REPORT ON MINI PROJECT PHASE II

REMOTE SENSING, GIS & HEC-RAS FOR KOLONGCHU FLOOD HAZARD MAPPING

VENUE:
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1. Introduction

Bhutan has been hit with heavy rainfall and flash floods through most of the country and has a history of loss of lives and damages to property due to flooding. Rivers are characterised by steep slopes in upper catchment, subject to intense seasonal rainfall and high rates of erosion. As the river flow towards southern foothills, the transition from mountainous areas to flat plains typically occurs and is accompanied by extensive flooding with heavy sedimentation. With the climatic change, rainfall pattern has become erratic with prolonged drought period followed by unusually high precipitation. Climate change and variability has resulted in changing rainfall and temperature patterns, thereby aggravating these disaster risks, leading to higher risks, especially for the poor and vulnerable.

2. Objective

The overall objective of this study area is to develop a capacity building and technology programme in the application of space technology of Bhutan. The specific objectives are as follows:

1. To prepare Flood Hazard Map of Kolong Chu river basin by using Hydrological and Hydrodynamic modelling.
2. To generate flood maps by using ALOS/PALSAR data
3. To familiarize with different flood mapping software.

3. Study Area

Kolongchu basin along Bumdelling in far eastern district of Trashiyangtse has been chosen for this mini-project which are shown in figure 1. The Kolongchu joins the mighty Drangme Chuu/Manas River, the largest river system in Bhutan, which becomes the transboundary river in the Himalayan foothills between southern Bhutan and India.Kolongchu has lots of history of flooding, whereby the farmers along the river in Bumdelling Gewog has lost acres of their agricultural lands. Once green and beautiful Bumdelling valley is now filled with sand, boulders, and logs and have become barren. The farmers are however trying with cultivation.

The valley is known for the roosting ground of the rare black-necked crane, different other bird species and other endangered species. It has also been identified as one of the RAMSAR site (Wetlands of International Importance).

3.1 Study Area Details:

- ✓ Geographic Location:

  longitude : between 91.3 & 91.6 E

  latitude : between 27.1 & 27.9 N

- ✓ Area of the Basin : 1177.40 km^2

  River length is about 70 km.

- ✓ Approximate river length considered for modelling : 33km
- ✓ No Guaging station at the upstream of the river. Station towards the end of the floodplain.
- ✓ Rainfall stations not in the desired location for the modelling.
- ✓ Rare images on the flood incidences.

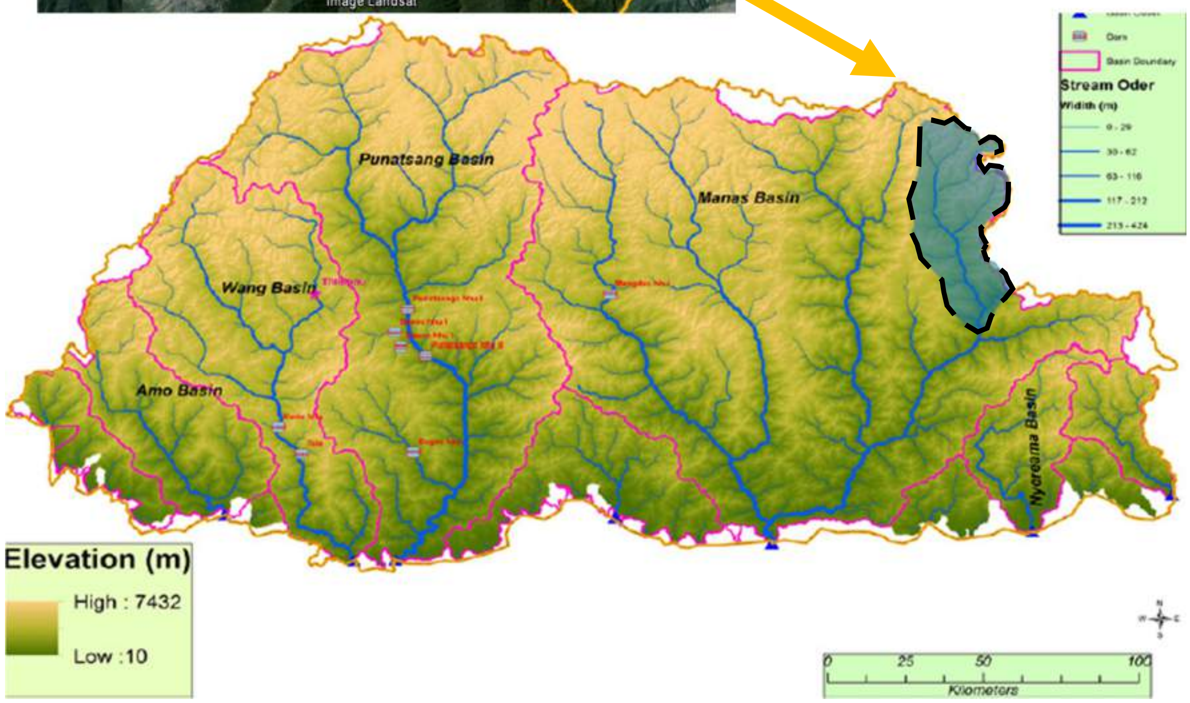


Figure 1. Study Area

Kolongchu river in Bumdelling floodplain has destroyed acres of public agricultural land. Numerous flood protection works has been carried out in the past along the different flood threatened paddy fields which has all become useless during the monsoon triggered floods. The flood protection works funded by different organizations couldn't withstand the flood as it was constructed without understanding of the flood behavior and discharge level expected.

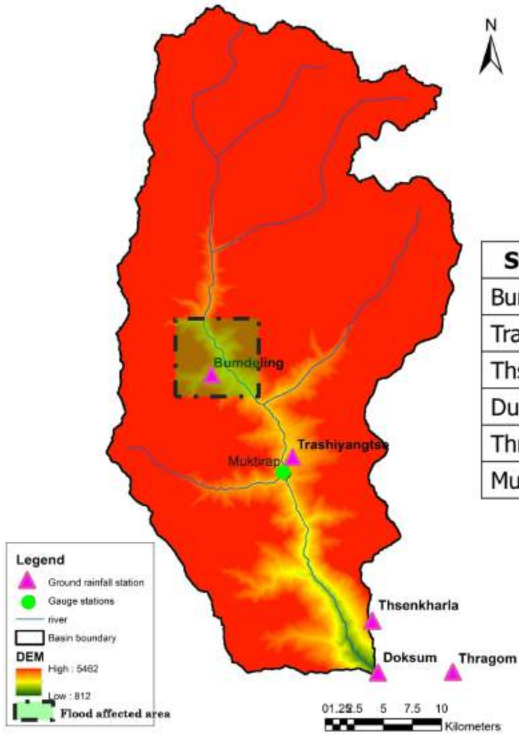
4. Data used

Requirement of all the essential data sufficiently for the flood modelling flood mapping using ALOS/PALSAR is important to prepare the Flood hazard and inundation map. The data required were collected from the agencies concerned. The data used are three categories, including GIS data, meteorological data and satellite Images.

a) GIS data
  - Watershed Boundary
  - Streamline
  - Meteorological stations
  - Topography data/Digital Elevation Map (DEM) – 30meter SRTM
  - Land cover data
  - Soil type data

b) Meteorological data (as Figure 2)
  - Daily Rainfall 2007-2010
  - Daily discharge 2001-2014

c) Satellite Images.
  - Images ALOS PALSAR (Before flood and during flood in 2007, 2008, 2009 and 2010 based on flooding history)



Station name	Type of data	Period data	Remark
Bumdeling	Daily Rainfall	-	No data
Trashiyangtse	Daily Rainfall	1996-2015	-
Thsenkharla	Daily Rainfall	1996-2015	Outside basin
Duksum	Daily Rainfall	2000-2014	Outside basin
Thragom	Daily Rainfall	1996-2015	Outside basin
Muktirap	Daily Discharge	2001-2015	-

Figure 2. Meteorological and Hydrological station

5. Methodology

A schematic diagram of the overall methodology is shown in the Figure 3. The overall methodology is categorized into two phases. The first phase is the preparedness phase that is developed for the element at-risk for the study area by using hydrological and hydrodynamic models and generating flood hazard map.

The second phase is the emergency response phase that is performed by processing of satellite image data to generate flood map during the time of disaster. The inundation map is prepared from the satellite observed pre and post images from JAXA. The images are processed using the NEST, MapReady, SNAP and QGIS software. When a disaster occurs next time in the future, the disaster charter would be activated and the satellite images would be acquired which would be used derive the flood map quickly. After getting flood maps from the two processes, field verification was conducted to validate the accuracy of flood maps.

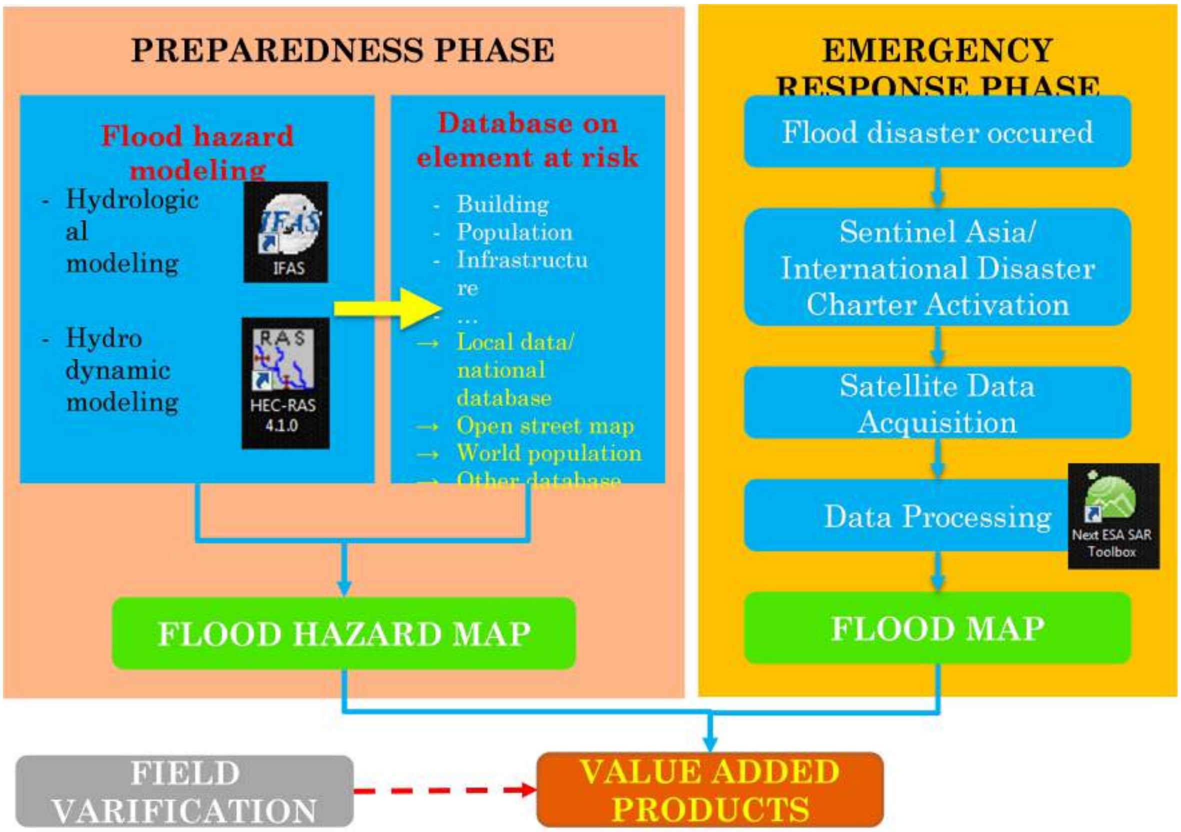


Figure 3. Overall methodology of Project

5.1 Preparedness phase

The methodology of flood modeling for this study is showed in Figure 4. Integrated Flood Analysis System (IFAS) model was done by using global elevation map, global land cover, soil & geology (DSMW) and rainfall data as input. Otherwise, the model result of IFAS could not get good calibration. Therefore, to determine discharge as the input for hydrodynamic model flood frequency analysis has been used. Hydrologic Engineering Centers River Analysis System (HEC-RAS) software has been used to generate the Flood Hazard Map as dimensional flood model. For this study, data input of HEC-RAS model including annual peak discharge from flood frequency analysis, topographic data as DEM 30 m and Manning's Coefficient for ground surface has been used.

