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Mapping Flood Risk Buildings

Using QGIS and HEC-RAS

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This thesis is a comprehensive study of 2D hydrodynamic flood modelling of Koshi river situated in Eastern territory of Nepal. In 2008 August Koshi levee breach caused a devastating flood event that affected millions of people from Nepal and India. Every year Koshi causes significant impact to the people and infrastructure in the catchment area. Thus, this thesis Studies a small portion of Koshi catchment area and establishes the flood inundation scenario in case of levee breached in its peak flow. The output of the study demonstrated the probable number of buildings in risk in the case of flooding. As for the occurrence of flooding, it was assumed that in peak discharge condition the levee on the eastern side would be breached in a point. This thesis also included a brief description of data preparation techniques and the required tools. Flow rate data from gauge station, building's data from Arial imagery and OpenStreetMap, DEM data form JAXA and HydroSHEDS were used to meet the objective.

Keywords	flood, hydrodynamic modeling, QGIS, JOSM, HEC-RAS, Mannings equation, DEM, iundation,Koshi

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ABBREVIATIONS

2D	Two-Dimensional
HEC-RAS	Hydrological Engineering Centre-River Analysis System
GIS	Geographical Information System
DEM	Digital Elevation Model
QGIS	Quantum Geographic Information System
OSM	OpenStreet Map
JOSM	Java OpenStreet Map
VDC	Village Development Committee
GDAL	Geospatial Data Abstraction Library
HydroSHEDS	Hydrological data and map based on Shuttle Elevation Derivatives at Multiple Scales

s

1 Introduction

Monsoon flooding have become an inevitable disaster in most of the South Asian countries. Millions of people are affected by the flood hazard every year. According to the report of (UNSIDR, 2015) in 20 years (1995-2015) 47% of the weather-related disasters were caused by flooding. Total number of affected people reached 2.3 billion, out of which 95% of victims live in Asia (Fgure1).

In general definition, flood means over flow of water from its source such as lake, reservoir, river and ocean due to high precipitation or severe melting of snow. Inundation extent occurs when accumulation of significant amount of rain water covers the land surface (Yen Yi Loo, 2015). Rising temperature and corresponding precipitation are major drivers of hydrological hazards.(Ntajal, Lamptey, & MianikpoSogbedji, 2016).

Scientist claim that severe rainfall during monsoon and flood wrath are some strong indications of climate change. According to IPCC(Cruz et al., 2007), Asia is more likely to suffer from rainfall intensity basically during summer monsoon, glacial melting due to temperature rise, which could result in severe flood conditions.

Most of the flood risk can be prevented and minimized by assessment of flood risk. There are still a substantial number of catchment areas to study and to map the risk associated with them, meaning that a significant number of vulnerable region exists, and nobody knows how large the risk is. The only way to reduce the risk is to study and get informed about it before it really occurs.

There are many case studies on levee breach, flood inundation modelling and its accuracy. The study made by (Gharbi, Soualmia, Dartus, & Masbernat, 2016) compares the benefit and limitations of 1D and 2D flood model. In the study, HECRAS and MIKE 11 software are used to perform the 1D flood model, and TELEMAC is used to compute the 2D model. The result suggests 2D model more accurate over 1D. On other hand 1D model is useful for long river where small error is negligible. Some studies are based on comparison of error and accuracy of the modelling tools.

The study by (Nanshan Zheng and Kaoru Takara, n.d.) presents the flood inundation model using rainfall runoff process for large area using DEM and remote sensing data sets in GIS platform. The model is made for the Maruyama River basin, Japan, and the study claims the consistency of the result is 75%.

Out of several methods of mapping inundation extent, the most trivial, agreed and economical method is to integrate the flood elevation data in various location (Younghun Jung, 2014).This thesis is a comprehensive study of the area which have substantial probability of exposure to the flood hazard. It establishes a flood risk map of small portion of Koshi catchment area. The final output of the study consists of number of vulnerable building and agricultural area in digital topographic layer.

Main purpose of the Thesis was 1) to gain greater understanding of the GIS related Tools.
2) to demonstrate flood extent using 2D hydrodynamic modelling in HEC-RAS 5.0.3, and
3)to estimate the number flood vulnerable buildings.

The aim was to map the possible flood inundation area in a simplified perspective, which could visualize the vulnerable buffer area. To obtain the objective, open source data and open source software were used.

This thesis consists of 7- chapter, chapter 1 introduces flood risk, flooding scenario and objective of the study. Chapter 2 describes the flood history and its impact in Asia and Nepal. Chapter 3 presents the methods that describes the introduction of hydrodynamic modelling, depth and velocity calculation form Manning's equation and a brief workflow chart. Similarly, chapters 4 and 5 explain the detail process of data preparation modelling and the tools used to meet the objective of the thesis. Chapter 6 depicts the 2D model of the flood extent, and finally, chapter 7 and 8 consist the discussion and conclusions, respectively.

2 Background

2.1 Flood scenario In Asia

In the year 2013 flood disaster accounted for almost 44 % of the world's natural disasters, and Asia was the worst affected region in the globe. More than 4 thousand lives and the highest economic loss of 2.6billion were faced by the continent in 2014 (floodlist.com, 2014). In 2011 flood toll reached 1,302 in southeast Asian countries Thailand, Cambodia, Vietnam, Laos, and Philippines where Thailand and Philippines lost highest number of people,567 and 102, respectively. India faced the death of 15 people with 1.7 million affected due to flood in 2016 (IFRC, 2016).

Similarly, in 2008 Koshi flood affected more than 1.4 million destroying about 200 thousand houses of Nepal and India (UNICEF, 2008).Recently in the year 2017 monsoon flood toll exceeded 800 affecting more than 24 million in Nepal, India and Bangladesh (The Guardian, 2017).

Figure 1: depicts south East Asia is the most vulnerable regarding Flood mortality risk (Global risk data platform, 2017).

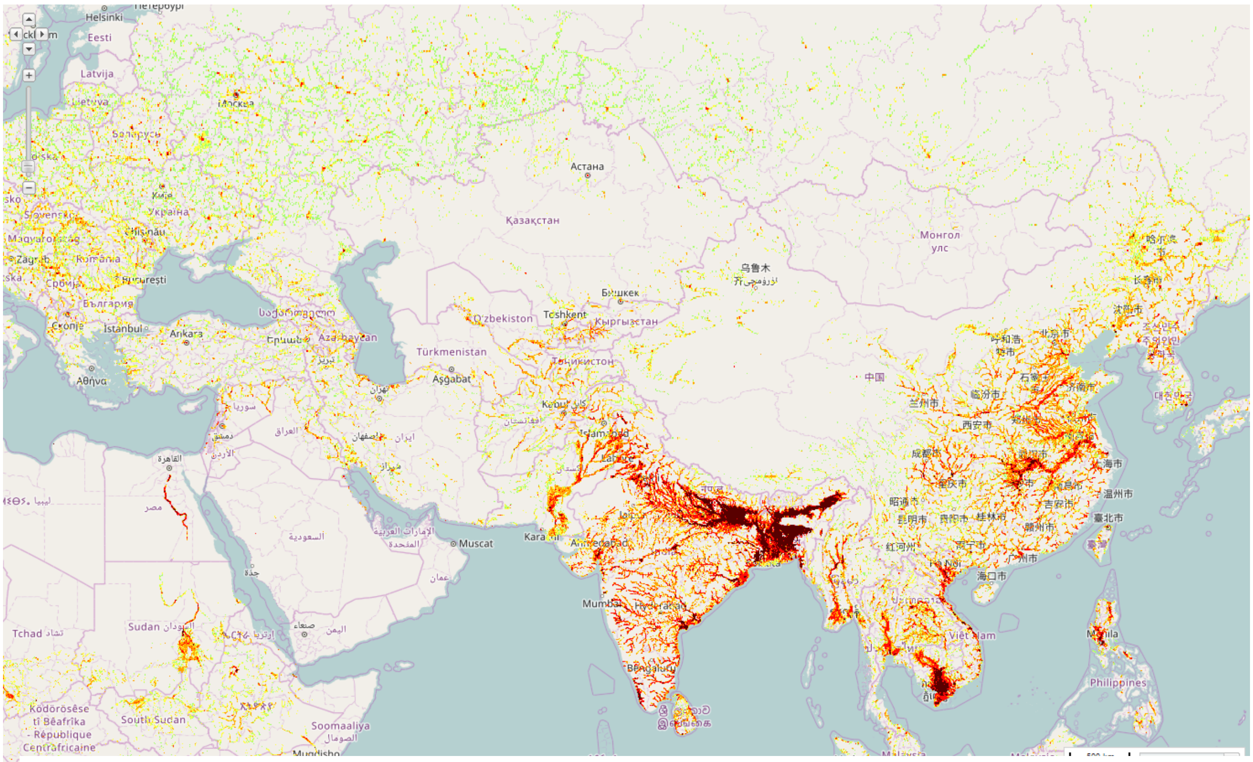

Figure 1:. Annual global flood Mortality risk map

2.2 Flood scenario In Nepal

Situated in South Asia, Nepal is one of the most vulnerable countries for flood related natural disasters due to significant variation of elevation and typical geography.

In 1978 intense rainfall of 125 mm for few hours caused the huge flood in Tinau river destructing the bridge along East-West Highway. It also damaged the huge number of infrastructure, irrigation projects. In 1993 a flood in central Nepal killed 1,336 people destructed sixty thousand hectare of agricultural land and 67 irrigation systems. (Adhikari, 2013).

In 2008 Koshi eastern embankment breached with 90% of water flowing through the 7 VDCs (village development communities) of Sunsari district of Nepal. Koshi flood took 270 lives and about 6,500 people of Nepal were affected. All Together 11,783 houses were damaged. Agricultural land was covered with a thick layer of sand. Most of the flood covered area are deserted till now. All together 4,800 hectares of land were destroyed with total 16,800 Mt crop loss(Nepal Goverment, 2009).In the same year several parts of Far-Wstern region experienced flooding inundating the adjacent agricultural land, roads, transmission line and in fracture(Adhikari, 2013). Figure2 demonstrate the flood disasters in Nepal from year 2008 to 2015.

Table 1: Flood loss data from the year 2008-2016. (Nepal, 2013, 2015; Nepal Government, 2009).

