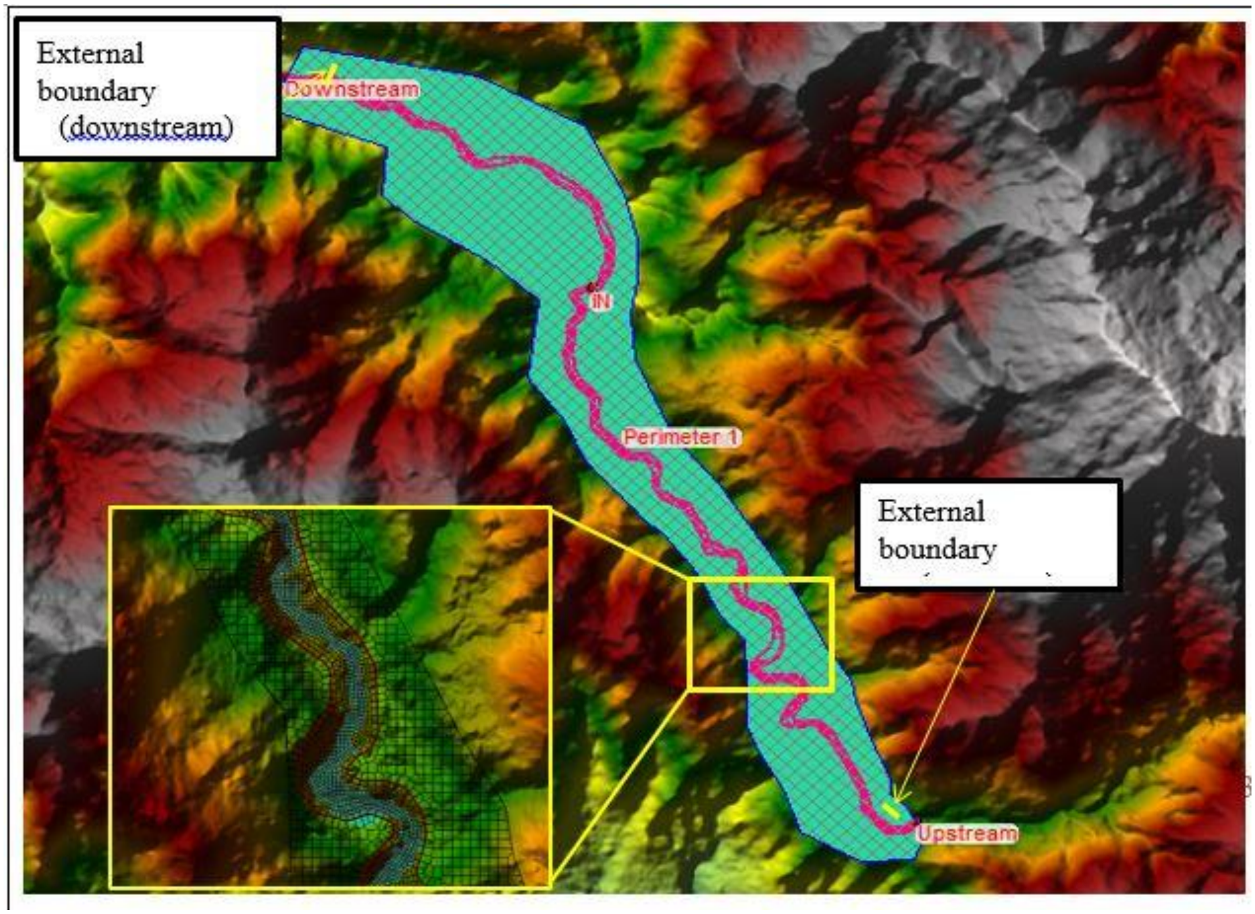


Figure 26: Kerong Chhu 2D Mesh

Scenario (upstream boundary conditions)

Two external boundary conditions have been applied. The output flow hydrograph from the hydrological model (SWAT) was used as the upstream boundary conditions. Normal depth of **0.03** (Calculated from the slope of the river bed) has been used at the downstream boundary

The 100 YRP has been used as upstream boundary condition. It is because calibration cannot be conducted due to a lack of observed discharge data and past flood records.