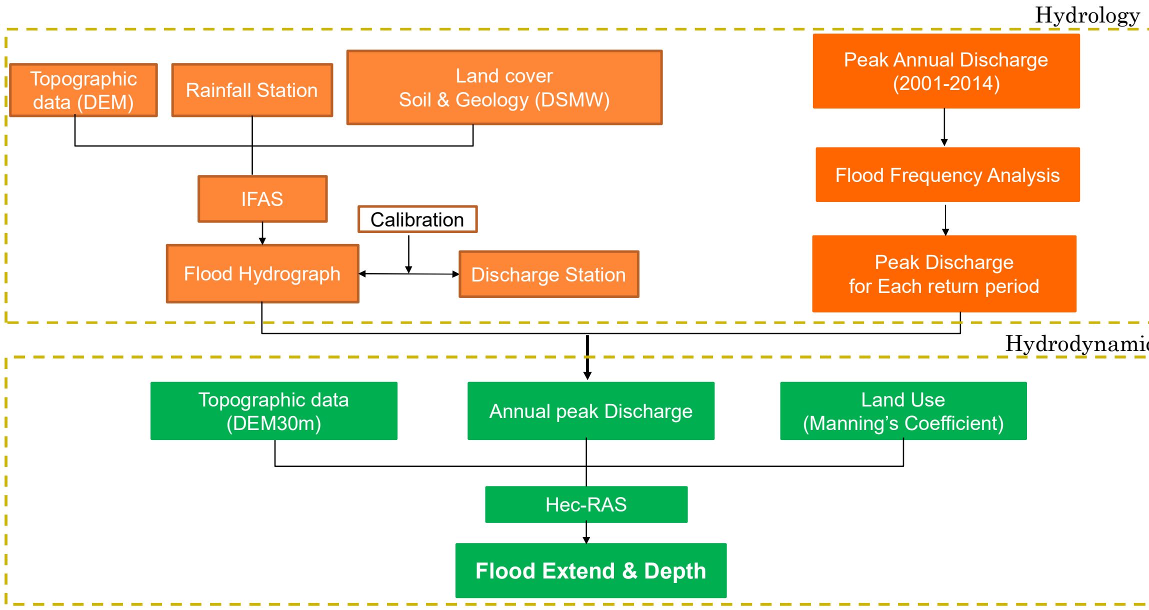


Figure 4. Methodology for preparedness phase

5.1.1 Hydrological Model

Integrated Flood Analysis System (IFAS) performs the hydrological model to generate the runoff from rainfall. IFAS had been developed by ICHARM as a concise flood-runoff analysis system. It can utilize freely available global data sources and satellite based rainfall products for the model development. The distributed hydrological model divides a basin into each cell and calculates per cell. The vertical direction flow is expressed by 2 or 3 kinds of tanks as Figure 5. The surface tank (upper tank) simulates the surface flow, rapid intermediate flow (subsurface flow), and percolation to the groundwater tank. Although parameters required for run-off calculation need to set up for each cell, IFAS categorizes all cells to some classification and estimates parameters based on the GIS data of land use, geology, soil, etc.

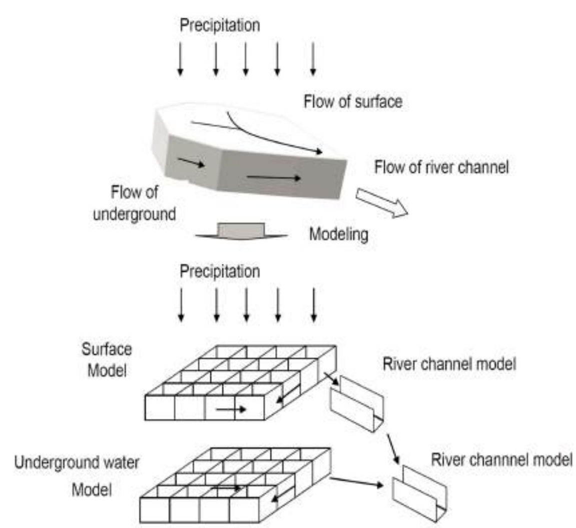


Figure 5. Tank layer for IFAS model

Moreover, one advantage of IFAS is utilization of satellite rainfall data as Global Satellite Mapping of Precipitation (GSMaP). GSMaP is very much useful for those regions where there are not enough rainfall gauging stations and radar measurement system working in ground. The flowchart as figure 6 is the process of the production of GSMaP data. It uses Multi satellite data basically more than 9 satellites which are in the constellation. Rainfall data are retrieved from each microwave sensor which is combined with the rain models to produce the hourly microwave rainfall map. This microwave rainfall map is again processed with the cloud moving vectors obtained from Geo stationary Satellite. This produces the GSMaP rainfall data in a spatial resolution of 10 km and temporal resolution of 1 hour. GSMaP data after processing is distributed through internet free of cost. This data is available in binary and text file formats.

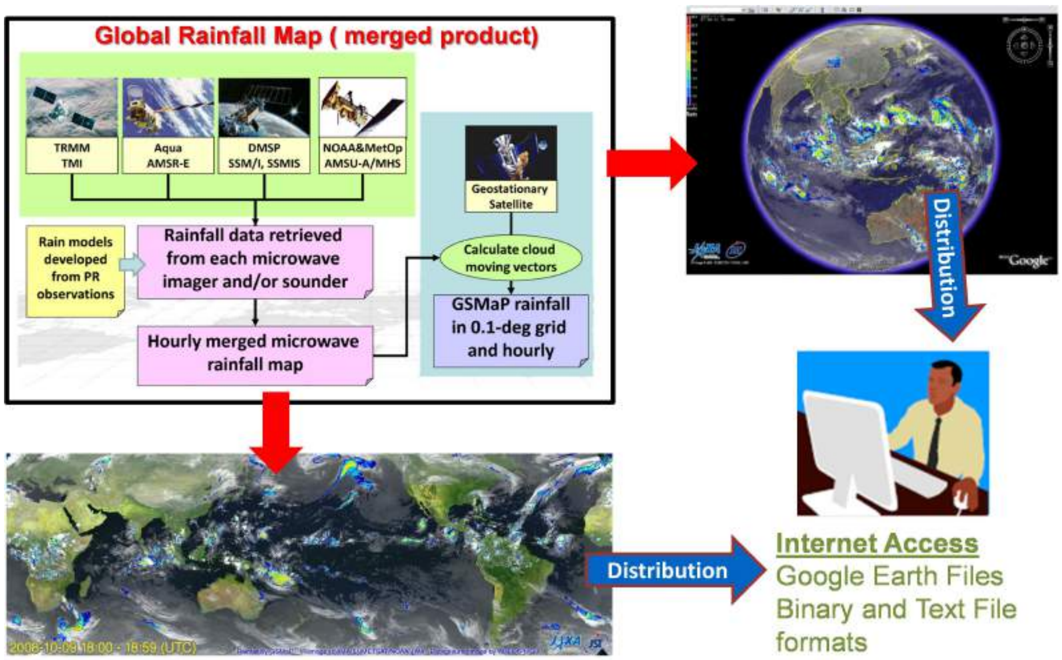


Figure 6. Flowchart of processing GSMaP

The model result from IFAS as discharges could be used as the input data for the hydrodynamic model as HEC-RAS to generate the flood map at the flood affected area as downstream.

5.1.2 Determination of discharge

This study area is lacks the discharges due to ungauged basins and other data requirded in the HEC-RAS. Therefore, to determine the discharge as the input of hydrodynamic model and to generate flood map, this study proposed the flood frequency analysis and unit hydrograph method.

Flood Frequency Analysis

Hydrologic system 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 is the probability distribution function. The frequency factor equation was propose 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. Four of the common forms are:

1. Normal Distribution
2. Log-Normal Distribution
3. Gumbel Distribution
4. Log-Pearson Type III Distribution

The four methods are used to predict design floods by selecting the accurate method for this study. This is done by comparing the probability plotting curve with the four methods. The data may be plotted on specially designed probability paper, or using a plotting scale that linearizes the distribution function. The plotted data are then fitted with a straight line for interpolation and extrapolation purpose. Therefore, plotting positions refers to the probability value assigned to each piece of data to be plotted. This method depends on data collected.

Unit Hydrograph

The unit hydrograph is the unit pulse response function of a linear hydrologic system which is defined as a direct runoff hydrograph resulting 1 unit (1 cm or 1 in) of excess rainfall generated uniformly over the drainage area. Therefore, this study proposed double triangle unit hydrograph method to identify the discharge at the upstream as assumption due to lack of discharge data at upstream of the basin. Double triangle unit hydrograph method is to identify unit hydrograph of basin which do not have observed data that based on characteristic of the basin. This method composes of the four parameters as following;

- UP is Peak discharge (mm/hrs)
- TP is time of peak discharge (hrs)
- TR is duration of time from peak discharge of first triangular to peak discharge of second triangular (hrs)
- TL is duration of time from to peak discharge of second triangular to final discharge of second triangular (hrs)

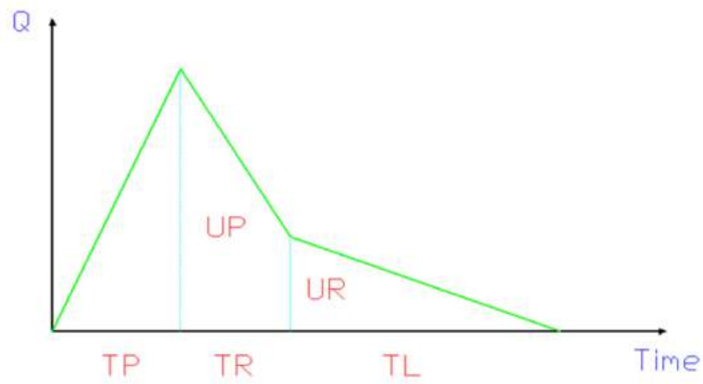


Figure 7. Double triangular unit hydrograph

For each parameter, this method calculate as following formula;

$U_p = K_1\ A^{a1}\ L^{b1}\ CR^{c1}\ ST^{d1}$

$T_p = K_2\ A^{a2}\ L^{b2}\ CR^{c2}\ ST^{d2}$

$T_R = K_3\ A^{a3}\ L^{b3}\ CR^{c3}\ ST^{d3}$

$T_L = K_1\ A^{a4}\ L^{b4}\ CR^{c4}ST^{d4}$

$U_R = (2 - U_P\,(T_P + T_R))/(T_R+T_L)$

Where A is area of river basin (km^2)

L is the length of the main stream from the outlet to the upstream divide (km)

CR is shape factor equal the ratio of length of basin (CL) and wide of basin (CB) by dragging through the watershed centroid ST is slope of the main stream. Moreover, this method need to identify time of concentration (T_c) which is the longest time required for a particle to travel from the watershed divide to the watershed outlet to find out duration of flooding as following equation.

$$T_C = \frac{0.87L^3}{H^{0.385}}$$

Where L is Length of the river (km)

H is Difference in the elevation (m)

T_c is Time of concentration (hour)

Therefore, this method found out the assumption of upstream of basin due to lack of discharge data.

5.1.3 Hydrodynamic model

Hydrologic Engineering Centers River Analysis System (HEC-RAS) allows the user to perform one-dimensional steady flow, unsteady flow, sediment transport/mobile bed computations, and water temperature modeling. HEC-RAS is a product of the Corps' Civil Works System Wide Water Resources Research Program (SWWRP).