<table>
<tr><th>SN</th><th>Year</th><th>People (Death)</th><th>Family affected</th><th>Number of house destroyed</th></tr>
<tr><td>1</td><td>2008</td><td>429</td><td>65000</td><td>-</td></tr>
<tr><td>2</td><td>2012</td><td>52</td><td>104</td><td>-</td></tr>
<tr><td>3</td><td>2013</td><td>132</td><td>-</td><td>-</td></tr>
<tr><td>4</td><td>2014</td><td>202</td><td>36949</td><td>10,193</td></tr>
<tr><td>5</td><td>2015</td><td>248</td><td rowspan="2">36949</td><td rowspan="2">26,756</td></tr>
<tr><td>6</td><td>2016</td><td>149</td></tr>
</table>

According to the report of IFRC (2016) Nepal suffered from early monsoon rain which brought floods and landslide in 25 districts. At least 65 lives were taken by the disaster and 5600 people were displaced from their homes. The 2017 monsoon flood severely breached roads, bridges, buildings and airports. Until 13 September 2017, 24 districts out of 75 are badly impacted by flood.160 people lost their lives and 43,000 people faced their house destroyed(UN RC, 2017).

Figure 2:Flooding in the Biratnagar Airport runway 2017

2.3 Flood risk assessment

For easy understanding, risk means probability of danger (hazard). In the same way, flood risk means potential danger from flood. According to the European commission, “food risk” is the combination of flood event and its potential adverse consequences to the living beings, infrastructure and surrounding environment.

A complete flood risk analysis covers the detailed study of the possibility of damage, its frequency, associated consequences and suggests the mitigation method to prevent the risk. It estimates the worst-case scenario of life, ecology, infrastructure, cultural, social and psychological aspect. Generally, a complete flood risk assessment consists of three major parts: first, what can possibly would go wrong; second, how frequently it will occur; and thirdly, if it occurs what the likely outcomes are. (Thieken & Merz, 2006).

2.4 Study area

Koshi is one of the 3 biggest rivers draining the eastern part of Nepal. Its total length is 225 km, and its drainage area is 87,311 km^2 before it reaches to Ganges river of India. Its major tributaries, the Sunkoshi, the Arun and the Tamor travel from the glaciers in Tibet and meet the Koshi Confluence in15 km before the feet of the hills. Number of small rivers and tributaries contributes tremendous amount of water for levee breach and monsoon flooding. Capricious and devastating nature of Koshi River starts form the foot of the hill all the way down till it mixes with Ganges Bihar India. (chinnasamy, et al., 2015).

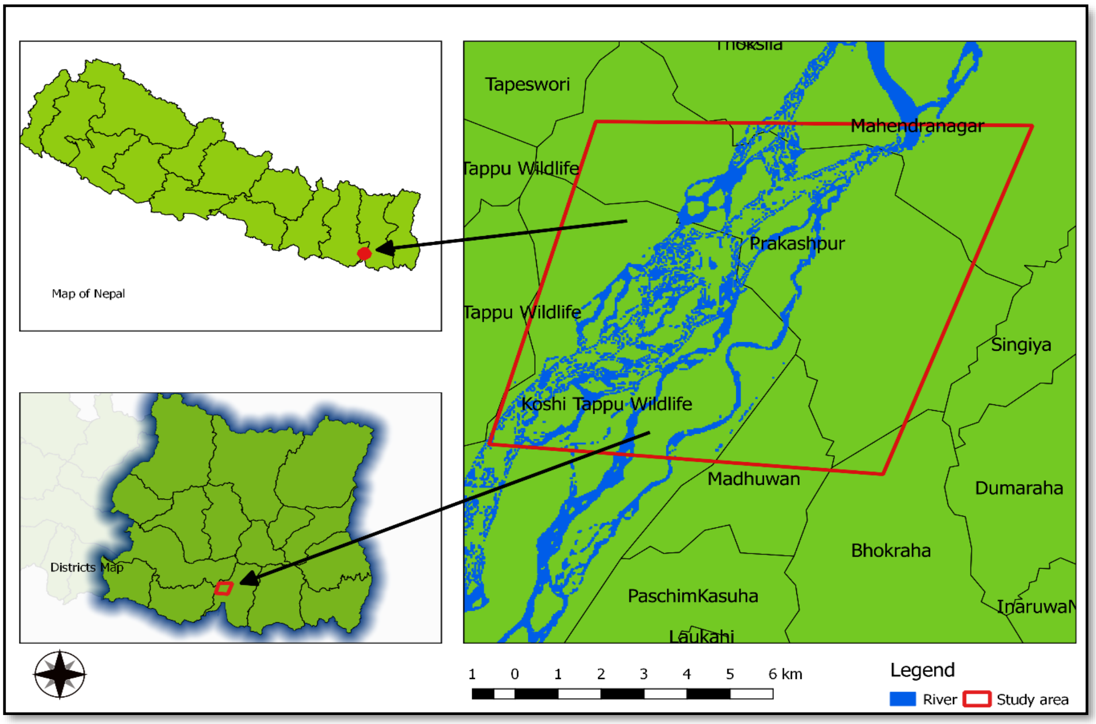

Figure 3: Study area created in QGIS

The study area is in Sunsari district eastern development region of Nepal. It covers certain portion of Koshi tapu (Koshi island) wild life reserve, huge part of Prakashpur Village Development Committee (VDC) and small part of other 2 VDCS namely Madhuwan and Mahendranagar. The study area Covers 82 Km ^{2} rectangular boundary. Study area consist of 3456 Houses. The Vector data of the house is obtained from the OpenStreetMap(OSM) which was digitized manually. The process how the houses of study area was digitized and uploaded in the OpenStreet Map has been explained in Chapter 5.

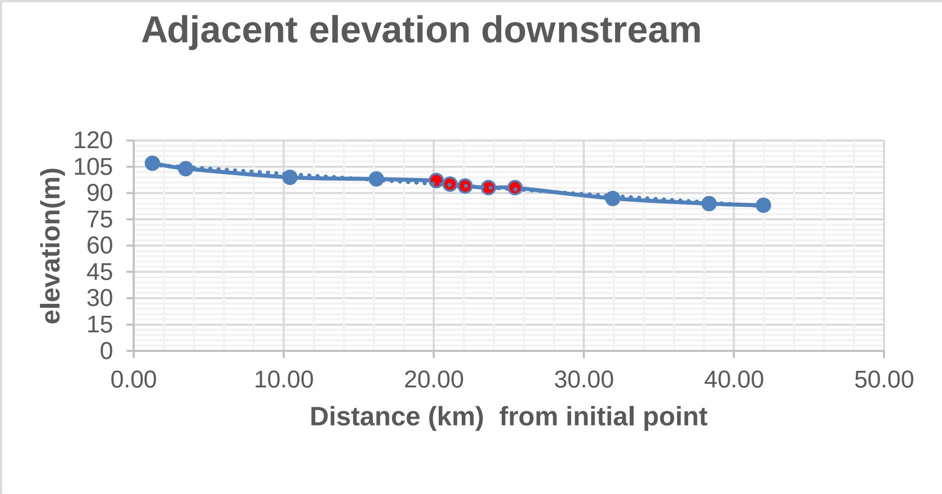

Figure 4:Downstream elevation of Koshi river

Figure 4 is the downstream elevation of the river from the gauge station (Chatara Kothu). The 4 red dots on the lines indicates the study area points. The cross sections and bathymetry of the study area is shown in (Figure 5: red line graph on the right side of the figure represents the bathymetry of the river. River bathymetry was generated in via 'profile tool' plugin in QGIS. Similarly, the line left side indicates the cross-section vector. Google Earth was used as base river layer and the cross-section polygon layer was constructed with toggle editor option in QGIS.

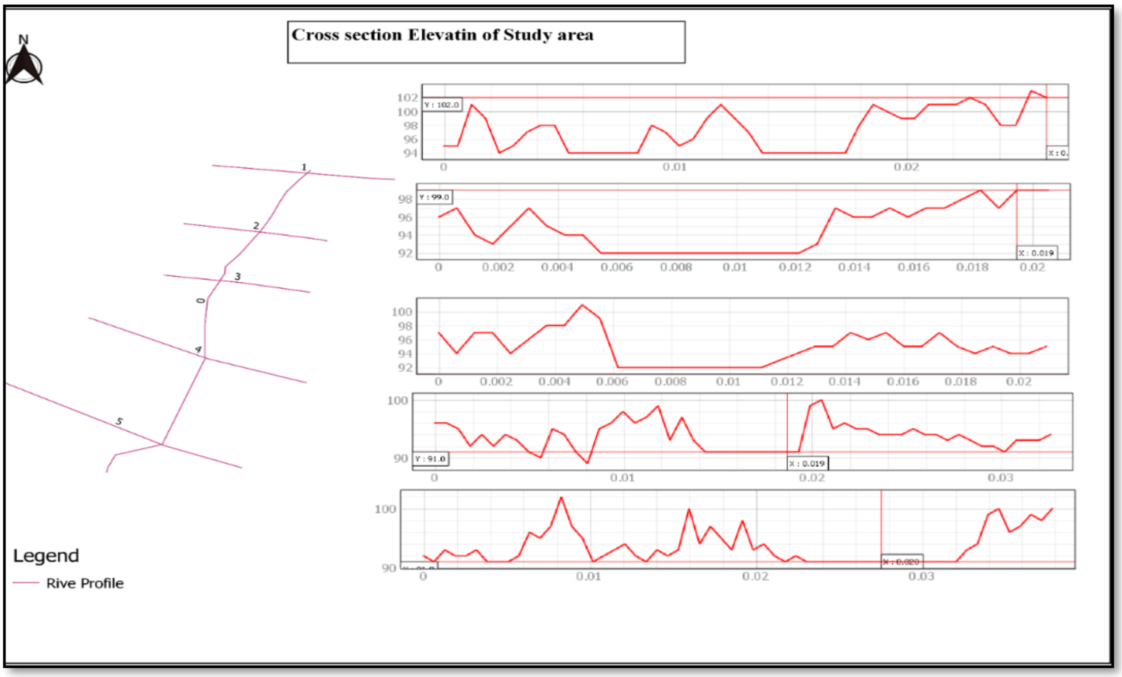

Figure 5: River: Cross-section in 5 different point in study area

3 Methods

3.1 Workflow chart

Figure 6 portrays the summary of the procedure followed to achieve the objective of the study.

