DEPARTMENT OF ENGINEERING SERVICES,
MINISTRY OF WORKS AND HUMAN SETTLEMENT
ROYAL GOVERTMENT OF BHUTAN

Flood Management Plan for Kerongchu, Nganglam, Pema Gatshel Dzongkhag.

PREPARED BY FEMD, DES, MOWHS

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Disclaimer

The Flood Management Plan (FMP) for Kerongchu under Nganglam Dungkhag, Pema Gatshel Dzongkhag is prepared mainly for recommendation of flood intervention based on findings of the study. Therefore, it is not recommended for application in any sort of administrative zonation purposes, since other hazards have not been considered during the study.

Abbreviation and Acronym

FEMD	Flood Engineering and Management Division.
Kerongchu	River flowing through Nganglam Dungkhag under Pema Gatshel Dzongkhag.
HEC-RAS	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 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.
SWAT	Soil & Water Assessment Tool is a small watershed to river basin-scale model used to simulate the quality and quantity of surface and ground water and predict the environmental impact of land use, land management practices, and climate change.
GIS	Geographical Information System is a computer-based method for analyzing geographical information and maps.
DES	Department of Engineering Services.
NCHM	National Centre for Hydrology and Meteorology.
MoWHS	Ministry of Works and Human Settlement.
Nu.	Bhutanese currency in Ngultrum.
FMP	Flood Management Plan
ECoP	Environment Code of Practice
GLOF	Glacial Lake Outburst Flood
SPCR	Strategic Programme for Climate Resilience
DEM	Digital Elevation Model
SRTM	Shuttle Radar Topography Mission
RCC	Reinforced Cement Concrete
DCCL	Dungsum Cement Corporation Limited
DPCL	Dungsum Polymers Corporation Limited
MoAF	Ministry of Agriculture and Forestry
UTM	Universal Transvere Mercator

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1. Introduction

1.1 Background

Bhutan has witnessed multiple Climate and Hydrological extreme events, in particular glacial lake outburst floods (GLOF) resulting from glacial melting, flash floods, localized changes in rainfall patterns. Flash floods are among the most common climate induced hazard in Bhutan and which is exacerbated by global change in the climate. People have lost lives, properties, agricultural products during such disaster.

To combat these issues and develop a long-term strategic program to address climate resilience, the World Bank had provided fund to develop a Strategic Program for Climate Resilience (SPCR). The SPCR document is expected to provide a long-term vision for addressing climate resilience, outline country priorities, and articulate a program of investments to achieve goals.

As a study component of the SPCR, the Flood Engineering and management Division under Department of Engineering Services, Ministry of Works & Human Settlement carried out Flood Hazard Assessment for Kerongchu in Nganglam under Pema Gatshel Dzongkhag in 2019. Although there is no past data of flooding caused by Kerongchu due to extreme hydrological event, in June 2012, an artificial lake formed upstream of Dungsum Cement Corporation Limited area washed away the Nganglam-Gyalpozhing highway, after heavy rainfall caused the artificial lake to burst.

The study on "Flood Management Plan (FMP) of Kerongchu" in Nganglam, Pemagatshel has been prepared in continuation of flood hazard study carried out in 2019, within the in-house capacity of the Division. The FEMD Engineers, visited entire lengths of the river and critical locations in the beginning of 2020, for validation of flood hazard map. During the site visit all structural interventions such as gabion walls, gabion revetment and RCC wall were identified along both banks of the river. Survey points have been taken in critical locations of bank protection structures as well as for probable alignments of proposed protection and to raise the embankment level. The FMP had included all the existing structures, proposed structures with detailed survey points and typical design. The Report serves as a prerequisite for planning, designing and construction of flood protection structures along any flood prone river.

1.2 Objectives

It is known that Bhutan is highly exposed to the hydro-meteorological hazards like flood, flash flood, landslide and glacial lake outburst (GLOF), windstorm and cyclones. The Flood Management Plan for Kerongchu in Nganglam is therefore carried out to identify the risks and come out with resilient measures against the climate induced threats.

The main objectives of this study are as below:

- To identify the flood risk areas along Kerongchu in Nganglam.
- To assess the potential adverse impacts of flood hazard areas.
- To provide appropriate recommendations and mitigation measures along with detail engineering design, drawings and estimates.

1.3 Study Area

Nganglam under Pemagatshel 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 (Figure 1). 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 Kerongchu flows through the Nganglam town and Dungsum Cement Corporation Ltd. Factory. Flowing from Kerong and Dazema village, it has a total catchment area of 496 km until it joins Manas River.

A major flooding event can be of great threat to low lying settlements and the DCCL plants and structures along the river. The river swells dangerously during every summer season and with increased intensity of rainfalls due to climate change, it poses grave threat of flooding in future.

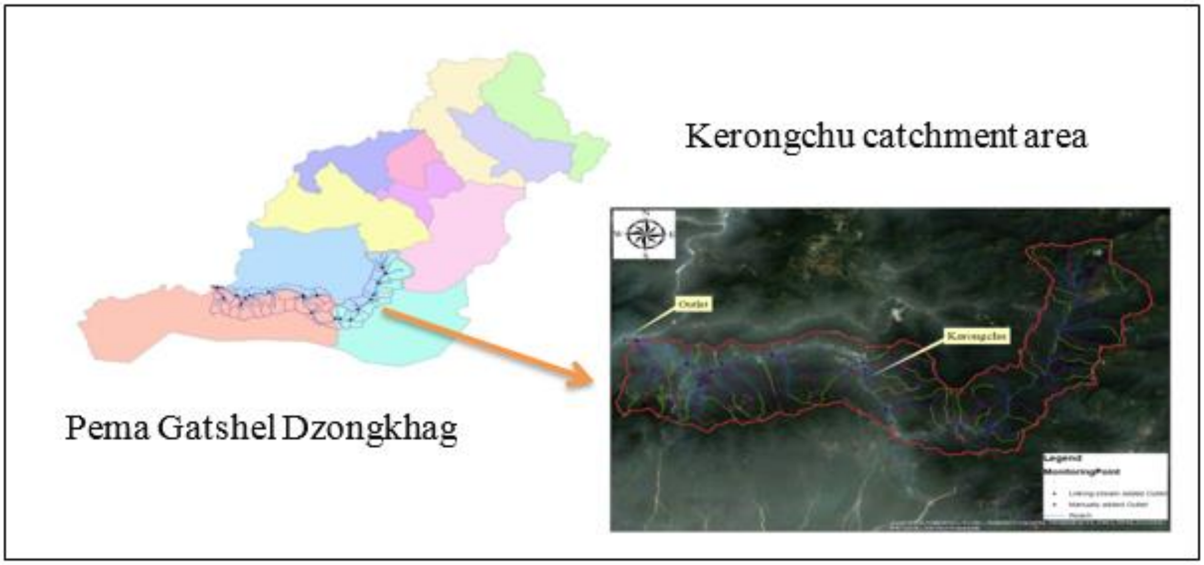


Figure 1 Study Area Map

2. Methodology

The Figure 2 shows the steps and the model used for the preparation of the Kerongchu Flood Management Plan. All the relevant data were collected and prepared to be used as model input. A hydrological model was built with SWAT Models and the results from the model were analyzed. The flood hydrograph computed from the flood frequency analysis were used as an input data for the HEC-RAS Hydrodynamic model. The flood hazard maps simulated from the model were analyzed and site validation of the hazard areas were carried out. The appropriate structural and non-structural measures were proposed and the detailed design and cost estimate for the measures were prepared. The implementation plan was prepared along with a few recommended Environment Code of Practice (ECoP) to be followed pre-construction, construction and post-construction phase.

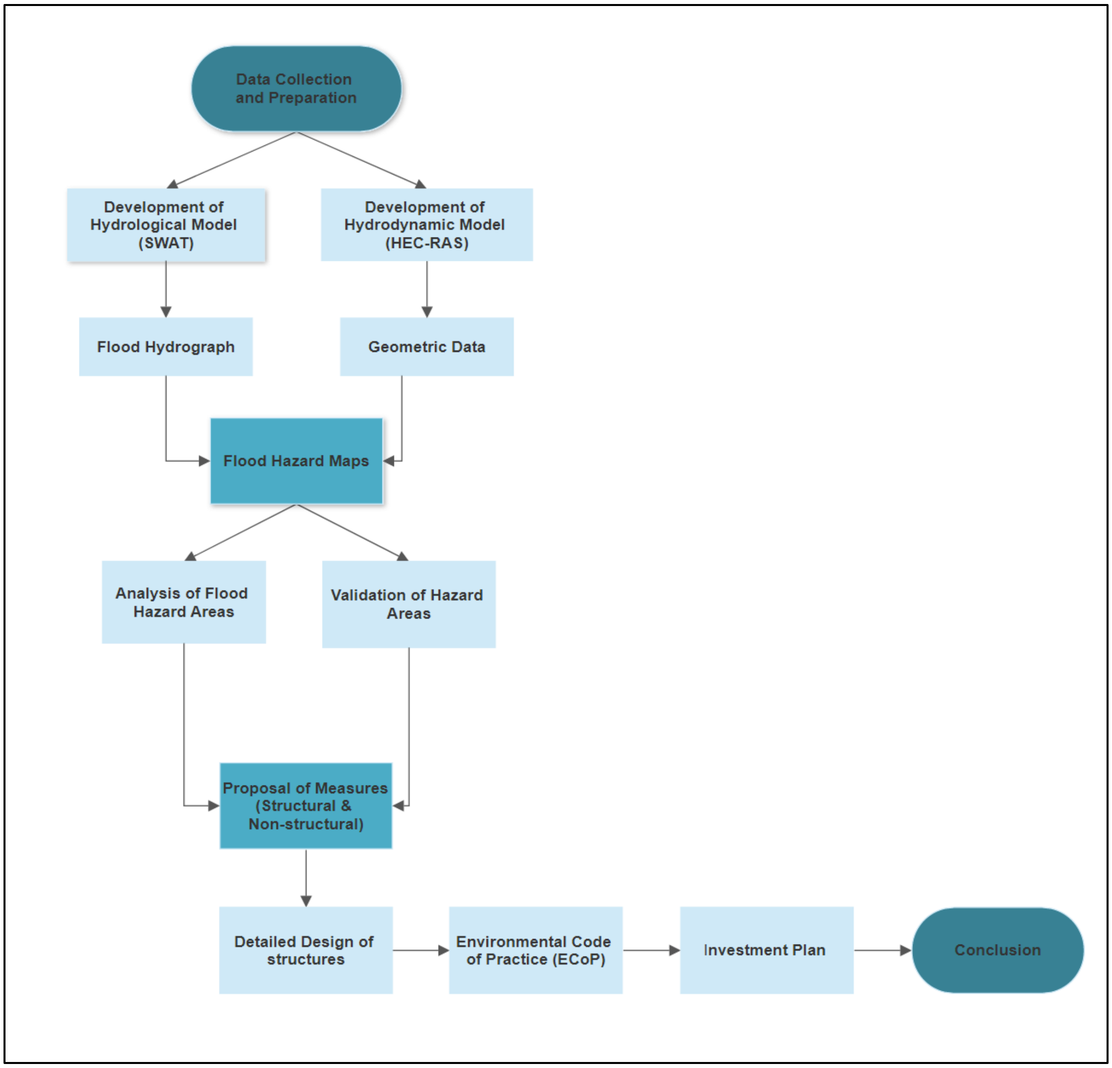


Figure 2 Flow chat for the preparation of the Kerongchu Flood Management Plan

3. Development of Hydrological Modelling

3.1. SWAT Model Set Up

The hydrological model was developed by using Soil and Water Assessment Tools (SWAT). 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 management practices on water, 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).Among the many utilities it is used to quantify the impacts from land use changes on runoff and it is designed to run hydrological model to get the water balance ratios such as stream flow-precipitation ratio, base flow-total flow ratio, ET-precipitation ratio.

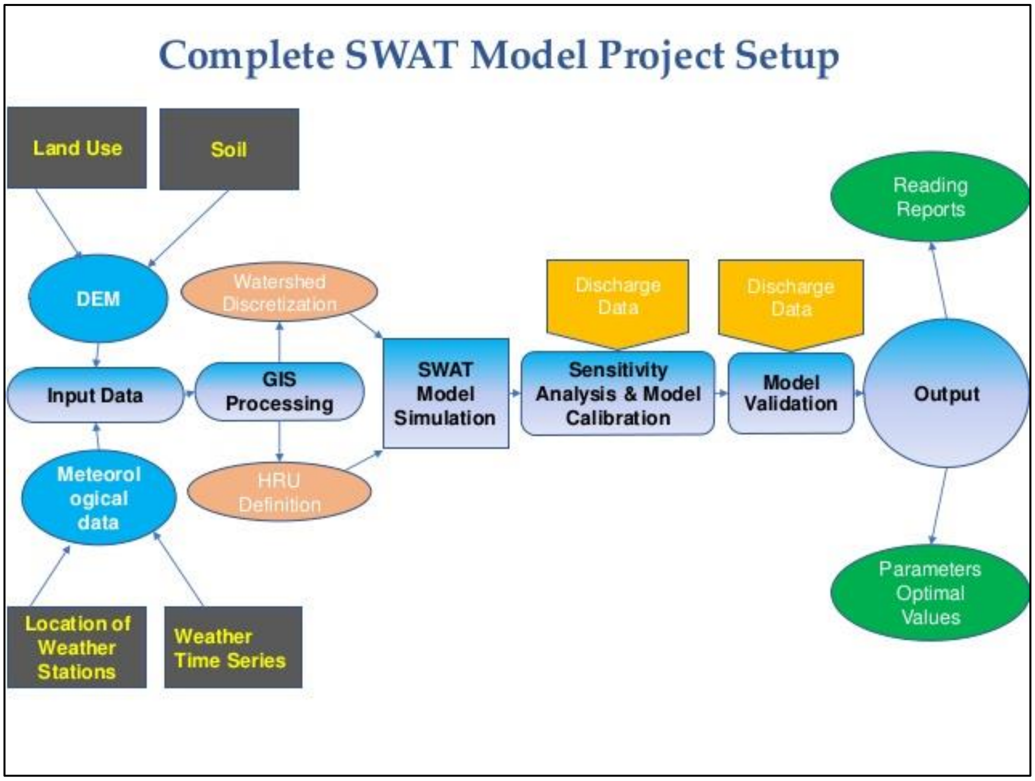


Figure 3 Model set up flow chart

The model set up as shown in Figure 3 will be explained subsequently in relation to the specific project area.