Theory of model

HEC-RAS uses the 1-D energy equation with energy losses due to friction evaluated with Manning's equation to compute water surface profiles, an iterative computational procedure, Standard Step Method is used. The steady flow describes conditions in which depth and velocity at a given channel location do not change with time. Gradually varied flow is characterized by minor changes in water depth and velocity from cross-section to cross-section. The primary procedure used by HEC-RAS to compute water surface profiles assumes a steady, gradually varied flow scenario, and is called the direct step method. The basic computational procedure is based on an iterative solution of the energy equation:

$$Z_2 + Y_2 + \frac{\propto_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{\propto_1 V_1^2}{2g} + h_e$$

Where:

Z_1, Z_2 = elevation of the main channel inverts

Y_1, Y_2 = depth of water at cross sections

V_1, V_2 = average velocities (total discharge/ total flow area)

α_1, α_2 = velocity weighting coefficients

g = gravitational acceleration

h_e = energy head loss

The energy equation parameters are illustrated in the following graphic:

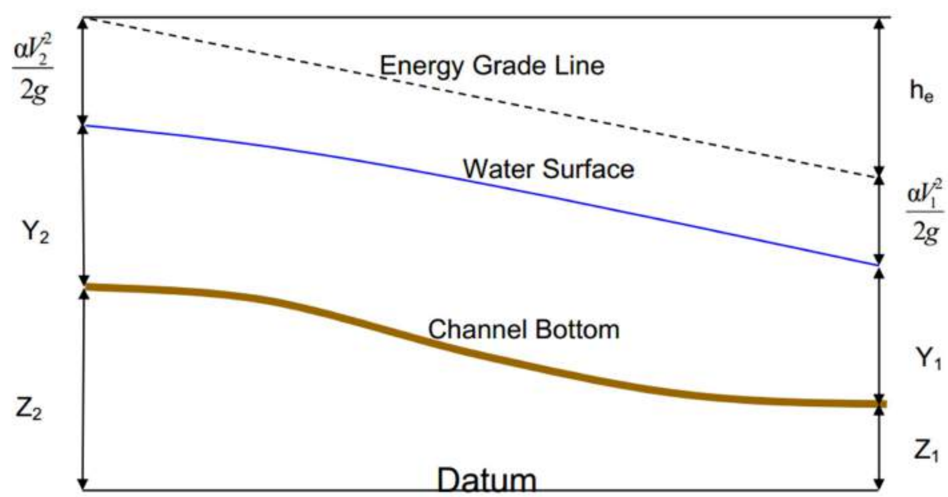


Figure 8. Representation of Term in the Energy Equation Source: http://www.hec.usace.army.mil

The energy head loss (h_e) between two cross sections is comprised of friction losses and contraction or expansion losses.

Additional, the determination of total conveyance and the velocity coefficient for a cross section requires that flow to be subdivided into units for which the velocity is uniformly distributed. The approach used in HEC-RAS is to subdivide flow in the overbank areas using the input cross section n-value break points (locations where n-value change) as the basis for subdivision (figure 9). Conveyance is calculated within each subdivision from the following form of Manning's equation.

$$Q = KS_f^{1/2}$$

$$K = \frac{1}{n}AR^{2/3}$$

Where Q =Discharge

K = Conveyance for subdivision

n = Manning's roughness coefficient for subdivision as Table 1

A = Cross-sectional area

R = Hydraulic radius = A/P where P = wetted perimeter

S_f = Slope of energy line between two points (water surface slope for uniform flow)

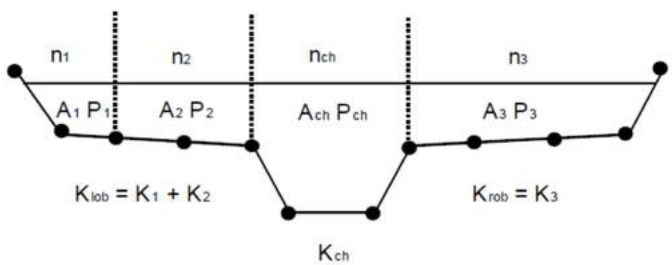


Figure 9. HEC-RAS Default Conveyance Subdivision Method

Table 1 Manning's n for channels (Chow, 1959)

Type of Channel and Description	Minimum	Normal	Maximum
Natural streams - minor streams (top width at floodstage < 100 ft)			
1. Main Channels			
a. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective	0.040	0.048	0.055
f. same as "d" with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or floodways	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles with large boulders	0.040	0.050	0.070
3. Floodplains			
a. Pasture, no brush			
1.short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050

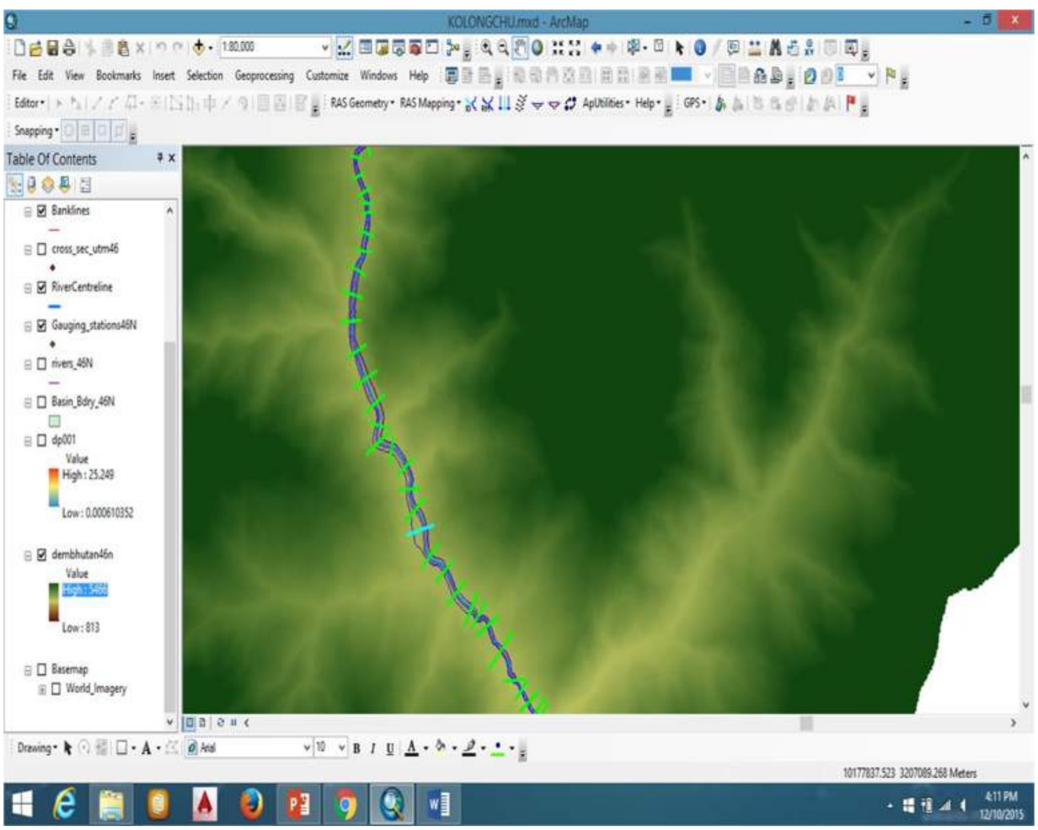
c. Brush			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. dense willows, summer, straight	0.110	0.150	0.200
2. cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy stand of timber, a few down trees, little	0.080	0.100	0.120
5. same as 4. with flood stage reaching branches	0.100	0.120	0.160
4. Excavated or Dredged Channels			
a. Earth, straight, and uniform			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, uniform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140
5. Lined or Constructed Channels			
a. Cement			
1. neat surface	0.010	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood			
1. planed, untreated	0.010	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. unplaned	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.010	0.014	0.017
c. Concrete			
1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel on bottom	0.015	0.017	0.020
4. unfinished	0.014	0.017	0.020
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025
7. on good excavated rock	0.017	0.020	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.020
2. random stone in mortar	0.017	0.020	0.024
3. cement rubble masonry, plastered	0.016	0.020	0.024
4. cement rubble masonry	0.020	0.025	0.030
5. dry rubble or riprap	0.020	0.030	0.035

e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.020	0.025
2. random stone mortar	0.020	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
f. Brick			
1. glazed	0.011	0.013	0.015
2. in cement mortar	0.012	0.015	0.018
g. Masonry			
1. cemented rubble	0.017	0.025	0.030
2. dry rubble	0.023	0.032	0.035
h. Dressed ashlar/stone paving	0.013	0.015	0.017
i. Asphalt			
1. smooth	0.013	0.013	
2. rough	0.016	0.016	
j. Vegetal lining	0.030		0.500

Method of HEC-RAS

1. Digitization of the river in ArcGIS

The data or input for the HEC-RAS are all prepared in the ArcGIS. The 30 meter SRTM DEM of the study area is imported to GIS and then data like watershed boundary, riverline, hydrological and meteorological station are brought subsequently. The river is digitized from upstream to downstream on the DEM followed by digitization of the banks, flowpath, cross sections as figure 17. The digitized river on the DEM is then made ready to be exported to HEC-RAS where the river analysis is done.



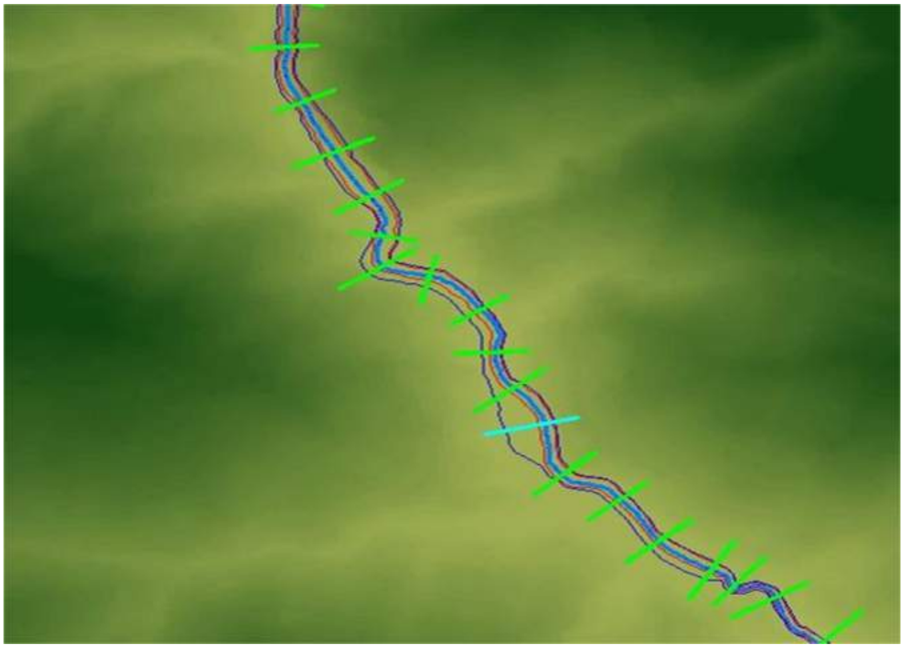


Figure 10. River Digitization in ArcGIS

a) River Modelling in HEC-RAS

The digitization are performed in the GIS with the help of HEC- GeoRAS toolbox. After digitizing the river in ArcGIS and setting up the layer, the GIS file is then exported to HEC-RAS. The river cross-section and river bed elevation corrections are done here. The geometric data, steady flow data and manning's values of the river are entered and saved. The return period of 10yrs, 25ys, 50yrs and 100yrs are considered and their discharges are accordingly taken from Log-Normal frequency analysis.

The simulation is performed and the file is exported again to ArcGIS for result visualization. In GIS, the post processing layer set up is performed. Finally, from the Ras Mapping, the inundation mapping is generated.