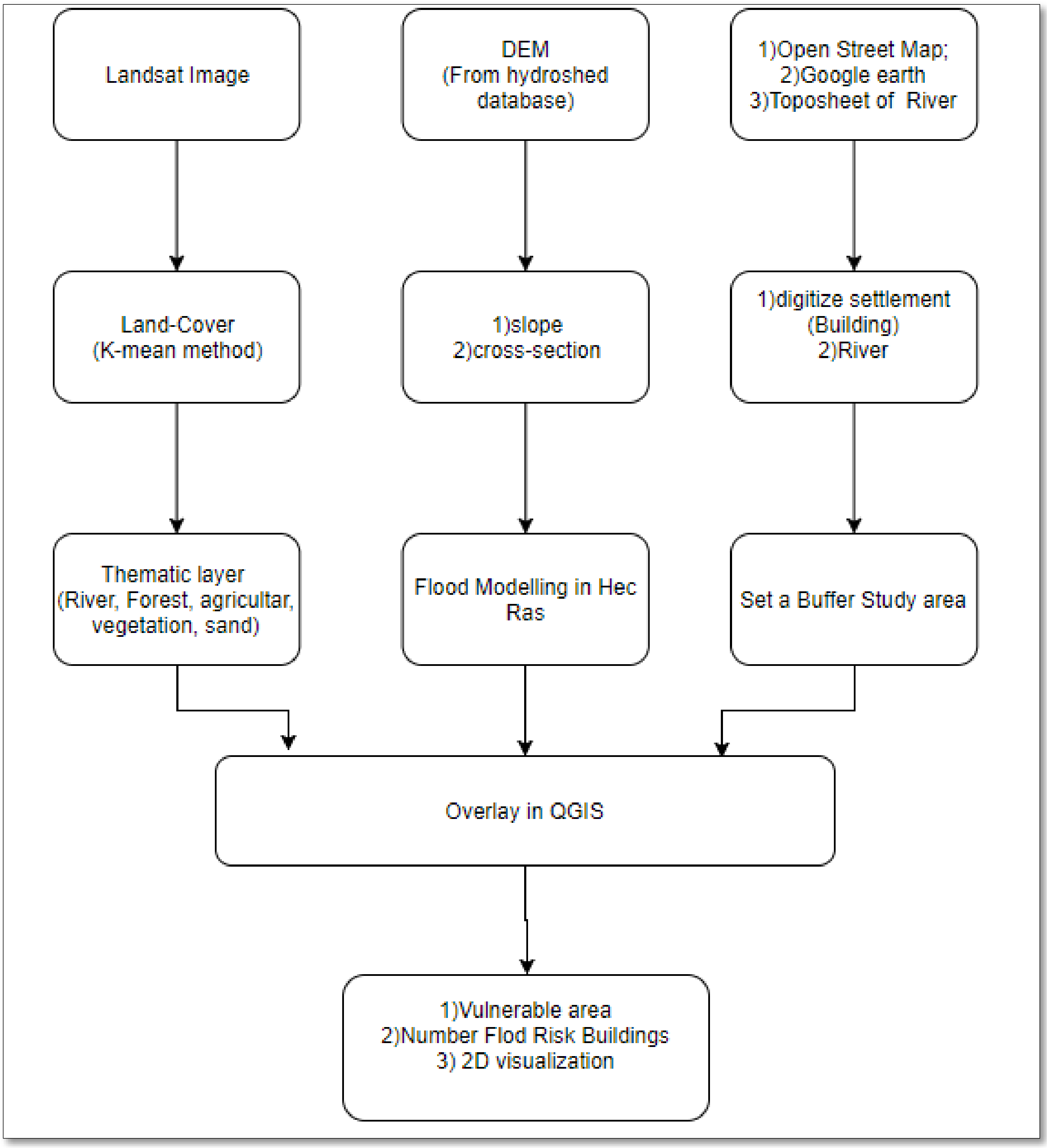

Figure 6: Work flow process

3.2 Hydrodynamic modelling

Hydrodynamic modelling is the mechanism which portrays the behaviour of water. Hydrodynamic model is a computational tool made from set of equation (Naiver-stokes equations) that relates the conservation of momentum and mass (newtons second law) in the water. With the development of computational power hydrodynamic modelling has wide range of applications such as in marine forecast ecology, flood inundation modelling, and so on (NOAA, n.d.) .

Hydrodynamic modelling mechanism has become popular to predict and provide the information to prevent and reduce the risk of worst flood inundation scenario. 1D,2D and 3D hydrodynamic modelling as well as one and half D hydrodynamic modelling are in use.1D and 2D hydrodynamic modelling are widely chosen methods. Recently the 2D model has become more popular as it can generate depth and velocity of the water column in the space. (Chen, 2007)

The 2D model is considered as more accurate than 1D model. The 1D model can only computes one dimensional result. For instance, 1D computes only the depth, but 2D model can compute water depth and its velocity at each calculation point in specific simulation time (Gharbi et al., 2016).

3.3 Depth and velocity calculation

Velocity is one of the governing elements in direction and flow variation of downstream. In this thesis, Manning's equation was used for mathematical calculation of river. The river was considered as a half-filled rectangular channel also termed as open channel. Since the nearest gauge station from the study area was 20 km up stream. To calculate the normal depth of the study area, the gauge station's value had to be transferred to the study area.

To avoid random error, the study area during calculation was considered as ideal rectangular channel where infiltration, evaporation and local accumulation down from the gauge station was not taken into consideration.
In this part, depth and velocity of 5 different places of the study area was calculated using Manning's equation.

$$V = \frac{Q}{A} = \frac{k}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} = \frac{k}{n} A R^{\frac{2}{3}} S^{\frac{1}{2}} \quad , \qquad 1$$

where

V = mean velocity (m/s)

k = 1.00 for SI units

n = Manning's roughness value

R = hydraulic radius (m,)

S = friction slope (m/m)

A = width (W) * depth (H) = cross sectional area (m^2)

P = width (W) + 2* depth (H) = wetted perimeter (m)

Manning's equation was further simplified to equation (2)

$$Q * \frac{n}{s^{\frac{1}{2}}} = AR^{\frac{2}{3}} , \qquad 2$$

For the calculation of the depth of the water, 20 years flow rate data of Koshi river near the study area, elevation value from Dem, Google Earth (to measure cross section), and the Manning's constant was taken into consideration in the Manning's equation.

sn	Cross section (W)	elevation	Elevaction_diff (ds)	Slope distance	S (m/m)	(Q*n)/s^0.5	depth(H)
1	970	97	16	19770	0.0008	618.16	1.24
2	1158	95	18	917	0.0196	125.52	0.69
3	1510	94	19	1000	0.0190	127.58	0.63
4	1140	93	20	1555	0.0129	155.06	0.743
5	807	93	20	1778	0.0112	165.81	0.852

Table 2: Depth calculation using the Manning equation

In Table 2, first three columns of table present cross section (W), elevation, and elevation difference (ds). The last column shows the normal depth of Koshi in December. The depth of each interest point was computed by using iterative process in Excel. During calculation the annual average flow rate of 502 cubic meter was considered.

4 Tools

This section includes the tools that were used to create and prepare the data. It briefly explains the general feature of the software.

4.1 QGIS

Quantum Geographic information system (QGIS platform) is the major tool used in this study for spatial analysis and visualization. It is easy to download, handy to use and has many plugins available that could be utilized according to the user's requirements.
QGIS is an open source (i.e. free to download, install and update) geographical information system licensed under the GNU (Public License) meaning that users can inspect and modify the source code. Since it is available almost all major operating systems such as Windows, Mac OS X, Linux and Android. It is a popular platform among personal as well as enterprise users (qgis.org, 2017)

4.2 JOSM

JOSM (Java OpenStreet Map) is a free-to-download software. It is essential for an OSM user. It is mostly used for digitization and validation of the digitized features from the OpenStreetMap id editor. JOSM is more powerful, and faster to work with than the OSM ID editor.

A certain area of interest can be downloaded from the satellite map to the desktop and the missing entities such as place names, built-up locations, buildings, river buildings and even photo imagery could be added using specific tools that are available in the software. Specific tags must be given to the corresponding type of entities while digitalization process. Digitized entities finally can be uploaded to the Open street map.

The idea behind using JOSM is to upload the digitized buildings during the study onto an OSM platform so that it will be useful for everybody in future.

4.3 R
R is a well-known and powerful open source environment for statistical computing and graphics. There are significant number of packages available which can be installed according to the requirements. Spatial package called rgdal in one of the handy packages which provide bindings to the Geospatial data abstraction library(GDAL) (Rproject.org, n.d.)

4.4 HEC-RAS
HEC-Ras is hydraulic modelling computation tool that models the water surface profile that flows through rivers, streams and other channels. 2D hydrodynamic modelling is popular for flood inundation modelling. The latest version 5.0.3 has a Ras mapper included, which has made way easier to create a terrain. The mesh is constructed on the terrain in the geometry editor.

The HEC programme was written by the senior US Army corps of Engineers who were soon going to be retired after the World war II. The Purpose of the programme was for the management of flood plain and flood risk areas. Later it was widely appreciated by users after it was made public in 1995.There have been several series of HEC-RAS(US Army corps of Engineers, n.d.). version 5.0.3 is used to Model The flood extent in this thesis.

5 Data creation and preparation

Data preparation is the first step that is done before the real study on spatial analysis.
Significant amount of time has been spent on preparing and creating the data. Tools such as JOSM, QGIS, Excel, RStudio were used to add, clip, merge, clean, and conversion of the data obtained from various sources.

Being very new in GIS field and as a beginner user of some tools such as JOSM and QGIS, it took abundant time to manipulate even a very routine data operation. mastering the skills of GIS tools and preparing data has become the important part in this thesis study. This chapter contains a brief description of the data creation and preparation process.

5.1 DEM data

DEM (digital elevation model) is a raster representation of the continuous surface. Raster data are measured in pixel to get the dimension and quantity of spatial feature. For instance, satellite image ortho photos, elevation, temperature, precipitation information is stored in raster cell. Values are associated with them are continuously changing. These types of data symbolized in row and column pattern (Bolstad, 2012).

DEM data has wide range of application in studies related to topography. For basic understanding DEM is regular gird of elevation of earth surface in a raster form. In DEM, each cell contains the altitude value of the earth surface. There are several DEM Sources such as JAXA's (Japan Aerospace Exploration Agency's) Global ALOS 3D World, SRTM (Shuttle Radar Topography Mission), ASTER global elevation data, LiDAR. (gisgeography.com, 2017).