The SRTM DEM of resolution 90x90 projected to WGS 1984 UTM zone 46N and clipped in Arc GIS environment which was then loaded to DEM raster in ArcSWAT. An outlet of the basin was selected which resulted in delineation of Nganglam catchment with an area of 498 square km consisting of 132 sub basins. Further the catchment of Kerongchu with an area of 88 square km was delineated by selecting an outlet near the confluence of Drangme chu. The sub-basins were further divided into multiple Hydrologic Response Unit (HRU). The projected land use map and soil map were overlaid in the watershed to process the HRU definitions. 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. After the HRU definition, the weather data of Nganglam station was loaded into the model in the weather stations tab. SWAT requires various weather data, such as rainfall, temperature, relative humidity, solar radiation and wind data for rainfall runoff simulation. In this case, only daily rainfall data and daily maximum and minimum temperature data were entered in the model. As, only the two variables were provided for the model, in the subsequent steps for the calculation of evapotranspiration, Hargreaves method was chosen for the simulation. The model was run from 1988 till 2017. The Figure 4 shows the simulated annual maximum daily discharge from 1988 to 2017.

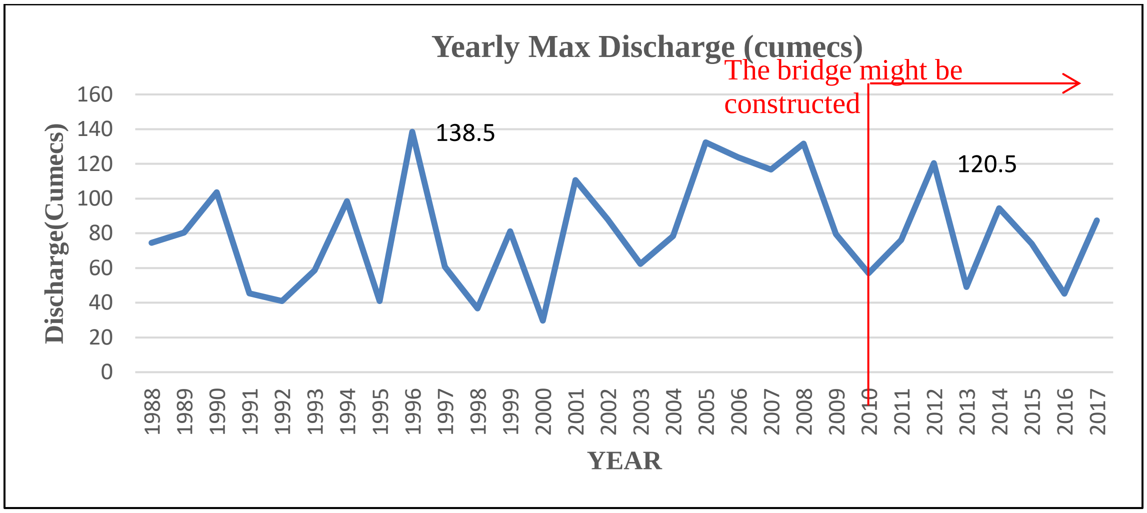
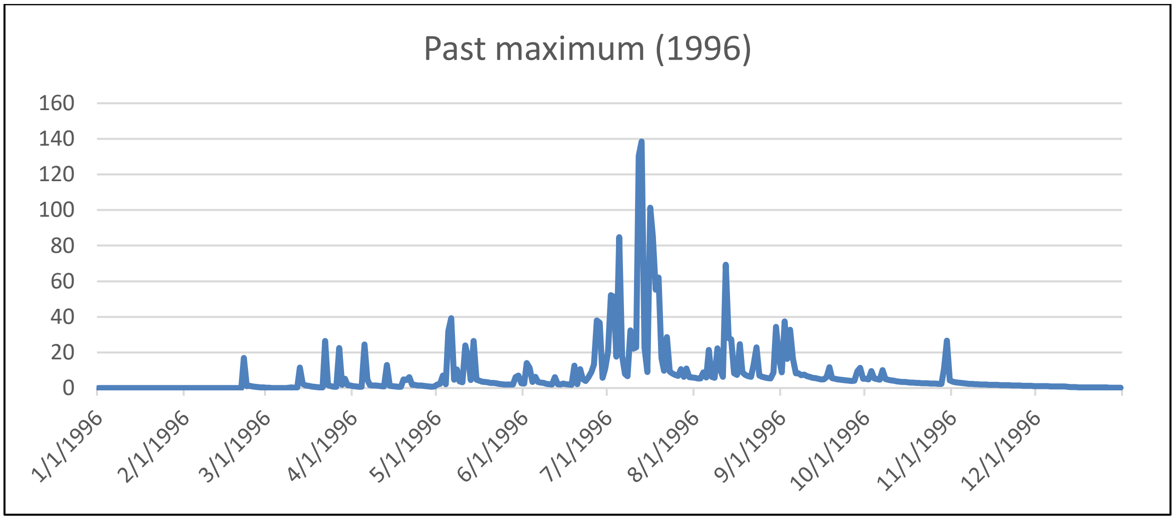


Figure 4 Simulated annual maximum daily discharge

The simulated discharge was validated against the measured discharge from Floating method carried out during the site visit in October 2018 at the Bridge point where the peak discharge was determined 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). After comparing the measured discharge with the simulated discharges of past years (1988 to 2017), the simulated discharge in the year 2012 with 120.5 Cumecs has been seemed as corresponding to the floating method discharge, as from the historical google satellite image it can be seen that the bridge with the flood mark was completed at least after in 2010 (Figure 5).

Hence, this simulated discharge can be found to be more or less reliable and thus the past maximum discharge (viz. 1996) was considered to produce hydrograph for return year period as input data for hydrodynamic model.



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

Figure 5 Hydrograph showing past maximum daily discharge in 1996.

3.2. Flood Frequency Analysis

Subsequently, flood frequency analysis were carried to determine the 100 years return period discharge which will be then used as input for upstream boundary for HECRAS modelling. Two methods namely Gumbel Distribution and Log-Pearson type III Distribution were used to analyse the flood frequency. Table 1 and Table 2 below show the results from the two methods.

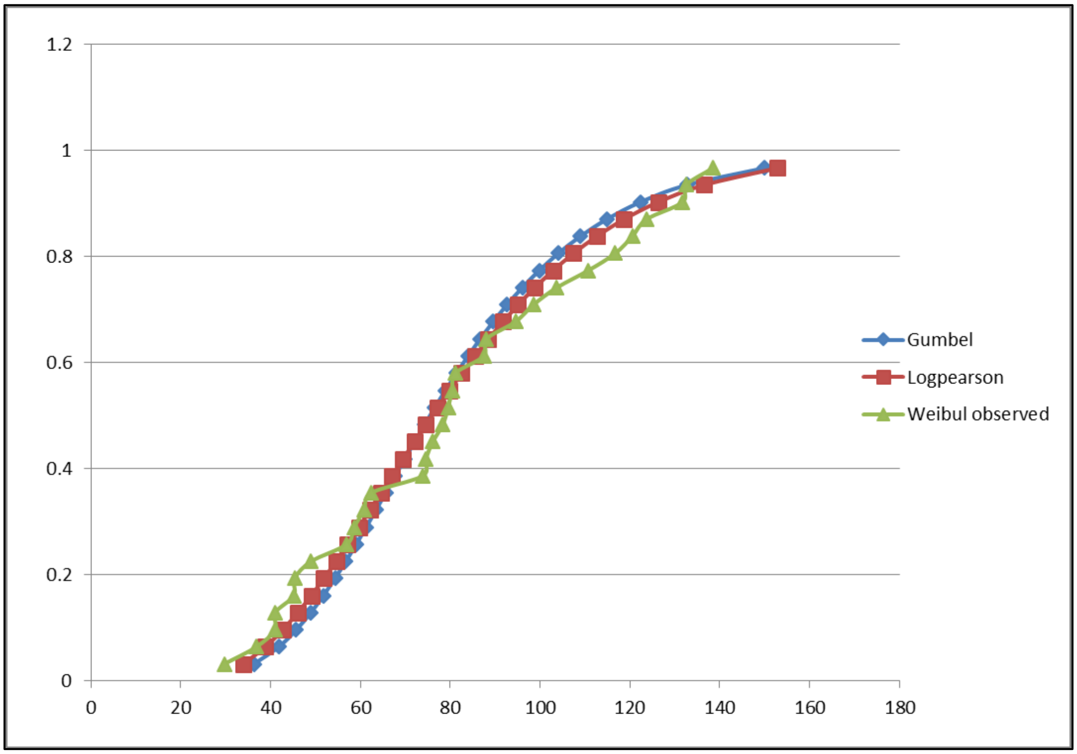
Table 1 Result of frequency Analysis in Gumbel distribution

Sl No.	Return Period	Discharge (Peak Method) (m^3/s)
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

Table 2 Result of frequency analysis in log-Pearson distribution

Sl No.	Return Period	Discharge (Peak Method) (m^3/s)
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

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 6. Therefore, Gumble's method has been adopted to predict the discharge in return year periods.



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

Figure 6 Result of the best fit analysis of frequency analysis method

The Peak discharge for 100 years return period is **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 (Figure 7).

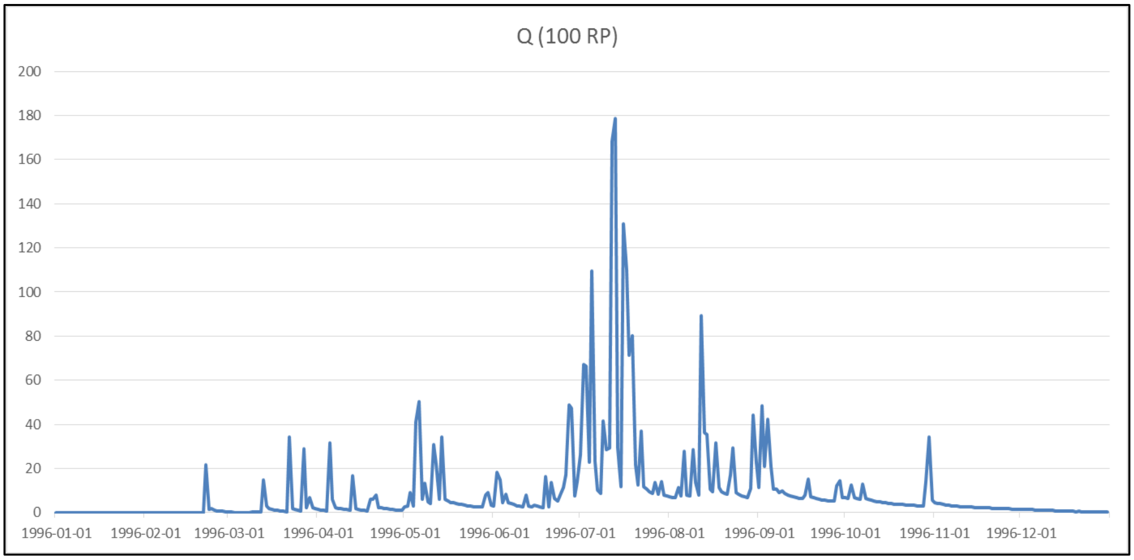


Figure 7 Hydrograph for 100 year return period at Kerongchu

4. Hydrodynamic model development

The hydrodynamic model for the Kerongchu was developed by using the HEC-RAS tool. 2D modelling technique was used for model development. 2D modelling has been selected because DEM can be suitable to develop hydrodynamic models in this study area. 1D modelling could not be applied due to cross section data limitation. SRTM 30 DEM and the cross sections taken were significantly differing in terms of elevations and couldn't be superimposed, the ALOS 10m DEM 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, simulation, calibration and validation are the major steps for Hydrodynamic modeling. The Hydrologic Engineering Center 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. The Figure 8 shows the 2D model setup was completed by performing the following steps:

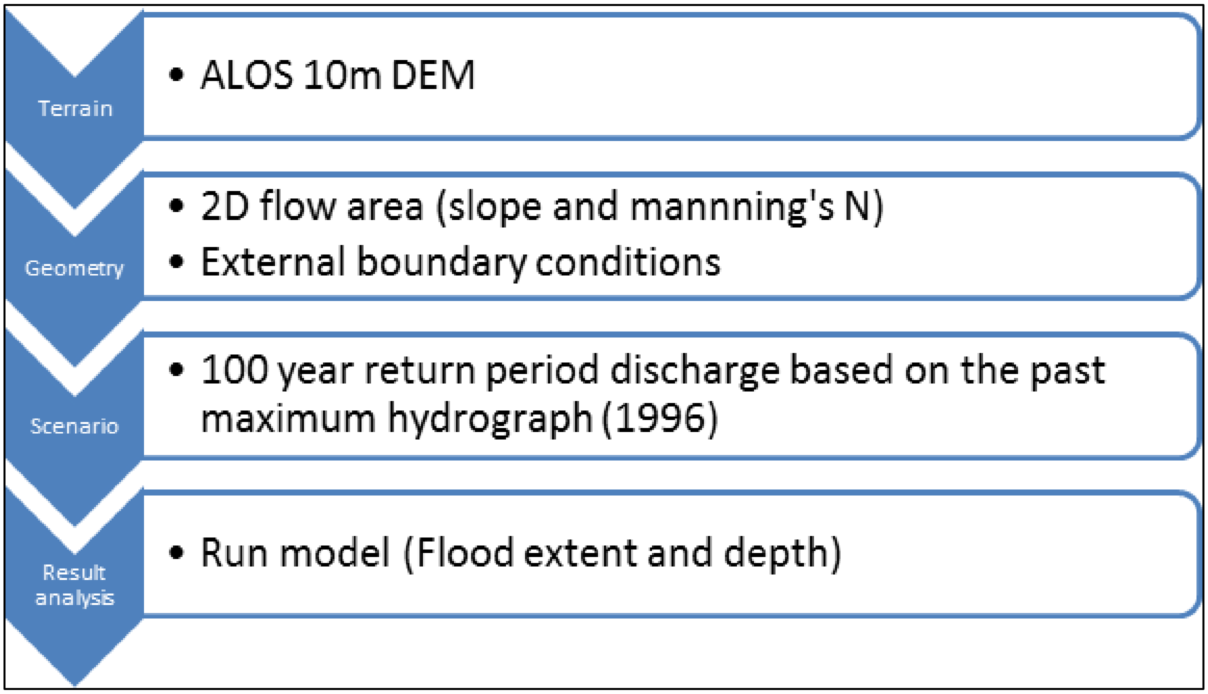


Figure 8 Methodology adopted for developing 2D Hydrodynamic Model

4.1 Generation of flooding scenario

The 100-year return period scenario has been considered as an upstream boundary condition for simulation for Kerongchu 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.