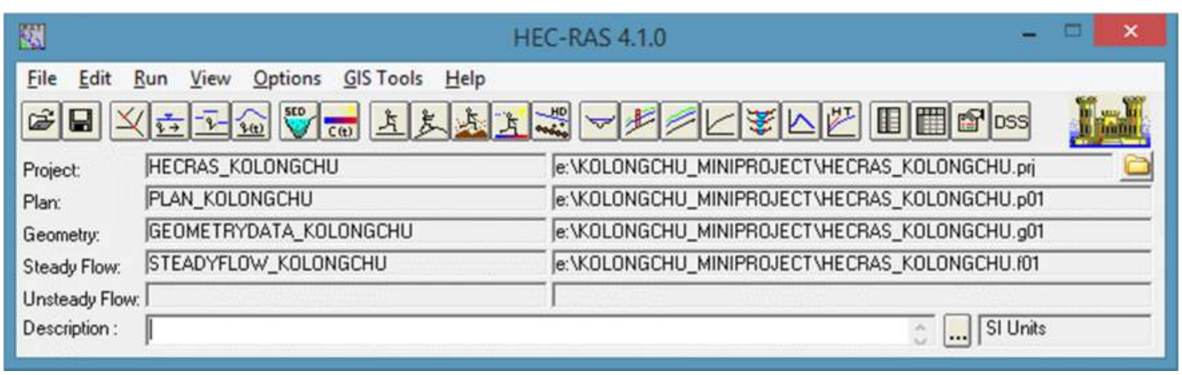


Figure 11. Main menu of HEC-RAS

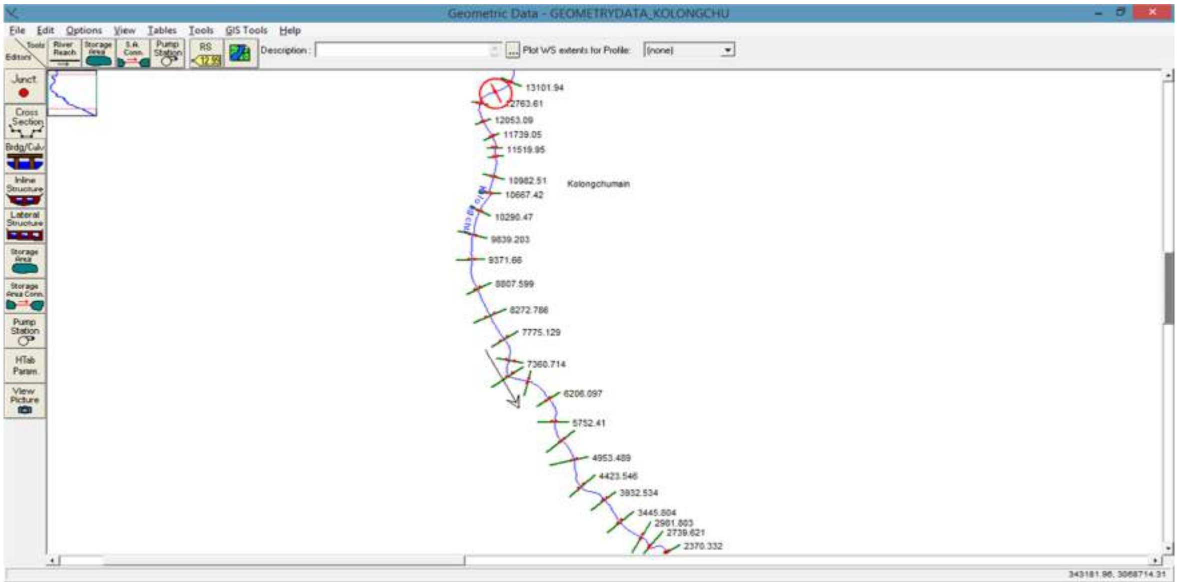


Figure 12. Geometric Data

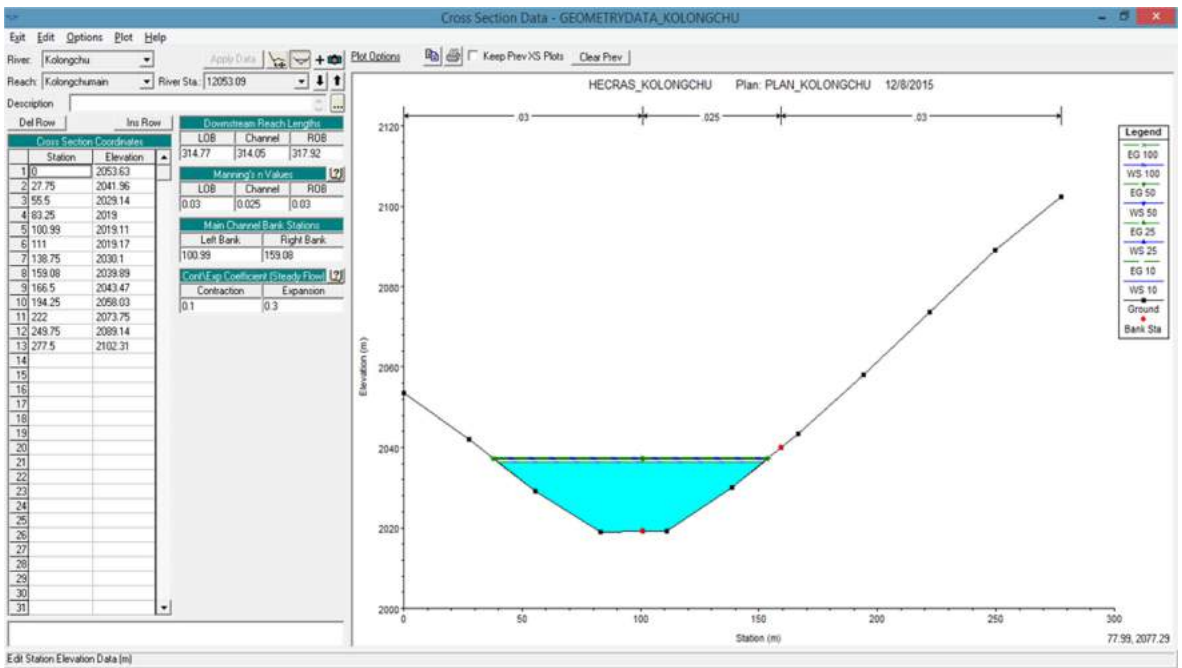


Figure 13. River Cross-Section

5.2 Emergency response phase

To process satellite image for deriving flood inundation map is showed in Figure 14. The flood inundation map from SAR data is prepared by processing the Pre and Post Flood images observed by the ALOS and ALOS-2 Satellite. For the mini-project, the SAR (Synthetic Aperture Radar) images were provided by JAXA. The SAR images are different from optical image. Unlike Optical images from sunlight, SAR images are from the reflection of microwaves beamed from an antenna of a satellite. The SAR images can be operated day and night and are not affected by the rainfall. However, the images requires knowledge and techniques to interpret.

For obtaining the Pre and Post flood images, the date or month of the flood event should be known. However, in case of this project, 4th August 2009 was the date during which a massive flood occurred in the Bumdelling plain. Accordingly, JAXA provided the images dated 30/07/2007, 01/08/2008, 04/08/2009 & 07/08/2010.

The images should be identified Pre and Post from the dates of acquisition considering the date of flood event. The images provided cannot be used directly for preparing the inundation map as it has to be processed depending on the level of the images (Level 1.1, Level 1.5, Level 2.1). Based on the different levels of the images, different types of software are used for processing.

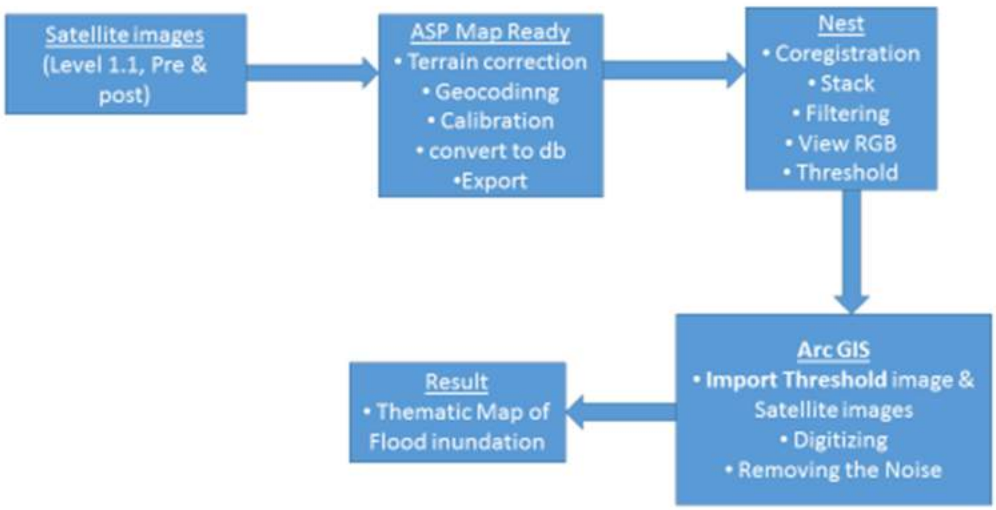


Figure 14. SAR Data Processing

The images for Kolongchu Floods were of the Level 1.1 and has to be processed and analyzed in all the software – ASP Map Ready, Nest and ArcGIS. The images are performed terrain correction, calibration, co-registration, staking, filtering and finally the thematic map of the flood inundation area is prepared in ArcGIS.

6. Results and discussions

6.1 Hydrological model

IFAS as hydrological model was used to simulate rainfall to be discharge as input of HEC-RAS as hydrodynamic modeling. The period of simulated modeling was from June to August in 2009 during rainy season in Bhutan. IFAS Model setup was completed using global data sets of land use and soil. Among various parameters, sensitive parameters were identified for the calibration process as figure

15. For the calibration process, 3 tank layer configuration was adopted. Moreover, ground-based rainfall data and satellite rainfall data as GSMaP and TRMM was inputted in the model.

The model result as Figure 16 could not be used to determine the calibrated discharge as there is only one rainfall station and that does not give good simulation. For initial parameters of model, ground-based and satellite rainfall data as GSMaP and TRMM, which are input of IFAS, were not good correlation between observed and simulated discharge that were less than 0.2 as Figure 17. Therefore, IFAS could not be used to determine the calibrated discharge.