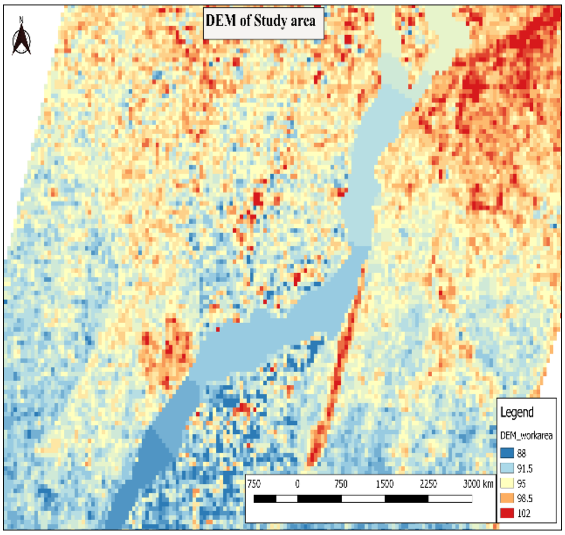

Figure 7(a): DEM of study area

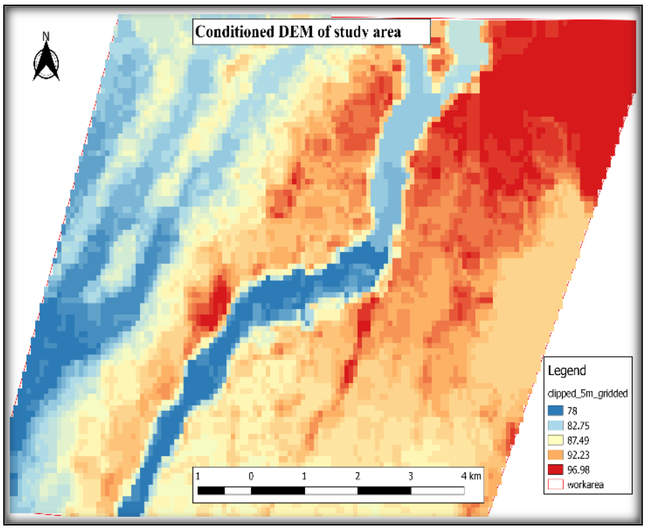

Figure 7(b): Hydrologically conditioned DEM of study area

Topographic data is essential for the visualization and modelling of the flood prone area. Thus, much effort and interest has been invested to obtain the Flawless data.

First Elevation (DSM) data of 30m height was downloaded from("ALOS Global Digital Surface Model," 2016). The raster DEM was clipped using raster clipper tool in QGIS. Then it was re-projected in WGS 84 EPSG: 32645. A DEM of 30m resolution was resampled to 60m (Figure 7(a)) for easier and faster algorithm processing using geoprocessing tool SAGA.

During the 2 D flood modelling process, the movement of water was not good enough. Thus,90-meter (1 second) hydrologically conditioned DEM(Figure 7(b)) from (Lehner, B., Verdin, K., Jarvis, 2008) was used unsteady flow analysis in HEC-RAS 2D. The water surface elevation was in the range of 78 to 83 meter and the eastern embankment (levee) height of the study area is in the range of 93 – 96 meters.

Since, the cause of Flood was assumed to be a levee breach due to the increase of discharge rate. The elevation of breaching point was made closer to the land elevation. To do so, first a polygon layer was created in QGIS; its field was assigned with -9999 (which was not the value of the DEM), and it was rasterized with respect to the copy of DEM. Later the elevation from each raster cell was subtracted by 7 meters using a raster calculator function in QGIS.

5.2 Buildings data

In the geospatial field, buildings are part of Vector data model. Vector data are the type of data that represents a road, a river, a building or location and are symbolized by a line, a polygon and a point. Points are represented by Cartesian co-ordinate pairs. Line is a combination of points. Polygon is a closed surface area connected by lines. Map scale, map type and the cartographer decide whether to use a point or a polygon. It means that for a global map an entire city could be a point and that for local map a small lake could be a polygon. In comparison to raster vector data, there is a huge volume of data stored in the form of attributes (gisgeography.com, 2017).

For the modelling of vulnerable buildings in case of flooding in the study area, spatial information (digitized form) is essential. Unfortunately, Very Few buildings had been digitized in the study area, which means additional digitization work was needed before downloading the building information. Thus, more than Three thousand buildings had to be digitized manually using the tool JOSM (Java Open street map) during this thesis work. Figure 8 and 9 are snap shots from the OpenStreetMap before and after the digitization.

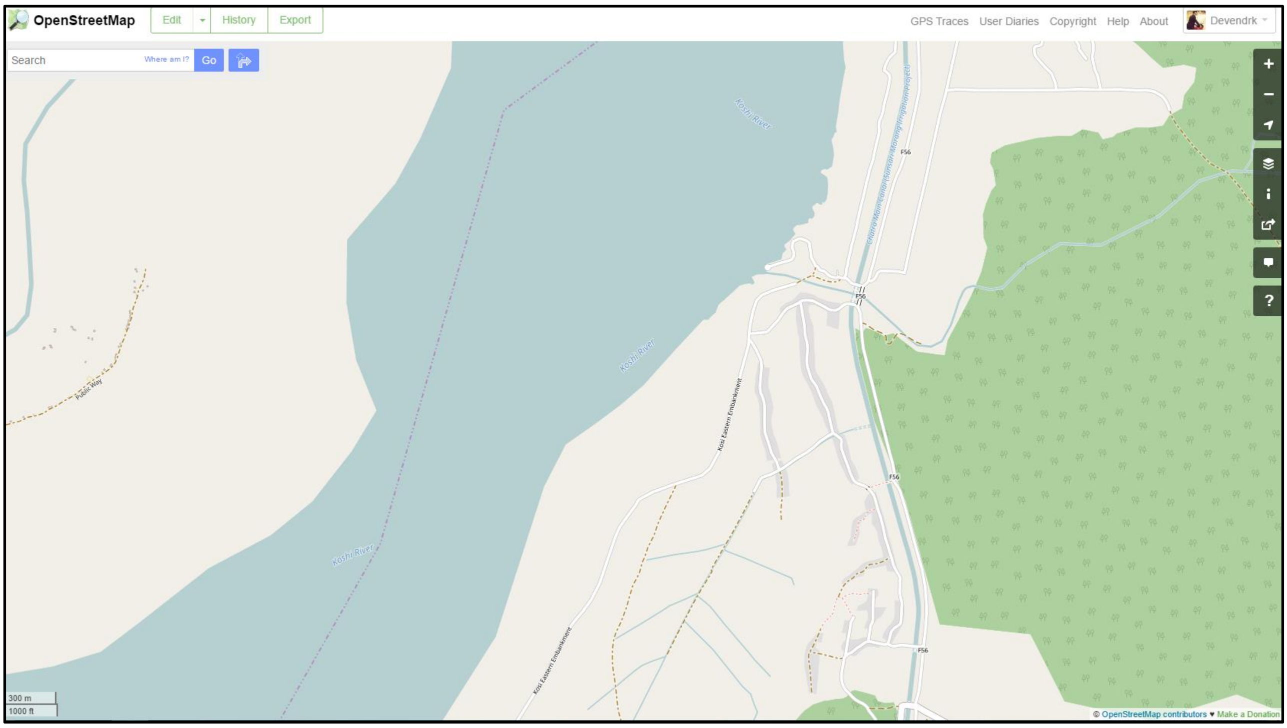

Figure 8:Buildings before digitization

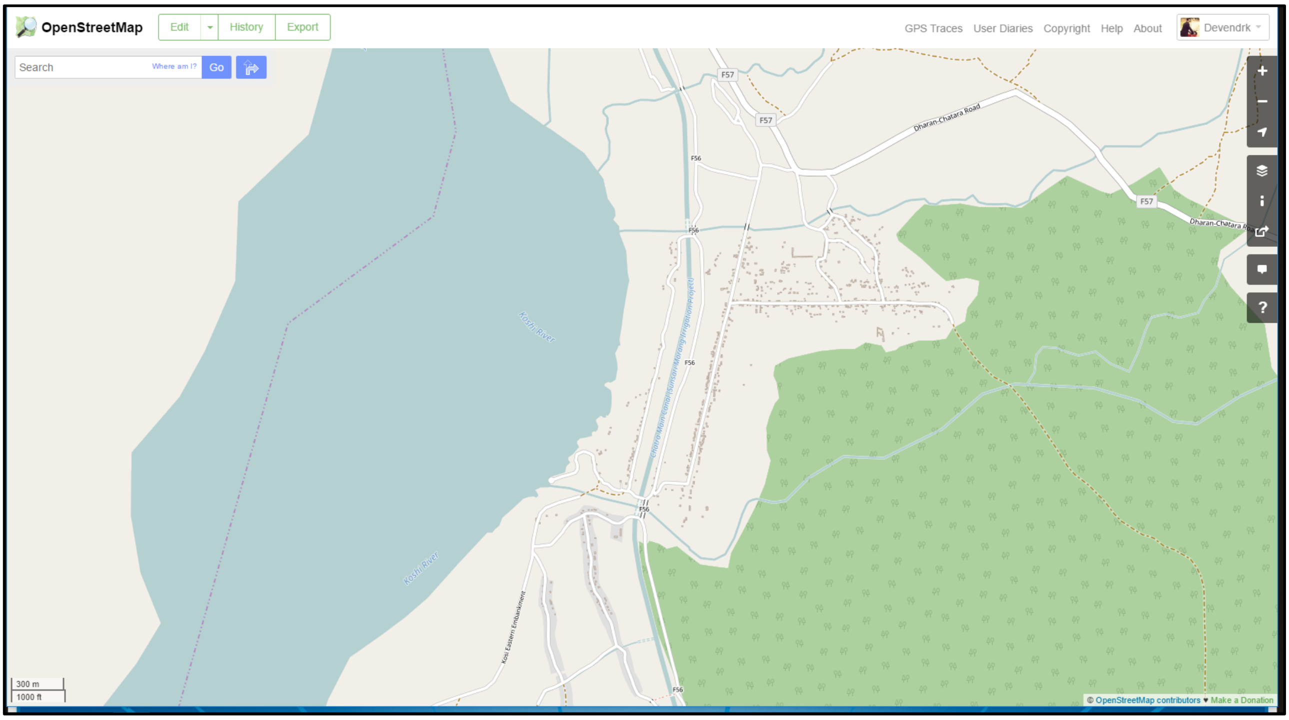

Figure 9: Buildings after digitizing

5.3 Land-use data

Latest land-use data is unavailable readily. Thus, the most recent (2016 December) Landsat image was used from the Earth Explorer ((U.S.G.S, n.d.) data store.