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.

4.2 Flood Hazard Mapping and Analysis

The flood extent map for the 100-year return period has been prepared which shows the detail on inundation area and depth at each point. The critical areas have been plotted for terrain profile in the RAS Mapper as shown in the Figure 9, Figure 10 and Figure 11 for ascertaining flood depth. Some areas show unreasonable elevation. This is because of lack of appropriate terrain data and since the terrain model in this hydrodynamic model has been created by ALOS 10m DEM due to the limitation.

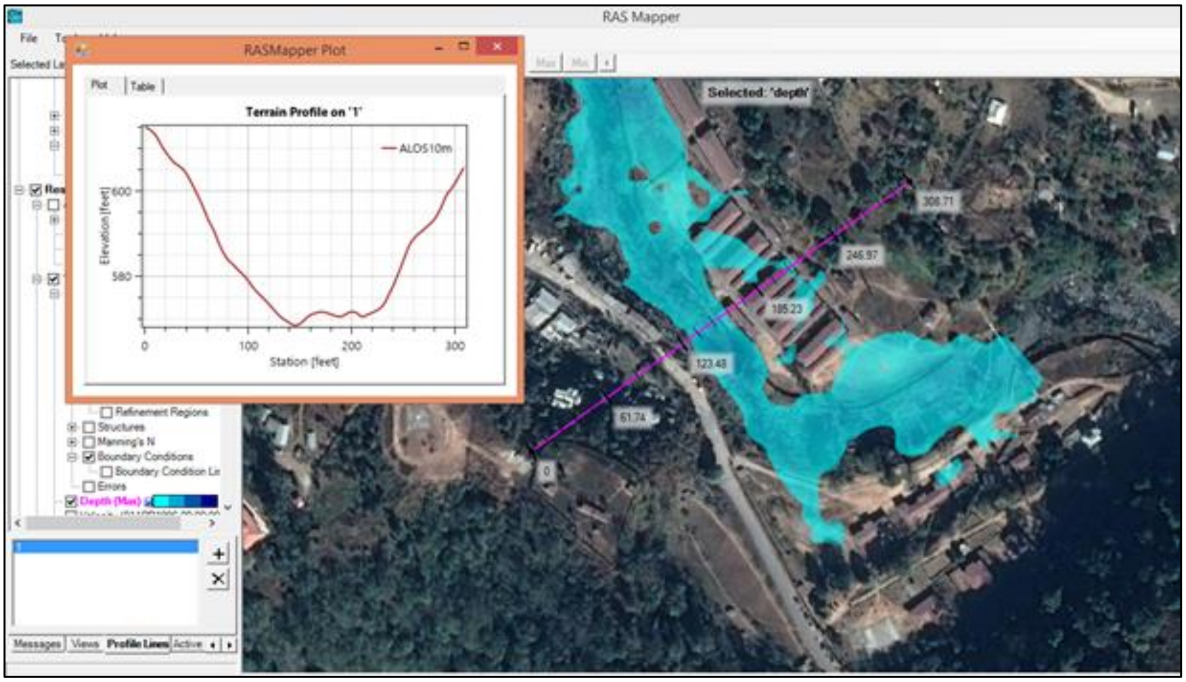


Figure 9 Terrain profile in the RBA Colony

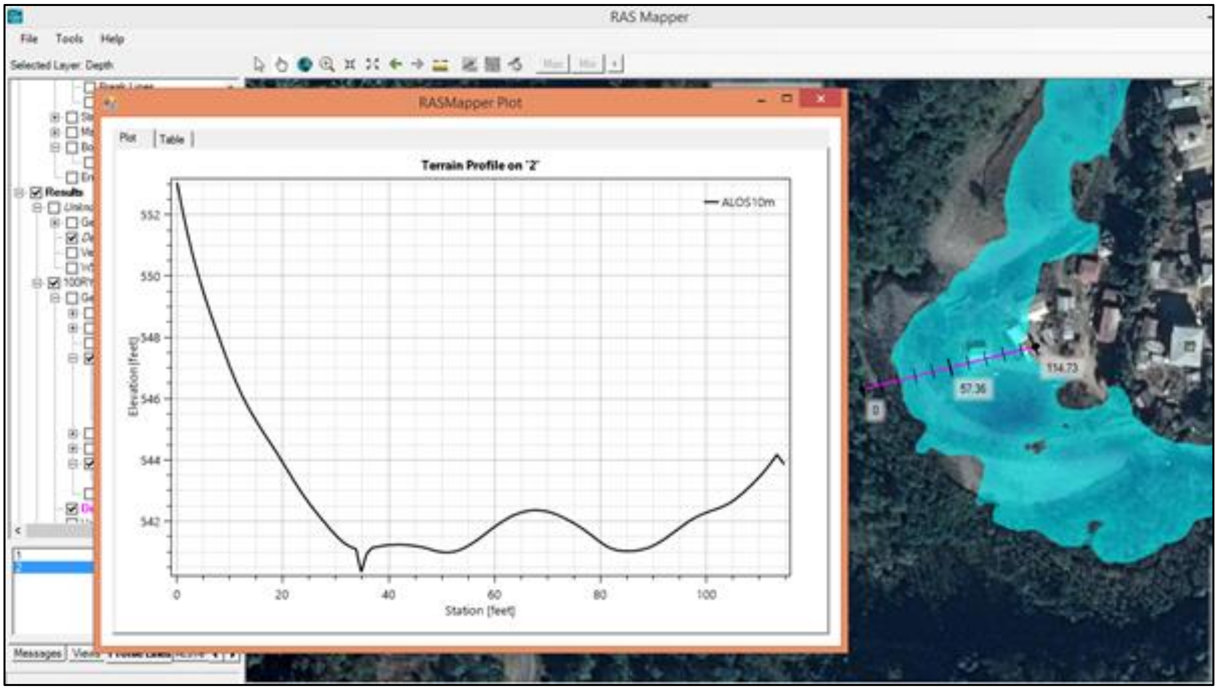


Figure 10 Terrain profile in the Town Area

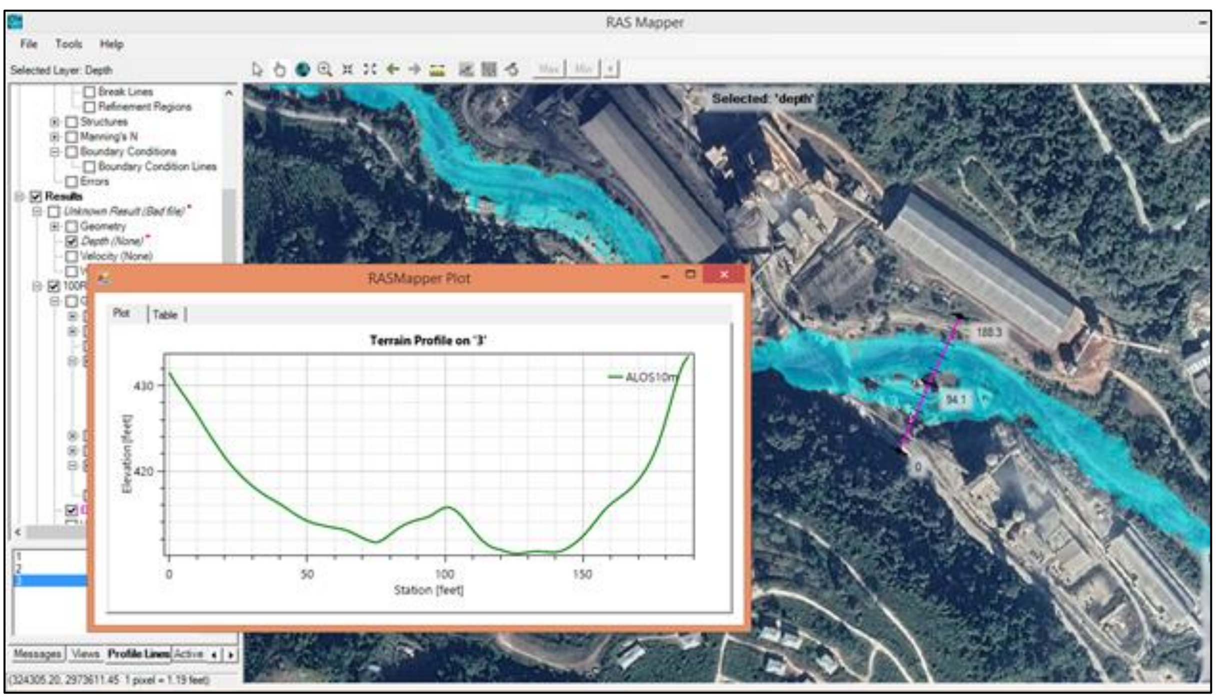


Figure 11 Terrain profile in the DCCL area

The following Figure 12, Figure 13, Figure 14 shows the flood hazard maps of Kerongchu under Nganglam from the HEC-RAS modelling:

Figure 12 Overall Flood Hazard map of the study area

Figure 13 Flood Hazard Map for Nangalam Town area and RBA Colony

Figure 14 Flood Hazard Map at Dungsam Cement Corporation Limited Area

5. Validation of hazard areas

The Flood hazard map for 100-year return period has been prepared which indicates the details on inundation area and depth at each point. The flood hazard zone developed from the HEC-RAS flood modeling was tested for validation with the satellite-based historical inundation maps.

All the inundation areas shown in the model were mapped and identified specific location in the hazard map for validation purposes. While analyzing in the map it shows that about 9 areas of total inundation lie in high hazard and very high hazard zones, respectively; while, about 5 areas of inundation comes under low and moderate hazard zones, respectively.

The comparisons in spatial distributions of land use types hazard zones and satellite data-derived inundation map indicate that settlement area along the river are most vulnerable to floods. As specific areas mostly lie in a very high hazard zone are mapped as critical areas which are settled along the river banks. Overall, the analysis showed that the estimated flood hazard zones are few areas only.

5.1 Analysis of flood hazard maps

The estimation of flood hazard areas can be a useful tool for the mitigation of the devastating impact of floods. Moreover, the applied validation technique that also considers historical flood events leads to the calculation of the flood hazard index that can support the analysis.

In particular the critical areas that are riverbeds in the lowland are even more prone to flood, compared to the estimation of the flood hazard areas plotted in the RAS-Mapper in DEM.

The critical areas have been plotted for Terrain Profile in the RAS Mapper as shown in the Figure 15Figure 15 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.

The comparison between the flood hazard areas plotted in the RAS-Mapper in DEM and flood hazard map in the google satellite image indices has revealed valuable information for the influence and the weight of each parameter in the assessment of flood hazard areas.

The single-parameter sensitivity analysis served as a validation technique in order to overcome this drawback. The method can be further modified using different techniques to determine the parameters' weights. It is also important to handle qualitative parameters such as geology and land use according to the specific characteristics of each region however, due to scarcity of data sensitivity analysis were not carried out.