The 100 year return period scenario has been considered for simulation for Kerong River as this will provide the potential areas that might be flooded during the occurrence of such flood event and accordingly appropriate interventions to be recommended for flood protection works along the river.

Result analysis and Conclusion

The Flood hazard map for 100 year return period has been prepared which shows the details of the inundation area and depth at each point. The flood hazard maps and Flood Extent for Kerong Chhu under Nganglam from the HEC-RAS flood modelling as depicted in the figures below:

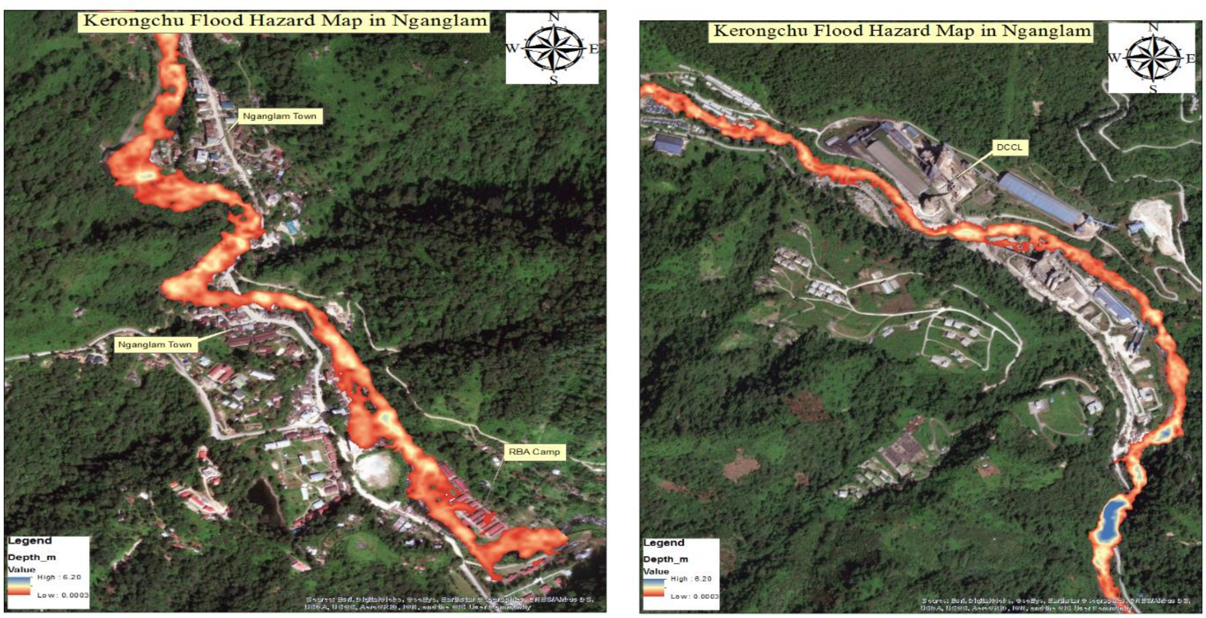


Figure 27: Flood Hazard Map of Nganglam town area (R) and DCCL area (L)

Figure 28: Overall Kerong Chhu Flood Hazard Map in Nganglam

Flood Extent:

The critical areas have been plotted for Terrain Profile in the RAS Mapper as shown in the figures below for ascertaining Flood Depth. Some areas show unreasonable elevation. This is because of a lack of appropriate terrain data and since the terrain model in this hydrodynamic model has been created by DSM (ALOS 10m) due to the limitation.