Land-use data was created in QGIS platform using the unsupervised k mean classification method.

During the classification process, 10 unique classes were created. Later those classes were reclassified to 5 major classes in R Studio using the 'rgdal' package. One can see the R used in reclassification of Raster classes syntax in Appendix 1. The land use map (Figure 10) shows the result of five reclassified classes which are namely forest, agricultural and barren land, water river, sand and vegetation (bushes). Buildings would be another useful land-use class, but due to very low resolution of satellite image, most buildings contain the similar pixel value as the bare land. Thus, buildings were excluded in the land-use classification.

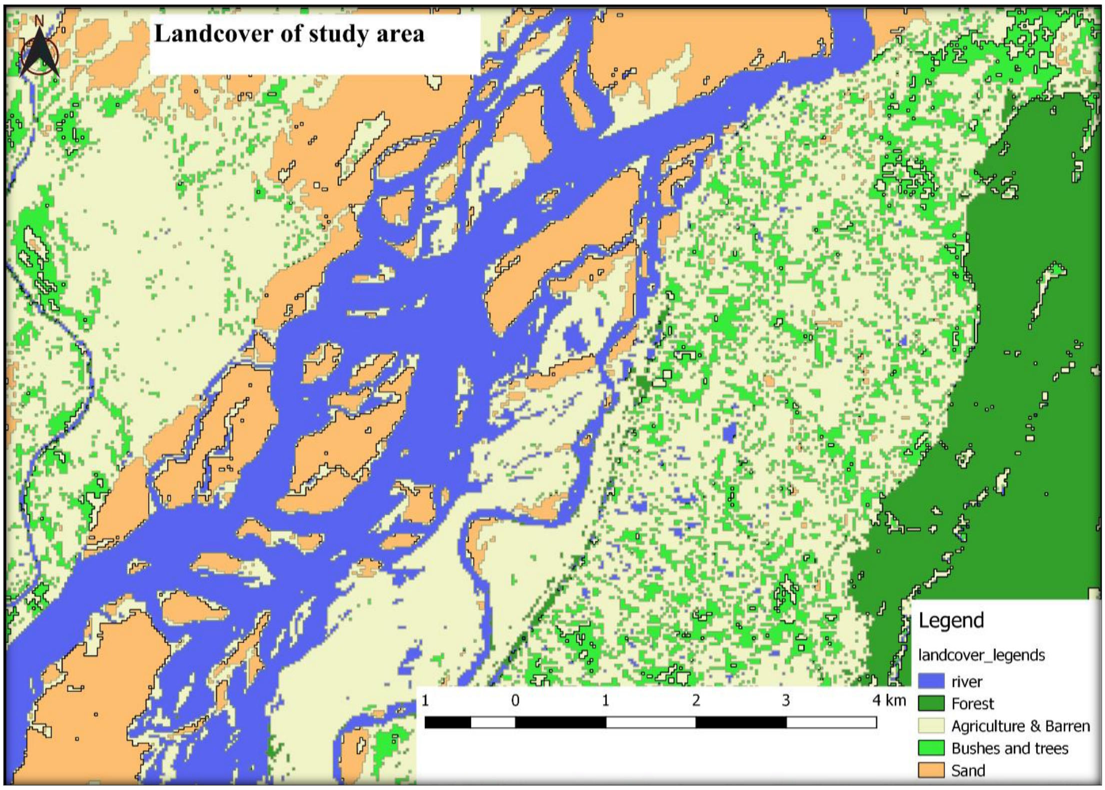

Figure 10: Land cover of study area.

Table 3 shows the land use data which depicts that out of 111 km^2 land-use map area, where agriculture accounts for almost half of the land-use, while river/water, sand, vegetation and forest together cover the other half of the land-use.

Land use	Surface area	
	In sq. km	%
Agriculture	51	46
Vegetation	13	12
Forest	12	11
Water/River	19	17
Sand	16	14
Total	111	100

Table 3: Land-use data

5.4 Drainage basin

About 45 percent of its total catchment area drains through Nepal, which is equivalent to 39470 km^2; similarly 33 percent drain through China and 22 percent through India, which is equivalent to 28,300 km^2 and 19,604 km^2 , respectively. The Koshi Basin elevation-difference ranges from over 8000 m in Himalayas to 60 m on the Plains (Terai) with an average elevation of 3,800.

The drainage basin of Koshi river was generated in SAGA with the Wang & Liu hydrology algorithm. The river network downloaded via HydroSHEDS was overplayed.

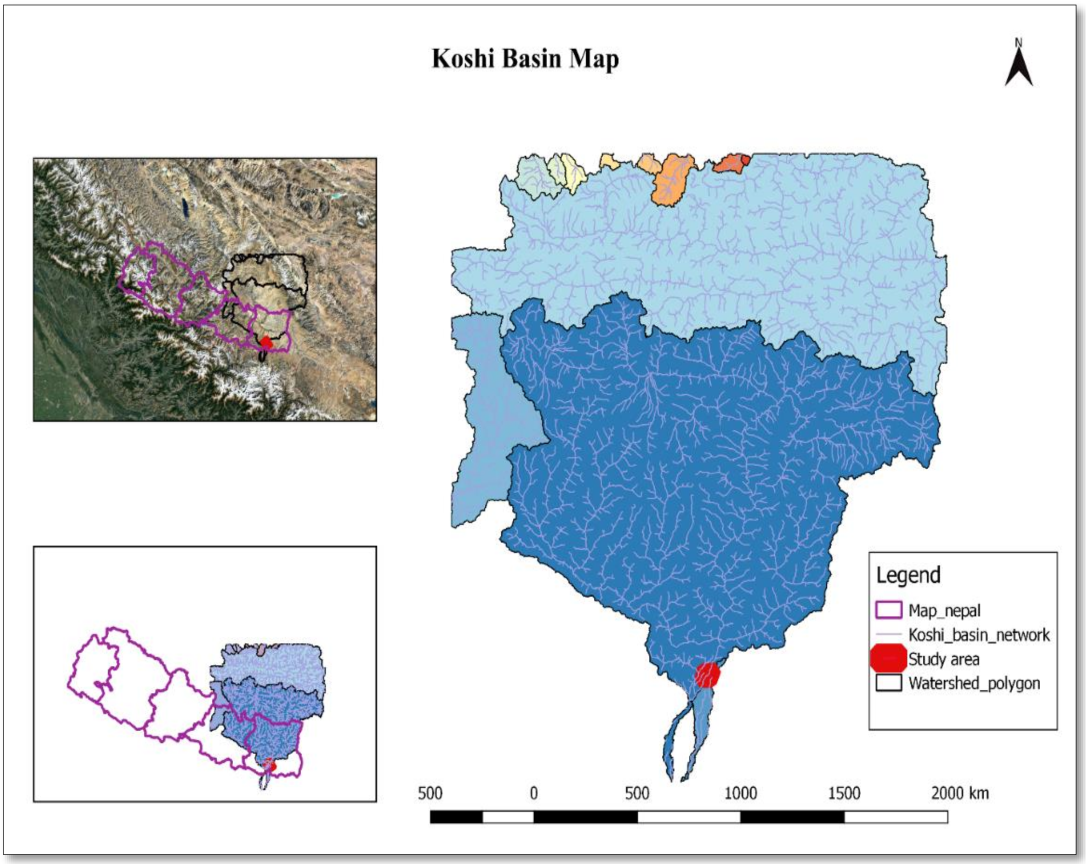

Figure 11:Drainage Basin of Koshi River

5.5 Flowrate data

According to the data provided by Department of Hydrology and Meteorology Nepal, the average annual discharge of the river ranges between 1240 to 1740 m^3/s.

Figure 13 shows Monthly Peak flow of the Koshi river during 20 years from 1991 till 2010.Most part of Koshi basin receives the precipitation of about 1800 mm annually (Bharati, Gurung, Maharjan, and Bhattarai,2016). In comparison of the other months, May to September has highest flow rate in the Koshi river (Figure 11).

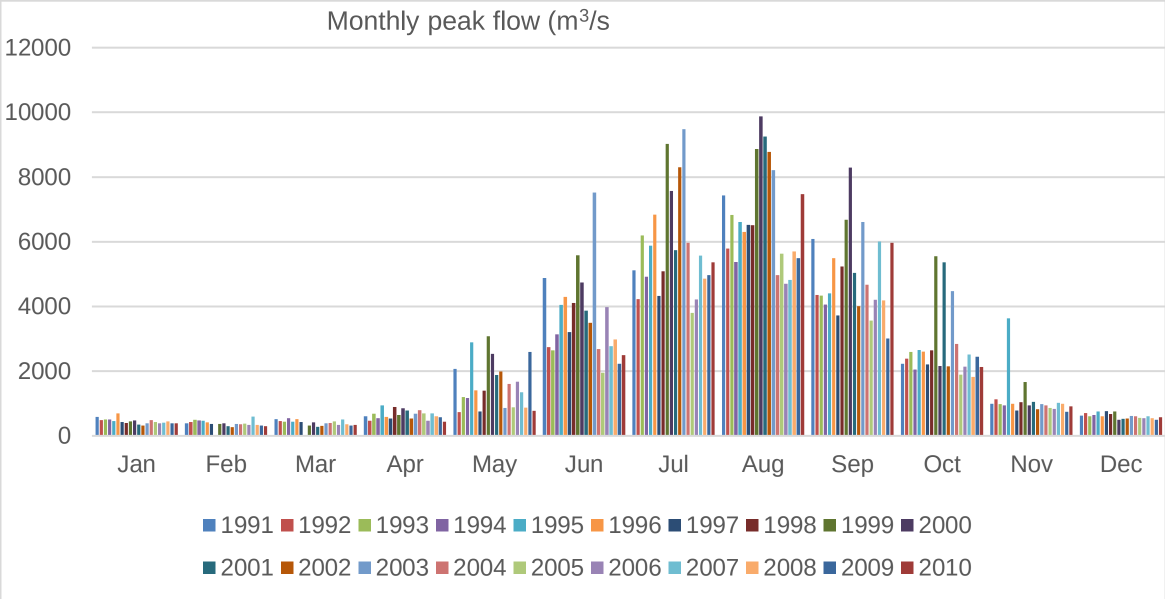

Figure 12: 20 years Flow rate chart

Table 3, 4 and 5 Presents the flow rates of 3 different scenarios of the Koshi River. Each of them were used as hydrograph data in HEC-RAS for 2D modelling. Table 3 indicates the 2008 historical flood event's flow rates Table 4 consists of the highest 8 peak flow rates in 20 years and similarly, Table 5represents the average flow rate of August (peak monsoon period). More details of discharge data can be seen in Appendix 2.