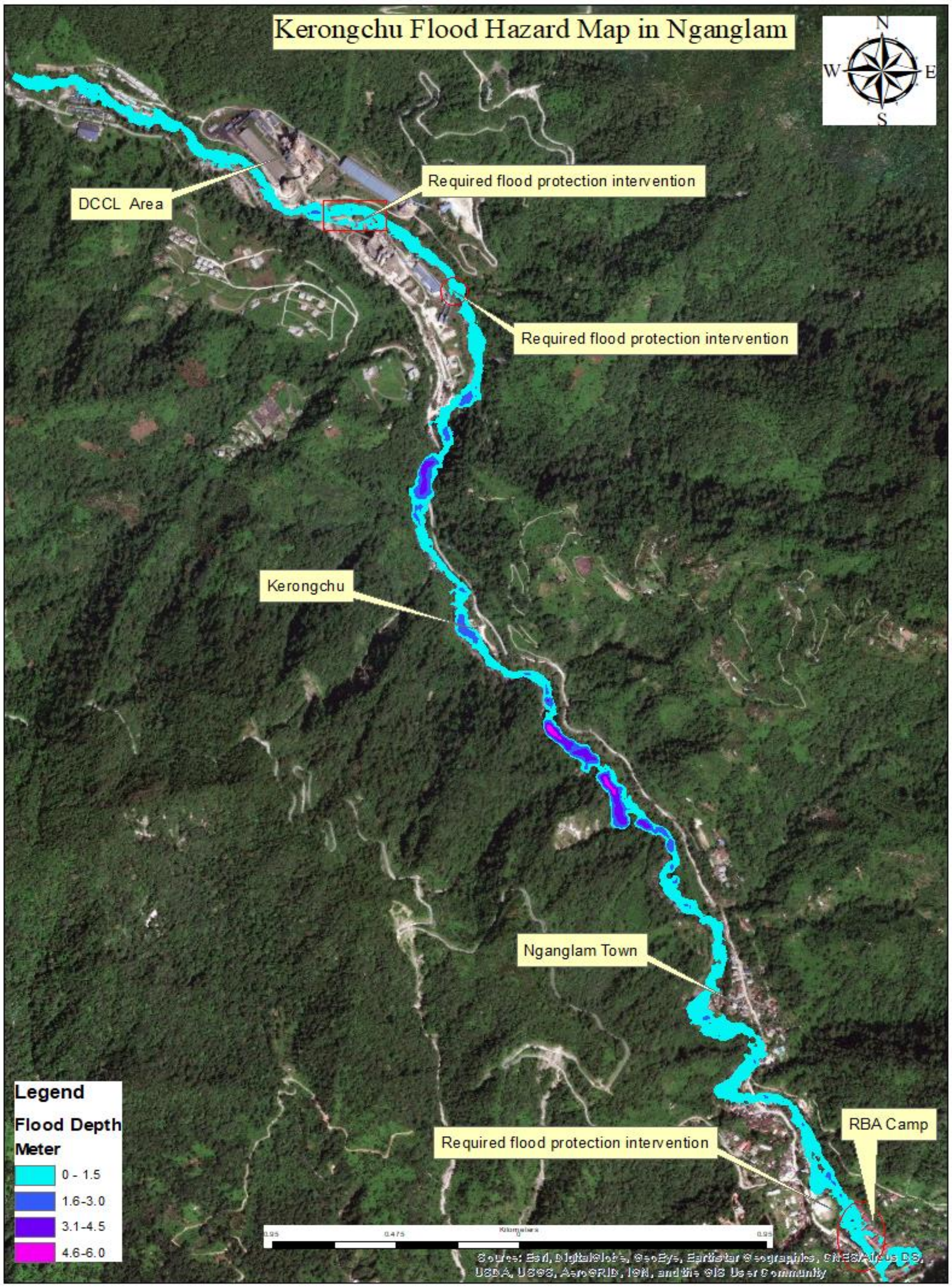


Figure 15 Map showing the identified critical areas along the Kerongchu

5.2 Site validation of hazard areas

The primary purpose of the detailed field visit was to pick up point and validate the flood hazard map prepared by the Division. The detail assessment of the surroundings as well as existing conditions and physical interventions along the rivers of the study domain. More specifically, this visit is to fulfil the following key objectives:

- Detail condition of structures along the Kerongchu
- Investigate critical locations along rivers and observe existing structures
- Identify site specific solution
- Identification of key infrastructures required to propose

The detailed field visit was carried out and entire lengths of the river as well as visit the critical locations for validation. All existing structural interventions such as gabion walls, gabion revetment and RCC wall have been identified along both banks of the river. Survey point locations have been taken in entire locations of bank protection structures as well as for probable alignments for proposed protection and embankment level rising to calculate the probable length for proposed measures.

Preliminary adequacy checking as well as functionality of existing structures have also been observed during the field visit via means of visual observation by the study team, from which ideas regarding preliminary solutions and measures will be perceived.

The points from different section were picked, that start from Royal Bhutan Army colony upstream of Kerongchu to downstream point to last settlement above the bridge (Figure 16). The team also surveyed the existing structures and critical areas along the Kerongchu. Team validated hazard at the site and actual height of existing structures (river bed level and bank height) and entire length also surveyed.

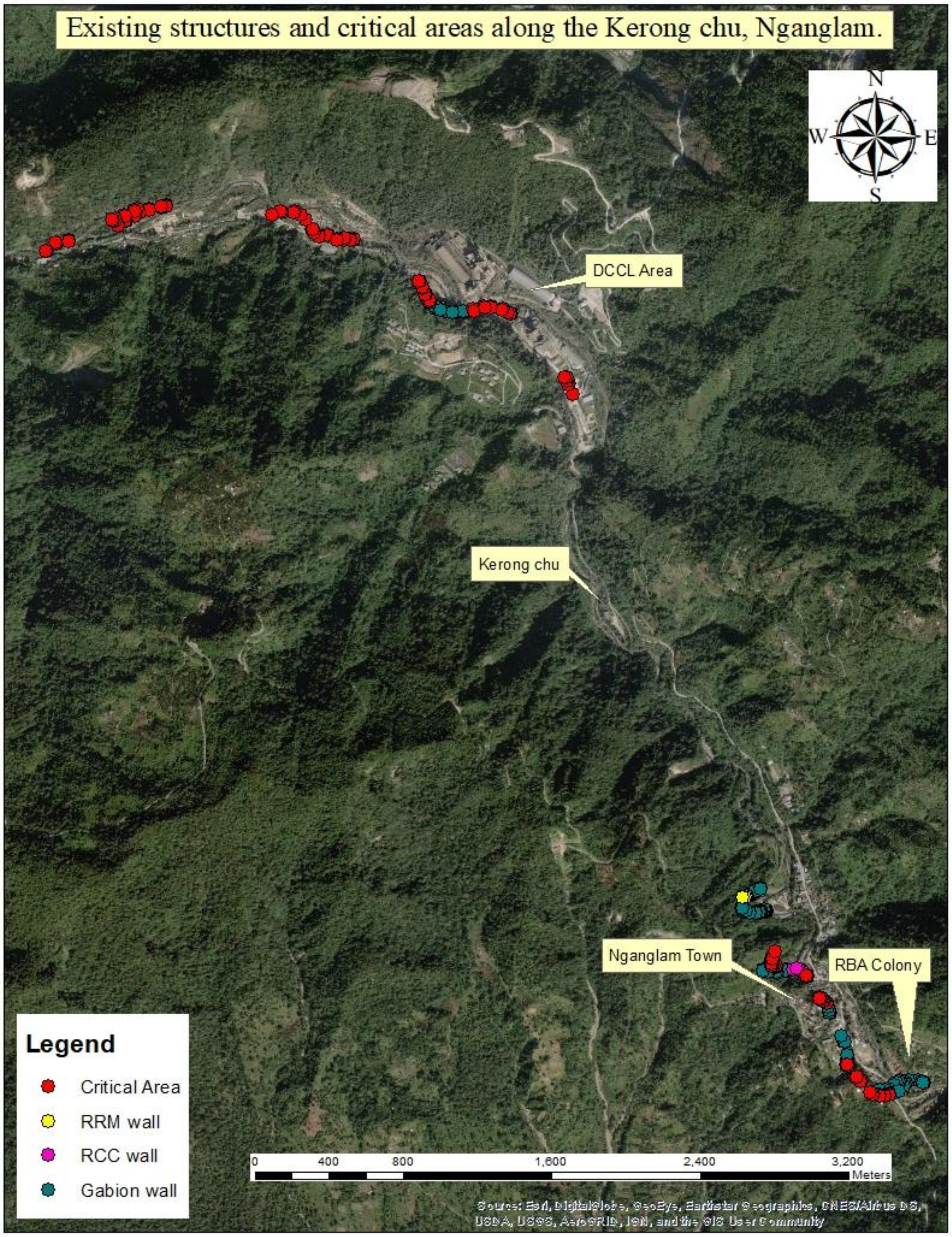


Figure 16 Map of survey point along the Kerongchu

General observations synthesized from the detailed field visit coincide with field observation findings. However, the team took a wide array of data and information specific area and critical location. Summary of generic findings are presented below –

- The main cause of flooding is monsoon rainfall. The flow of the rivers become very high after a storm event due to high slope of terrain, consequently causes flood;
- There are some large boulders at the upstream of the rivers which increase the friction of the river;
- Lots of vegetation covers the river banks which reduces the flow area and increases friction;
- There is no flood management plan for the Nganglam area;
- There is no disaster risk mitigation and preparedness programme for the area;
- There is no land zoning plan to reduce the impact of major flooding;
- There is no flood forecasting and early warning system.
- There is no periodically maintenances of flood protection structures built

The site validation concluded, the analysis shown in the estimated flood hazard zones are quite realistic and closely match with the inundation map.

Figure 17 Front of DCCL colony

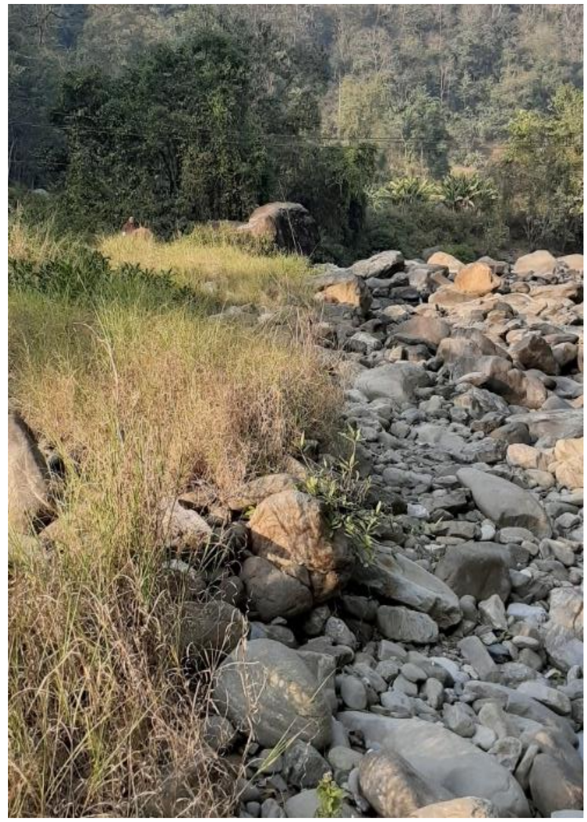


Figure 18 Near the proposed cremation ground

Figure 19 Upstream of Kerongchu, near the RBA office

Figure 20 Below the football ground

Figure 21 RCC wall near the automobile workshop

Figure 22 Gabion revetment below the motorable bridge

6. Finalization of mitigation measures

6.1 Principle of Measures

Principles considerations behind the conceptualization of measures to mitigate flood hazard in Kerongchu are:

1. Structural measures should be environment friendly and sustainable.
2. Both non-structural and structural measures have to be formulated.
3. Availability and accessibility to potential construction materials.
4. Budget constraints of local administration for implementation and maintenance.

On the basis of the above principles following both non-structural and structural measures have been outlined which is assumed to stop bank erosion and scour of the beds fully as well as flooding problem.

6.2 Proposed Structural Measures

Structural measures for the study area has been formulated to deliver a climate resilient flood management solutions for extreme flood events via assessment of flood hazard and vulnerability of a given area through relevant analyses. In accordance with the result obtained from the hydraulic modelling, the detailed field assessment has been carried out with best knowledge to identify the critical locations which are more prone to be affected adversely by the flood (Refer Figure 23 and Figure 24).

Accordingly, the appropriate long term flood mitigation measures have been proposed through carefully considering flooding hazards and erosion tendency information gathered from the field visit. This long term measures were proposed considering the efforts the structures will have in defending the Nganglam settlements from the flood events. The proposed flood mitigation along the Kerongchu in Nganglam were:

- **River bank protection –** (a) The gabion revetment walls with launching apron of total length 1375 m in different locations. (b) Gabion wall with lunching apron of 740m length. (c) RCC wall of 15m length. List of proposed flood protection measures are given in Table 3 with its coordinate for the references.