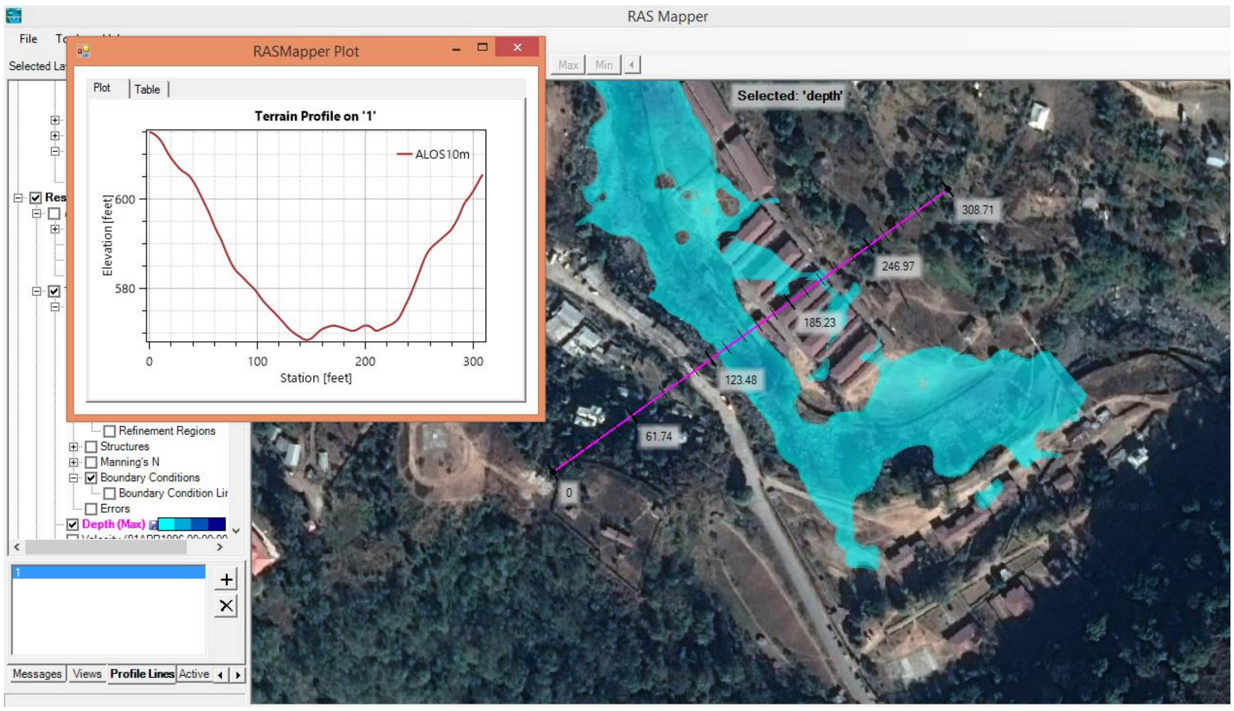


Figure 29: Terrain profile in the RBA Colony

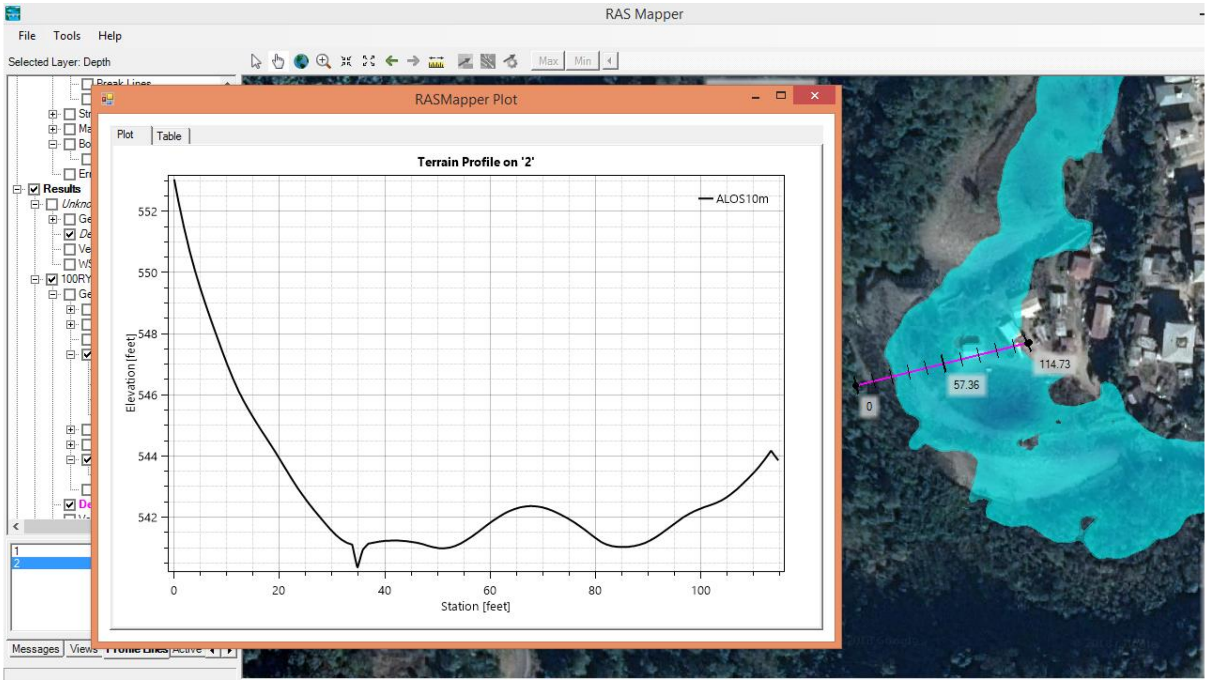


Figure 30: Terrain profile in the Town Area

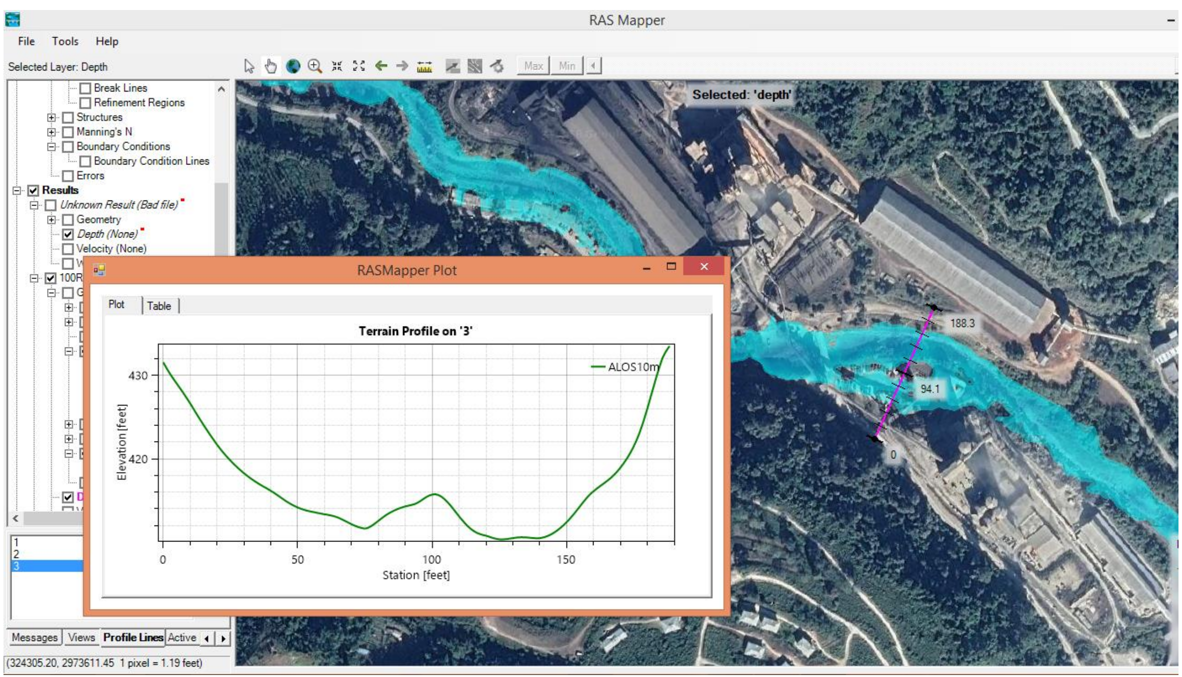


Figure 31: Terrain profile in the DCCL area.

Recommendation for flood management

As depicted in the Figure 32, critical areas for flood management are as follows:

a) RBA Colony area and Downstream of Bridge under Nganglam Town

b) Two locations as depicted in the DCCL area.