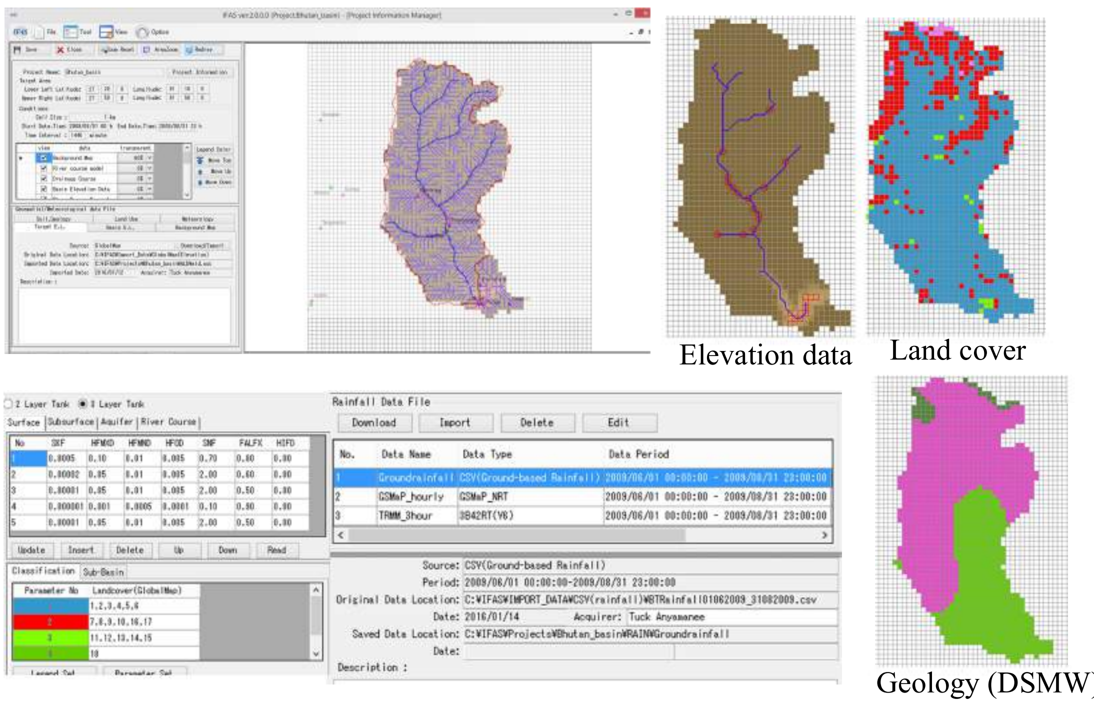


Figure 15. IFAS model set up of Bhutan

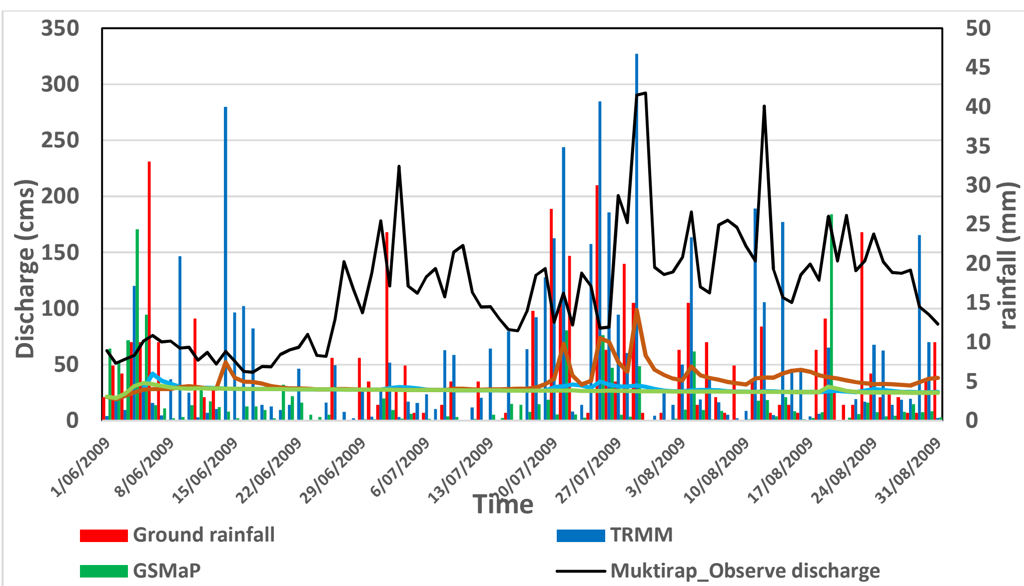


Figure 16. The model result of IFAS

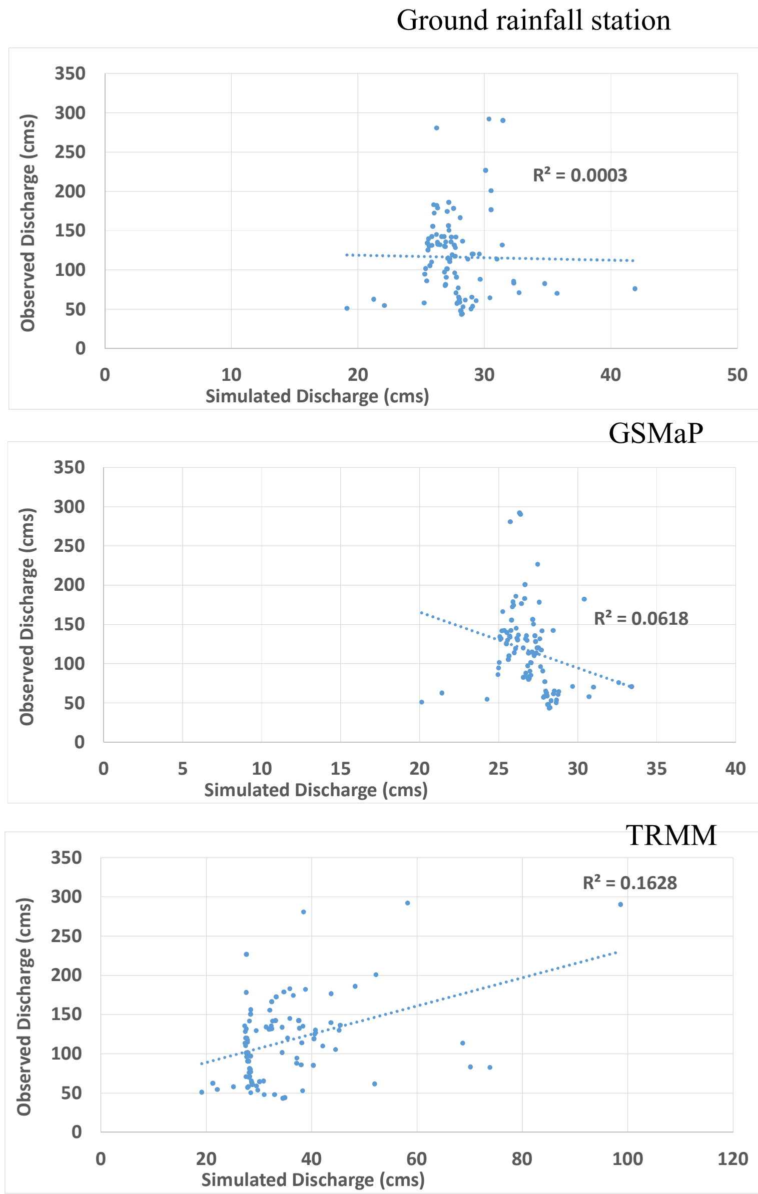


Figure 17. Comparison between observed and simulated discharge from satellite and ground rainfall data

6.2 Determination of discharge

For study, to generate flood hazard map there is only one discharge station at downstream of the study area. The study used the discharge data discharge station from of Muktriap discharge station. For flood frequency analysis, annual peak discharge from 14 years (2001-2014) was taken at Muktriap discharge station. The analysis are showed in Table 2 and Figure 18.

Table 2 Summary of Flood frequency analysis

Flood frequency analysis method	Peak Discharge for each return period (cms)						
	2 yrs	5 yrs	10 yrs	25 yrs	50 yrs	100 yrs	1000 yrs
LOG-PEARSON	424.72	566.27	641.56	719.85	768.42	810.18	846.53
LOG NORMAL	404.48	563.06	669.31	821.17	938.70	1008.67	1361.75
NORMAL	431.74	556.96	622.40	699.81	750.45	777.67	891.29
GUMBEL	407.31	538.74	625.76	735.71	817.27	898.24	1165.77

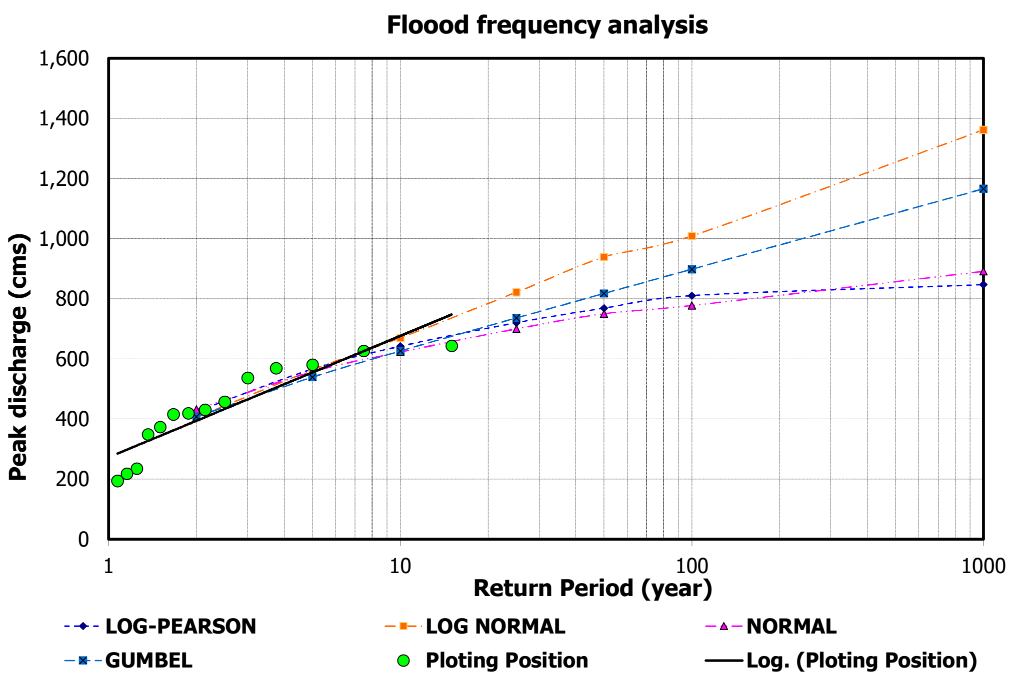


Figure 18. The comparison of four methods of flood frequency analysis and plotting position

According to the graph, the comparison of four methods of flood frequency analysis and plotting position found out that graph of Log-normal method followed the trend line of plotting position. Thus, this study chose the peak discharge from Log-normal method to be input of HEC-RAS.

However, the peak discharge from flood frequency analysis was downstream of river basin that could not directly represent the discharge of upstream. Therefore, the study identified the assumption for discharge of upstream by using double triangular unit hydrograph. Double triangular unit hydrograph was considered at 2 points which are the upstream of flood affected area and Muktriap discharge station. This method has to digitize new boundary of sub basin at considered point as figure 15. Also, this method created two unit hydrographs as figure 19. The result found that peak discharge of unit hydrograph at point 1 is 60% of peak discharge of unit hydrograph at point 2. Therefore, for this study, the assumption of discharge at upstream basin which input to HEC-RAS was 60% of discharge at Muktriap discharge station.

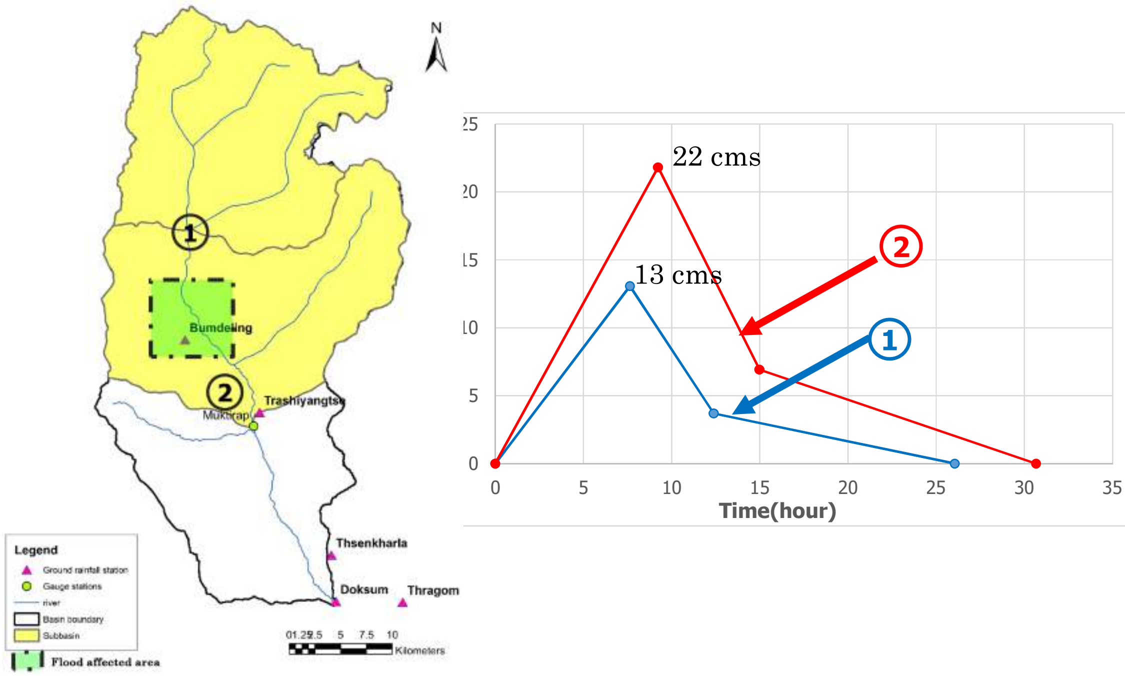


Figure 19. Unit hydrograph for considered point

Moreover, to determine unit hydrograph, time of concentration (T_c) of this study was identified at 3 point that is showed as Figure 20. T_c was calculated based on slope of river. The first point is point of data input in HEC- RAS. The second point is discharge station as Muktirap station. The third point is outlet of basin which T_c is 8.3 hours. This analysis also found that this study would have hourly meteorological stations because flood duration occurs few hours.