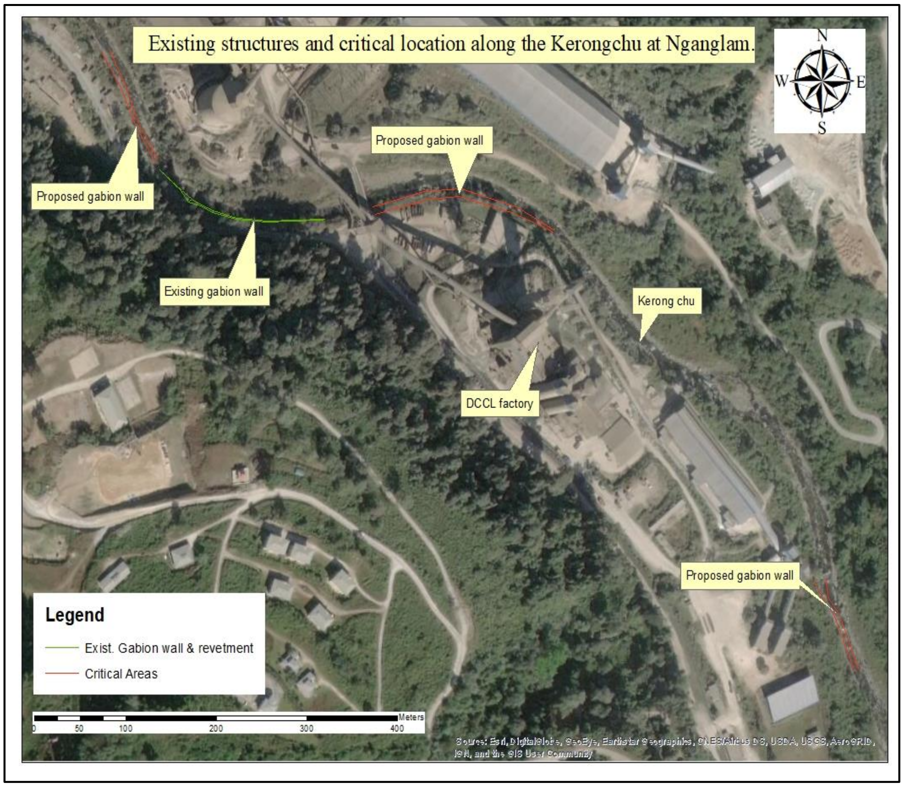


Figure 23 Map of DCCL with existing and proposed flood protection structures

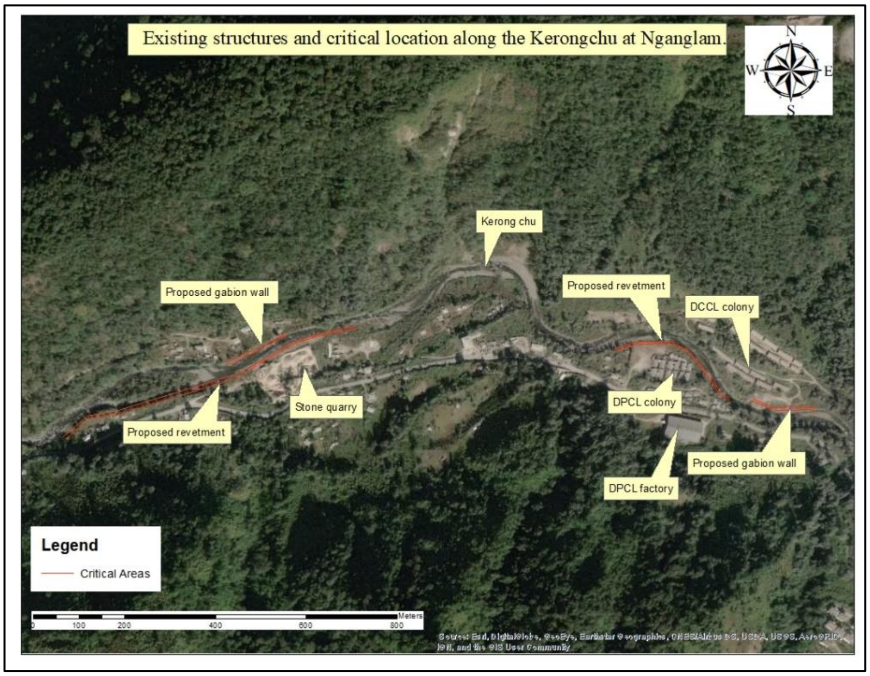


Figure 24: Map of DCCL colony and DPCL factory with existing and proposed flood protection structures

Table 3 Location of proposed structures with survey point

Sl No.	Types of Structures	Length (m)	Easting	Northing	Location	Remarks
1	Gabion walls with lunching apron	110	240,508.180 & 469,338.044	469,338.044 & 469,425.886	Left bank	Above the football round
2	Gabion walls with lunching apron	50	240,331.702 & 240,290.692	469,755.888 & 469,782.677	Left bank	Below the football round
3	Gabion walls with lunching apron	150	237,786.957 & 237,642.759	473,866.694 & 473,889.184	Right bank	DCCL colony area
4	Gabion walls with lunching apron	100	238,961.819 & 238,928.085	473,034.247 & 473,127.513	Left bank	Upstream of the DCCL factory
5	Gabion walls with lunching apron	210	238,629.767 & 238,431.329	473,467.503 & 473,484.701	Left bank	Above the DCCL motorable bridge
6	Gabion walls with lunching apron	120	238,190.557 & 238,132.349	473,534.311 & 473,642.790	Left bank	Below the motorable bridge at factory
7	Gabion revetment with lunching apron	115	240,666.613 & 240,488.283	469,268.194 & 469,356.565	Left bank	Near the RBA office
8	Gabion walls without lunching apron	120	240,107.748 & 239,988.289	469,934.437 & 469,937.612	Right bank	Below motorable bridge
9	Gabion walls without lunching apron	105	240,056.535 & 240,049.590	469,954.657 & 470,038.993	Right bank	Below the DoR office
10	Gabion revetment with lunching apron	310	237,596.877 & 237,344.067	473,888.012 & 474,001.122	Left bank	Adjacent to the Dungsum polymers colony
11	RCC wall	15	240,225.538 & 240,218.593	469,901.409 & 469,908.024	Left bank	Above the Auto mobile workshop

6.3 Non-structural Measures

Non-structural measures have been formulated to intensify the effectiveness of climate resilient measures and make all of the stakeholders as opportunist of structural measures. The non - structural measures recommended for the Kerongchu at Nganglam were as detailed below:

- Floodplain Zoning.
- Preservation of catchment area.
- Capacity development of local engineers and awareness raising among local residents and stakeholders.
- Adequate drainage system following the natural flow path with plantation must be Introduced.
- Maintaining necessary cautions and protections before making any kind of future interventions

6.3.1 Flood plain Zoning

Floodplain Zoning for the Kerongchu Basin will have to be determined according to the flood depth as per the results generated from hydrodynamic modeling for different portions of the floodplain area. This data will undergo a detailed comparison and matching with historical flood depth data for the region via field studies to device separate flood zones. The probable flood zones in conjunction with model generated climate change considerate flood maps for 25/ 50/ 100 years flood events are as follows –

- Zone A: This zone has flood depth range equal to or exceeding 2.0 meters and represents the flowing channels such as rivers and associated steams. As the prime bearers of flood

  flow from the Kerongchu basin, these represent the pinnacle of flood management and will have to be maintained rigorously as per designed sections with ample bank protection measures.

- Zone B: This zone consists of the locations immediate to the flowing water bodies and represent the region that is at high risk should a substantial flood event occurs. As per flood maps, the corresponding depths can be from 1.0-2.0 m.

- Zone C: This zone consists of the locations with relative higher average elevation than high risk flood zones and represent the region that is at moderate risk should a substantial flood event occurs. As per flood maps, the corresponding depths can be from 0.5-1.0 m.

- Zone D: This zone consists of the locations relatively near the upper echelon of the floodplain in comparison to the flood risk zones and represent the region that is at low risk should a substantial flood event occurs. As per flood maps, the corresponding depths can be from 0.0-0.5 m. Figure 25 illustrates a basic exemplary concept schematic section of flood plain zoning for Kerongchu Basin.

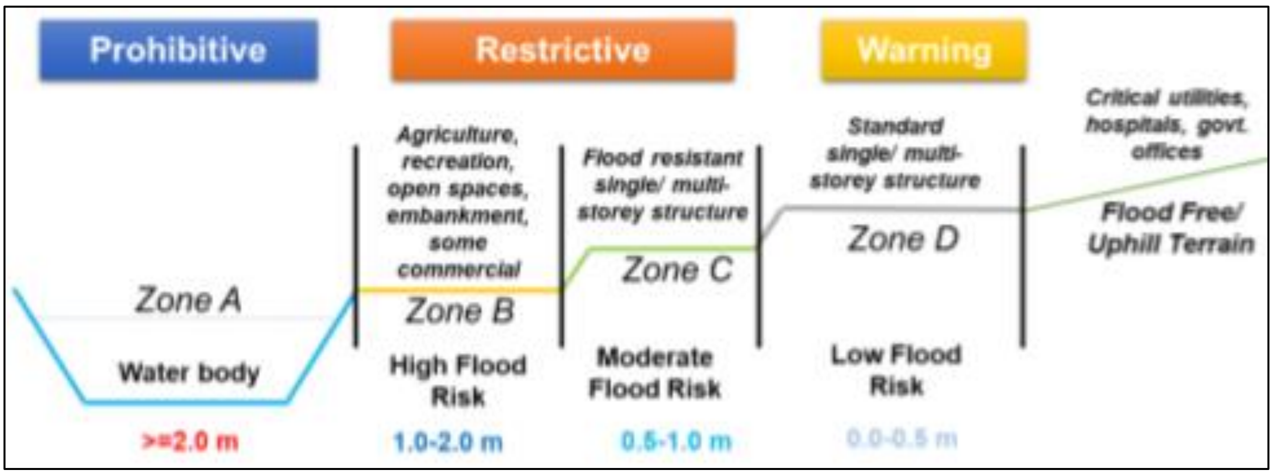


Figure 25 Generic exemplary schematic section of floodplain zoning for Paro Basin

6.3.2 Preservation of catchment area

As observed, most of the catchment area of Kerongchu are densely populated with the full vegetation on the steep slopes to moderately sloppy areas at the upstream portion of river have to be properly maintained for natural water and soil retention. Thereby maintaining the vegetation, it will reduce accumulation of flow through enforcing retardation of flood flow contributing to the flood management of the basin. This vegetation, especially at the catchment area should include the following –

- Restoration of degraded forest with proper afforestation.

- Privately owned forest land should be brought under appropriate management systems, if necessary, through legal reforms;
- Sustainable use and equitable benefit sharing, habitat conservation and integrated management at all stages involving participatory and collaborative processes;
- Active and informed participation of civil society in the conservation of vegetation will be encouraged.

6.3.3 Capacity development of local engineers and awareness raising among local residents

The flood management intervention discussed above both structural and non-structural measures can be achieved through capacity development sessions for –

- Knowledge on flood management on a basin-scale including proper envisioning of problems in both upstream and downstream of a channel and all other associated environmental factors;
- Attain necessary knowledge on hydrological and hydrological analyses for determining design parameters and design criteria for development of flood management/ mitigation measures;
- Strengthening of existing institution for implementation and monitoring of engineering activities;
- Capacity development of local engineers and awareness raising among local residents and stakeholders; and
- Incentives and mode of research activities should be performed for geotechnical stabilities of sources and bank of streams with bio-engineering.

6.4 Existing measures

The Dungkhag Administration with the technical and financial support from the FEMD, DES has constructed the flood protection works along the banks of Kerongchu during the financial year 2017-2018 which has immensely helped in protection of Nganglam Town form flash flood in the later year. Those structures consist mainly of RCC wall, gabion wall and gabion revetments constructed near the automobile workshop and downstream of the bridge (Refer Figure 26).

Never the less, it has also been observed that the gabion walls have been constructed adjacent to RBA camp and near DCCL colony to protect the respected areas from the river flood (Refer Figure 28 and Figure 29). In some places, due to scouring of the bank, some gabion walls were at the verge of failure and needs immediate replacement or maintenances. List of existing flood protection structure are given in Table 4 with its coordinate for kind references.