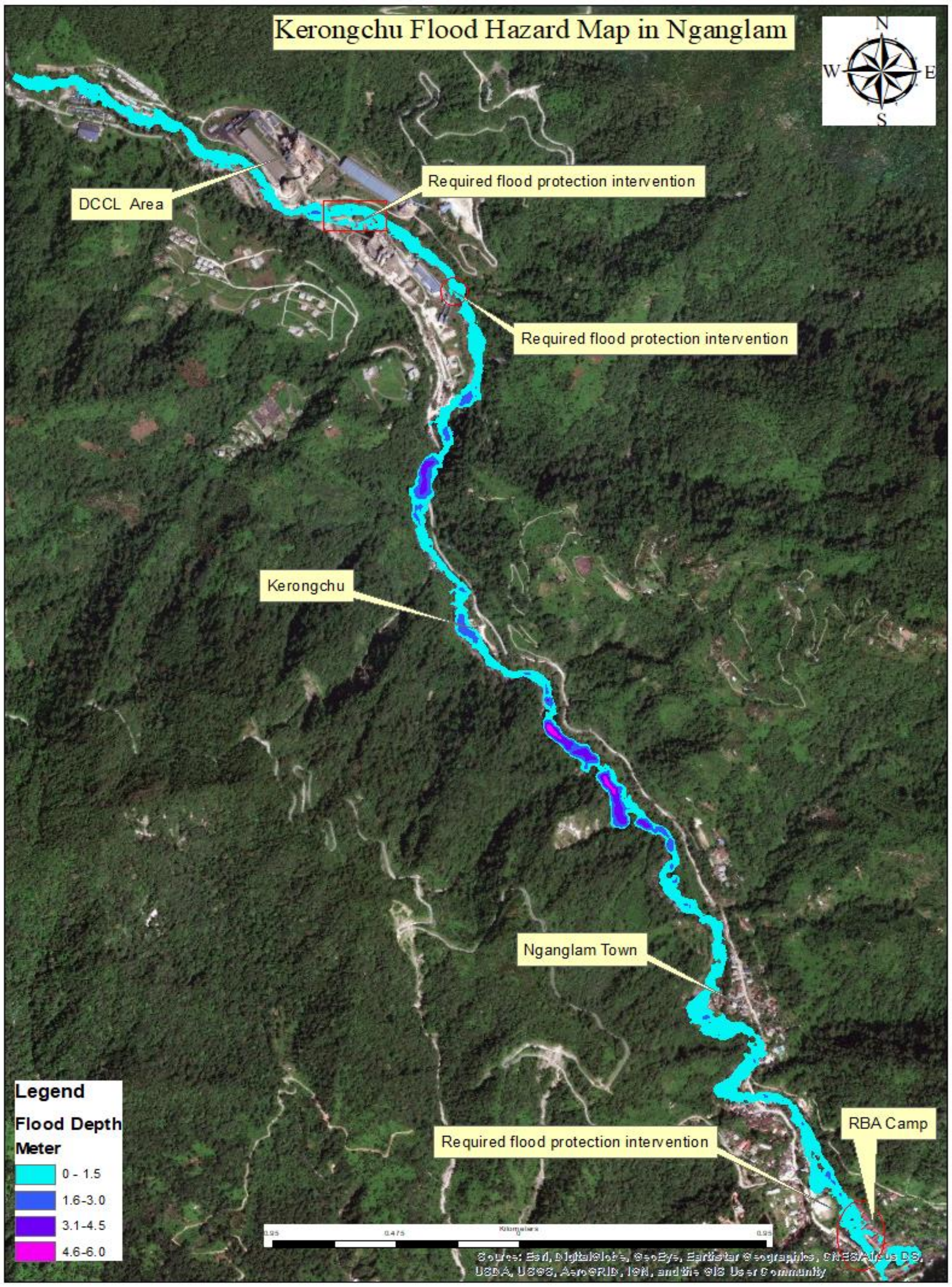


Figure 32: Critical areas to Flooding has been identified

Intervention

There are already some flood interventions carried out by the Nganglam Dungkhag Administration such as Gabion walls and Cement Concrete walls along the Kerong Chhu in the Town area.