Table 4: Flow rate in Historical flooding

S. N	Date	Flow Rate(m^3/s)
1	15/08/2008	5060
2	16/08/2008	5120
3	17/08/2008	4560
4	18/08/2008	4270
5	19/08/2008	5230
6	20/08/2008	4320

Table 5: Maximum flow rate in 20 years

S. N	Date	Discharge (m^3/s)
1	09/08/2000	8870
2	10/08/2000	9880
3	11/08/2000	9250
4	12/08/2000	8780
5	13/08/2000	8210

Table 6: Yearly average flow rate

1	Year	Flowrate
2	2005	4060
3	2006	3080
4	2007	3720
5	2008	4650
6	2009	3770
7	2010	4530

5.6 2 D unsteady Model

HEC-RAS 5.0.3 is a computing platform that can perform 1D,2D and combined 1D/2D hydrodynamic simulations. In this thesis flood inundation model was obtained with a 2D unsteady flow analysis algorithm. Details of the modelling process are explained below.

HEC-RAS consists of the RAS mapper tool where the grid format of DEM can be imported to construct the terrain layer (Figure 13). The DEM imported to RAS mapper was initially downloaded from the hydrosheds database(Lehner, B., Verdin, K., Jarvis, 2008).DEM resolution was 3 arc second (90 meters).First, the DEM was imported in QGIS and projected in the required CRS which is WGS 84 EPSG 32645. The elevation of one point of the study area was reclassified to generate a broken levee. The point was assumed to be a levee breached in a peak flow condition. After reclassification, the DEM was then imported to the Ras mapper.

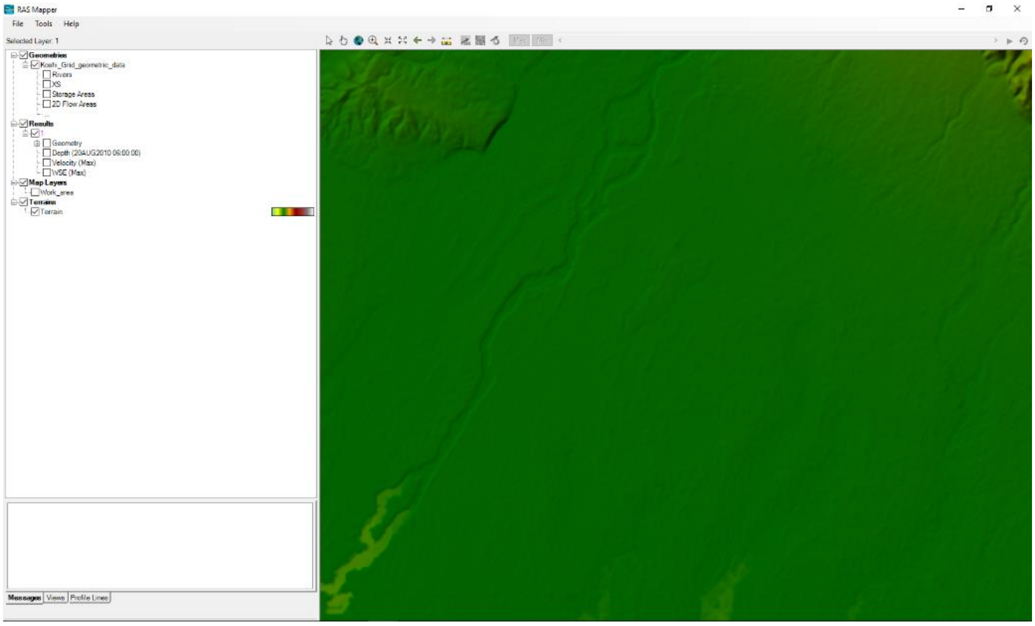

Figure 13: Terrain created with RAS Mapper

The computational mesh (Figure 14) is a net that allows 2D flood modelling. Thus, the size of the mesh is one of the factor that affects the accuracy of the model. Each cell represents a detail of the terrain layer (Gharbi et al., 2016).

To create geometric data, a 2D flow area boundary was constructed. Then the mesh was generated assigning the Manning’s n value and the mesh cell centre DX and DY with the value 30m and 30m.Then, the 2D area boundary condition (BC) line was constructed in both upstream and downstream (Figure 14).

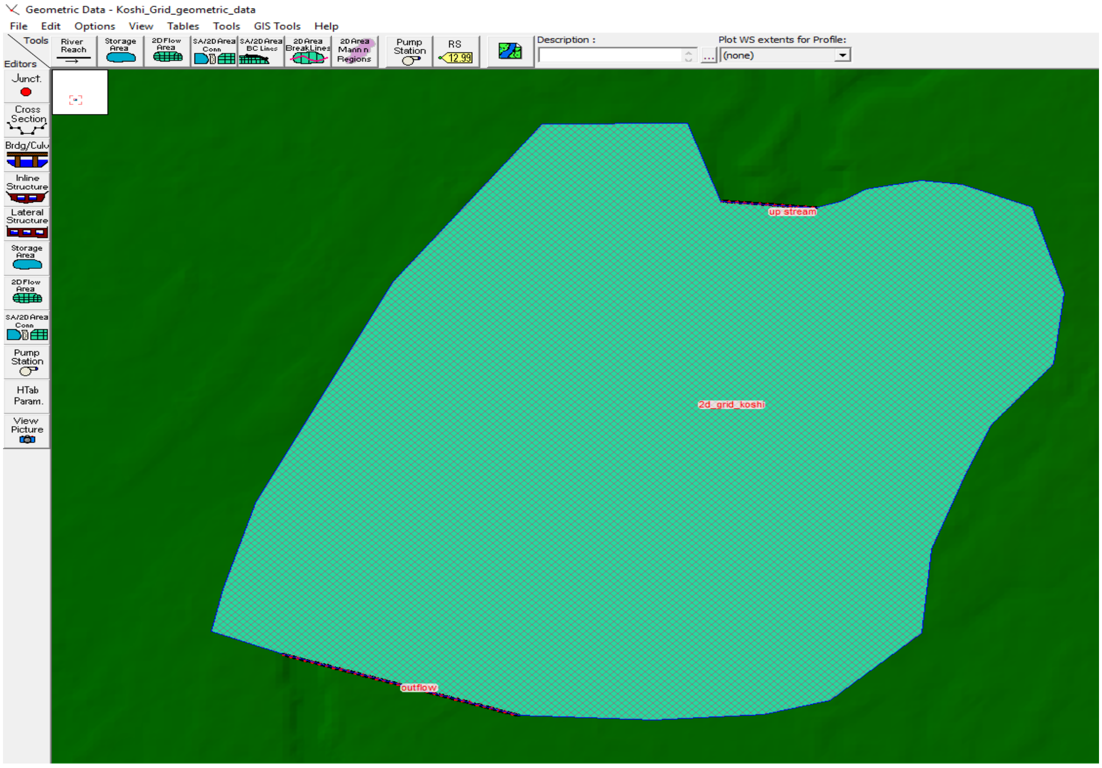

Figure 14: 2D Flow mesh with up and down BC Line

Once mesh was set up, it was fine-tuned by editing the points of the boundary cells. After this, it was ready to proceed to the boundary condition set up.

Five days of flow rate data (Table 5) and (Table 6) were used as upstream boundary. Normal depth obtained from the Manning's equation calculation (Table 2) value was used as the downstream boundary. Each scenario discharge was assigned separately in two different model plans. Flow hydrographs in (Figure 15 and Figure 16) are obtained from the average and peak flow rate data. Energy slope of the river was assumed to be 0.01 same as the river slope (Table 2).

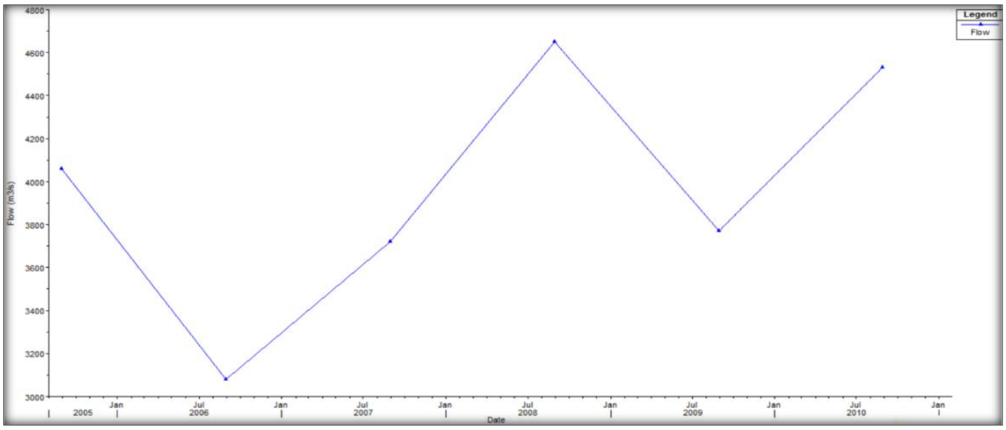

Figure 16:Flow hydrograph of Peak Flow rate in 20 years

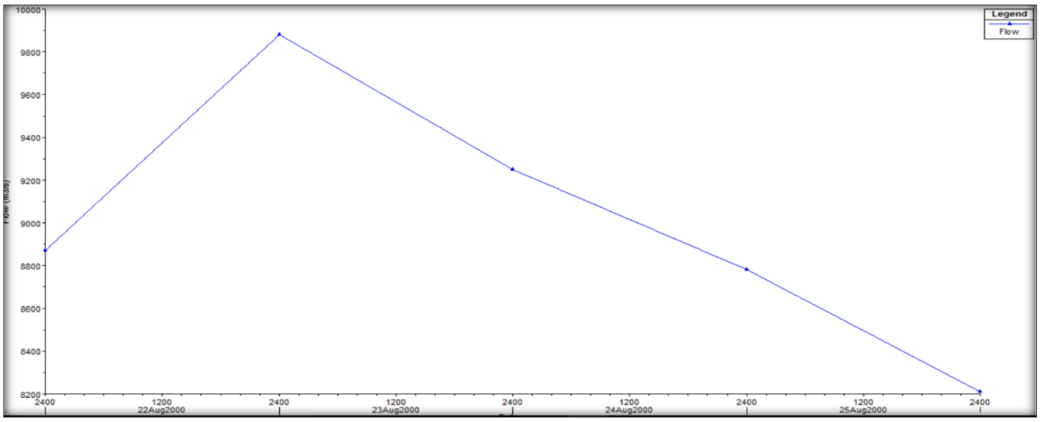

Figure 15: Flow hydrograph of Average Flow rate in August from2005-2010

The last step (Figure 23) to be followed was to create the unsteady flow analysis algorithm. The starting and ending date was assigned for 2 days and time was adjusted to 10 hours in the simulation time window. Here the most important factor was to set the computation interval, which is also known as time step. It is recommended to set a smaller computation interval for reliable result. Hence the computation interval was set to 30 seconds. In 2D flow calculation tolerance option, the initial tolerance time was set to 4 hours,10 hours and the diffusion wave equation was chosen for the 2D model computation.