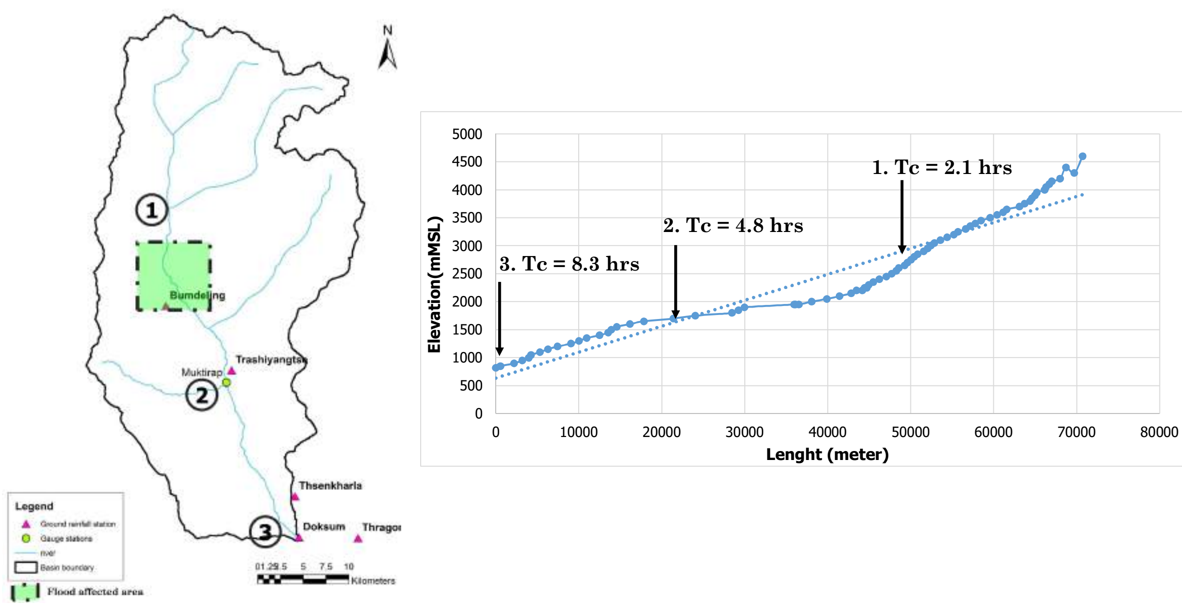


Figure 20. Time of concentration of the study area

6.3 Hydrodynamic model

After determining discharge as input in hydrodynamic modeling, HEC-RAS as hydrodynamic modeling was used to generate flood hazard map at flood affected area. The Flood hazard map for four different return period are prepared which shows the details on inundation area and depth at each point. The flood hazard map from the HEC-RAS flood modelling are as follow:

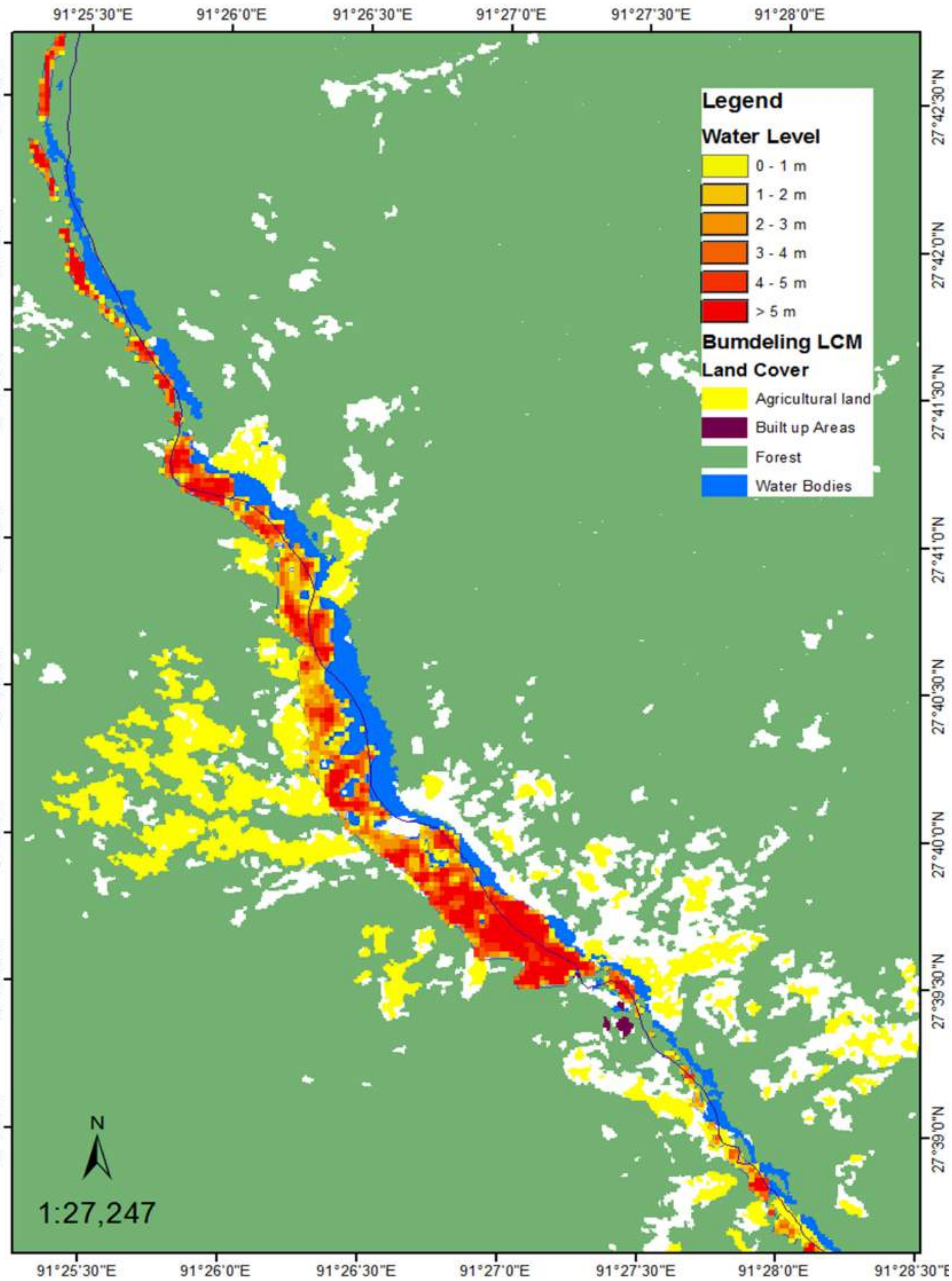


Figure 21. Flood Hazard Map (10yrs Return Period)

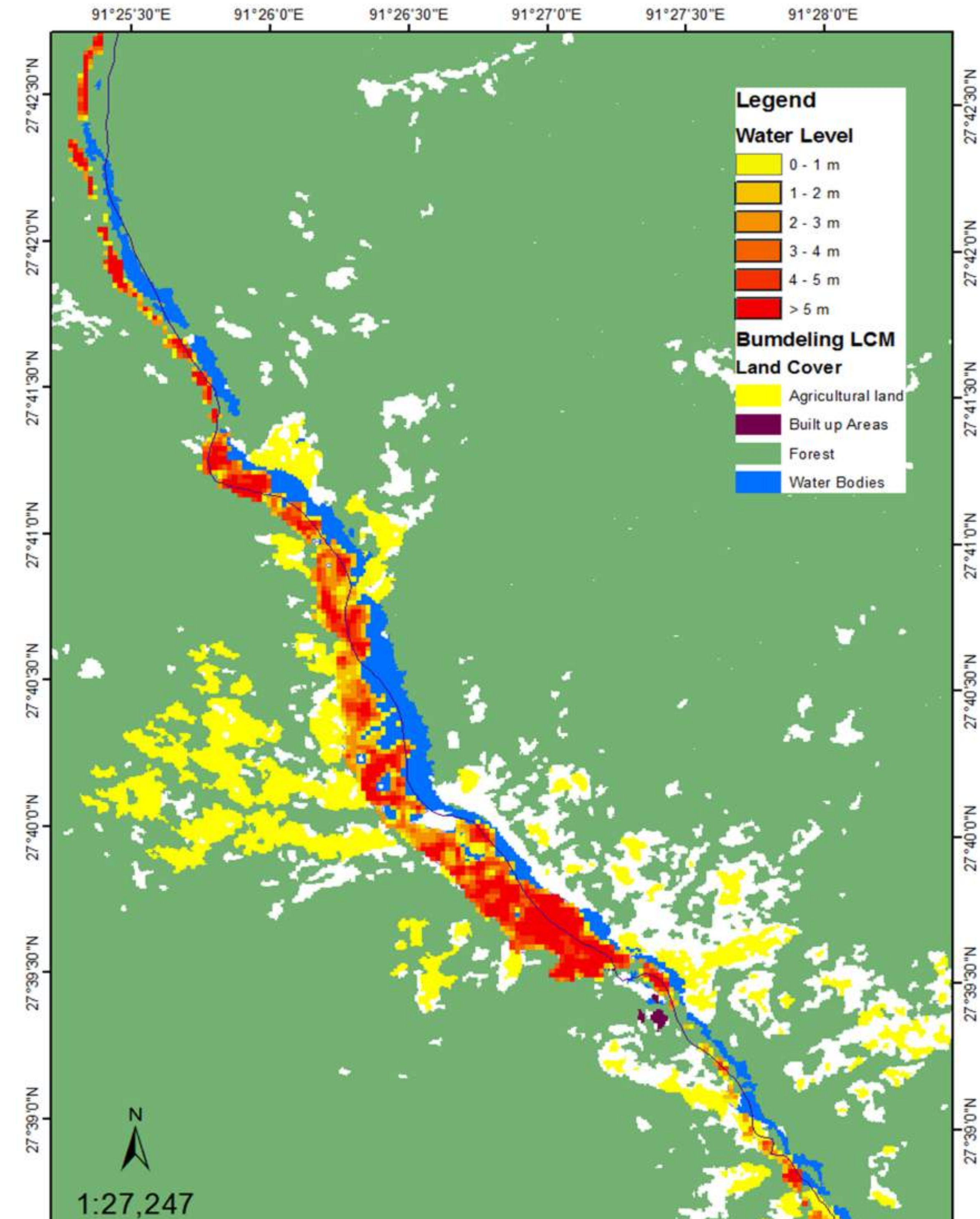


Figure 22. Flood Hazard Map (25yrs Return Period)

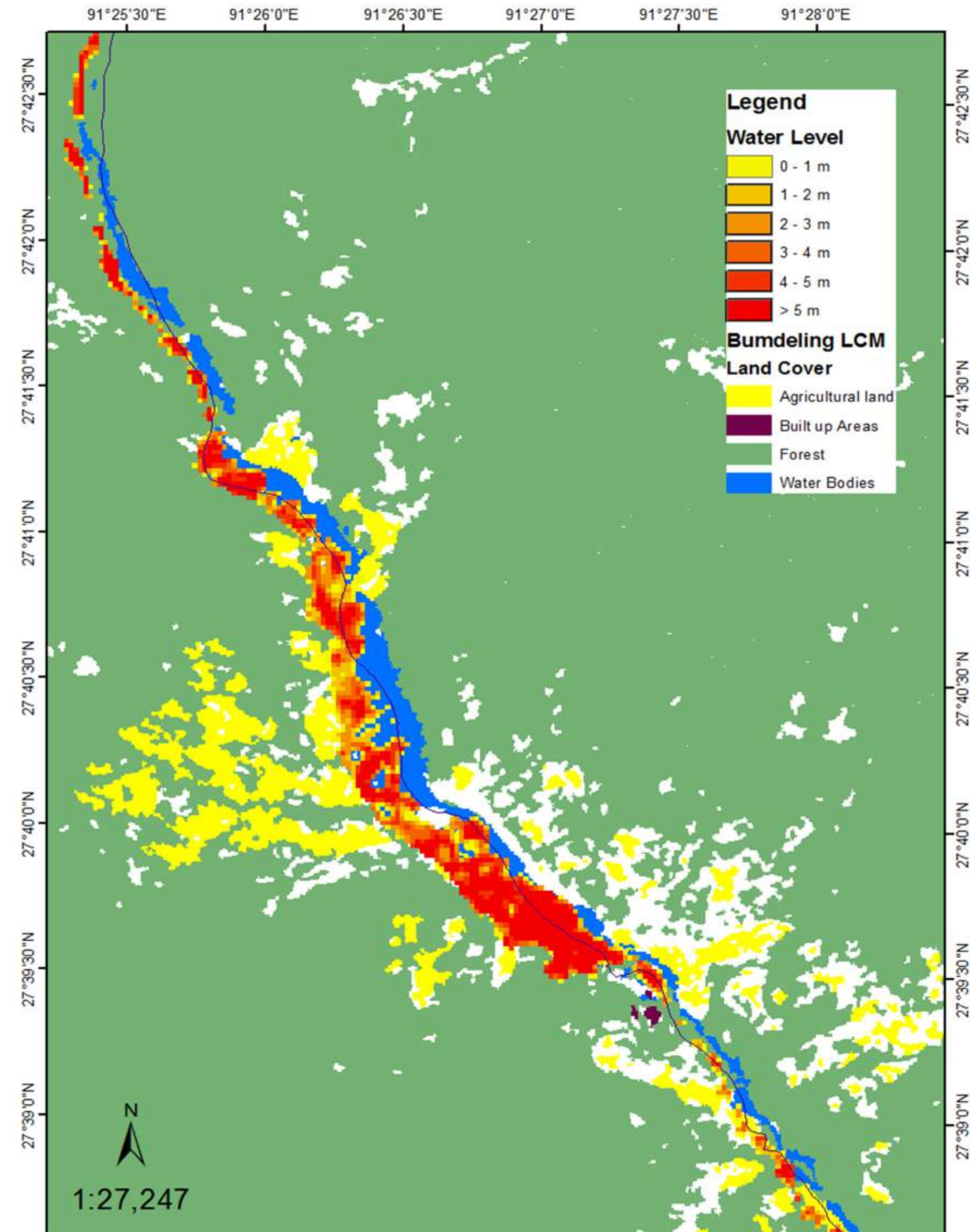


Figure 23. Flood Hazard Map (50yrs Return Period)