Figure 26 Existing RCC structures

Figure 27 Existing gabion wall

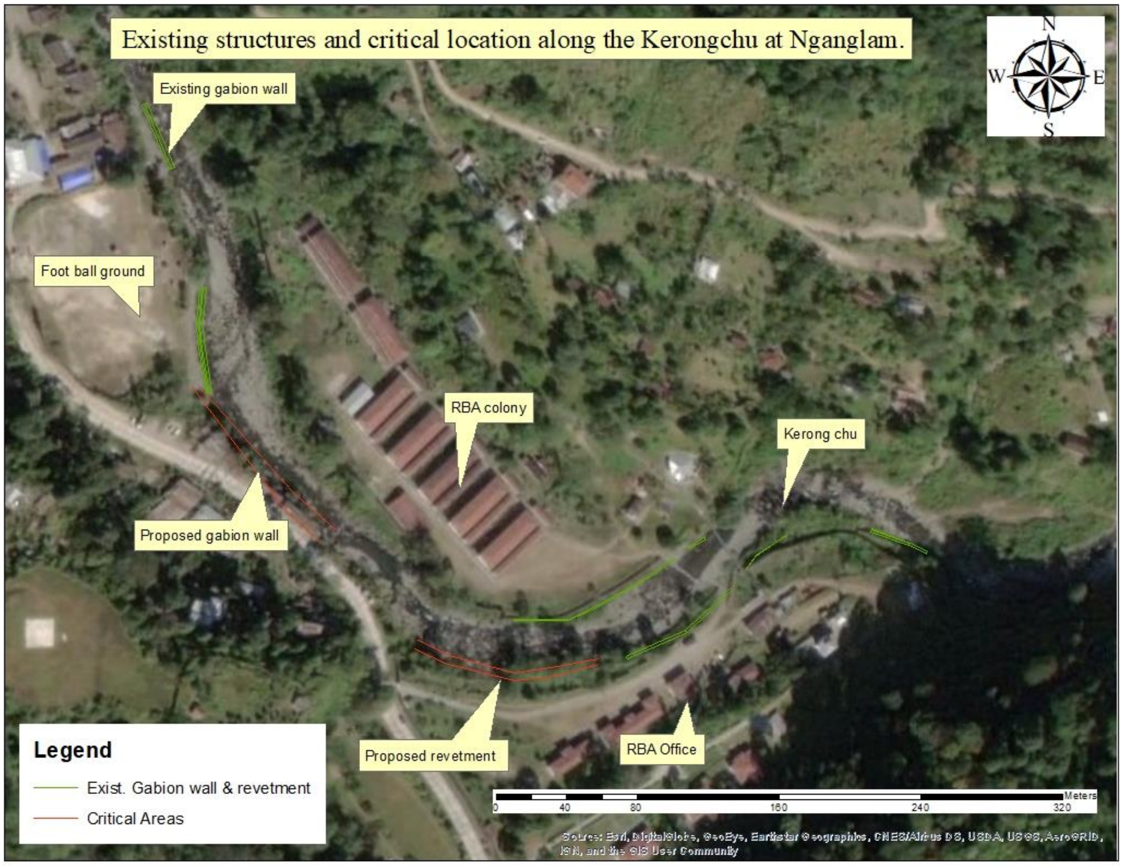


Figure 28 Map near the RBA colony

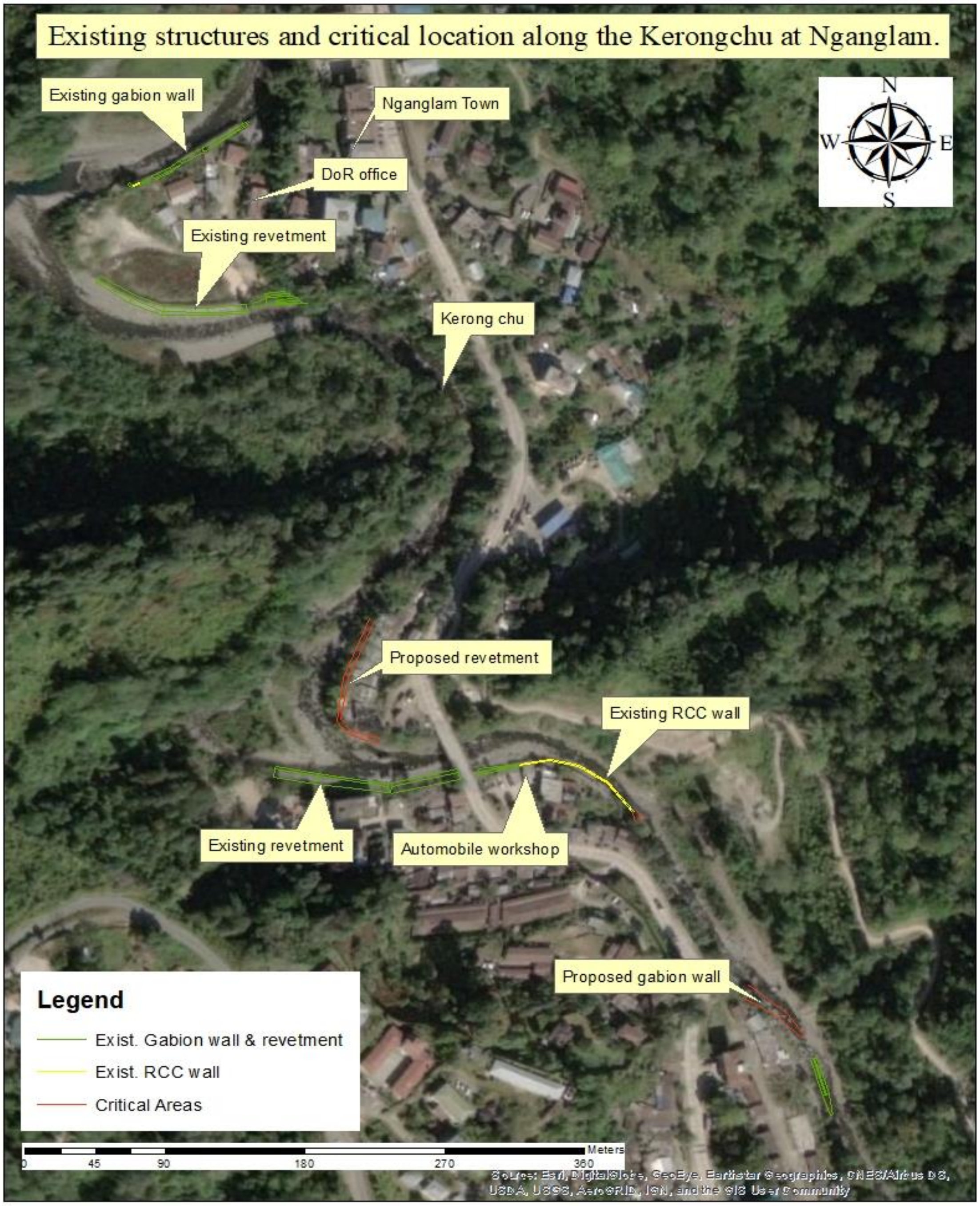


Figure 29 Map of Nganglam town with existing and proposed flood protection structures

Table 4 Location of existing structures

Sl No.	Types of Structures	Length (m)	Easting	Northing	Location	Remarks
1	Gabion walls without lunching apron	34	240,851.280 & 240,819.266	469,330.621 & 469,343.189	Left bank	Upstream of RBA office
2	Gabion walls without lunching apron	30	240,772.037 & 240,748.225	469,341.205 & 469,321.361	Left bank	Upstream of RBA Office
3	Gabion walls without lunching apron	121	240,726.000 & 240,617.653	469,338.426 & 469,293.183	Right bank	Near the RBA colony
4	Gabion walls without lunching apron	72	240,741.478 & 240,680.359	469,309.851 & 469,272.148	Left bank	Near the RBA office
5	Gabion walls with lunching apron	60	240,423.977 & 240,408.102	469,420.977 & 469,481.699	Left bank	Near the football ground
6	Gabion walls with lunching apron	40	240,423.977 & 240,408.102	469,549.168 & 469,585.283	Left bank	Below the football ground
7		40	240,346.269 & 240,335.157	469,702.758 & 469,742.446	Left bank	Below the Road junction
8	Gabion walls without lunching apron	30	240,147.037 & 240,120.050	469,939.164 & 469,935.460	Right bank	Below the DoR office
9	Gabion walls without lunching apron	82	239,901.504 & 239,972.677	470,332.336 & 470,374.669	Right bank	Upstream of the DoR office
10	Gabion walls without lunching apron	200	238,376.376 & 238,195.467	473,477.907 & 473,528.178	Left bank	Below the DCCL motorable bridge
11		35	240,009.189 & 239,974.529	470,252.961 & 470,249.521	Right bank	Above the DoR office
12	Gabion revetment with lunching apron	120	240,107.350 & 239,988.816	469,934.666 & 469,936.783	Left bank	Below the motorable bridge
13		100	239,970.825 & 239,875.310	470,247.669 & 470,268.836	Right bank	Above the DoR colony

14	RRM wall	20	239,879.543 & 239,895.154	470,324.398 & 470,334.188	Right bank	Below the bakery shop
15	RCC wall	87	240,220.327 & 240,146.508	469,908.472 & 469,940.487	Left bank	Near the Automobile workshop
16		5	239,897.799 & 239,901.239	470,332.600 & 470,333.923	Right bank	Adjacent to the bakery shop

7. Detail Engineering Design and Estimates

7.1 Proposed Design and Drawing of Structural Measures

Design and drawing of structural measures have been selected as design discharge for each of the section considering structural stability as well as scour depth are as below:

A) Gabion Revetment with launching apron.

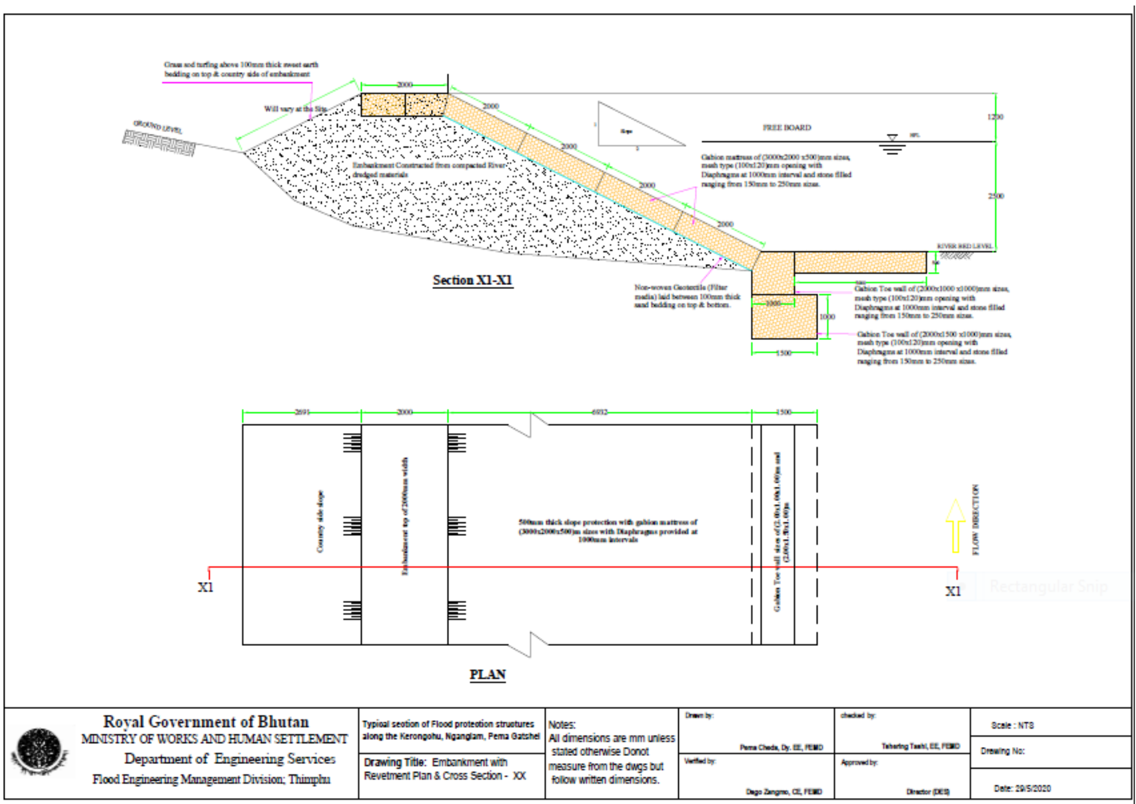


Figure 30 Proposed gabion revetment

B) Proposed Gabion wall with launching apron

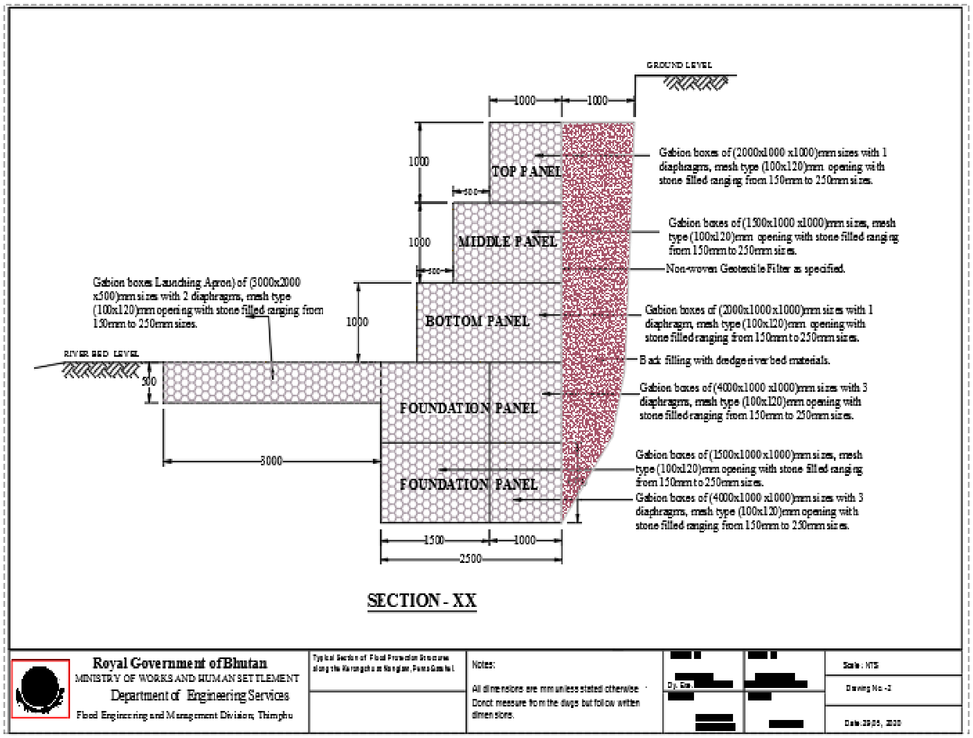


Figure 31 Proposed gabion wall

C) Proposed RCC wall

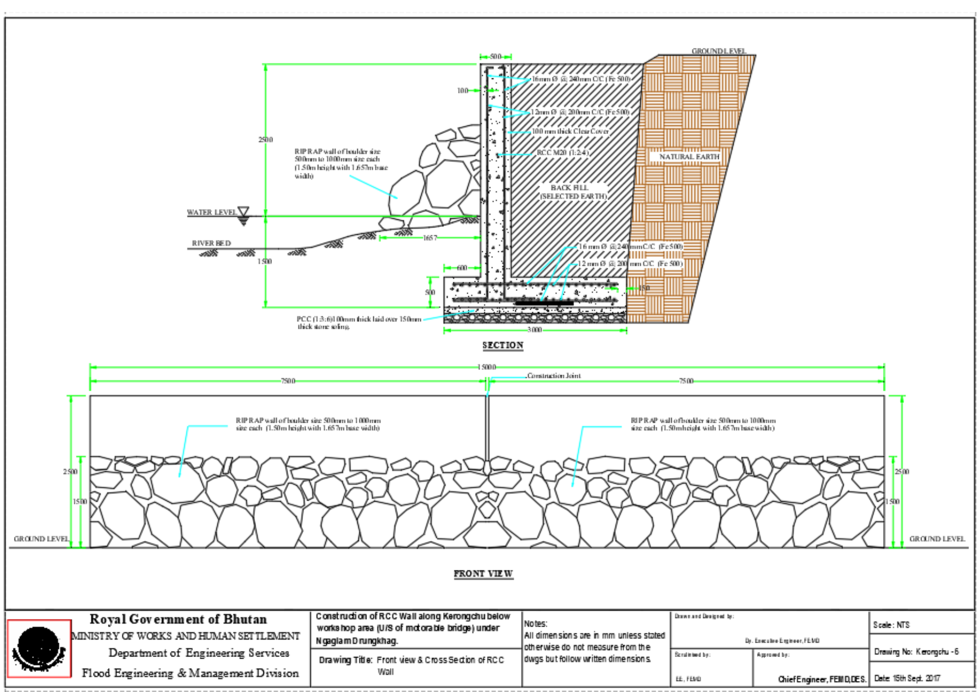


Figure 32 Proposed RCC wall

7.2 Estimates of Structural Measures

Cost estimation for three different types of engineering typical design sections has been done through Bhutan Schedule of Rate, 2020 and estimated amount as follows:

A) Estimate of Gabion Revetment with Lunching apron

Name of work: Unit length estimate of Gabion Revetment along the Kerongchu under Nganglam Dungkhag, PemaGatshel.