6 Result

After computing the 2 different scenarios in HEC-RAS, the output map (Figure 17) was obtained. The map demonstrates the hydrodynamic models with a boundary condition of average discharge and historical peak discharge value. In average discharge scenario, the water depth was 8.03 meter, which was not enough to reach the land. The peak discharge (Figure 17 b) condition has a depth of 11.5 meters and reveals the fact that flood extent occurs in case of a levee break in the peak discharge condition. The depth plot of peak and average discharge can be found in Appendix (3) and Appendix (4) respectively.

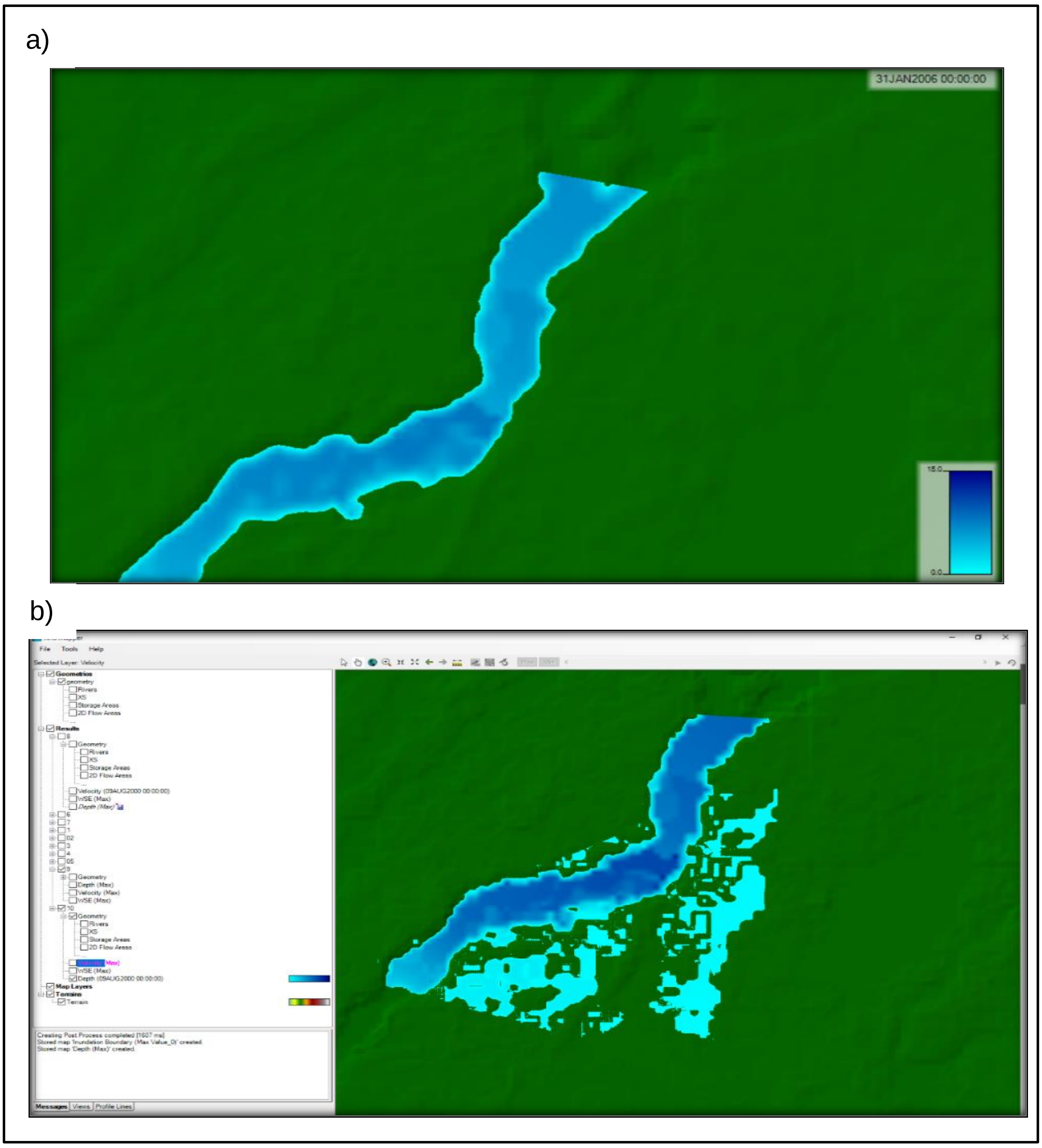

Figure 17: Flood inundation Ma in average and peak discharge condition

The result obtained from HEC-RAS was exported in raster format (.TIF file). The exported raster was polygonised in QGIS and finally overplayed with the buildings data from OSM. The affected number of buildings (Figure 19) were obtained by intersecting buildings and flood polygon in QGIS. similarly, the inundated land area is obtained by selecting the flood polygon in the land and calculating the area of polygon with basic statistical calculation tool in QGIS.As Figure 18 reveals the depth of the flood in study area. In case of a levee break, the flooding with a depth between 0 to 2.6 meters could occur in the village. Flood extent covers the total land area of 2.73 square kilometres of 2 VDCs Prakashpur and Madhuwan.

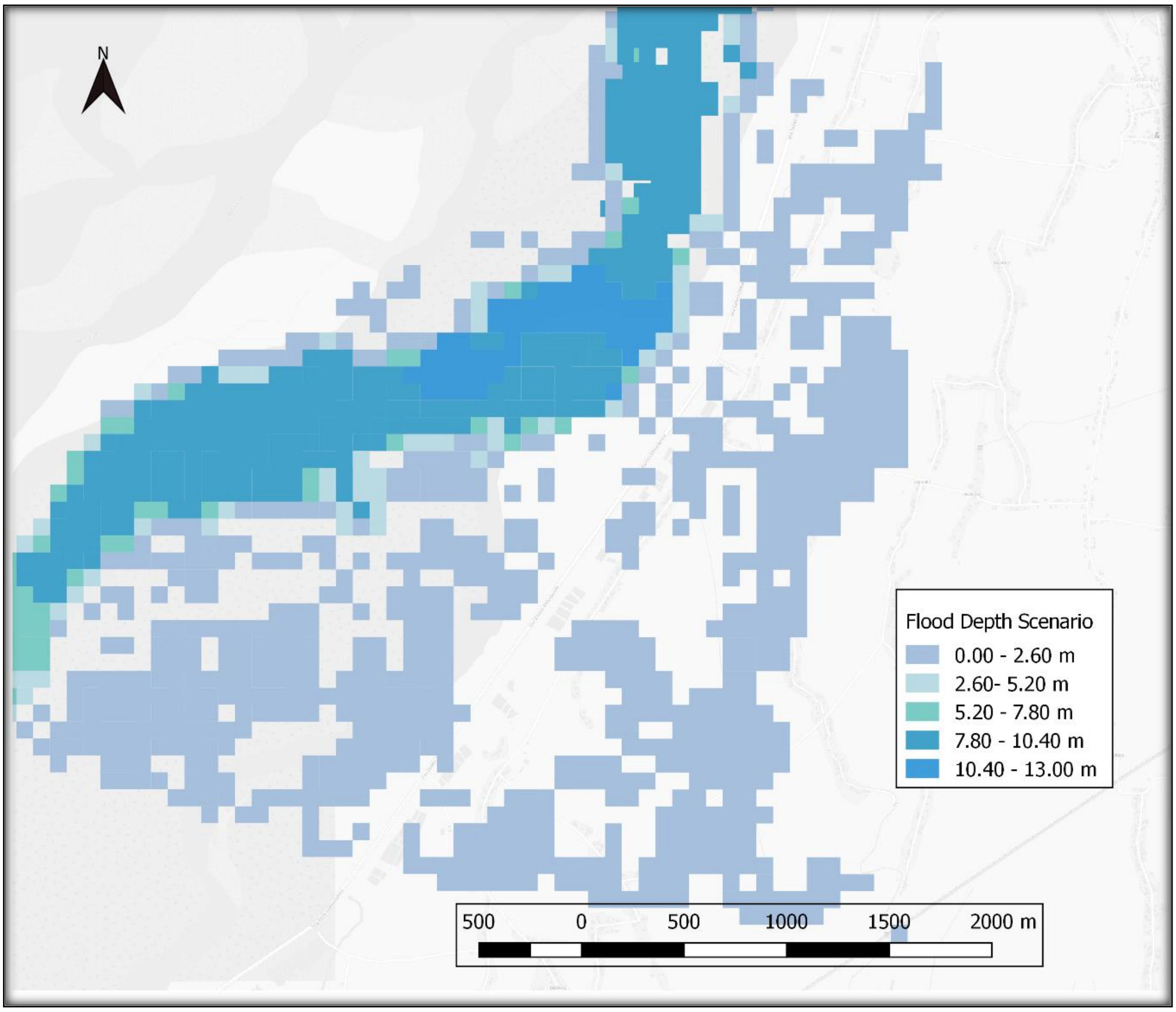

Figure 18: Flood inundation map with depth

The flood map (Figure 19) indicates the areas and buildings that are vulnerable incise of a levee breach during the high discharge rate of the river. The result depicts that out of 3456 buildings in the study area 235 gets the flood water. If we assumed the building to be a single-storey house, the total vulnerable buildings (Table 6) covers an area of 13941m^2.