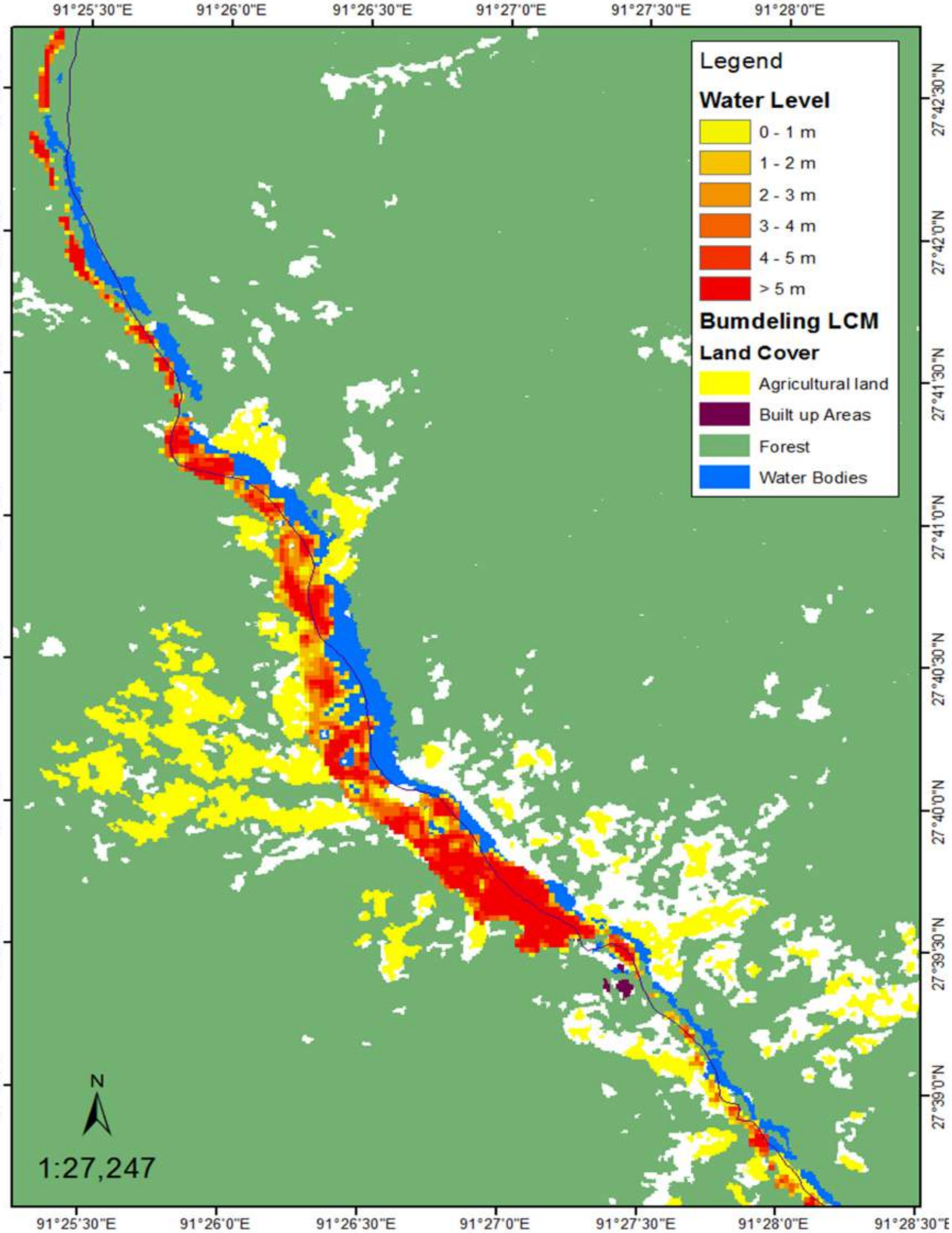


Figure 24. Flood Hazard Map (100yrs Return Period)

7. SAR Data Processing

Flood inundation area of the past flood event has been traced by processing the PRE and POST flood images in the software like NEST, MapReady, SNAP and QGIS. Images known as SAR images (Synthetic Aperture Radar) are contributed to the project by JAXA (Japan Aerospace and Exploration Agency) who is initiating and funding the project. The images are observed by ALOS and ALOS-2 satellites. The images from JAXA have different level according to which stages of processing and use of software are identified. However, exact date of the flood event in the past has to be given in order to obtain the images from JAXA. The flood inundation map from the SAR data processed are as follows:

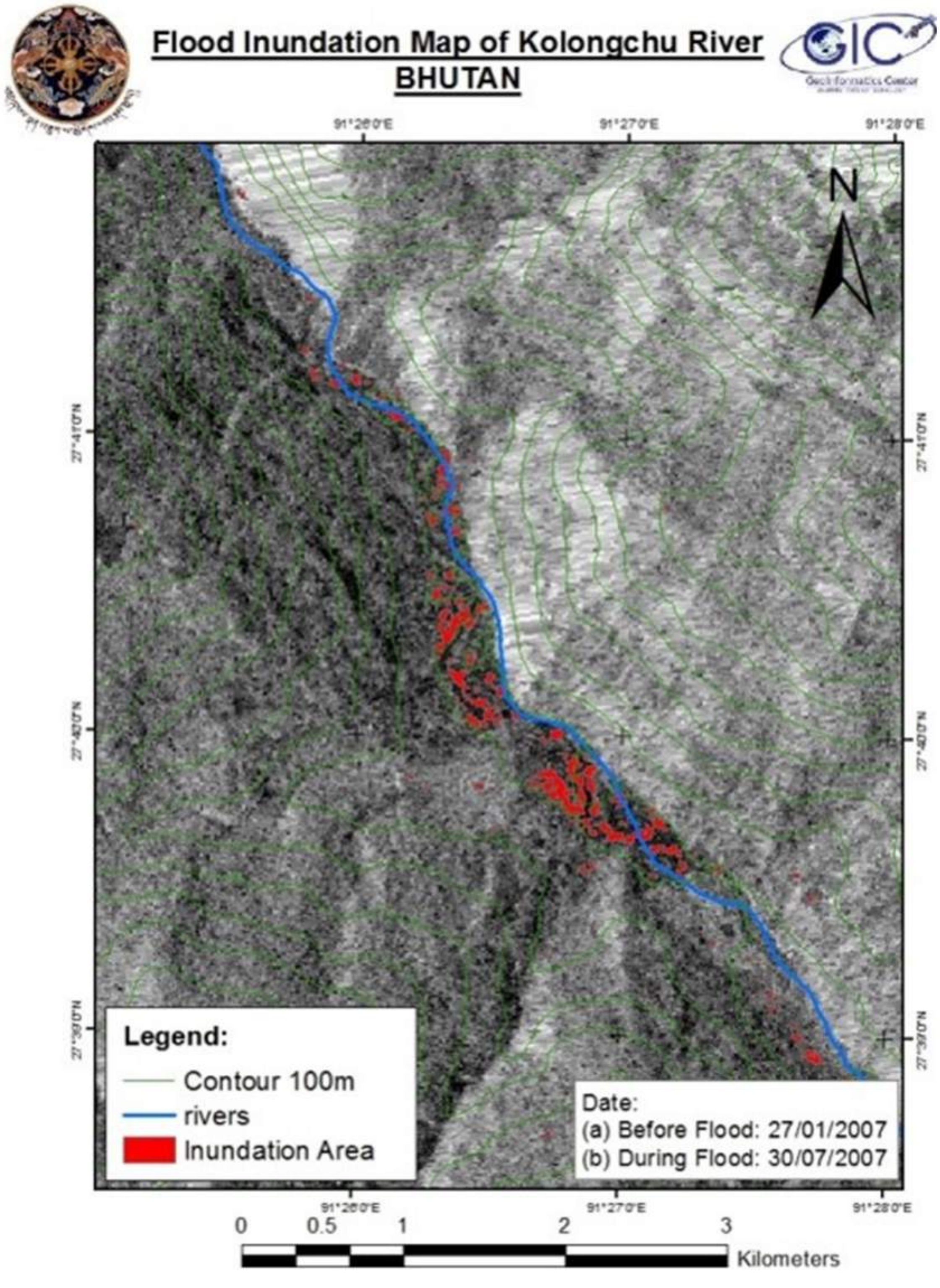


Figure 25. Flood Inundation Map for year 2007

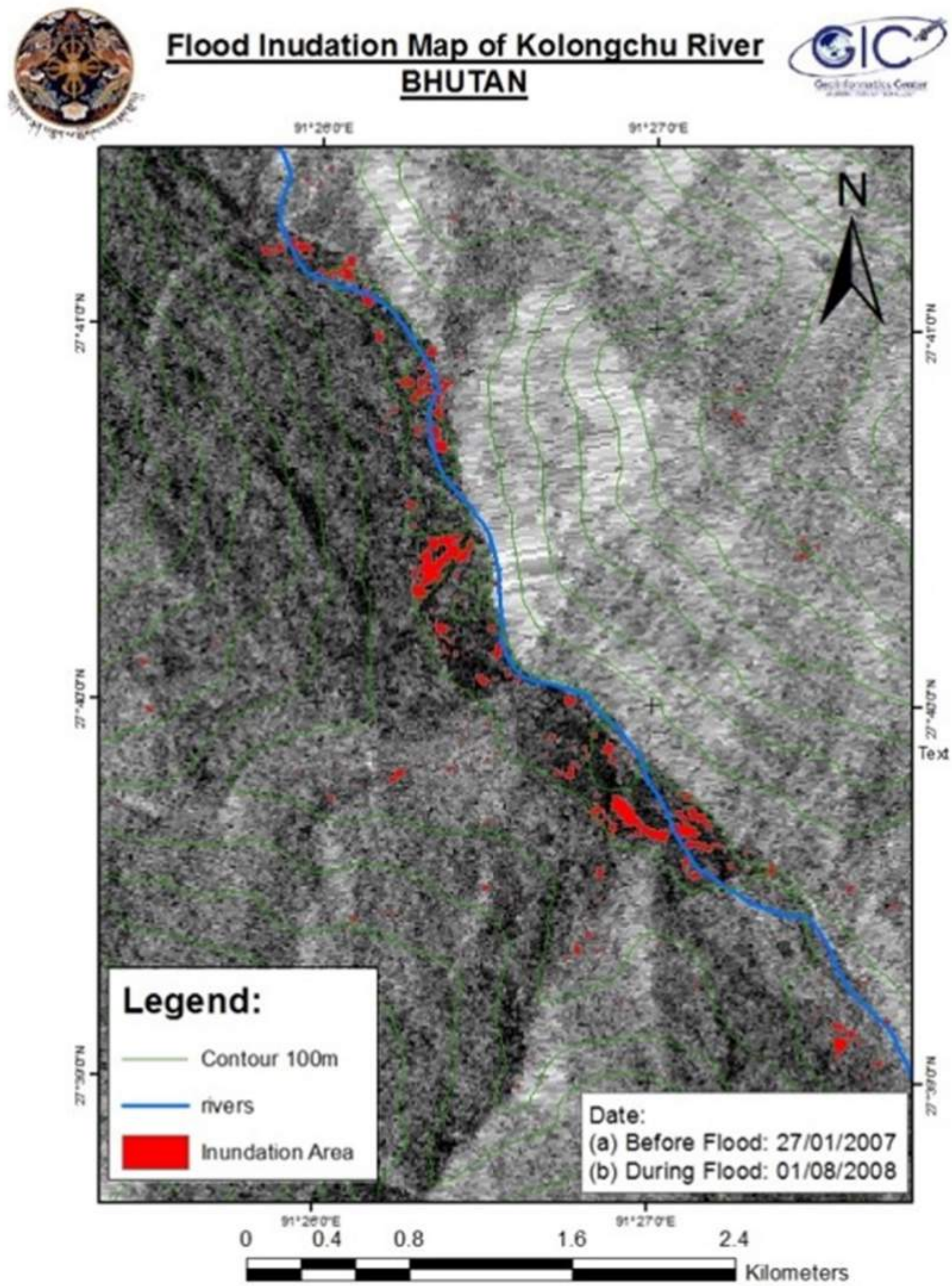


Figure 26. Flood Inundation Map for year 2008

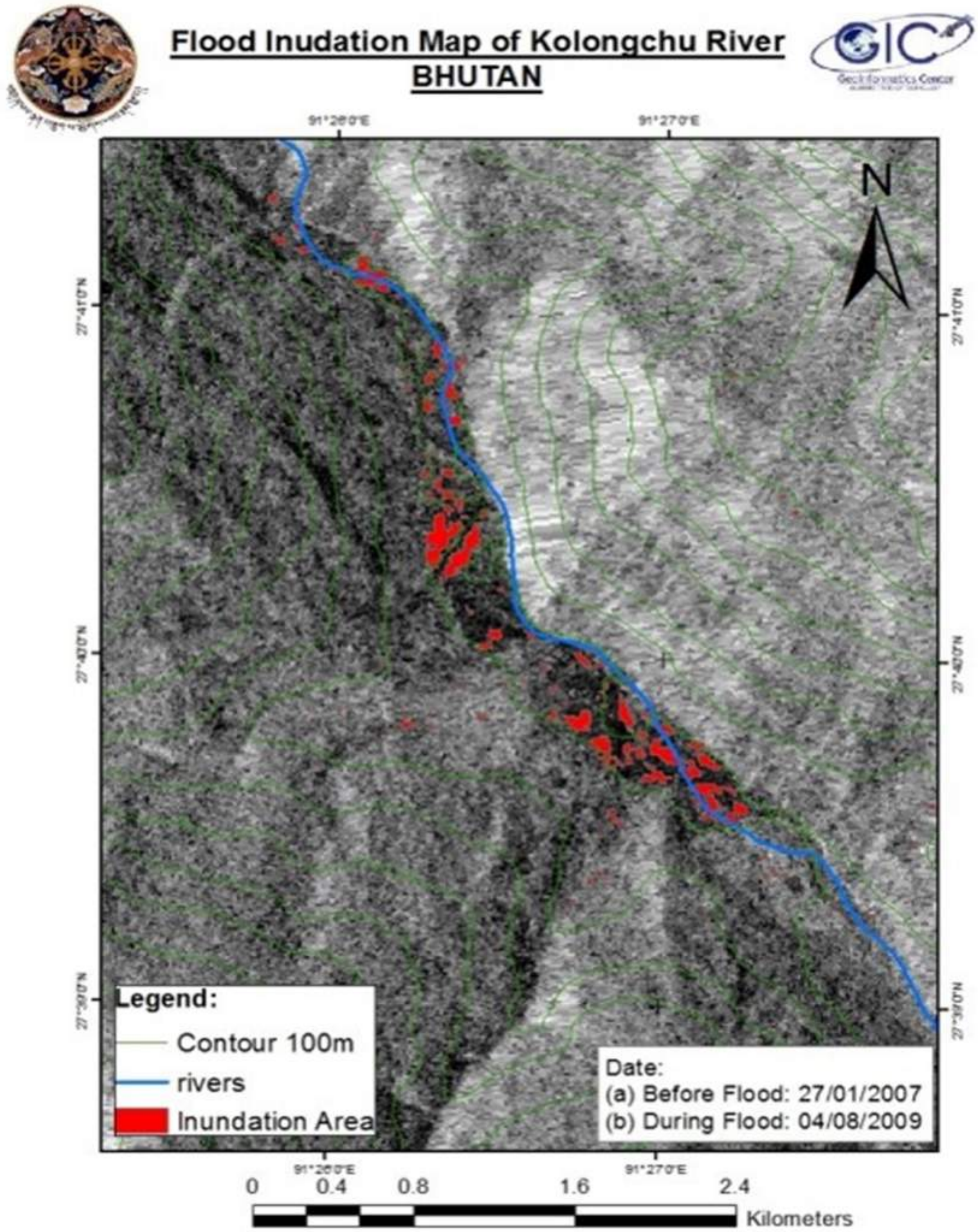


Figure 27. Flood Inundation Map for year 2009

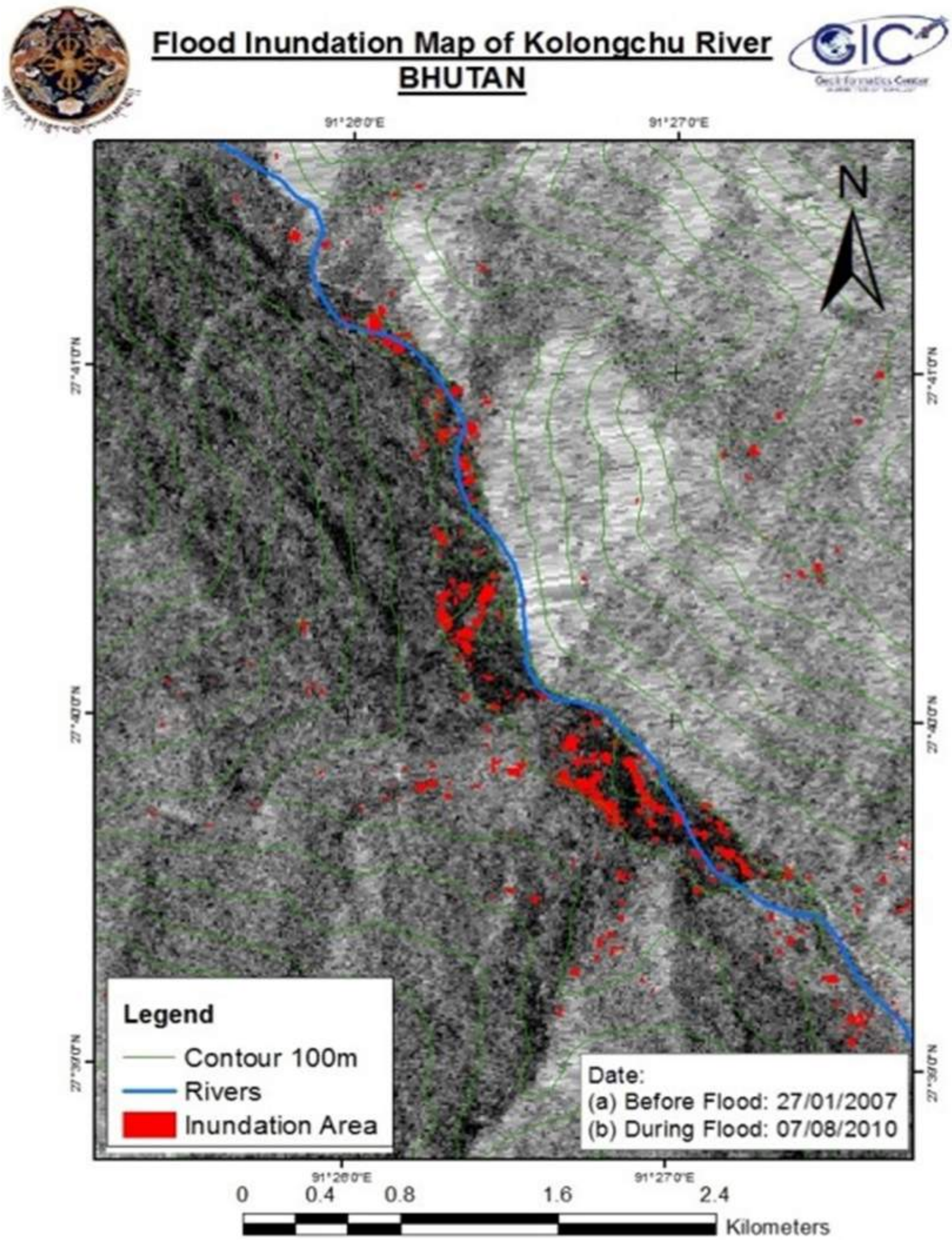


Figure 28. Flood Inundation Map for year 2010

8. Results

The result of the study as following:

- The Flood Hazard Map for Four different Return Period (10yrs, 25yrs, 50yrs, and 100yrs) has been prepared from the HEC-RAS flood modelling.
- The extent and the depth of the flood various in all the return periods.
- The inundation map for the study area has also been prepared after processing the different SAR Images.
- Both inundation and hazard map shows the same area inundated during the flood.
- SAR data processed method to produce the inundation map would be more reliable and convenient as often the lack of discharges due to ungauged basins and other data are faced in the HEC-RAS Modelling.

After generating flood hazard and inundation map from flood modeling and satellite image, the result overlaid with land use of the study to identify the area which are affected by flood. Thus, the study found that the flood area affected as table 3.

Table 3 the area affected by flood.

Types of Land	Area (Acres)
Chuzhing (Wetland)	39.934
Kamzhing (Dryland)	10.702
Built up Areas	0.158
Broad Leaved Forest	162.982
Mixed Conifer Forests	0.205
Meadows	1.269
Shrubs	42.575
Rivers	153.516

9. Conclusion.

The mini-project has been a great learning to the engineers from Flood Engineering and Management Division. The Phase II of the mini-project conducted at Geoinformatics Centre in Asian Institute of Technology has opened our eyes to many new ideas and methodologies to address the flood disaster. The preparation of Flood Hazard Map and Flood Inundation Map through hydrodynamic modelling and Satellite based data are very useful in placing the mitigation structures. However, it is also understood that for the preparation of flood hazard maps, primary data like rainfall and discharge are the most important which has been one of the limitation of the project. Most river basin in Bhutan has only one to two gauging stations and meteorological stations. The mini-project couldn't use IFAS because there were no rainfall stations at the catchment area of the flood plain in Bumdelling. There was one station at the downstream of the floodplain and that does not give good simulation result. Hence, the hazard map has to be taken using the discharge from the unit hydrograph in the HEC RAS. The peak discharge for different return period has been calculated using flood frequency method.

The flood inundation mapping using the SAR data was a new and exciting tool to predict and conduct the damage assessment after the flood. In general, the hazard maps prepared would help the decision makers and engineers in carrying out the mitigation works as well as determine evacuation route during the disaster. The flood monitoring and prediction can be made much easier if the satellite based inundation map is integrated in the validation of the hazard maps prepared from the hydrological and hydrodynamic software.

10. Recommendation

The recommendation of the result of the study as follows:

- There is a need to install a number of hydrological stations along the river basins in the country for flood modelling and flood hazard map.
- More than one number of meteorological stations should be installed in an area as rainfall varies from a place to another.
- Rainfall reading on hourly basis should be taken as the flood duration in our country is normally 6 to 7 hours.
- Hazard maps should be encouraged for all kinds of disaster as it would help the decision makers and engineers in carrying out the mitigation works, evacuation during the disaster and conducting damage assessment.
- The flood monitoring and prediction can be made much easier if the satellite based inundation map is integrated in the validation of the hazard maps prepared from the hydrological and hydrodynamic software.

11. Reference

Fukami, K., Sugiura, T., Magome, J. & Kawakami, T. 2009. Integrated Flood Analysis System (IFAS Version 1.2) User's Manual . Jepang: ICHARM.

Chow, V.T., Maidment, D. and Mays, L. (1988). Applied Hydrology

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