Sl No.	Description	Qty	Units	Rate	Amount (Nu.)	Remarks
1	Earth work in excavation over areas by Excavator including levelling and dressing	4.50	m^3	64.66	290.97	Apron
2	Construction of embarkment by providing and laying dry earth and gravels in horizontal layers not exceeding 200mm in depth(compacted), including watering, power	10.12	m^3	120.83	1222.80	
3	Providing & filling hand-packed stone in G.I mesh of wire 3.25mm (10swg) including supplying of machine woven mesh complete. Doubly twisted hexagonal mesh 100mm x 120mm opening.	9.00	m^3	2993.10	26937.72	
4	Providing and laying non-woven geo-textile filter fabric as per the specification provided placed at the locations as in the drawing.	10.50	m^2	98.20	1031.10	
				Sub Total Nu:	**29,773.56**	
				Add 5% contingency Nu:	1488.68	
				Total Amount Nu:	**31,262.24**	
				Therefore, total cost of revetment per meter = Say Nu.	**31,263.00**	

(Ngultrum Thirty one Thousand two hundred sixty-three) only.

The total length of gabion revetments required in different locations is 1495 m.

Therefore, the total amount required = 1495m x 31,263.00 = ***Nu. 46,738, 185.00***

B) Estimate of Gabion wall with Lunching apron

Name of work: Unit length estimate of Gabion wall along the Kerongchu under Nganglam Dungkhag, PemaGatshel.

Sl No.	Description	Qty	Units	Rate	Amount (Nu.)	Remarks
1	Excavation in foundation trenches or drains not exceeding 1.5m in width or area 10 sq.m on plan, including dressing & ramming, disposal of surplus soil within 50m lead & 1.5m lift	6.50	m^3	116.87	759.66	
2	Providing & filling hand-packed stone in G.I mesh of wire 3.25mm (10swg) including supplying of machine woven mesh complete. Doubly twisted hexagonal mesh 100mm x 120mm opening.	11.00	m^3	2993.10	32923.88	
3	P&L **Non-woven Geotextile** filter (The fabric should sustain a load of not less than 10 KN/m at break and have a minimum failure strain of 10 per cent when determined in accordance with BS: 6906 (Part 1) or shall have a grab tensile strength more than 0.4kN/m and elongation corresponding to this limit in accordance with ASTM D 4632. And Have a minimum tear resistance of 150N when determined in accordance with ASTM Standard D 4533) (For more details refer **Specification of Building and Road Works)**, A 150 mm thick sand layers over the filter may be laid to avoid rupture of the fabric by armored layer. .	4.00	m^2	98.20	392.80	
4	Filling of trenches, sides of foundations, back of the walls, etc. including filter material (600 mm wide) with 100 to 200 mm stones wherever applicable including filling with selected suitable excavated material in layer not exceeding 200 mm in depth	1.15	m^3	80.29	92.33	

	(compacted), consolidating each deposited layer with power roller or portable compactor, watering etc. within 50 lead.					
				Sub Total Nu:	**34,168.67**	
				Add 5% contingency Nu:	1708.43	
				Total Amount Nu:	**35,877.10**	
	Therefore, total cost of Gabion wall per meter = Say Nu.				**35,877.00**	

(Ngultrum Thirty five Thousand eight hundred seventy-seven) only.

The total length of gabion wall required in different locations is 740 m.

Therefore, the total amount required = 740m x 35,877.00 = ***Nu. 26,548,980.00***

C) Estimate of RCC wall.

Name of work: Unit length estimate of RCC wall along the Kerongchu under Nganglam Dungkhag, PemaGatshel.

Sl No.	Description	Qty	Units	Rate	Amount (Nu.)	Remarks
1	Clearing grass including removal of rubbish within 50m of site	5.00	m^2	2.88	14.40	
2	Excavation in foundation trenches or drains not exceeding 1.5m in width or area 10 sq.m on plan, including dressing and ramming, disposal of surplus soil with in 50m lead and 1.5 m lift Ordinary soil. (Extra for trench, pit works per cu.m per m depth)	5.25	m^3	151.16	793.59	
3	Providing and Laying Hand pack stone filling or soling with stones	0.45	m^3	1341.00	603.45	
4	Providing and laying in position plain cement concrete excluding of centering and shuttering in CM, 1:2:4- All work up to plinth level.	0.30	m^3	4478.91	1343.67	
5	P/L in position reinforced cement concrete excluding the cost of centering and shuttering and reinforcement. All works up to	3.25	m^3	4649.01	15109.28	

	plinth level in cement concrete 1:1.5:3				
6	Providing and fixing centering and shuttering (form work), including strutting, propping etc and removal of form work. In walls, pilasters, buttresses, string course etc. (Stem)	16.50	m^2	603.33	9954.95
7	P/F thermo mechanically treated reinforcement bar (Fe500) for RCC work including cutting, bending, binding and placing in position complete.	280.99	Kg	67.51	18969.33
8	Providing and laying HDPE 90mm weep hole pipe.	3.00	m	288.12	864.36
9	Back filling in layers < 200 mm using selected excavated earth, ramming etc complete..	21.88	m^3	80.29	1756.75
10	Providing and constructing boulder barrier, height not exceeding 1.5 m, max. inclination of 20 deg. to the road alignment and width not less than 900mm within 50m lead	1.00	m	1144.22	1144.22
				Sub Total Nu:	**50,554.30**
				Add 5% contingency Nu:	2527.72
				Total Amount Nu:	**53,082.00**
	Therefore, total cost of RCC wall per meter = Say Nu.				**53,082.00**

(Ngultrum Fifty three Thousand eighty two) only.

The total length of RCC wall required in different locations is 15 m.

Therefore, the total amount required = 15m x 53,082.00 = ***Nu. 7.96, 230.00***

The overall, project cost estimated for protecting settlements, DCCL factory and public infrastructures along the Kerongchu is amounting ***Nu.74, 083,395.00***

8. Environmental Code of Practice

The Environmental Code of Practices (ECOP) has been developed for minor impact and small scale civil works interventions. It sets out standard practices and procedures for managing the potential negative impacts on local environment and rural communities of all civil works to be carried out.

8.1. ECoP-1: Bank Revetment Works

Locations have been identified for protection of river bank in the project area. The following Environmental Code or Practice should be followed during implementation of the bank revetment works.

Pre-Construction phase

- Design should be prepared on the basis of modelling outputs. Collect all design documents for execution and prepare a plan accordingly which should be submitted to the Department of engineering Services, Ministry of Works and Human Settlement, Royal Government of Bhutan.
- Plan should include all activities starting from mobilization of stone materials and equipment to handover of the revetment works to the property authority for operation and maintenance.
- Site office and labour shed with provision of hygienic toilet and pure drinking water facility for all must be ensured during implementation of the civil works.
- Effluent from washroom/ labour shed toilets must not be disposed into the near streams (Chu) and should be handled properly.
- All vegetation or debris and wastes should be cleaned up before removing the stones along the deepest point of the rivers/streams (Chu).
- Netting quality along the bank side of the rivers should be ensured by the staff with specified laboratory test and it must comply with specification.
- Stone size must comply with the specifications.

Construction Phase

- All movement of stone works should be executed in accordance with design and plan and these are to be displayed at site office so that local stakeholders can see and understand them.
- Safety measures should be taken up in every activity for the construction labor, students near the school during school time and also for the dwellers of the settlement.
- First Aid box should be at hand so that it is readily available or can be used when needed.
- Implementation work should be monitored properly and regularly by project engineer so that the work can be completed in accordance with design specification and plan.
- All the Stone works should be placed as per specification.
- All the nests of the trees along the bank should be kept as it is. No nests should be destroyed during project works.
- All the stone works should be implemented to keep the trees as it is.
- Use noise-control methods such as fences, barriers or deflectors.
- minimize transportation of construction materials through community areas during regular working time;
- Maintain a buffer zone (such as open spaces, row of trees or vegetated areas) between the project site and residential areas to lessen the impact of noise to the living quarters
- Do not burn site clearance debris (trees, undergrowth) or construction waste materials
- keep stockpile of aggregate materials covered to avoid suspension or dispersal of fine soil particles during windy days or disturbance from stray animals
- the flow of natural waters should not be obstructed or diverted to another direction, which may lead to drying up of river beds or flooding of settlements
- No cutting of trees or destruction of vegetation other than on construction site
- No hunting, fishing, capture of wildlife or collection of plants

Post-Construction Phase

- Monitor completed work by government staff.
- Any type of movement and activity such as children playing on the protected portion should be prohibited.
- Agricultural /vegetable gardening practices on the bank should be prohibited.

8.2. ECoP-2: Plantation of broadleaf trees

Planting should be done in both bank of the rivers to enhance river ecosystem and also wildlife of the project area. The study area consists of only broadleaf forest. The dominating tree species in the area are Nyssa javonica, Exbucklendia sp., Phoebe sp., Terminalia sp., Quercus sp. and Engelhardtia sp., Chirpine, scientifically known as Pinus roxburghii (Khengzore Forest Management Plan, MoAF, 2019).

Pre-Construction phase

All the plantation program should be displayed on a notice in board in the project site (1)for public awareness.

Construction Phase

- Trees should be planted in such a way that the agriculture field can get adequate sunlight.
- Native plants should be given priority as they are part of the local ecosystem.
- Trees which provide fruit as well as timber should be given more importance. These also act as financial security of vulnerable peoples near the rivers.
- Plantation programs should be implemented before the wet season.

Post-Construction Phase

- Monitoring growth of plantation by local stakeholders through group formation.

9. Implementation Plan

9.1 Rationale of Investment Plan

Kerongchu is evidently facing recurrent problems of flooding and all these flood and associated hazards are creating havoc to life and properties, damaging settlements, farmlands, and hampering education. The frequency and intensity of these hazards will be increased in the future due to climate change impact, to the devastating nature, which needs to be reduced through mitigation measures with other associated research, planning, and implementation activities. Sporadic planning an initiative by local government agencies did not bring any fruitful outcomes due to a lack of detailed scientific and technical studies. Moreover, lots of specific problems, issues, and challenges have been identified throughout this study. To address those issues, both structural and non-structural measures are proposed with specific recommendations to bring out the effective outcome of those proposals. Hence, the need for an investment plan comes into point amalgamating all proposed structural, non-structural measures, and recommendations to successfully implement the proposed interventions in an organized manner.

9.2 Investment priority

This investment plan comprises three investment priority projects for 2021-2030 with indicative costs. Priorities have been given to select investment projects based on how the project will address the proposed structural, non-structural measures, and recommendations of this study. The recommended measures from the study have to be implemented priority-based for effective management of flooding in the area (Refer Table 5). The priority investment projects are as follows:

- Investment Project 1: Flood Mitigation of **Nu. 12,281,610.00**
- Investment Project 2: Flood Mitigation of **Nu. 24,201,450.00**
- Investment Project 3: Flood Mitigation of **Nu. 37,600,335.00**

9.2.1 Priority-based Flood Protection measures along the Kerongchu

Priorities have been given based on critical location; therefore, the investment plan will address the proposed structural.

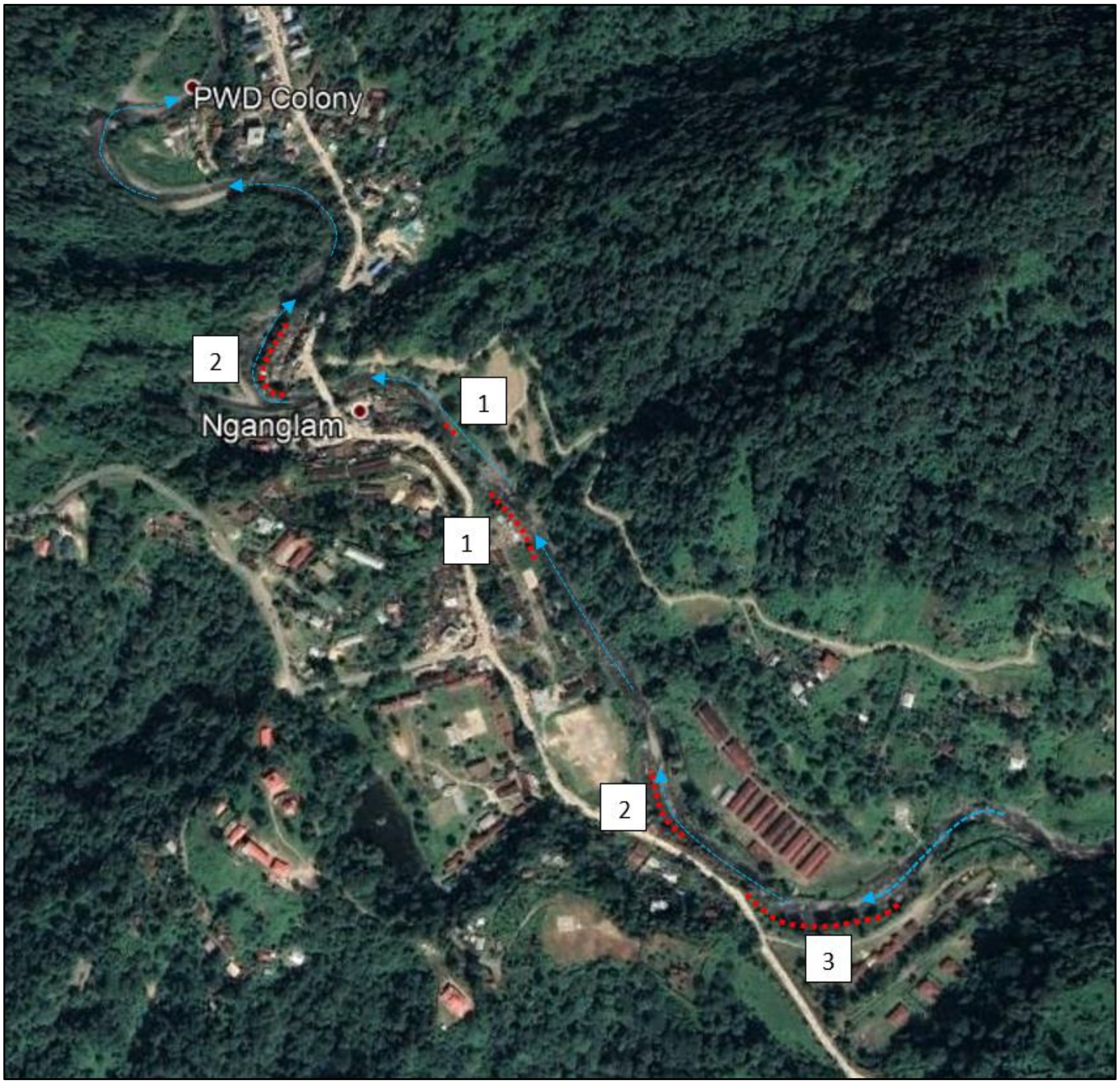


Figure 33 Priority map for upstream of Nganglam town

Figure 34 Priority Map near the DCCL factory

Priority 1

- Below the football ground, left bank: The left bank area has been found critical and needs to be protected with gabion walls with an apron (50m).
- Near the automobile workshop: The left bank, RCC walls needs to be extended (15m).
- Above the DPCL colony: The left bank needs to be protected by providing Gabion Revetment (310m).