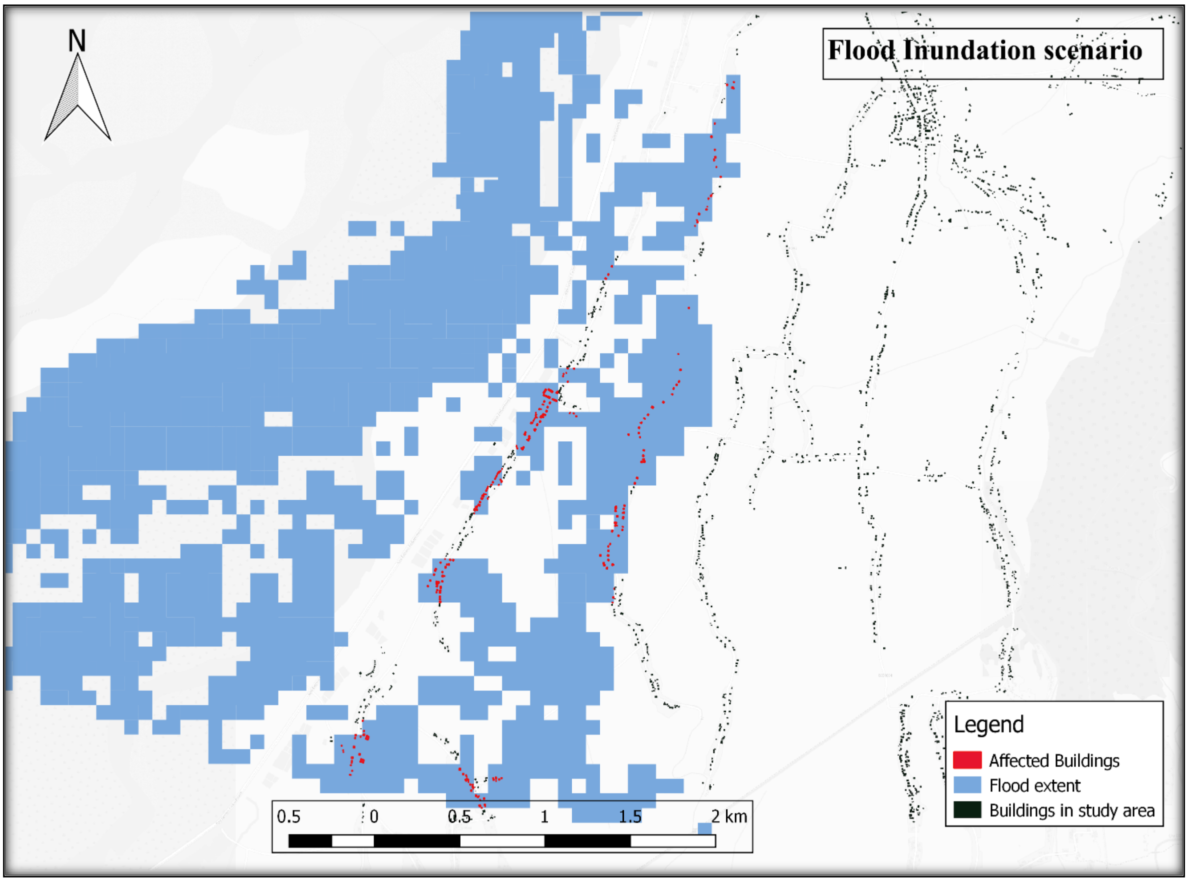

Figure 19: Flood Imapct map

SN	Discerption	Number
1	Total buildings	3456
2	Flood affected Buildings	235
3	Area of buildings under flood	13941m^2
4	Land area under flood	2.73 km^2

Table 7: Flood impact data table

7 Discussion

From the available discharge data and history of flooding in the plain region of Koshi, the possibility of flood event is very high in the monsoon season. Especially the August month has the highest flowrate in the river. People residing near Koshi bank have faced severe floods in this month.

Since the flow rate data was taken from nearest gauge station, which was approximately 20 km north from the study area. Some parameters such as the local accumulation, evaporation, and infiltration were not taken into consideration.

More than 85% of the known buildings were digitized by the author during this thesis. Due to the absence of a clear satellite image there might be a possibility of digitizing an object wrongly as a building. With the unclear aerial image, there is also a high possibility of error in the building area calculation.

8 Conclusion

Results of the thesis reveal the possible flood extent in a small part of the Koshi river. During the thesis project, the author acknowledged that high discharge is not only the cause of a levee break and flooding in the region. It is assumed that the interruption of natural flow of water and sediment due to the barrage situated about 20 km south of the study area could be another strong force to encourage the levee break and frequent floods which could be the next interesting topic to study.

Since the author of thesis was very naïve user of the GIS tools, a major portion of the time in this Thesis project was utilized for learning the GIS tools, which is also a Great achievement of the thesis.

There are some limitations in this thesis project too. First, the flood vulnerable buildings in this thesis were covered only inside the study area, meaning that larger coverage of the area could visualize more details of the possible damage. To cover in larger scale is beyond the scope of this study. The second limitation was that the area of study was chosen arbitrarily and assumed the case of a levee break in peak discharge condition.

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Appendix 1: R-code to reclassify the 10 classes of raster cell to 5

```
stewed ("working Directory path")
install. Packages("rgdal")
library("rgdal")
r<- raster ("File path")
plot(r)
r[r==3] <- 1
r[r==4] <- 4
r[r==5] <- 4
r[r==7] <- 4
r[r==8] <- 4
r[r==9] <- 10
r[r==10] <- 10
plot(r)
summary(r)
writeRaster (r,filename="ReclassifiedLandcoverfile.tif", format="GTiff", overwrite=TRUE)
```

Appendix 2: Annual discharge rate data from 1990-2010**.**

Latitude: 26 52 00 Station number: 695

Longitude: 87 09 30

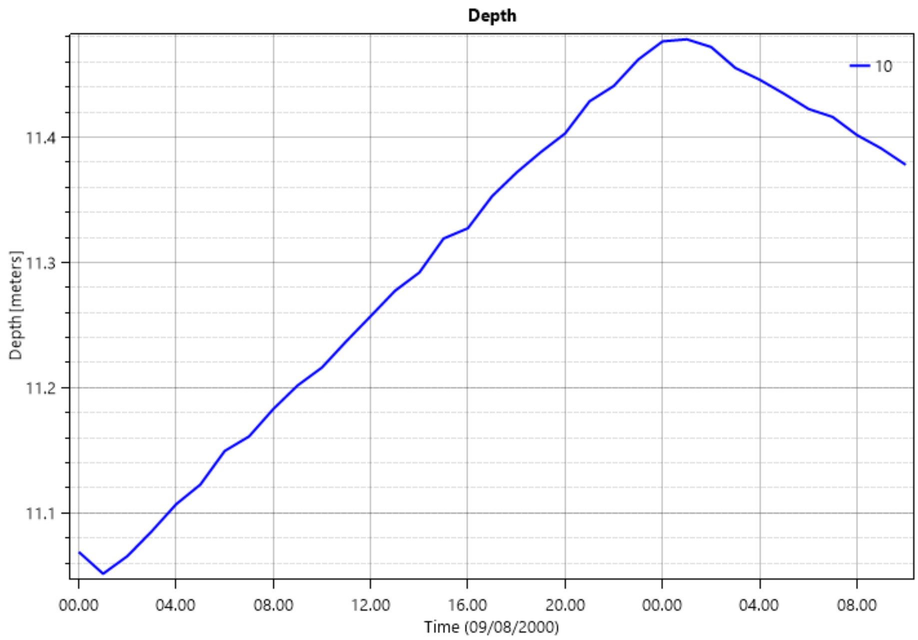
River: Sapta Koshi

Discharge in in m3/s

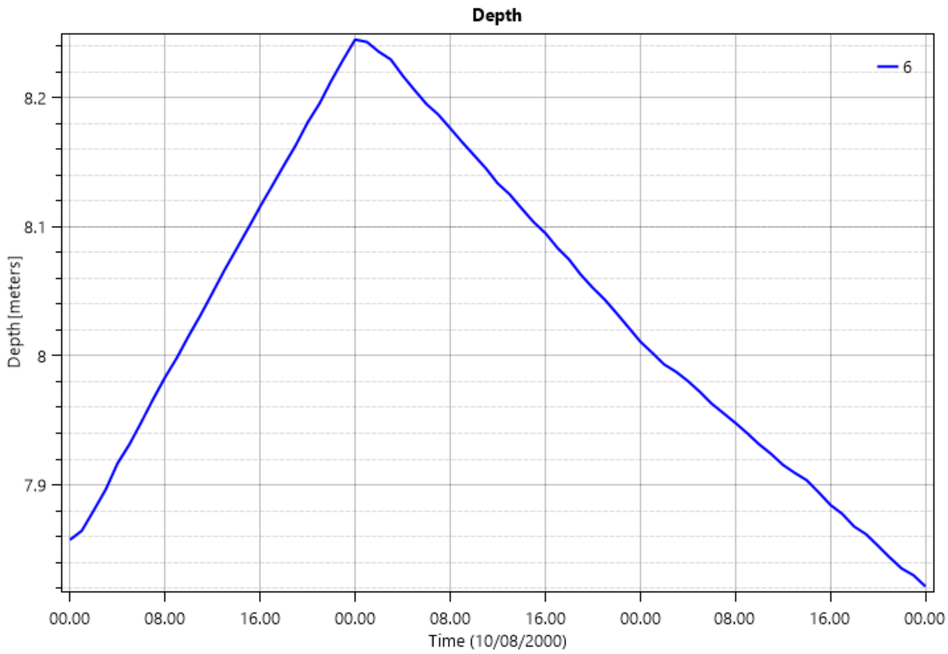
year	Max	Mini	Average
1991	7430	330	1740
1992	5790	337	1350
1993	6830	291	1590
1994	5370	324	1420
1995	6610	391	1780
1996	6840	364	1680
1997	6520	305	1300
1999	9030	290	2070
2000	9880	286	2030

2001	9250	200	1760
2002	8780	201	1650
2003	9480	214	2040
2004	5970	296	1450
2005	5630	312	1240
2006	4700	274	1310
2007	6010	323	1530
2008	5700	308	1450
2009	5490	259	1150
2010	7470	244	1460

Appendix 3: Water depth in historical discharge in August.



Appendix 4: Average discharge of august.



Appendix 5: unsteady flow analysis computation tab in HEC- RAS.