Ideally, the Interventions needs to be properly designed. 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).

However, due to limited data and modelling challenges, Gabion revetment flood mitigation measures are found to be more applicable for the areas identified as critical to flood inundation.

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 33.*

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.

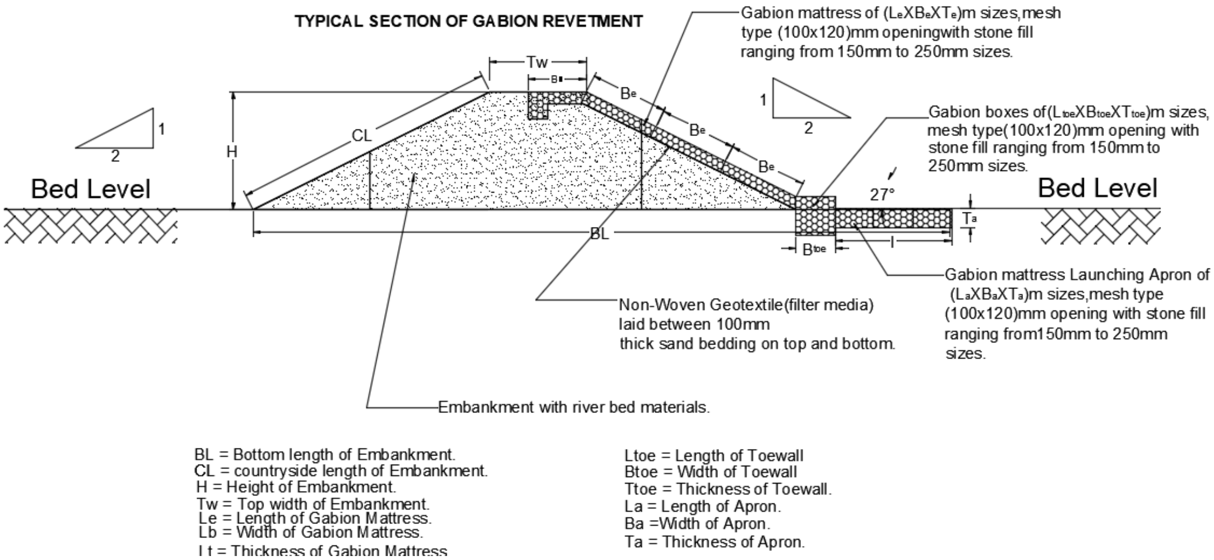


Figure 33: Typical cross section of a gabion revetment

Limitations

- Kerong Chhu didn't have Hydrological station and thus no historical discharge data to conduct calibration or validation in hydrology and hydrodynamic models.

- Only one number of meteorological stations has been installed in the Kerong Chhu Catchment area.

- The Digital Elevation Model used in this study was ALOS DSM with 10 meter resolution which is freely available. Since it takes vegetation and building heights as surface level.

- 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. Pema Gatshel, Dzongkhag Administration website, www.Pema Gatshel.gov.bt
2. Department of Engineering Services, MoWHS, June 2016, *Preliminary Flood Hazard Assessment for Dungsumchu in Samdrupjongkhar Dzongkhag*, MoWHS, Thimphu, Bhutan.
3. Asian Disaster Preparedness Centre, 2014, *Coursework book for Training in Flood Risk Assessment and Planning of Mitigation Measures,* ADPC, Bangkok, Thailand.
4. Engineering Service, Office of Public Works,*National Preliminary Flood Risk Assessment (PFRA)*, Ireland.
5. *Floodplain definition and flood hazard assessment*,http://www.oas.org/CDMp/document/NHP/oea66e/ch08.htm (21st December, 2016)
6. ClimateTechWiki, *A clean technology platform*,http://www.climatetechwiki.org/content/flood-hazard-mapping (21st December, 2016)
7. *HEC-HMS*, https://en.wikipedia.org/wiki/HEC-HMS (21stDecember, 2016)
8. *GumbelDistribution*,https://en.wikipedia.org/wiki/Gumbel_distribution (21stDecember, 2016)