Priority 2

- Above the football ground: The left bank needs to be protected by providing a Gabion wall with a launching apron (110m).
- Below the motorable bridge: The right bank needs to be protected by providing Gabion Revetment (120m).
- Upstream of DCCL factory: The left bank needs to be protected by providing a Gabion wall with a launching apron (100m).
- Above the DCCL motorable bridge: The left bank needs to be protected by providing a Gabion wall with a launching apron (210m).

- DCCL colony area: The left bank needs to be protected by providing a Gabion wall with a launching apron (150m).

Priority 3

- Near the RBA office: The left bank needs to be protected by providing Gabion Revetment (115m).

- Below the motorable bridge at factory: The left bank needs to be protected by providing a Gabion wall with a launching apron (120m).

- Near the stone quarry: The left bank needs to be protected by providing Gabion Revetment (695m).

- Opposite to the stone quarry: The left bank needs to be protected by providing Gabion Revetment (150m).

- Below the DoR office: The left bank needs to be protected by providing Gabion Revetment (105m).

Table 5 Summary of investment priorities indicating major components of investment

Sl No.	Prioritized Locations	Type of structure	Length of the structure	Cost estimate Amount in Nu.	Priority
1	Below the football ground, left bank	Gabion wall with launching apron	50 m	1,793,850.00	1
2	Near the automobile workshop	RCC wall	15 m	7,96,230.00	1
3	Above the DPCL colony	Gabion Revetment	310 m	9,691,530.00	1

4	Above the football ground	Gabion wall with launching apron	100 m	3,587,700.00	2
5	Below the motorable bridge	Gabion Revetment wall	120 m	3,751,560.00	2
6	Upstream of DCCL factory	Gabion wall with launching apron	110m	3,946,470.00	2
7	Above the DCCL motorable bridge	Gabion wall with launching apron	210m	7,534,170.00	2
8	DCCL colony area	Gabion wall with launching apron	150m	5,381,550.00	2
9	Near the RBA office	Gabion Revetment	115m	3,595,245.00	3
10	Below the motorable bridge at factory	Gabion wall with launching apron	120m	4,305,240.00	3
11	Near the stone quarry	Gabion Revetment	695 m	21,727,785.00	3
12	Opposite to the stone quarry	Gabion Revetment	150m	4,689,450.00	3
14	Below the DoR office	Gabion Revetment	105m	3,282,615.00	3
			Total estimated cost	**74, 083,395.00**	

9.2.2 Benefits of Investment

Although the social-economic study could not carry out due to lack of economic knowledge, however, lots of benefits will be achieved through the implementation of these proposed priority projects but not limited to as follows:

1. Bank protection will be ensured and bank erosion will be reduced, and will be stopped.
2. Bed scouring will be reduced.
3. The river will get its room for extreme flood passage.
4. The environment-friendly and durable solution.
5. Huge life and property safe value will be gained.
6. One-time investment will give protection for a couple of years at least 50 years with some maintenance cost only. Therefore, recurring cost will be reduced.

9.3 Operation and Maintenance

The term 'operation and maintenance' refers to all the works and activities that are required to operate and maintain the flood mitigation works to the design standard. Regular inspection and maintenance of flood mitigation works are necessary to ensure serviceability of the flood mitigation works up to the design flood event and to maintain the dependency of the mitigation system.

9.3.1 General

(a) The structures and facilities constructed by the Dungkhag Administration, Nganglam for flood protection shall be continuously maintained in such a manner and operated at such times and for such periods as may be necessary to obtain the maximum benefits.

(b) It shall be the duty of the Dungkhag Administration to submit a semi-annual report to the Dzongkhag covering inspection, maintenance, and operation of the protective works.

(c) The Dzongkhag or his authorized representatives shall have access at all times to all portions of the protective works.

(d) Maintenance measures or repairs that the Dungkhag Administration deems necessary shall be promptly taken or made.

(e) Appropriate measures shall be taken by local authorities to ensure that the activities of all local organizations operating public or private facilities connected with the protective works are coordinated with those of the Dungkhag Administration during flood periods.

(f) The Dungkhag Administration should not allow any unauthorised excavation or construction in, on or adjacent to the flood mitigation works if deemed to be detrimental to the integrity or performance of the flood mitigation works.

(g) The Dungkhag Administration should carry out Inspection during high water events to monitor the performance of the flood mitigation works.

9.3.2 Maintenance of Flood Protection Structures

The Dungkhag administration shall provide at all times such maintenance as may be required to ensure the serviceability of the structures in time of the flood. Inspections shall be made by the Dungkhag Administration to be certain that:

(a) No trees exist, the roots of which might extend under the walls or revetment and which may lead to accelerated seepage paths;

(b) The concrete has not undergone cracking, chipping, or breaking to an extent which might affect the stability of the wall or its water tightness;

(c) There are no encroachments upon the right-of-way which might endanger the structure or hinder its functioning in time of the flood;

(d) Care is being exercised to prevent the accumulation of trash and debris adjacent to walls.

(e) No bank caving conditions exist riverward of the RCC wall, gabion wall, or gabion revetment which might endanger its stability;

Such inspections shall be made immediately prior to the beginning of the flood season, immediately following each major high-water period. Measures to eliminate encroachments and effect repairs found necessary by such inspections shall be undertaken immediately. All repairs shall be accomplished by methods acceptable in standard engineering practice.

9.3.3 Maintenance of Channels or flow path

Periodic inspections of improved channels and flow path shall be made by the Dungkhag Administration to be certain that:

(a) The channel or flow path is clear of debris, weeds, and wild growth;

(b) The channel or flow path is not being restricted by the depositing of waste materials, the building of unauthorized structures, or other encroachments;

(c) The capacity of the channel or flow path is not being reduced by the formation of shoals;

(d) Banks are not being damaged by rain and that no sloughing of banks has occurred;

(e) Riprap sections and deflection dikes and walls are in good condition;

(f) Approach and egress channels adjacent to the improved channel or flow path are sufficiently clear of obstructions and debris to permit the proper functioning of the project works

Such inspections shall be made prior to the beginning of the flood season. Immediate steps will be taken to remedy any adverse conditions disclosed by such inspections. Measures will be taken by the Dungkhag Administration to promote the growth of grass on bank slopes and earth deflection dikes. Sediment removal in channels is necessary if the sediment bar and vegetation blocks flow and reduces conveyance. The Dungkhag Administration shall provide for periodic repair and cleaning of debris basins, check dams, and related structures as may be necessary.

9.3.4 Maintenance of miscellaneous facilities

Miscellaneous structures and facilities constructed as a part of the protective works and other structures and facilities which function as a part of, or affect the efficient functioning of the protective works, shall be periodically inspected by the Dungkhag Administration and appropriate maintenance measures taken. Damaged or unserviceable parts shall be repaired or replaced without delay. Areas used for ponding in connection with pumping plants or for the temporary storage of interior run-off during flood periods shall not be allowed to become filled with silt, debris, or dumped material. The Dungkhag Administration shall take proper steps to prevent restriction of bridge openings and, where practicable, shall provide for temporary raising during floods of bridges which restrict channel capacities during high flows.

10. Conclusion

The preparation of Flood Management Plan (FMP) for Kerongchu in Nganglam under Pema Gatshel Dzongkhag has been undertaken as a component study under the Strategic Programme for Climate Resilience, World Bank and is a comprehensive Report prepared within the in-house capacity of Flood Engineering and Management Division.

Detail hydrological and hydrodynamic analysis and modelling using SWAT and HECRAS software applications respectively, were utilized to determine the Flood Hazard areas. FEMD carried out field survey to take stock of existing structures and also validate and identify critical areas prone to flooding, congruent to the Flood Hazard Maps.

Suitable environmentally friendly and sustainable mitigation measures such as Gabion Revetment with launching apron and Gabion wall with launching apron have been proposed along the critical stretches of Kerongchu. A stretch near the Workshop area was left without flood protection structure and was susceptible to flooding during monsoon season. RCC wall of about 15 meters has been proposed along that stretch to protect the Workshop area from flooding. Various non-structural measures are also recommended in the Report to intensify the effectiveness of climate resilient measures.

The overall project cost is estimated at **Nu. *74, 083,395.00*** (Ngultrum Seventy-four Million eighty three thousand three hundred ninty-five). However, the structural measures are prioritized into three segments viz. Investment project 1,2 &3, and accordingly strategies and implementation plan has been prepared for flood measures along the river.

The Report also constitutes Environmental Code of Practices, which outlines standard practices and procedures for managing the potential negative impacts during implementation stages. Often operation and maintenance are neglected after completion of Projects. Thus, the FMP Report provides works and activities that are required to be carried out by Dungkhag Administration, Nganglam in order to ensure smooth functioning and timely maintenance of flood protection structures along Kerongchu.

Consequently, the Flood Management Plan for Kerongchu in Nganglam is envisioned to provide holistic and conscientious flood mitigation strategies and measures to be implemented, and protect human settlements, lives and livelihood of people residing in the Nganglam Valley.

10.1 Limitation of the Study

The quality of the management plan purely depends on the input data used in the flood model for the preparation of flood hazard maps. Kerongchu FMP has been prepared with following shortcomings and limitations:

- There were no discharge gauge stations along Kerongchu.
- The spatial distribution of rainfall gauge was very low, which might have compromised the hydrological model.
- SRTM 90m DEM and ALOS 10m DEM have been used as the 5m, 10m and 30m SRTM DEM were found to have error and not usable for the assignment.
- Detailed river cross section survey could not be done as it is difficult to cross the rivers at some critical locations.
- The hydrodynamic models could not be validated due to lack of data.
- Although the risk map was not prepared, detailed field validation of the hazard areas have led to the proposal of the appropriate measures.

References

1. **Forest, Ministry of Agriculture &.** *Khenzore Forest Management Plan.* 2019.

2. **Ltd, AECOM Australia Pty.** Operations and maintenance manual. *South Rockhampton Flood Levee.* 2019, p. 35.

3. **Corps of Engineers, US Army.** Operation and maintenance Manual. *Flood Control works.* 1955, p. 76.

4. **Team, JICA EXPERT.** *Operation and Maintenance Manual for Hydraulic Structures.* Bangladesh Water Development Board. 2017. p. 320.

5. **ENTRO, Ephrem Tamiru &.** *Flood Embankment Design, Operation & Maintenance Manual.* Eastern Nile Technical Regional Office (ENTRO). Ethiopia : s.n., 2010. p. 345.

6. **(JPA), San Francisquito Creek Joint Powers Authority.** Operation & Maintenances Manual. *San Francisquito Creek Flood Reduction, Ecosystem Restoration and Recreational Project* . San Francisco : s.n., 2014, p. 137.

7. **Engineers, Corps of.** *Local Flood protection; maintenance & Structures & Faclities.* Department of Army, Department of Defense. 2011. p. 5.

8. **National Centre for Hydrology & Meteorology, Royal Government of Bhutan.** *Compendium of Climate & Hydrological Extremes in Bhutan since 1968 from Kuensel.* Thimphu : s.n. ISBN No. 978-99936-721-7-3.

9. **Consultancy-CEGIS, APECS.** *FLood Management Plan for Paro Dzongkhag.* Department of Engineering Services, Ministry of Works & Human Settlement. Thimphu, Bhutan : s.n., June 2020.

10. —. *Assessment of Flooding Hazard & Development of Climate-Resilient Flood Mitigation Measures in Shetekheri & Aiepoly (Big & Small) Streams.* Department of Engineerings Services , Ministry of Works & Human Settlement. Thimphu, Bhutan : s.n., March 2019.

11. **Flood Engineering & Management Division.** *Preparation of Flood Hazard Map of Kerong River in Nganglam, Pemagatshel.* Department of Engineering Services , Ministry of Works & Human Settlement. Thimphu, Bhutan : s.n., March 2019.

12. **Division, Flood Engineering & Management.** *Detailed Project Report for Flood Mitigation works along Dungsumchu, Samdrupjongkhar.* Department of Engineering Services, Ministry of Works & Human Settlements. Thimphu, Bhutan : s.n., October 2019.

13. *Rainfall-runoff modelling of Ajay river catchment using SWAT model.* **Kangsabanik, Subhadip Murmu, Sneha.** s.l. : IOP Publishing, 2017, IOP Conference Series: Earth and Environmental Science, p. 012033.

14. *Sensitivity Analysis of Mountain Flash Flood Risk: Case of Licheng County in China.* **Haofang Wang, Jincun Zhang, Ruan Yun, Ranhang Zhao.** 2017.